20. Southwest

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Key Messages

1. **Snowpack and streamflow amounts are projected to decline in parts of the Southwest, decreasing surface water supply reliability for cities, agriculture, and ecosystems.**
2. **The Southwest produces more than half of the nation's high-value specialty crops, which are irrigation-dependent and particularly vulnerable to extremes of moisture, cold, and heat. Reduced yields from increasing temperatures and increasing competition for scarce water supplies will displace jobs in some rural communities.**
3. **Increased warming, drought, and insect outbreaks, all caused by or linked to climate change, have increased wildfires and impacts to people and ecosystems in the Southwest. Fire models project more wildfire and increased risks to communities across extensive areas.**
4. **Flooding and erosion in coastal areas are already occurring even at existing sea levels and damaging some California coastal areas during storms and extreme high tides. Sea level rise is projected to increase as Earth continues to warm, resulting in major damage as wind-driven waves ride upon higher seas and reach farther inland.**
5. **Projected regional temperature increases, combined with the way cities amplify heat, will pose increased threats and costs to public health in southwestern cities, which are home to more than 90% of the region's population. Disruptions to urban electricity and water supplies will exacerbate these health problems.**

Introduction

The Southwest is the hottest and driest region in the U.S., where the availability of water has defined its landscapes, history of human settlement, and modern economy. Climate changes pose challenges for an already parched region that is expected to get hotter and, in its southern half, significantly drier. Increased heat and changes to rain and snowpack will send ripple effects throughout the region's critical agriculture sector, affecting the lives and economies of 56 million people – a population that is expected to increase 68% by 2050, to 94 million. Severe and sustained drought will stress water sources, already over-utilized in many areas, forcing increasing competition among farmers, energy producers, urban dwellers, and plant and animal life for the region's most precious resource.

The region's populous coastal cities face rising sea levels, extreme high tides, and storm surges, which pose particular risks to highways, bridges, power plants, and sewage treatment plants. Climate-related challenges also increase risks to critical port cities, which handle half of the nation's incoming shipping containers.

Agriculture, a mainstay of the regional and national economies, faces uncertainty and change. The Southwest produces more than half of the nation's high-value specialty crops, including certain vegetables, fruits, and nuts. The severity of future impacts will depend upon the complex interaction of pests, water supply, reduced chilling periods, and more rapid changes in the seasonal timing of crop development due to projected warming and extreme events.

Climate changes will increase stress on the region's rich diversity of plant and animal species. Widespread tree death and fires, which already have caused billions of dollars in economic losses, are projected to increase, forcing wholesale changes to forest types, landscapes, and the communities that depend on them (See also Ch. 7: Forests).

Tourism and recreation, generated by the Southwest's winding canyons, snow-capped peaks, and Pacific Ocean beaches, provide a significant economic force that also faces climate change challenges. The recreational economy will be increasingly affected by reduced streamflow and a shorter snow season, influencing everything from the ski industry to lake and river recreation.

Observed and Projected Climate Change

The Southwest is already experiencing the impacts of climate change. The region has heated up markedly in recent decades, and the period since 1950 has been hotter than any comparably long period in at least 600 years (Ch. 2: Our Changing Climate, Key Message 3).[1,2,3,4,5] The decade 2001-2010 was the warmest in the 110-year instrumental record, with temperatures almost 2°F higher than historic averages, with fewer cold air outbreaks and more heat waves.[3] Compared to relatively uniform regional temperature increases, precipitation trends vary considerably across the region, with portions experiencing decreases and others experiencing increases (Ch. 2: Our Changing Climate, Key Message 5).[3] There is mounting evidence that the combination of human-caused temperature increases and recent drought has influenced widespread tree mortality,[6,7] increased fire occurrence and area burned,[8] and forest insect outbreaks (Ch. 7: Forests).[9] Human-caused temperature increases and drought have also caused earlier spring snowmelt and shifted runoff to earlier in the year.[10]

Regional annual average temperatures are projected to rise by 2.5°F to 5.5°F by 2041-2070 and by 5.5°F to 9.5°F by 2070-2099 with continued growth in global emissions (A2 emissions scenario), with the greatest increases in the summer and fall (Figure 20.1). If global emissions are rapidly reduced (as in the B1 emissions scenario), projected temperature increases are 2.5°F to 4.5°F (2041-2070), and 3.5°F to 5.5°F (2070-2099). Summertime heat waves are projected to become longer and hotter, whereas the trend of decreasing wintertime cold air outbreaks is projected to continue (Ch. 2: Our Changing Climate, Key Message 7).[11,12] These changes will directly affect urban public health through increased risk of heat stress, and urban infrastructure through increased risk of disruptions to electric power generation.[13,14,15,16] Rising temperatures also have direct impacts on crop yields and productivity of key regional crops, such as fruit trees.

