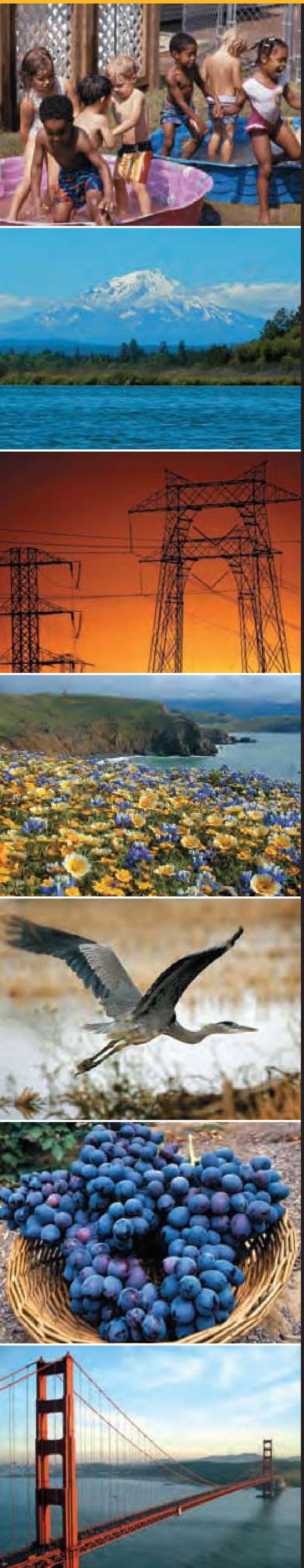
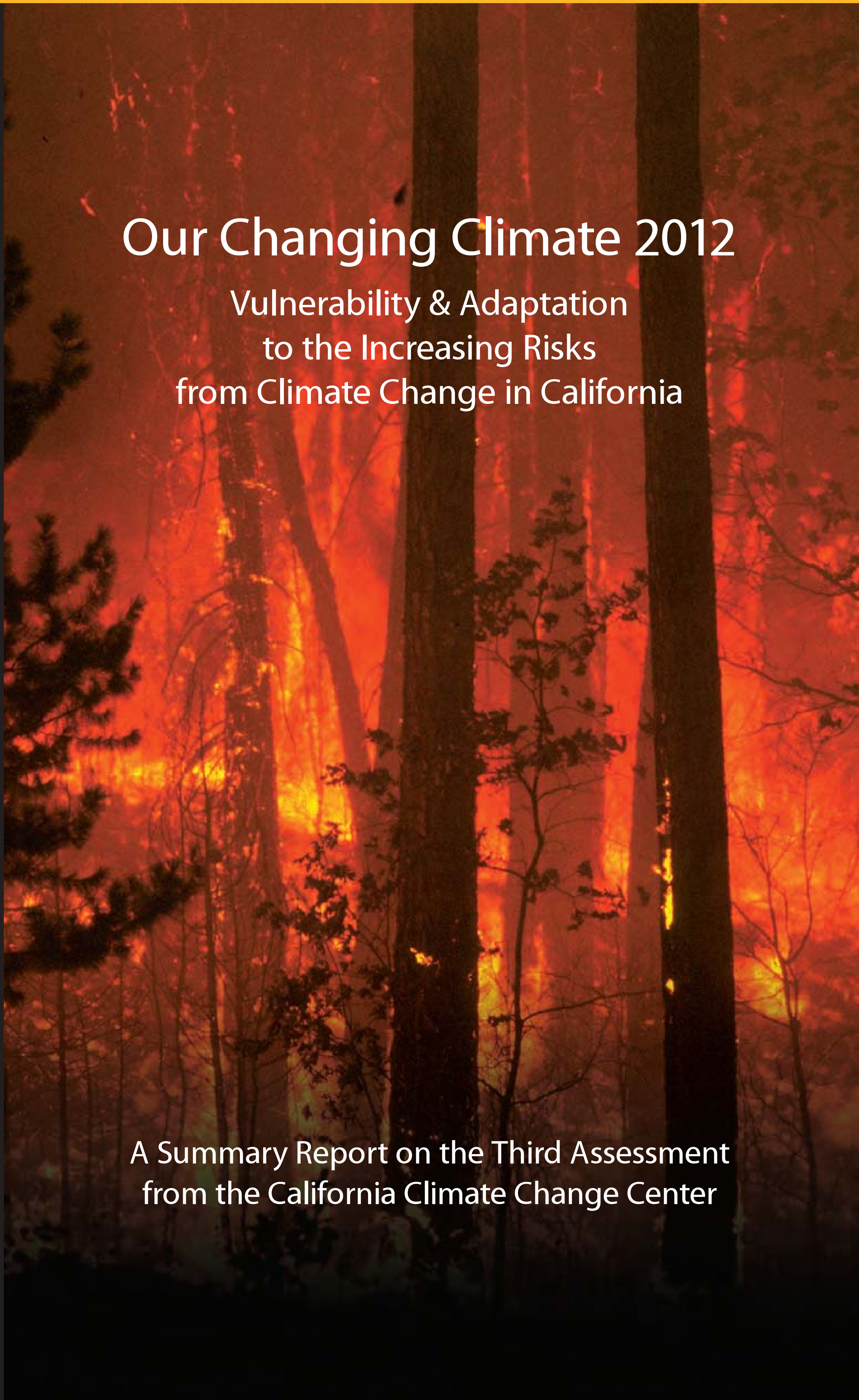




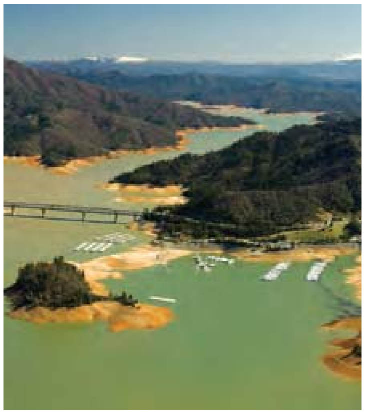
Our Changing Climate 2012

Vulnerability & Adaptation to the Increasing Risks from Climate Change in California

A Summary Report on the Third Assessment from the California Climate Change Center

As the nation faces record heat, storms, drought, and wildfires, California has an advantage in its scientific understanding of climate change. A solid body of vital data is available to assist state and local leaders to better understand how climate change is affecting us now, what is in store ahead, and what we can do about it.

State-sponsored research has played a major role in recent advances in our understanding of the potential impacts of climate change on California. A first assessment, published in 2006, made clear that the level of impacts is a function of global emissions of greenhouse gases and that lower emissions can significantly reduce those impacts. The second study, released in 2009, made the case for adaptation as a necessary and urgent complement to reducing emissions.



Extended droughts have posed difficult challenges for California in recent years and could pose increasing problems with climate change.

The *2012 Vulnerability and Adaptation Study*, the State's third major assessment on climate change, is summarized here. In contrast to the previous two assessments, this one explores local and statewide vulnerabilities to climate change, highlighting opportunities for taking concrete actions to reduce climate-change impacts. This assessment examines adaptation options in regional case studies and offers insights into regulatory, legal, socioeconomic and other barriers to adaptation so that they can be addressed effectively at the local and state levels. A regional study of the nine-county San Francisco Bay Area is also included.

The third assessment, like its two predecessors, reflects a powerful collaborative process. Guided by a Steering Committee of senior technical staff from State agencies and outside scientific experts, 26 research teams from the University of California system and other research groups produced more than 30 peer-reviewed papers. They offer crucial new insights for the energy, water, agriculture, public health, coastal, transportation, and ecological resource sectors that are vital to California residents, businesses and government leaders.