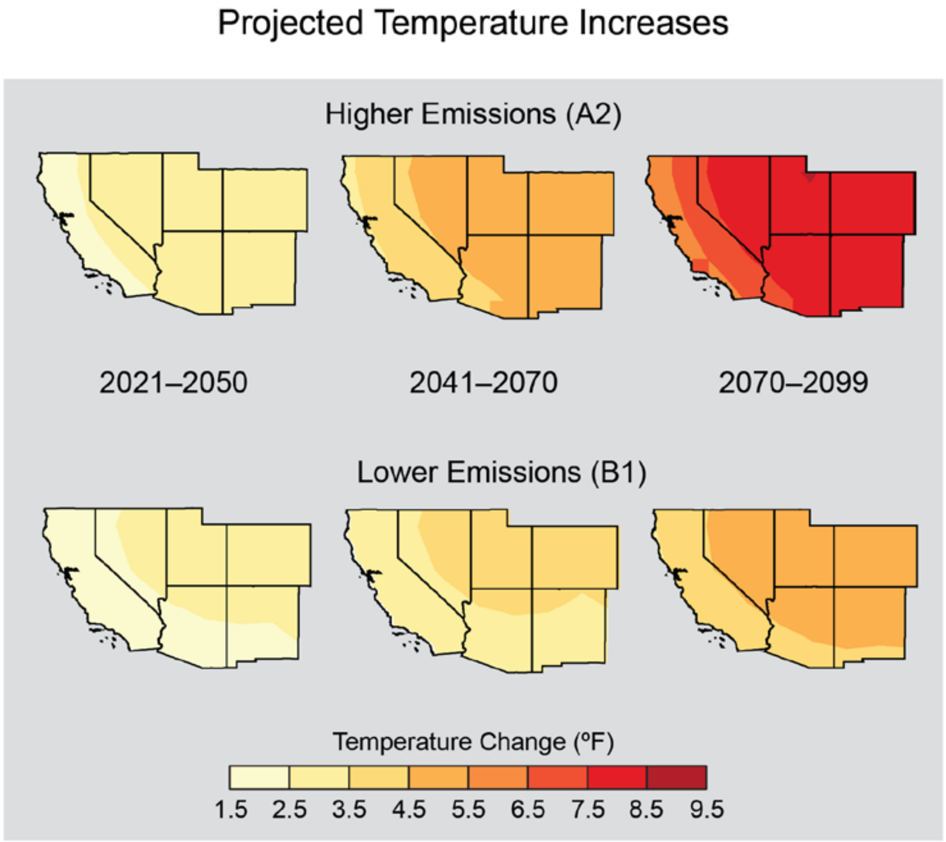

Figure 20.1: Projected Temperature Increases

Caption: Maps show projected changes in average, as compared to 1971-1999. Top row shows projections assuming heat-trapping gas emissions continue to rise (A2). Bottom row shows projections assuming substantial reductions in emissions (B1). (Figure source: adapted from Kunkel et al. 2013[17]).

Projections of precipitation changes are less certain than those for temperature.[17,18] Under a continuation of current rising emissions trends (A2), reduced winter and spring precipitation is consistently projected for the southern part of the Southwest by 2100 as part of the general global precipitation reduction in subtropical areas. In the northern part of the region, projected winter and spring precipitation changes are smaller than natural variations. Summer and fall changes are also smaller than natural variations throughout the region (Ch. 2: Our Changing Climate, Key Message 5).[17] An increase in winter flood hazard risk in rivers is projected due to increases in flows of atmospheric moisture into California's coastal ranges and the Sierra Nevada (Ch. 3:

Water).[19] These “atmospheric rivers” have contributed to the largest floods in California history,[20] and can penetrate inland as far as Utah and New Mexico.

The Southwest is prone to drought. Southwest paleoclimate records show severe mega-droughts at least 50 years long.[21] Future droughts are projected to be substantially hotter, and for major river basins such as the Colorado River Basin, drought is projected to become more frequent, intense, and longer lasting than in the historical record.[18] These drought conditions present a huge challenge for regional management of water resources and natural hazards such as wildfire. In light of climate change and water resources treaties with Mexico, discussions will need to continue into the future to address demand pressures and vulnerabilities of groundwater and surface water systems that are shared along the border.

Box: Vulnerabilities of Native Nations and Border Cities

The Southwest’s 182 federally recognized tribes and communities in its U.S.-Mexico border region share particularly high vulnerabilities to climate changes such as high temperatures, drought, and severe storms. Tribes may face loss of traditional foods, medicines, and water supplies due to declining snowpack, increasing temperatures, and increasing drought (see also Ch 12: Indigenous Peoples).[22] Historic land settlements and high rates of poverty – more than double that of the general U.S. population[23] – constrain tribes’ abilities to respond effectively to climate challenges.

Most of the Southwest border population is concentrated in eight pairs of fast-growing, adjacent cities on either side of the U.S.-Mexico border (like El Paso and Juarez) with shared problems. If the 24 U.S. counties along the entire border were aggregated as a 51st state, they would rank near the bottom in per capita income, unemployment, insurance coverage for children and adults, and high school completion.[24] Lack of financial resources and low tax bases for generating resources have resulted in a lack of roads and safe drinking water infrastructure, which makes it more daunting for tribes and border populations to address climate change issues. These economic pressures increase vulnerabilities to climate-related health and safety risks, such as air pollution, inadequate erosion and flood control, and insufficient safe drinking water.[25]

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Reduced Snowpack and Streamflows

Snowpack and streamflow amounts are projected to decline in parts of the Southwest, decreasing surface water supply reliability for cities, agriculture, and ecosystems.

Winter snowpack, which slowly melts and releases water in spring and summer, when both natural ecosystems and people have the greatest needs for water, is key to the Southwest's hydrology and water supplies. Over the past 50 years across most of the Southwest, there has been less late winter precipitation falling as snow, earlier snow melt, and earlier arrival of most of the year's streamflow.[26,27] Streamflow totals in the Sacramento-San Joaquin, the Colorado, the Rio Grande, and in the Great Basin were 5% to 37% lower between 2001 and 2010 than the 20th century average flows.[3] Projections of further reduction of late winter and spring snowpack, and subsequent reductions in runoff and soil moisture[28,29] pose increased risks to the water supplies needed to maintain the Southwest's cities, agriculture, and ecosystems.

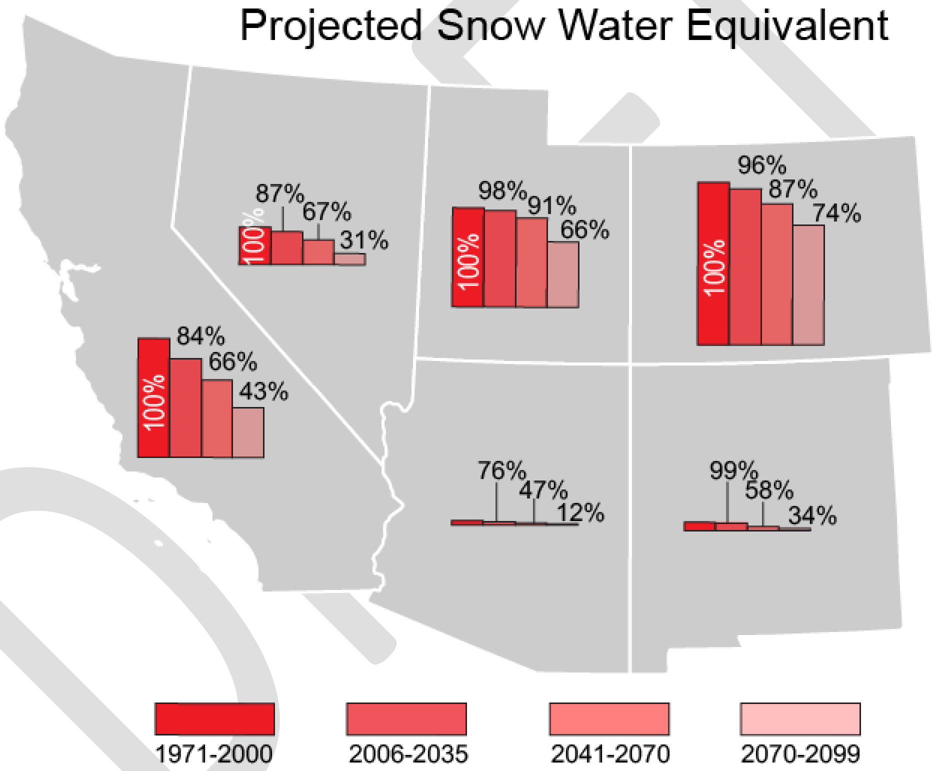

Figure 20.2: Projected Snow Water Equivalent

Caption: Snow water equivalent (SWE) refers to the amount of water held in a volume of snow, which depends on the density of the snow and other factors. Figure shows projected snow water equivalent for the Southwest, as a percentage of 1971-2000, assuming continued increases in global emissions (A2 scenario). The size of bars is in proportion to the amount of snow each state contributes to the regional total; thus, the bars for Arizona are much smaller than those for Colorado, which contributes the most to region-wide snowpack. Declines in peak SWE are strongly correlated with early timing of runoff and decreases in total runoff. For watersheds that depend on snowpack to provide the majority of the annual runoff, such as in the Sierra Nevada and in the Upper Colorado and Upper Rio Grande River Basins, lower SWE generally translates to reduced reservoir water storage. (Data from Scripps Institution of Oceanography).

Temperature-driven reductions in snowpack are compounded by dust and soot accumulation on the surface of snowpack. This layer of dust and soot, transported by winds from lowland regions, increases the amount of the sun's energy absorbed by the snow. This leads to earlier snowmelt and evaporation – both of which have negative implications for water supply, alpine vegetation, and forests.[30,31] The prospect of more lowland soil drying out from drought and human disturbances (like agriculture and development) make regional dust a potent future risk to snow and water supplies.

In California, drinking water infrastructure needs are estimated at $4.6 billion annually over the next 10 years, even without considering the effects of climate change.[32] Climate change will increase the cost of maintaining and improving drinking water infrastructure, because expanded wastewater treatment and desalinating water for drinking are among the key strategies for supplementing water supplies.

Box: The Southwest's Renewable Potential to Produce Energy with Less Water

The Southwest's abundant geothermal, wind, and solar power-generation resources could help transform the region's electric generating system into one that uses substantially more renewable energy. This transformation has already started, driven in part by renewable energy portfolio standards adopted by five of six Southwest states, and renewable energy goals in Utah. California's law limits imports of baseload electricity generation from coal and oil, and mandates reduction of heat-trapping greenhouse gas emissions to 1990 levels by 2020.[33]

As the regional climate becomes hotter and, in parts of the Southwest, drier, there will be less water available for the cooling of thermal power plants,[34] which use about 40% of the surface water withdrawn in the United States.[35] The projected warming of water in rivers and lakes will reduce the capacity of thermal power plants, especially during summer when electricity demand skyrockets.[36] Wind and solar photovoltaic installations could substantially reduce water withdrawals. A large increase in the portion of power generated by renewable energy sources may be feasible at reasonable costs,[37,38] and could substantially reduce water withdrawals (Ch. 10: Energy, Water, and Land).[39]

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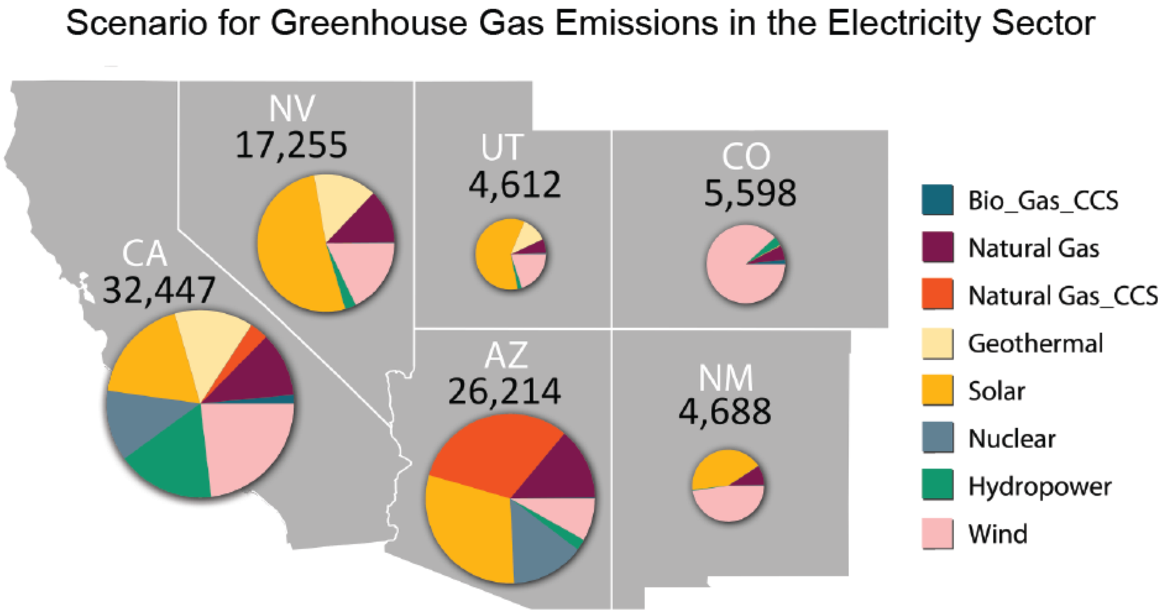