WHAT'S NEW IN 2012?

***Our Changing Climate 2012* highlights important new insights and data, using probabilistic and detailed climate projections and refined topographic, demographic and land use information.**

The findings include:

- The state's electricity system is more vulnerable than was previously understood.
- The Sacramento-San Joaquin Delta is sinking, putting levees at growing risk.
- Wind and waves, in addition to faster rising seas, will worsen coastal flooding.
- Animals and plants need connected "migration corridors" to allow them to move to more suitable habitats to avoid serious impacts.
- Native freshwater fish are particularly threatened by climate change.
- Minority and low-income communities face the greatest risks from climate change.
- There are effective ways to prepare for and manage climate change risks, but local governments face many barriers to adapting to climate change; these can be addressed so that California can continue to prosper.

Executive Order #S-3-05, signed on June 1, 2005, called for the California Environmental Protection Agency (Cal/EPA) to prepare periodic science reports on the potential impacts of climate change on the California economy. Cal/EPA entrusted the California Energy Commission and its Climate Change Center to lead this effort. The 2009 Adaptation Strategy prepared by the California Natural Resources Agency also called for a statewide vulnerability and adaptation study. This report summarizes the third of these periodic assessments, the product of a multi-institution collaboration among Cal/EPA, Natural Resources Agency, Department of Water Resources, Energy Commission, Air Resources Board, Ocean Protection Council, Department of Public Health, Department of Forestry and Fire Protection, Bay Conservation and Development Commission, Department of Transportation, Office of Environmental Health Hazard Assessment, State Coastal Conservancy, Department of Fish and Game, Department of Food and Agriculture, and State Parks. It keeps Californians apprised of new scientific developments, documents the emerging impacts of climate change, and alerts them to the increasing risks of a warming climate. Clear awareness of these risks is an important prerequisite for Californians to fully engage in efforts to reduce greenhouse gas emissions, and to prepare and plan for those impacts that cannot be avoided by emission reduction efforts.

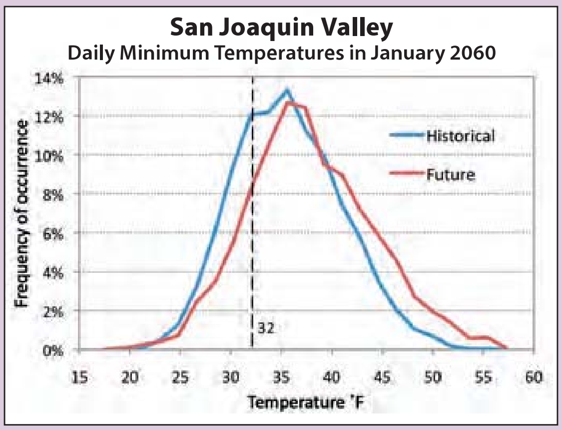
California's Changing Climate

Observed changes over the last several decades across the western United States reveal clear signals of climate change. Statewide average temperatures increased by about 1.7°F from 1895 to 2011, and warming has been greatest in the Sierra Nevada. Throughout the past century, precipitation (rain and snow) has followed the expected pattern of a largely Mediterranean climate with wet winters and dry summers, and considerable variability from year to year. No consistent trend in the overall amount of precipitation has been detected, except that a larger proportion of total precipitation is falling as rain instead of snow. In addition, during the last 35 years, the Sierra Nevada range has witnessed both the wettest and the driest years on record of more than 100 years. While intermittent droughts have been a common feature of the state's climate, evidence from tree rings and other indicators reveal that over the past 1,500 years, California has experienced dry spells that persisted for several years or even decades.

Warmer temperatures combined with long dry seasons over the last few decades have resulted in more severe wildfires. Substantially higher temperatures, more extreme wildfires, and rising sea levels are just some of the direct impacts experienced in California that can be attributed, at least partially, to climate change. Projections of California's future climate served as the basis for all studies in the third assessment.

How Likely Are Future Climate Changes?

The third assessment offers a key innovation over previous ones: *probabilistic* climate and sea-level-rise projections. The likelihood of possible climate futures represents the best estimate of what may happen under specified emissions scenarios, given current scientific understanding of the climate system. Resource managers have requested this type of information to start putting long-term planning into a risk-based framework.



This figure shows how the probability of certain daily minimum temperatures occurring will shift in 2060 (red curve) relative to their historical distribution (blue curve). It illustrates that the most frequently occurring (that is, the most likely) daily minimum temperatures will shift upward, reflecting the expected overall warming trend. Extremely cold nights with below freezing temperatures will decrease in frequency, but not completely disappear. This finding has important implications for farmers' adaptation choices as they may plant new crops that are more resilient to high temperatures but still robust in the face of occasional freezes or choose fruit trees that are less dependent on extended chill hours.

Projected Changes for the Remainder of this Century

Projecting future climate requires sophisticated computer models. Studies from the third assessment used projections from six global climate models, all run with two emissions scenarios, one lower (B1) and one higher (A2) (the same as were used in the 2009 assessment). Both the models and scenarios are well established, but future emissions may be even higher or lower depending on the choices society makes, resulting in greater or smaller climate changes. Global modeling results were then "scaled down" using two different methods to obtain regional and local information. In addition to projections of future climate, several studies in the third assessment also used several scenarios of population growth and land use policy (Business as Usual, Smart Growth, Infill, Fire Risk Avoidance, Agricultural Land Preservation, and Biodiversity Preservation) to shed light on how development patterns could make California more or less vulnerable to climate change.

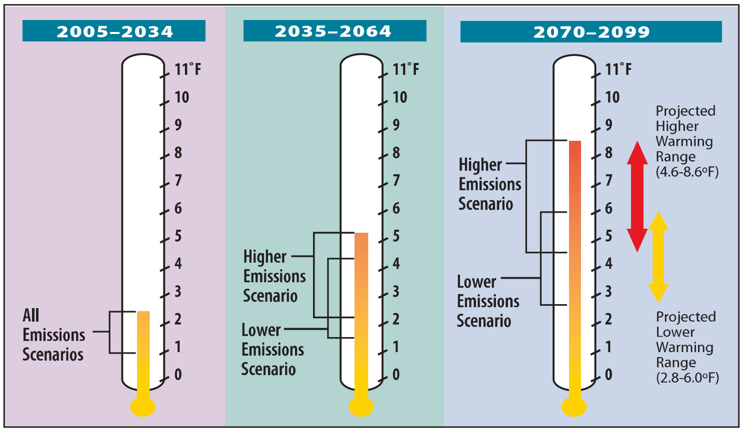
Temperatures in California will rise significantly during this century as a result of the heat-trapping gases humans release into the atmosphere. This broad conclusion holds regardless of the climate model used to project future warming. However, warming will be significantly greater with higher emissions than with lower emissions.

In the early part of this century — warming under the higher emissions scenario differs little from what is seen in the lower emissions scenario, largely because temperature increases over the next few decades are already determined by past emissions. By the latter part of this century, study findings show that the climate choices society makes today and in the coming years can have a profound impact on future conditions.