Figure 20.3: Scenario for Greenhouse Gas Emissions in the Electricity Sector

Caption: Major shifts in how electricity is produced can lead to large reductions in heat-trapping gas emissions. Shown is an illustrative scenario in which different energy combinations could by 2050 achieve an 80% reduction of heat-trapping gas emissions from 1990 levels in the electricity sector in the Southwest. For each state, that mix varies, with the circle representing the average hourly generation in megawatts (the number above each circle) from 10 potential energy sources. CCS refers to carbon capture and storage. (Data from Wei et al. 2012, 2013[38,40]).

Conservation efforts have proven to reduce water use, but are not projected to be sufficient if current trends for water supply and demand continue.[41] Large water utilities are currently attempting to understand how water supply and demand may change in conjunction with climate changes, and which adaptation options are most viable.[42,43]

Threats to Agriculture

The Southwest produces more than half of the nation's high-value specialty crops, which are irrigation-dependent and particularly vulnerable to extremes of moisture, cold, and heat. Reduced yields from increasing temperatures and increasing competition for scarce water supplies will displace jobs in some rural communities.

Farmers are renowned for adapting to yearly changes in the weather, but climate change in the Southwest could happen faster and more extensively than farmers' ability to adapt. The region's pastures are rain-fed (non-irrigated) and highly susceptible to projected drought. Excluding Colorado, more than 92% of the region's cropland is irrigated, and agricultural uses account for

79% of all water withdrawals in the region.[44,45,46] A warmer, drier climate is projected to accelerate current trends of large transfers of irrigation water to urban areas,[47,48,49] which would affect local agriculturally dependent economies.

California produces about 95% of U.S. apricots, almonds, artichokes, figs, kiwis, raisins, olives, cling peaches, dried plums, persimmons, pistachios, olives, and walnuts, in addition to other high-value crops.[50] Drought and extreme weather affect the market value of fruits and vegetables more than other crops because they have high water content and because sales depend on good visual appearance.[51] The combination of a longer frost-free season, less frequent cold air outbreaks, and more frequent heat waves accelerates crop ripening and maturity, reduces yields of corn, tree fruit, and wine grapes, stresses livestock, and increases agricultural water consumption.[52,53] This combination of climate changes is projected to continue and intensify, possibly requiring a northward shift in crop production, displacing existing growers and affecting farming communities.[54,55]

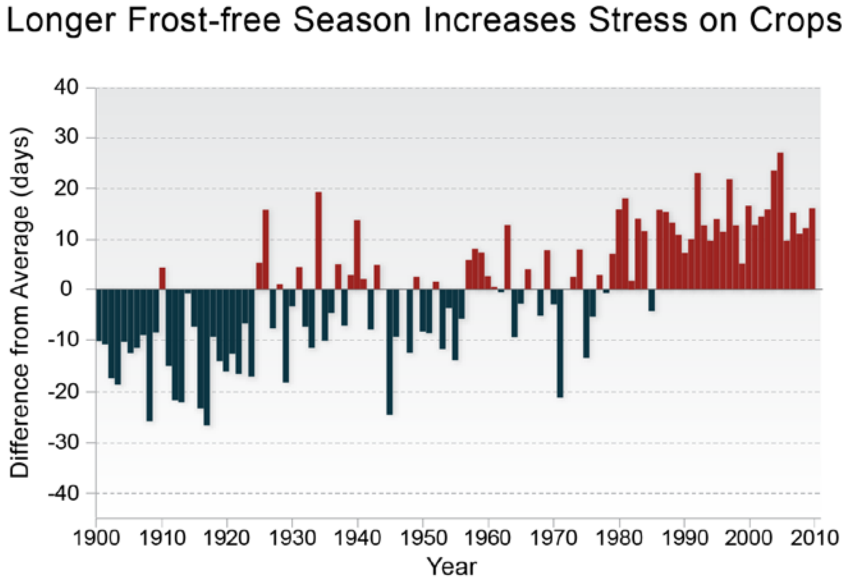

Figure 20.4: Longer Frost-free Season Increases Stress on Crops

Caption: The frost-free season is defined as the period between the last occurrence of 32°F in spring and the first occurrence of 32°F in the subsequent fall. The chart shows significant increases in the number of consecutive frost-free days per year in the past three decades compared to the 1901-2010 average. Increased frost-free season length, especially in already hot and moisture-stressed regions like the Southwest, is projected to lead to further heat stress on plants and increased water demands for crops. Higher temperatures and fewer frost-free days during winter can lead to early bud-burst or bloom of some perennial plants, resulting in frost damage when cold conditions occur in late spring (see Chapter 6, Agriculture); in addition, with higher winter temperatures, some agricultural pests can persist year-round, and new pests and diseases may become established.[47] (Figure source: Hoerling et al. 2013[3]).

Winter chill periods are projected to fall below the duration necessary for many California trees to bear nuts and fruits, which will result in lower yields.[56] Warm-season vegetable crops grown in Yolo County, one of California's biggest producers, may not be viable under hotter climate conditions.[54,57] Once temperatures increase beyond optimum growing thresholds, further increases in temperature, like those projected for the decades beyond 2050, can cause large decreases in crop yields and hurt the region's agricultural economy.

Increased Wildfire

Increased warming, drought, and insect outbreaks, all caused by or linked to climate change, have increased wildfires and impacts to people and ecosystems in the Southwest. Fire models project more wildfire and increased risks to communities across extensive areas.

Fire naturally shapes southwestern landscapes. Indeed, many Southwest ecosystems depend on periodic wildfire to maintain healthy tree densities, enable seeds to germinate, and reduce pests.[58] Excessive wildfire destroys homes, exposes slopes to erosion and landslides, threatens public health, and causes economic damage.[59,60] The $1.2 billion in damages from the 2003 Grand Prix fire in southern California illustrates the high cost of wildfires.[60]

Beginning in the 1910s, the federal government developed a national policy of attempting to extinguish every fire, which allowed wood and other fuels to over-accumulate[61] and urban development to encroach on fire-prone areas. These changes have also contributed to increasing fire risk.

Increased warming due to climate change,[2] drought, insect infestations,[62] and accumulation of woody fuels and non-native grasses[63,64] make the Southwest vulnerable to increased wildfire. Climate outweighed other factors in determining burned area in the western U.S. from 1916 to 2003,[65] a finding confirmed by 3000-year long reconstructions of southwestern fire history.[66,67,68] Between 1970 and 2003, warmer and drier conditions increased burned area in western U.S. mid-elevation conifer forests by 650% (Ch. 7: Forests, Key Message 1).[8]

Drought and increased temperatures due to climate change have caused extensive tree death across the Southwest.[7,69] In addition, winter warming due to climate change has exacerbated bark beetle outbreaks by allowing more beetles, which normally die in cold weather, to survive and reproduce.[70] Wildfire and bark beetles killed trees across 20% of Arizona and New Mexico forests from 1984 to 2008.[62]

Numerous fire models project more wildfire as climate change continues.[64,71,72,73,74] Models project a doubling of burned area in the southern Rockies,[73] and up to a 74% increase in burned area in California,[74] with northern California potentially experiencing a doubling under a high emissions scenario toward the end of the century. Fire contributes to upslope shifting of vegetation, spread of invasive plants after extensive and intense fire, and conversion of forests to woodland or grassland.[63,75] Historical and projected climate change makes two-fifths (40%) of the region vulnerable to these shifts of major vegetation types or biomes; notably threatened are the conifer forests of southern California and sky islands of Arizona.[71]

Prescribed burning, mechanical thinning, and retention of large trees can help some southwestern forest ecosystems adapt to climate change.[5,68,76] These adaptation measures also reduce emissions of the gases that cause climate change because long-term storage of carbon in large trees can outweigh short-term emissions from prescribed burning.[61,77]

Sea Level Rise and Coastal Damage

Flooding and erosion in coastal areas are already occurring even at existing sea levels and damaging some California coastal areas during storms and extreme high tides. Sea level rise is projected to increase as Earth continues to warm, resulting in major damage as wind-driven waves ride upon higher seas and reach farther inland.

In the last 100 years, sea level has risen along the California coast by 6.7 to 7.9 inches.[78] In the last decade, high tides on top of this sea level rise have contributed to new damage to infrastructure, such as the inundation of Highway 101 near San Francisco and backup of seawater into the San Francisco Bay Area sewage systems.

Although sea level along the California coast has been relatively constant since 1980, both global and relative Southwest sea levels are expected to increase at accelerated rates.[78,79,80] During the next 30 years, the greatest impacts will be seen during high tides and storm events. Rising sea level will allow more wave energy to reach farther inland and extend high tide periods, worsening coastal erosion on bluffs and beaches, and increasing flooding potential.[18,81,82,83,84]

The result will be impacts to the nation's largest ocean-based economy, which is estimated at $46 billion annually.[85,86] If adaptive action is not taken, coastal highways, bridges, and other transportation infrastructure (such as the San Francisco and Oakland airports) are at increased risk of flooding with a 16-inch rise in sea level in the next 50 years,[4] an amount consistent with the 1 to 4 feet of expected global increase in sea level (see Ch. 2: Our Changing Climate, Key Message 10). In Los Angeles, sea level rise poses a threat to groundwater supplies and estuaries,[82,87] by potentially contaminating groundwater with seawater, or increasing the costs to protect coastal freshwater aquifers.[88]