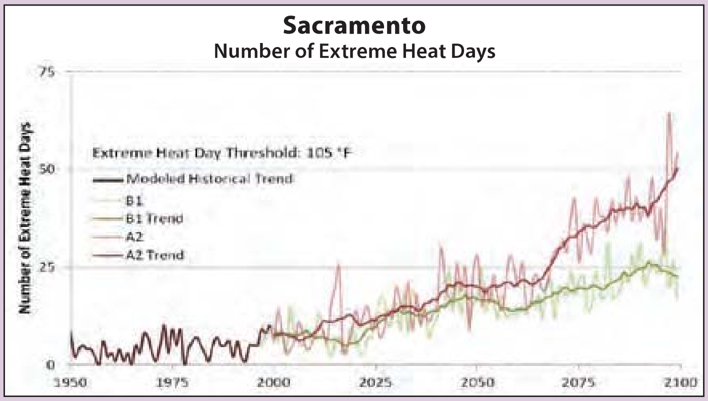
- By 2050, California is projected to warm by approximately 2.7°F above 2000 averages, a threefold increase in the rate of warming over the last century.
- By 2100, average temperatures could increase by 4.1–8.6°F, depending on emissions levels.
- Springtime warming — a critical influence on snowmelt — will be particularly pronounced.

- Summer temperatures will rise more than winter temperatures, and the increases will be greater in inland California, compared to the coast.
- Heat waves will be more frequent, hotter, and longer. There will be fewer extremely cold nights.

Projected Average Temperatures in California



California is expected to experience dramatically warmer temperatures during this century. The figure shows projected increases in statewide annual temperatures for three 30-year periods. Ranges for each emissions scenario represent results from state-of-the-art climate models.



"Extremely hot" days in Sacramento (at least 105°F) will become more common with climate change. By the middle of this century, the number of extremely hot days could increase fivefold (up to 20 days) compared to the historical period (black curve). By the end of this century, under the higher emissions scenario (red curve), they could occur as much as ten times more often than historically. Following a lower emissions scenario (green curve) could make a big difference: Sacramento would see only half that increase.

Model projections for precipitation over California continue to show the Mediterranean pattern of wet winters and dry summers with seasonal, year-to-year, and decade-to-decade variability. For the first time, however, several of the improved climate models shift toward drier conditions by the mid-to-late 21st century in Central and, most notably, Southern California.

- By mid-century, some climate models show that the 30-year average precipitation in the San Diego region will decrease by more than 8 percent compared to historical totals, even under a lower emissions scenario.
- By late-century, all projections show drying, and half of them suggest 30-year average precipitation will decline by more than 10 percent below the historical average.

This drying trend is caused by an apparent decline in the frequency of rain and snowfall. Even in projections with relatively small or no declines in precipitation, central and southern parts of the state can be expected to be drier from the warming effects alone as the spring snowpack will melt sooner, and the moisture contained in soils will evaporate during long dry summer months.

Wildfire risk in California will increase as a result of climate change. Earlier snowmelt, higher temperatures and longer dry periods over a longer fire season will directly increase wildfire risk. Indirectly, wildfire risk will also be influenced by potential climate-related changes in vegetation and ignition potential from lightning. Human activities will continue to be the biggest factor in ignition risk. Previous research estimated that the long-term increase in fire occurrence associated with a higher emissions scenario is substantial, with increases in the number of large fires statewide ranging from 58 percent to 128 percent above historical levels by 2085. Under the same emissions scenario, estimated burned area will increase by 57 percent to 169 percent, depending on location.

New studies in the third assessment demonstrate that the distribution of where and to what degree wildfire risk increases in California will also be driven to a large extent by changes in land use and development. Modeled simulations estimate that property damage from wildfire risk could be as much as 35 percent lower if smart growth policies were adopted and followed than if there is no change in growth policies and patterns.

VULNERABILITY AND ADAPTATION DEFINED

Vulnerability, in the most general sense, is the susceptibility to harm. Vulnerability to climate change is understood as the degree to which a system is exposed to, sensitive to, and unable to cope with or adapt to the adverse effects of change, including climate variability and extremes. It is determined by the character, magnitude, and rate of climate change (the climate hazard), as well as by non-climatic characteristics of the system that might experience such a hazard. The third assessment breaks new ground in understanding the differential levels of vulnerability and related equity concerns for California, the causes of vulnerability, and the range of interventions that could be used to make a system less vulnerable and more resilient.

Adaptation to climate change involves a myriad of small and large adjustments in natural or human systems that occur in response to already experienced or expected climate changes and their impacts. The goal of adaptation is to minimize harm and take advantage of beneficial opportunities that may arise from climate change. Adaptation involves a wide range of planning and management activities that can be taken well in advance of the manifestation of impacts, or reactively, depending on the degree of preparedness and the willingness to tolerate significant risk.

Health: Many Opportunities to Reduce Social Vulnerabilities

Climate change could have major impacts on public health and well-being throughout California if adequate adaptation measures are not taken. However, many climate adaptation opportunities exist for protecting the public welfare, many of which have already proven effective. Strategic placement of cooling centers, for instance, has been clearly shown to save lives during heat waves.

Many of the gravest threats to public health in California stem from the increase of extreme conditions, principally more frequent, more intense, and longer heat waves. Particular concern centers on the increasing tendency for multiple hot days in succession, and heat waves occurring simultaneously in several regions throughout the state. Public health could also be affected by climate change impacts on air quality, food production, the amount and quality of water supplies, energy pricing and availability, and the spread of infectious diseases. These impacts could have potentially long-term repercussions, and the severity of their impacts depends largely on how communities and families can adapt.

Heat waves are expected to occur more frequently and grow longer and more intense, posing particular risk to the most vulnerable.

Studies in the third assessment improve our understanding of Californians' vulnerability to extreme heat events and other extreme climate events. Some segments of the population are more sensitive than others and may have less ability to prepare for, cope with, or adapt to changing conditions, and will be impacted disproportionately. Understanding these characteristics (age, sex, race, education level, income, air conditioner ownership and others) can be helpful to develop and prioritize adaptation options that target those in greatest need.

For example, one study shows that mortality from various cardiovascular conditions on extremely hot days is up to 28 percent higher than normal background mortality. New studies also show elevated risks for hospitalization for stroke, diabetes, acute kidney failure, dehydration, and pneumonia for those 65 years and older, infants under 1 year of age, and African Americans. The need for emergency room visits for a variety of conditions also increase for many segments of the population, while preterm delivery is more likely for all pregnant women, especially for younger, African American and Asian American women.

The use of air conditioners significantly reduces the risk of mortality and hospitalization in times of extreme heat, which makes air conditioner ownership a useful indicator of short-term coping capacity. However, increased use of air conditioners should not be relied on as an effective long-term strategy given the risks of power outages during peak-demand periods and related higher energy demand, both of which increase costs to individual households and overall greenhouse gas emissions if the electricity comes from fossil fuel sources such as natural gas.

Outdoor workers are extensively exposed to extreme heat and, with fewer options to cope, they will be affected disproportionately by the impacts of climate change.

New studies for the San Francisco Bay Area and Fresno County find minority and poorer populations, have significantly lower access to common adaptation options for dealing with health threats from climate change, such as tree canopy for shading or car ownership to go to public cooling centers than other segments of the population. Another study finds Los Angeles to have a disproportionately large number of highly vulnerable people at risk during extreme heat.

Focus on adaptation planning is growing in public health departments across the state. Several universities and the California Department of Public Health are working together to identify climate-related health risks and those groups particularly susceptible to risks such as extreme heat and air pollution.

Higher temperatures also increase ground-level ozone levels. Furthermore, wildfires can increase particulate air pollution in the major air basins of California. Together, these consequences of climate change could offset air quality improvements that have successfully reduced dangerous ozone concentrations. Given this "climate penalty," as it is commonly called, air quality improvement efforts in many of California's air basins will need to be strengthened as temperatures increase in order to reach existing air quality goals.