Coastal Risks Posed by Sea Level Rise and High Tides

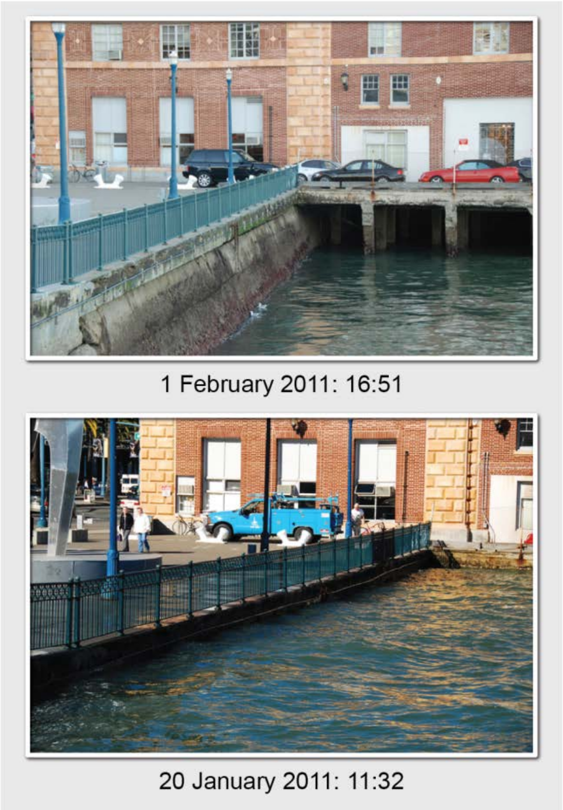

Figure 20.5: Coastal Risks Posed by Sea Level Rise and High Tides

Caption: While king tides are the extreme high tides today, with projected future sea level rise, this level of water and flooding will occur during regular monthly high tides. During storms and future king tides, more coastal flooding and damage will occur. The King Tide Photo Initiative encourages the public to visually document the impact of rising waters on the California coast, as exemplified during current king tide events. Photos show water levels along the Embarcadero in San Francisco, California during relatively normal tides (top), and during an extreme high tide or “king tide” (bottom). King tides, which typically happen twice a year as a result of a gravitational alignment of the sun, moon, and Earth, provide a preview of the risks rising sea levels may present along California coasts in the future. (Photo credit: Mark Johnsson).

Projected increases in extreme coastal flooding as a result of sea level rise will increase human vulnerability to coastal flooding events. Currently, 260,000 people in California are at risk from what is considered a once-in-100-year flood.[82] With a sea level rise of about three feet (in the range of projections for this century: Ch. 2: Our Changing Climate, Key Message 10)[78,80] and at current population densities, 420,000 people would be at risk from the same kind of 100-year flood event,[85] based on existing exposure levels. Highly vulnerable populations – people less able to prepare, respond, or recover from natural disaster due to age, race, or income – make up approximately 18% of the at-risk population (Ch. 25: Coasts).[85,89]

The California state government, through its Ocean and Coastal Resources Adaptation Strategy, along with local governments, is using new sea level mapping and information about social vulnerability to undertake coastal adaptation planning. NOAA has created an interactive map showing areas that would be affected from sea level rise (http://www.csc.noaa.gov/slr/viewer/#).

Heat Threats to Health

Projected regional temperature increases, combined with the way cities amplify heat, will pose increased threats and costs to public health in southwestern cities, which are home to more than 90% of the region's population. Disruptions to urban electricity and water supplies will exacerbate these health problems.

The Southwest has the highest percentage of its population living in cities of any U.S. region. Its urban population rate, 92.7%, is 12% greater than the national average.[90] Increasing metropolitan populations already pose challenges to providing adequate domestic water supplies, and the combination of increased population growth and projected increased risks to surface water supplies will add further challenges.[91,92] Trade-offs are inevitable between conserving water to help meet the demands of an increasing population, and providing adequate water for urban greenery to reduce increasing urban temperatures.

Urban infrastructures are especially vulnerable because of their interdependencies; strains in one system can cause disruptions in another (Ch. 11: Urban, Key Message 2; Ch. 9: Human Health).[16,93] For example, an 11-minute power system disturbance in September 2011 cascaded into outages that left 1.5 million San Diego residents without power for 12 hours;[94] the outage disrupted pumps and water service, causing 1.9 million gallons of sewage to spill near beaches.[95] Extensive use of air conditioning to deal with high temperatures can quickly increase electricity demand and trigger cascading energy system failures, resulting in blackouts or brownouts.[14,15]

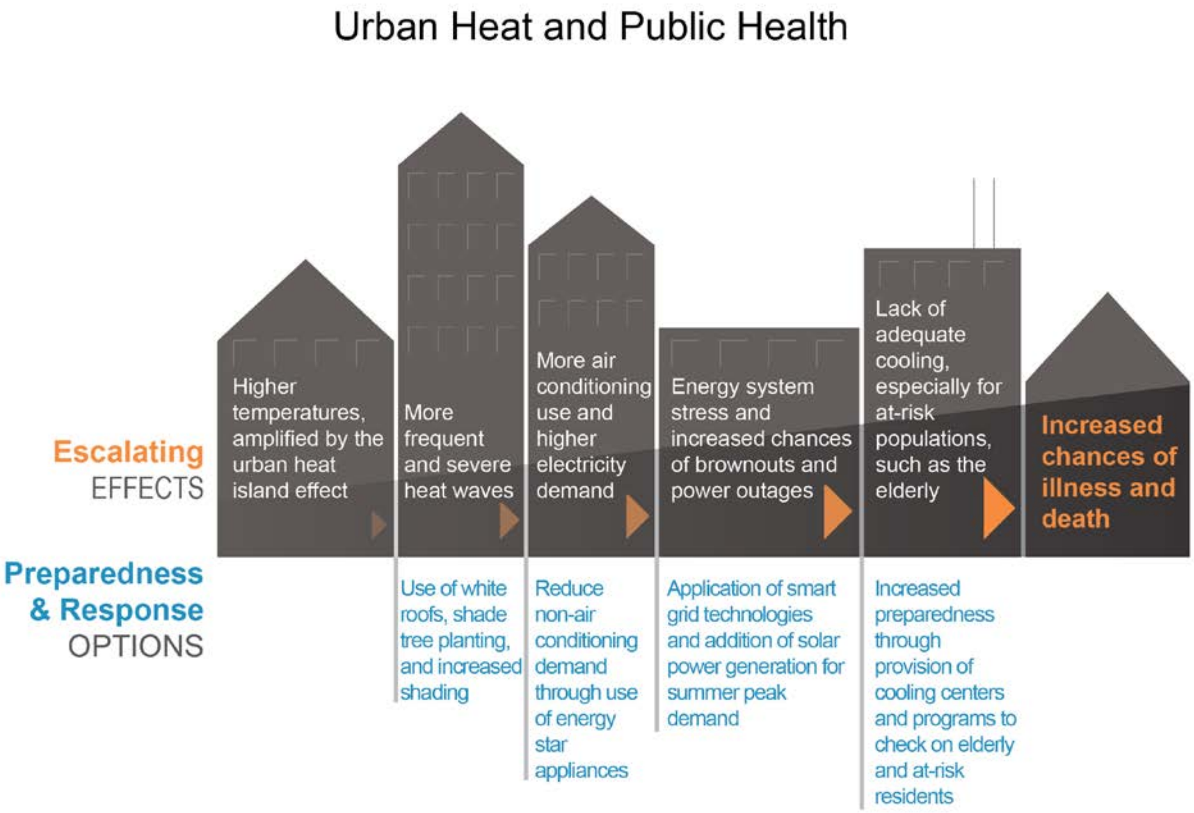

Figure 20.6 Urban Heat and Public Health

Caption: The projected increase in heat waves in Southwest cities (Ch. 2: Our Changing Climate, Key Message 7) increases the chances that a chain of escalating effects could lead to serious increases in illness and death due to heat stress. The top of the figure provides some of the links in that chain, while the bottom of the figure provides adaptation and improved governance options that can reduce this vulnerability and improve the resilience of urban infrastructure and community residents.

Heat stress, a recurrent health problem for urban residents, has been the leading weather-related cause of death in the United States since 1986 when record keeping began[96] – and the highest rates nationally are found in Arizona.[97] The effects of heat stress are greatest during heat waves lasting several days or more, and heat waves are projected to increase in frequency, duration, and intensity,[11,13,98] become more humid,[11] and cause a greater number of deaths.[99] Already, severe heat waves, such as the 2006 ten-day California event, have resulted in high mortality, especially among elderly populations.[100] In addition, evidence indicates a greater likelihood of impacts in less affluent neighborhoods, which typically lack shade trees and other greenery and have reduced access to air conditioning.[101]

Exposure to excessive heat can also aggravate existing human health conditions, like for those who suffer from respiratory or heart disease.[99] Increased temperatures can reduce air quality, because atmospheric chemical reactions proceed faster in warmer conditions. The outcome is that heat waves are often accompanied by increased ground-level ozone,[102] which can cause respiratory distress. Increased temperatures and longer warm seasons will also lead to shifts in the distribution of disease-transmitting mosquitoes (Ch. 9: Human Health, Key Message 1).[97]

Traceable Accounts

Chapter 20: Southwest

Key Message Process: A central component of the assessment process was the Southwest Regional Climate assessment workshop that was held in August 1-4, 2011 in Denver, CO with more than 80 participants in a series of scoping presentations and workshops. The workshop began the process leading to a foundational Technical Input Report (TIR) report.[103] The TIR consists of nearly 800 pages organized into 20 chapters that were assembled by 122 authors representing a wide range of inputs including governmental agencies, NGOs, tribes, and other entities. The report findings were described in a town hall meeting at the American Geophysical Union meeting in 2011, and feedback was collected and incorporated into the draft.

The chapter author team engaged in multiple technical discussions through more than 15 biweekly teleconferences that permitted a careful review of the foundational TIR[103] and of approximately 125 additional technical inputs provided by the public, as well as the other published literature, and professional judgment. The chapter author team then met at the University of Southern California on 27-28 March, 2012 for expert deliberation of draft key messages by the authors. Each key message was defended before the entire author team prior to the key message being selected for inclusion. These discussions were supported by targeted consultation with additional experts by the lead author of each message, and they were based on criteria that help define "key vulnerabilities, which include magnitude, timing, persistence and reversibility, likelihood and confidence, potential for adaptation, distribution, and importance of the vulnerable system."[104]

Key message #1/5	**Snowpack and streamflow amounts are projected to decline in parts of the Southwest, decreasing surface water supply reliability for cities, agriculture, and ecosystems.**
Description of evidence base	The key message was chosen based on input from the extensive evidence documented in the Southwest Technical Input Report[103] and additional technical input reports received as part of the Federal Register Notice solicitation for public input, as well as stakeholder engagement leading up to drafting the chapter. Key Message 5 in Chapter 2, Our Changing Climate, also provides evidence for declining precipitation across the U.S., and a regional study[17] discusses regional outlooks and trends for the Southwest. Over the past 50 years, there has been a reduction in the amount of snow measured on April 1 as a proportion of the precipitation falling in the corresponding water-year (October to September), which affects the timing of snowfed rivers. The implication of this finding is that the lower the proportion of April 1 snow water equivalent in the water-year-to-date precipitation, the more rapid the runoff, and the earlier the timing of center-of-mass of streamflow in snowfed rivers.[26,27] For the "recent decade" (2001 to 2010), snowpack evidence is from USDA Natural Resources Conservation Service snow course data, updated through 2010. One study[3] has analyzed streamflow amounts for the region's four major river basins, the Colorado, Sacramento-San Joaquin, Great Basin (Humboldt River, NV), and the Rio Grande; data are from the Bureau of Reclamation, California Department of Water Resources, USGS, and the International Boundary and Water Commission (U.S. Section), respectively. These data are backed by a rigorous detection and attribution study.[10] Projected trends[18] make use of downscaled climate parameters for 16 GCMs, and hydrologic projections for the Colorado River, Rio Grande and Sacramento-San Joaquin River System. Based on GCM projections, downscaled and run through the variable infiltration capacity (VIC) hydrological model,[105] there are projected reductions in spring snow