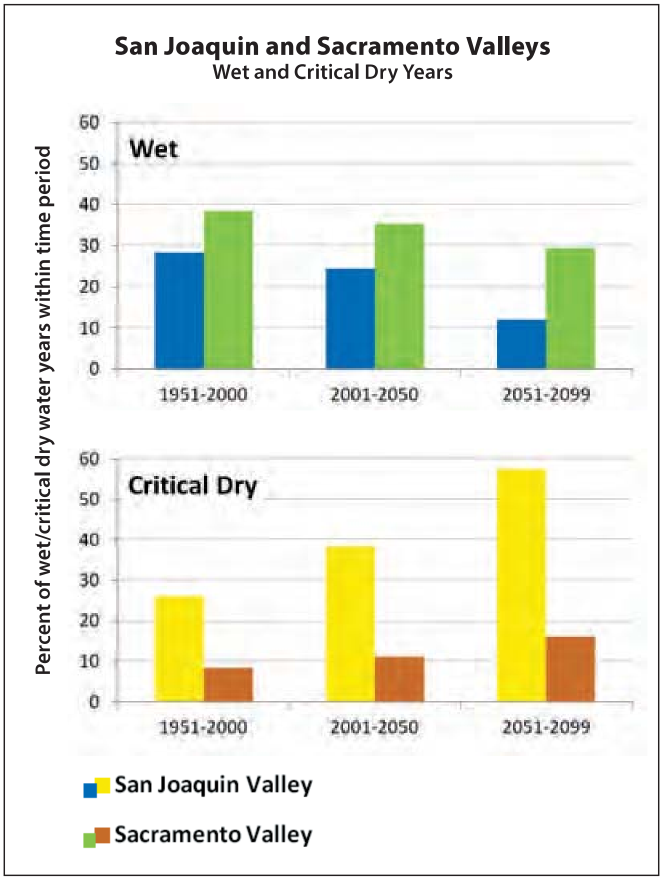
Water: Every Drop Counts

In California's semi-arid, Mediterranean climate, safe and reliable supplies of clean water are critical. The state's urgent water management challenges posed by climate change include increasing demand from a growing population as temperatures rise, earlier snowmelt and runoff, and faster-than-historical sea-level rise threatening aging coastal water infrastructure and levees in the Sacramento-San Joaquin Delta. Climate change effects on water supplies and stream flows are also expected to increase competition among urban and agricultural water users and environmental needs. Finally, increases in extreme precipitation and runoff are likely due to warmer storms and extreme "atmospheric rivers" — narrow bands over the Pacific Ocean that carry huge amounts of moisture into the state in occasional series of winter storms.

Water studies in the third assessment analyze water management options under these expected changes, and also examine the sector's sensitivity and capacity to adapt to climate change. They explore feasible adaptation strategies at the state and local levels, revealing major barriers hindering adaptation. Policies to overcome these barriers will be needed to ensure that Californians are well-prepared for climate change.

One study illustrates problems in California's water supply allocations (the amount of water that goes to different users each year) if the current allocation criteria and decision-making procedures continue to be used as the climate changes. Many water management decisions in California rely on a classification scheme of the year's water availability (distinguishing "wet," "normal," "dry," and "critically dry" years). Depending on what type of year it is, different amounts of water are allocated among the state's many users. Using the current allocation thresholds, the study projects changes in stream flow for the Sacramento and San Joaquin valleys, showing that by the latter half of the 21st century critically dry water years could occur substantially more often (8 percent more frequently in the Sacramento Valley and 32 percent more often in the San Joaquin Valley), compared to the historical period (1951-2000). During such critically dry years it is nearly impossible to satisfy the state's water needs, including those for agricultural and environmental purposes, which could affect the farm economy and endangered species. Adaptive changes in the water allocation framework could help lessen this problem.

The single most important step toward preparing for climate change in the water sector is to implement an accurate monitoring system that records water diversions.



Reductions in stream flow by the latter half of the century are estimated to lead to more frequent critically dry water years, resulting in less water available to support already threatened ecosystems and species.

The third assessment also highlights notable progress in adapting water management in California, but difficult legal and political barriers impede implementation of some of the most feasible and potentially most effective strategies. Clearly, adaptation requires much more than technical solutions; societal barriers must be addressed in appropriate forums to be overcome with durable commitments.

Another study, focusing on legal and institutional barriers to adaptation suggests that climate change will exacerbate ongoing conflicts over water by increasing demand and decreasing supply. The study concludes that the most important step toward preparing for climate change would be to implement and enforce an accurate monitoring system that records who is diverting water, in what quantities, and when. This would significantly improve decision-making compared to the current water management in which groundwater is essentially unmanaged.

INFORM: A decade of collaboration between scientists and California water managers has led to the development of a probabilistic-based decision-support software, called INFORM (Integrated Forecast and Reservoir Management), that has shown demonstrable success in increasing water supply availability and hydropower generation from the state's largest reservoirs in Northern California, while still protecting the public from flooding. These reservoirs represent about 68 percent of the total storage capacity in the Sacramento and San Joaquin region, and about two-thirds of the state's drinking water. Some of the world's most productive farmlands also depend on that water for irrigation. A new study tests this probabilistic forecasting system as a tool to support water utilities in their management efforts. To fully implement such a system in California, major obstacles would have to be overcome, including challenges in interagency coordination and cooperation at the local level, operational rules, norms of professional behavior, and legal barriers at the federal level, which may require Congressional action.

Smaller water agencies that do not import water but instead rely mostly on local sources can adapt to climate change by developing groundwater drought reserves to buffer against shortages.

For water districts where imported water is either limited or unavailable, and that rely on local sources for water, groundwater reserves are an especially important adaptation strategy in the face of increasing risk of drought. California has always relied heavily on its groundwater when surface water supplies have dwindled during droughts. One study of smaller water districts in Central and Northern California show that regulatory constraints on using surface water supplies, along with stakeholder and agency leadership, were key motivators to move toward more sustainable groundwater management and the establishment of reserves. Such efforts support adaptive water management at the local level.

Delta Subsidence and Levee Safety

The Sacramento-San Joaquin Delta is a critical freshwater resource for California and its reliability depends significantly upon the integrity of the earthen levees protecting dozens of Delta islands. These levees protect not only much of the state's water supply, but also important energy infrastructure such as underground natural gas storage fields, pipelines and transmission lines. Farmland, homes, and endangered species are also at risk. In the event of a levee failure — whether as a result of an earthquake or overtopping during storms — brackish water would fill the Delta lowlands and rapidly degrade freshwater quality and supplies and threaten the other assets. Consequently, it is critical to monitor the relationship between levee elevations and sea level. The island interiors have sunk from elevations near sea level at the end of the 1800s to current elevations as much as 15 feet below sea level. Sinking (or "subsidence") of delta islands has been attributed historically to compaction and loss of peat soils drained for agricultural purposes. A new study using satellite radar data finds that in addition to localized subsidence, the entire Delta may be sinking. Land subsidence together with rising sea levels may cause water levels to reach dangerous levels as early as 2050. However, ongoing monitoring of levee heights may provide sufficient advance notice to prioritize and take necessary protective measures.

More than 1,300 miles of levees currently protect islands in the Sacramento-San Joaquin River Delta. As the climate changes, altered river flows, higher sea levels, and changes in wind are likely to increase the risk of levee failure. In addition, the entire Delta region appears to be sinking, which may cause many levees to fall below safety design thresholds as early as 2050 unless additional protective measures are taken.

Difficult legal and political barriers impede implementing the most effective adaptation strategies.

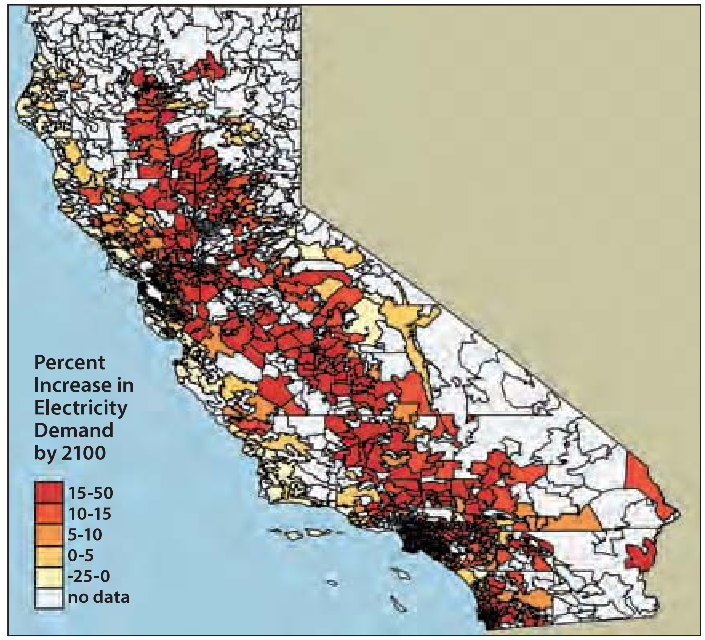
Energy: Meeting Growing Demand in a Warming World

Increases in average temperature and higher frequency of extreme heat events combined with new residential development across the state will drive up the demand for cooling in summertime. This growing demand will only partially be offset by decreased heating needs in the wintertime and improved energy efficiency. Californians derive about 15 percent of their electricity from hydropower with more than half of this energy generation occurring above 1,000 feet elevation in relatively small systems. Hydroelectricity is a premium asset during the peak-demand summer months. Past studies have already shown that this hydropower generation is declining, and it is expected to decrease more substantially as climate change progresses due to reduced snowpack, earlier runoff, and higher rates of evaporation.

Energy demand is increasing. The third assessment confirms that climate change will increase demand for cooling in the increasingly hot and longer summer season and decrease demand for heating in the cooler season. California's residential sector uses relatively little electricity for heating, and it is therefore expected that the demand for electricity will increase as households operate existing air conditioners more frequently. It is also expected that in many regions where currently there are few air conditioners, more will be installed. Using household level data to estimate how electricity consumption responds to hotter weather, researchers can project increases in annual electricity consumption at the ZIP code level. Their study finds that predominantly non-minority and wealthier ZIP codes are projected to experience smaller increases in energy consumption, while ZIP codes with a higher share of Latino and lower-income residents are projected to experience larger increases in energy use. This may in part be driven by the fact that wealthier people more often live near the coast where cooler ocean breezes reduce the amount of warming. In the near term, higher temperatures in the next decade could increase demand by up to 1 Gigawatt during hot summer months — a substantial amount that would require the construction of one large new power plant in California or the purchase of costly peak power from external sources.

Climate change will increase demand for cooling in the increasingly hot and longer summer season.

Increase in Electricity Demand by the End of this Century
(higher emissions scenario, compared to historical conditions, in percent)



Higher summer temperatures will notably increase the annual household electricity consumption for air conditioning (by ZIP code). Because inland areas will warm more, and are often home to less wealthy populations, energy use will grow most in the hottest areas where those who can least afford it reside.

Climate warming will decrease hydropower generation mostly in the summer months when hydropower generation is needed most to meet peak demand.

Energy supply from hydropower is generated in more than 150 high-elevation hydropower plants (above 1,000 feet). These units supply about 75 percent of all the hydropower produced in California. The small size of the high-elevation hydropower reservoirs allows little flexibility in operations and might make high-elevation hydropower plants more vulnerable to climate change and reduced snowpack. Researchers have developed a multi-purpose water resources management simulation model for the western slope of the Sierra, from the Feather River watershed in the north to the Kern River watershed in the south. Their study finds — importantly — that electricity generation will be reduced substantially in the summer when hydropower generation is needed most to meet peak demand.

For low-elevation hydropower, typically associated with larger reservoirs, there are ways to reduce climate change impacts using modern hydrological forecasting tools. The INFORM project demonstrates that probabilistic hydrologic forecasting could substantially reduce the negative impacts of climate change on water supply, hydropower generation, revenues, and flood protection. Managers of high-elevation hydropower plants have some, but generally less, flexibility to manage water adaptively. For example, changing the operating rules of the reservoirs can help minimize revenue losses in case of a drier, warmer climate with lower water flows. If hydropower plants were to generate 20 percent less power annually in a drier, hotter climate, they could see revenue losses of 8 percent, compared to current average revenues. While the high-elevation hydropower system can benefit from additional storage and generation capacities, more studies are needed to determine whether the expected increase in revenues will outweigh the expected economic and environmental costs of potential energy and storage capacity expansions.

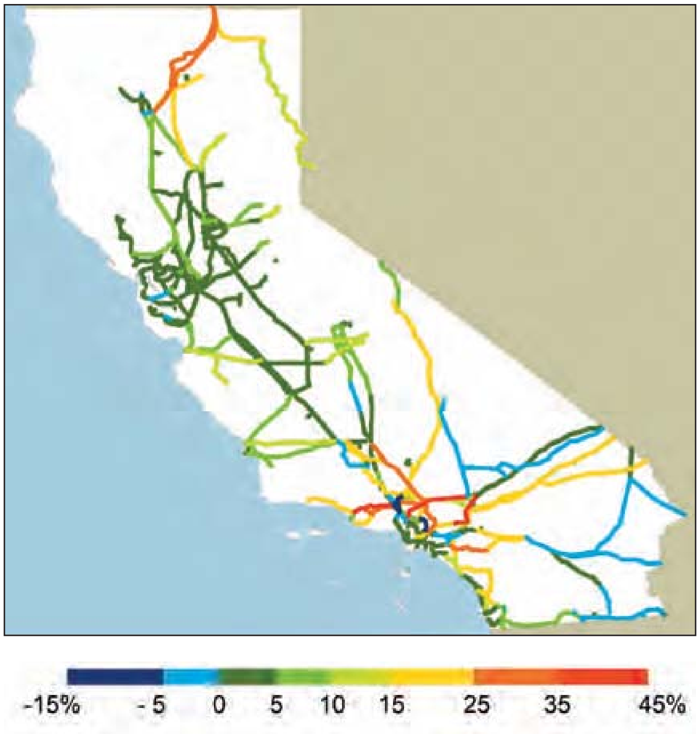
High-elevation hydropower is particularly vulnerable to climate change and reduced snowpack.

Transmission of electricity will also be affected by climate change. In addition to reduced efficiency in the electricity generation process at natural gas plants, reduced hydropower generation, losses at substations, and increasing demand during the hottest periods (resulting in more than 17 Gigawatts or 38 percent of additional capacity needed by 2100 due to higher temperatures alone), transmission lines lose 7 percent to 8 percent of transmitting capacity in high temperatures while needing to transport greater loads. This means that more electricity needs to be produced to make up for the loss in capacity and the growing demand.

In addition, key transmission corridors are vulnerable to increased frequency of wildfire. For example, one study in the third assessment finds a 40 percent increase in the probability of wildfire exposure for some major transmission lines, including the transmission line bringing hydropower from the Pacific Northwest into California during peak demand periods. Other key transmission lines at high risk bring power to the Los Angeles Metropolitan Area. These risks can be reduced by introducing more locally produced and distributed electricity.

Key electricity transmission corridors are increasingly vulnerable to increased frequency of wildfire.

Wildfire Risk to Electricity Transmission Lines
(Changing probability in fire risk by end of century compared to 1961-1990, higher emissions scenario)



Climate change will bring earlier snowmelt, higher temperatures, and longer dry periods over a longer season — exactly the conditions that increase the risk of wildfire. With more development and critical transmission lines at risk, property damages and firefighting costs could rise dramatically.

Coasts: Faster Rising Seas

Coastal counties in California are home to about 32 million people, generating billions in revenues from industry, shipping, tourism and other economic activities that support millions of jobs. Every California coastal community will experience the impacts of sea-level rise in the decades ahead, and some are already feeling the effects. Previous research estimated that property worth $50 billion and at least 260,000 people are currently located in areas vulnerable to a 100-year coastal flood (a flood that has a 1 percent chance of occurring in any single year). If population and development were kept at today's levels, a 100-year flood in 2100, after a 55-inch sea-level rise, would put at risk 480,000 people and $100 billion of property (in 2000 dollars) along San Francisco Bay and the open coast.

As early as 2050, today's 100-year storm event could strike annually on average as a result of sea-level rise.

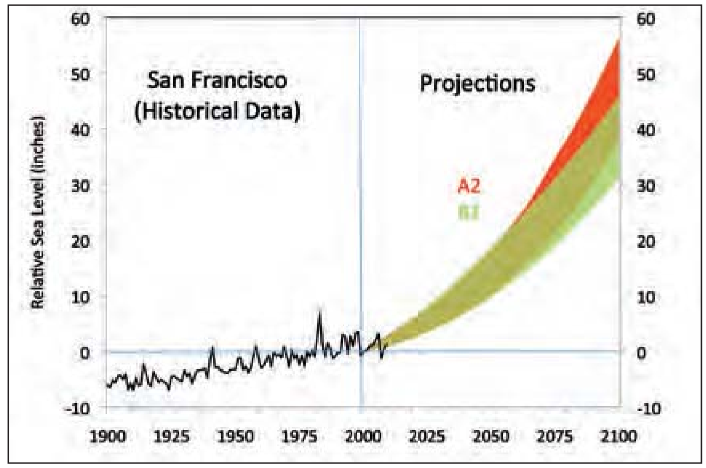
A wide range of critical infrastructure — such as schools, roads, hospitals, emergency facilities, wastewater treatment plants, airports, ports, and energy facilities — will also be at increased risk of flooding. Although reducing heat-trapping greenhouse gas emissions can reduce the magnitude of sea-level rise over the very long term (hundreds of years), adaptation is the only way to deal with the impacts from sea-level rise that cannot be avoided.

Sea level along California's coastline has risen about seven inches in the last century. This rate is expected to accelerate considerably in the future. Assuming that sea-level changes along the California coast continue to track global trends, sea level along the state's coastline in 2050 could be 10-18 inches higher than in 2000, and 31-55 inches higher by the end of this century. This represents a four- to eightfold increase in the rate of sea-level rise over that observed in the last century.

Besides global warming, sea level is driven even higher during certain times — such as when high tides coincide with winter storms or during El Niño events. Past experience shows that such extreme high sea levels, combined with high winds and big waves running up the beach, can cause severe flooding and erosion of beaches and cliffs. While wave extremes may not appreciably increase over the course of this century, higher sea levels ensure that waves and storms will cause more erosion damage than in the past.

The third assessment refines our understanding of the extent and timing of flooding from projected sea-level rise, showing that wind and waves could make coastal storms more damaging. As early as 2050, given current projections of sea-level rise, today's 100-year storm could occur once every year. Moreover, the risk from flooding in coastal counties is unevenly distributed with low-income and minority communities particularly vulnerable in some areas.

Sea-level rise: Historical Trend and Future Projections
1900-2100 under a Higher (A2) and Lower (B1) Emissions Scenario



Sea level along the California coast could be 10-18 inches higher in 2050 than in 2000, and 31-55 inches higher by the end of this century (depending on the emissions scenario). This represents a fourfold to eightfold increase in the rate of sea-level rise compared to what has been experienced historically.

More sophisticated mapping and modeling techniques used in the San Francisco Bay have vastly improved our ability to predict the location and extent of flooding by taking into account the flow of water and the vertical height of structures such as roads, levees, and seawalls. In some instances, this new technique reveals that fewer areas might be inundated in the future if these protective structures are maintained and other still vulnerable areas can be more clearly identified. In addition to risks of property damage, coastal storms combined with higher sea levels could have devastating effects on the ability of emergency responders to reach remote communities during disasters. Using more sophisticated maps of flood risk, scientists estimate that during a 100-year flood with just 16 inches of sea-level rise, 23 emergency responder fire stations in the

Risk from flooding in coastal counties is unevenly distributed, with low-income and minority communities particularly vulnerable in some areas.

New decision-support tools that incorporate sea-level rise into investment decisions for upgrading coastal infrastructure are vital to California's economy.

region could become inaccessible. Findings also show how extreme events with higher sea levels could lead to significantly longer driving times as some transportation corridors could be cut off. Adaptation measures that protect or relocate critical infrastructure, while expensive, could reduce the vulnerability of the transportation sector. Other coastal regions such as Los Angeles and Santa Barbara could similarly benefit from such advanced mapping tools.

Sea-level rise and associated coastal flooding are expected to put critical infrastructure at risk, including ports that support the economy and provide critical goods to the state and nation. How to alter port infrastructure to prepare for serious risks with low or unknown probability is a major challenge because substantial financial investments are at stake. The optimal time to alter infrastructure is during scheduled upgrades. One study in the third assessment applies a new approach to facilitate decision-making by port authorities in Los Angeles by incorporating low-probability high-impact uncertainties into planning for infrastructure upgrades. It shows that the costs of upgrading infrastructure for extreme sea-level rise at this time are too high to warrant incorporation for most of the facilities analyzed. However, the approach proves useful in helping the port authority to use sea-level rise scenarios to determine the most robust course of action in a scientifically informed way. Future infrastructure placement and upgrade decisions in Los Angeles and elsewhere will benefit from using a similar approach.

A statewide survey of coastal managers in 2011 updates a previous effort that tracked progress on adaptation in coastal California. Findings show a remarkable increase in awareness, concern, and understanding about climate change impacts and the need to adapt. But planning for the future with climate change in mind is still in the very early stages. The most familiar strategies to deal with sea-level rise are those that were used historically such as "coastal armoring," while more innovative approaches such as "planned retreat" and integrating natural ecosystems as buffers against sea-level rise and storms ("ecosystem-based adaptation") are less familiar. Findings are in line with results of a detailed set of case studies of local government and regional adaptation processes in San Francisco Bay, which show that communities are just beginning adaptation planning. Despite economic constraints and other obstacles, coastal communities with strong leadership and commitment to collaboration and communication are making important progress in preparing for the future.

Flooding Threatens Critical Transportation Routes

Emergency Response Delays Increase Vulnerability for Local Residents

Improved elevation data and mapping and modeling techniques better capture existing shoreline protection structures and more clearly identify the most vulnerable transportation access and connection points. In Richmond, emergency response could be delayed (dark orange, indicating delays up to nine minutes) or become unavailable (black) due to roadway flooding as shown for one area of the city in the inset aerial photo.

Ecosystems: Changing Landscapes, Vulnerable Species, More Fires

California is one of the most ecologically diverse places in the world. The state's ecosystems also provide a wide spectrum of goods and services supporting the economy of California and human well-being, including fresh water, fertile soil, biological and genetic diversity, crop pollination, carbon storage, climate stabilization, and recreational opportunities. All of these values and benefits can be lost when species are lost or ecosystems become unhealthy and fragmented, or burn in wildfires.

Studies from the third assessment refine estimates of future wildfires, this time also considering various population growth scenarios. Several studies have helped generate a better understanding of how California's ecosystems are sensitive to climate change and how natural resource managers can assist in their adaptation.

An increase in the frequency and extent of wildfires due to a hotter and possibly drier future, leading to significant property damage to homes, was already established in previous studies. The extent of the increased economic loss from fire, however, also depends on population growth and development in fire-prone areas. Studies from the third assessment refine the estimates by exploring the varied effects of emissions scenarios, population growth, and exposure at the wildland–urban interface.

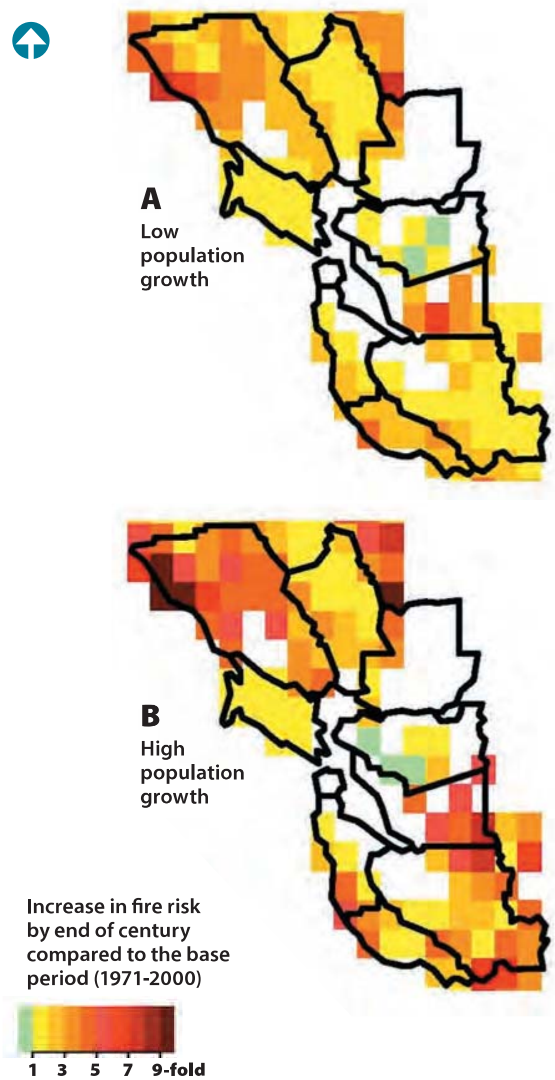
Wildfire risk is expected to increase — even under a lower emissions scenario — almost everywhere in the state. By 2050, annual fire damage could be between $200 million and $2.5 billion, largely driven by differences in human development at the wildland–urban interface.

Even with lower emission levels, wildfire risk still increases throughout most of the state. But the extent to which wildfire risk increases depends also on the way human development advances at the wildland–urban interface. In some instances, this factor is even more important than climate change alone. The most extreme increases in residential fire risks result from a combination of high-growth/high-sprawl/warmer-drier climate change scenarios, especially in San Francisco Bay and Southern California counties.

Improving knowledge of California's species and ecosystems provides a deeper understanding of the services they provide to society. Studies in the third assessment improve this understanding, especially which species and habitats are most exposed, sensitive, and able to adapt to climate change over time. They also reveal adaptation options specifically geared toward addressing underlying vulnerabilities, thus identifying and helping to prioritize management actions.

Several studies focus on how vegetation could shift with climate change and the capacity of species to migrate and keep up with geographic changes. We now know that

Wildfire Risk in San Francisco Bay under Different Population Growth Scenarios



Fire risk is expected to increase in much of the San Francisco Bay Area. Population growth will be a major factor, even if little changes at the wildland–urban interface. Yellow hues indicate smaller increases in fire risk, and darker reds and browns indicate greater increases compared to the risk during the base period (1971-2000). Green represents reductions in risk, white indicates areas that were not modeled.

Identifying migration corridors is critically important: As species try to keep pace with changing climate conditions, their chance of survival is greater when they can reach more suitable habitat.

ecological impacts of climate change could be more severe than anticipated if species are unable to overcome physical barriers (such as human settlements) to migrate to areas with suitable climatic conditions. Identifying migration corridors has important practical applications for land use planning. Areas that may not be of particular ecological importance at present and that may be considered for development could play a key role in the preservation of ecologically rich conditions in California as the climate changes.

To the extent that there are no suitable habitats nearby that species can reach on their own, managers may need to assist them in relocating to fitting habitats elsewhere.

Another study uses 100 years of historical observations of species behavior to understand what could happen in the future. Findings show that climate is changing conditions so rapidly that some vegetation cannot keep pace. In fact, some climates that currently still exist (such as alpine climates) could disappear entirely in the future, while other regional climates (such as desert climates) could expand significantly, resulting in some species losing their habitats and others expanding theirs. To the extent that there are no similar suitable habitats nearby that species can reach on their own, managers may need to assist them in relocating to new suitable environments.

California's Native Freshwater Fish

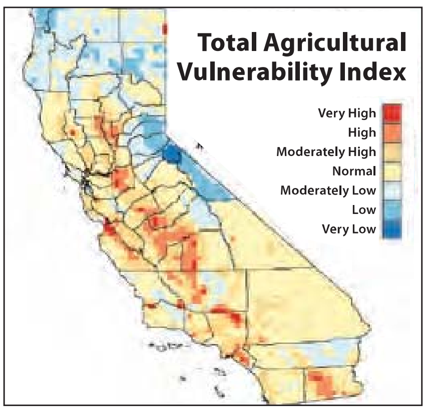
Many of California's 121 native freshwater fish species are already in decline and are particularly vulnerable to climate change, with 83 percent being at high risk of extinction as the climate changes. Commercially important species, such as coho salmon and steelhead trout, are particularly at risk for extinction because they require cold water below 72°F. In contrast, the 43 non-native species examined appeared to fare much better with many thriving and expanding their range, and only 19 percent falling into the high-vulnerability category. Managing invasive species, providing shading along river banks, and reducing other stresses on freshwater fish are among the most important adaptation options.

Agriculture: Vulnerable but Adaptive

Agriculture in California generates more than $30 billion per year, the highest crop value in the nation, provides more than 1 million jobs, and serves as an important source of the nation's food supply. The sector is already under stress from competing and growing urban and environmental water demands and continuing development on agricultural land. Climate change is expected to exacerbate stresses on the agricultural sector. Changes in temperature and water availability — annual and seasonal shifts as well as extremes — affect both crop yield and quality, making the sector highly sensitive to climate change.

Indirect impacts will also take a toll, including possible further decreases of pollinators and increases of pests and disease. Studies in previous assessments established that many impacts on perennials (such as peaches, strawberries, and almonds) vary by crop, while nearly all annual crops (such as wheat and sunflowers) are expected to decline under climate change. Agriculture will continue to be an important economic sector but some losses will be incurred and the ultimate impacts will be a function of how effectively farmers adopt adaptation measures.

California is one of the nation's largest producers of a diverse set of crops. While many factors will determine the choice of crops and production costs, many experts believe costs to consumers could go up.



Agriculture varies in its vulnerability to climate change. The map shows a composite index of vulnerability revealing the Sacramento-San Joaquin Delta, Salinas Valley, Imperial Valley, and the corridor between Merced and Fresno as particularly vulnerable. Underlying factors vary among regions, including differences in climate, crops, land use and socioeconomic factors.

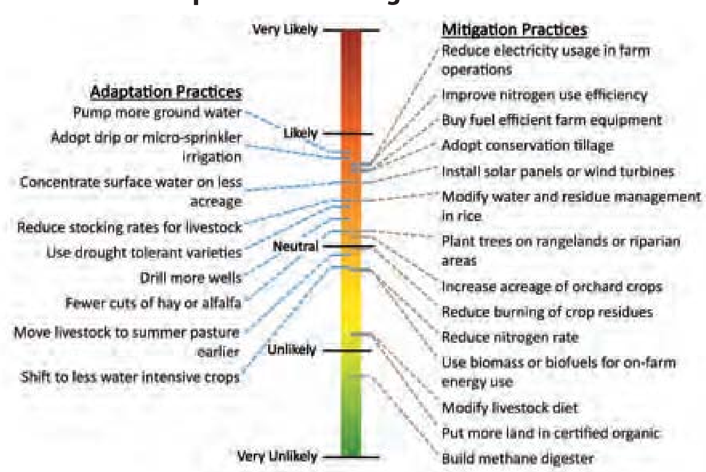
Planning for agricultural responses to climate change in California involves consideration of many factors — biological, environmental and socioeconomic — that influence the sector's vulnerability and resilience. The third assessment advances the understanding of vulnerability at the state and regional levels, reports on farmers' perspectives on adaptation, and highlights potential benefits of innovative adaptation practices that simultaneously contribute to reducing greenhouse gas emissions. Results point to the need for crop-specific and place-based approaches to reducing farmers' vulnerability to climate change.

Innovative practices illustrate mitigation and adaptation opportunities for the agricultural sector. The third assessment highlights farmers' interest in adopting certain adaptation and mitigation options. Some management practices simultaneously achieve co-benefits for both, such as irrigation technologies that provide a reliable water supply and also reduce emissions of nitrous oxide (a greenhouse gas). Other examples include soil carbon storage, renewable energy, and crop diversification in local farming systems. Overall, adopting adaptation strategies that work for specific locations and crops will increase farmers' capacity to manage changes while addressing the needs of natural resources and social issues such as farm labor and urbanization pressure.

Some agricultural management practices simultaneously achieve co-benefits for climate change adaptation and mitigation.

One study of Yolo County farmers reveals that growers worry most about a potentially hotter and drier future even though they show little awareness of the industry's vulnerability to climate change. Several strategies show high potential for increasing the sector's resilience, but these require investment and training for farmers.

Average Likelihood of Yolo County Farmers Adopting Adaptation and Mitigation Practices



Yolo County farmers prefer to adopt certain adaptation and mitigation practices over others. However, preferable options may not necessarily be the most effective or reliable over the long term, or may have negative side effects, such as pumping more ground water in times of drought.

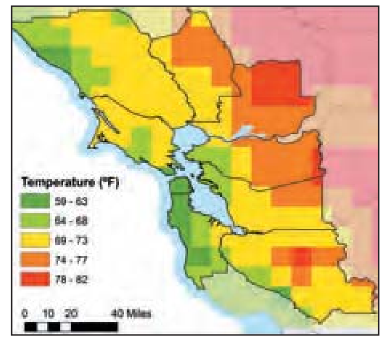
San Francisco Bay: A Regional Focus

The third assessment breaks new ground by explicitly including a regional focus. Eleven studies focus exclusively on the San Francisco Bay Area to integrate findings across sectors and to better support adaptation planning and implementation processes precisely at the level at which most adaptation decisions are made: locally.

The San Francisco Bay Area was selected because of its economic importance to the state, coverage of both rural and urbanized land uses, its diverse coastal and inland geography, and the many climate change risks the nine-county region will experience simultaneously. Also important was the willingness and high interest of regional decision-makers (the Joint Policy Committee) in policy- and management-relevant scientific information. Key climate vulnerabilities were examined for coastal areas, public health, ecosystems, agriculture, wildfire, transportation and energy infrastructure, and water resources.

Local governments face considerable barriers to adaptation. One study offers an in-depth analysis of adaptation initiatives to date in the San Francisco Bay Area (Marin and Santa Clara Counties, the cities of San Francisco and Hayward, and the Bay Area-wide adaptation effort under the Joint Policy Committee). The study reveals institutional and governance issues as the most important barriers for local governments, followed by attitudinal issues and economic hurdles, even in wealthy communities. The study shows that while many issues can be addressed locally, state and federal assistance is needed to ensure that communities can adequately prepare for the impacts of climate change.

Summer Temperatures in San Francisco Bay Area by Mid-Century



Projections of temperature across the Bay Area (under the higher emissions scenario) largely reflect differences in topography and distance from the ocean.

Other studies reveal how differences in social vulnerability make for inequality of impacts. Such studies provide crucial information to local governments for determining where to focus limited resources for adaptive risk management. Equipped with such locally specific information and a history of innovative leadership, the San Francisco Bay Area will be in a good position to create a safe and prosperous future.

Our Resilient Future

Strengthening mitigation: California has been a global and national leader in developing solutions to energy security and climate change. The state's landmark Global Warming Solutions Act (AB 32, passed in 2006) established greenhouse gas emission reduction targets for 2020. A separate Executive Order established a goal for even more dramatic reductions (80 percent below 1990 levels) by 2050 and beyond.

A study in the third assessment shows both the challenges for the existing energy system emerging from climate change and the possibilities for moving toward clean, renewable energy and more robust, distributed electricity production and transmission. Given the State's commitment to reducing emissions, the energy sector is changing rapidly. This presents both challenges and tremendous opportunities to change the sector to be more resilient to climate change. Solar photo-voltaic and wind energy are less vulnerable than conventional power plants to climate change, and these renewable sources use much less water than fossil fuel or nuclear power plants. These are important advantages in light of projected climate changes for California and the western United States.

Advancing adaptation: At the same time, the State has recognized the need to adapt to climate change impacts that can no longer be avoided. Currently, the State is developing its second adaptation strategy, acknowledging the steady progress made since the first one in 2009 and recognizing the enormous challenges ahead. The strategy will need to be updated periodically in the future. The many adaptation planning efforts underway in virtually every State agency, in local communities such as Chula Vista, San Diego, Los Angeles, Santa Barbara, Santa Cruz, San Francisco, Hayward, Marin County, and others, as well as in private businesses suggest that CEOs, elected officials, planners, and resource managers understand the reality that California and the world is facing.

In fact, the latest climate science makes clear that State, national and global efforts to mitigate climate change must be accelerated to limit global warming to levels that do not endanger basic life-support systems and human well-being. Success in mitigation will keep climate change within the bounds that allow ecosystems and society to adapt without major disruptions. Further advances in integrated climate change science can inform California's and the world's climate choices and help ensure a resilient future.

Thank you! **More than 120 researchers from California research institutions and others participated in the 2012 California Vulnerability and Adaptation Study. Space limitations allow only the principal researchers to be listed here, in alphabetical order, but the efforts of each and every researcher are gratefully acknowledged.**

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