	accumulation and total annual runoff, leading to reduced surface water supply reliability for much of the Southwest, with greater impacts occurring during the second half of this century.[18,28] Future flows in the four major Southwest rivers are projected to decline as a result of a combination of increased temperatures, increased evaporation, less snow and less persistent snowpack. These changes have been projected to result in decreased surface water supplies, which will have impacts for allocation of water resources to major uses, such as urban drinking water, agriculture and ecosystem flows.
New information and remaining uncertainties	Different model simulations predict different levels of snow loss. These differences arise because of uncertainty in climate change warming and precipitation projections due to differences among GCMs, uncertainty in regional downscaling, uncertainty in hydrological modeling, differences in emissions, aerosols, and other forcings, and because differences in the hemispheric and regional-scale atmospheric circulation patterns produced by different GCMs produce different levels of snow loss in different model simulations. In addition to the aforementioned uncertainties in regional climate and hydrology projections, projection of future surface water supply reliability includes at least the following additional uncertainties: 1) changes in water management, which depend on agency resources and leadership and cooperation of review boards and the public;[106] 2) management responses to non-stationarity;[107] 3) legal, economic, and institutional options for augmenting existing water supplies, adding underground water storage and recovery infrastructure, and fostering further water conservation (for example,[108]); 4) adjudication of unresolved water rights; and 5) local, state, regional and national policies related to the balance of agricultural, ecosystem and urban water use (for example,[43]).
Assessment of confidence based on evidence	There is **high** confidence in the continued trend of declining snowpack and streamflow in parts of the Southwest given the evidence base and remaining uncertainties. For the impacts on water supply, there is **high** confidence that reduced surface water supply reliability will affect the region’s cities, agriculture, and ecosystems.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter 20: Southwest

Key Message Process: See key message #1.

Key message #2/5	**The Southwest produces more than half of the nation's high-value specialty crops, which are irrigation-dependent and particularly vulnerable to extremes of moisture, cold, and heat. Reduced yields from increasing temperatures and increasing competition for scarce water supplies will displace jobs in some rural communities.**
Description of evidence base	Increased competition for scarce water was presented in the first key message, and in the foundational Technical Input Report (TIR).[103] U.S. temperatures, including those for the Southwest region, have increased and are expected to continue to rise (Chapter 2: Our Changing Climate, Key Message 3). Heat waves have become more frequent and intense and droughts are expected to become more intense in the Southwest (Chapter 2: Our Changing Climate, Key Message 7). The length of the frost-free season in the Southwest has been increasing, and is frost-free season length is projected to increase (Chapter 2: Our Changing Climate, Key Message 4). A regional study[17] discusses the outlooks and trends in the Southwest for moisture, cold, heat, and their extremes. There is abundant evidence of irrigation dependence and vulnerability of high value specialty crops to extremes of moisture, cold, and heat, including, prominently, the prior National Climate Assessment[109] and the foundational TIR.[103] Southwest agricultural production statistics and irrigation dependence of that production is delineated in the USDA 2007 Census of Agriculture[45] and the USDA Farm and Ranch Irrigation Survey.[46] **Reduced Yields.** Even under the most conservative emission scenarios evaluated (the combination of SRES B1emissions scenario with statistically downscaled winter chill projections from the HADCM3 climate model), one study[56] projected that required winter chill periods will fall below the number of hours that are necessary for many of the nut and fruit bearing trees of California, and yields are projected to decline as a result. A second study[54] found that California wheat acreage and walnut acreage will decline, due to increased temperatures. Drought and extreme weather may have more effect on the market value of fruit and vegetables, as opposed to other crops, because fruits and vegetables have high water content and because consumers expect good visual appearance and flavor.[51] Extreme daytime and nighttime temperatures have been shown to accelerate crop ripening and maturity, reduce yield of crops such as corn, fruit trees, and vineyards, cause livestock to be stressed, and increase water consumption in agriculture.[53] **Irrigation water transfers to urban.** Warmer, drier future scenarios portend large transfers of irrigation water to urban areas even though agriculture will need additional water to meet crop demands, affecting local agriculturally dependent economies.[55] In particular areas of the Southwest (most notably lower-central Arizona), a significant reduction in irrigated agriculture is already underway as land conversion occurs near urban centers.[48] Functioning water markets, which may require legal and institutional changes, can enable such transfers, and reduce the social and economic impacts of water shortages to urban areas.[47] The economic impacts of climate change on Southwest fruit and nut growers are projected to be substantial and will result in a northward shift in production of these crops, displacing growers and affecting communities.
New information and remaining	Competition for water is an uncertainty. The extent to which water transfers take place depends on whether complementary investments in conveyance or storage

uncertainties	infrastructure are made. Currently, there are legal and institutional restrictions limiting water transfers across state and local jurisdictions. It is uncertain whether infrastructure investments will be made or whether institutional innovations facilitating transfers will develop. Institutional barriers will be greater if negative third-party effects of transfers are not adequately addressed. Research that would improve the information base to inform future water transfer debates includes: 1) estimates of third party impacts, 2) assessment of institutional mechanisms to reduce those impacts, 3) environmental impacts of water infrastructure projects, and 4) options and costs of mitigating those environmental impacts. **Extremes and phenology.** A key uncertainty is the timing of extreme events during the phenological stage of the plant or the growth cycle of the animal. For example, plants are more sensitive to extreme high temperatures and drought during the pollination stage compared to vegetative growth stages. **Genetic improvement potential.** Crop and livestock reduction studies by necessity depend on assumptions about adaptive actions by farmers and ranchers. However, agriculture has proven to be highly adaptive in the past. A particularly high uncertainty is the ability of conventional breeding and biotechnology to keep pace with the crop plant and animal genetic improvements needed for adaptation to climate-induced biotic and abiotic stresses is highly uncertain.
Assessment of confidence based on evidence	Although evidence includes studies of observed climate and weather impacts on agriculture, projections of future changes using climate and crop yield models, and econometric models, show varying results depending on the choice of crop and assumptions regarding water availability. For example, projections of 2050 California crop yields show reductions in field crop yields, based on assumptions of a 21% decline in agricultural water use, shifts away from water-intensive crops to high-value specialty crops, and development of a more economical means of transferring water from northern to southern California.[47] Other studies, using projections of a dry, warmer future for California, and an assumption that water will flow from lower- to higher-valued uses (such as urban water use), generated a 15% decrease in irrigated acreage and a shift from lower- to higher-valued crops.[49] Because net reductions in the costs of water shortages depend on multiple institutional responses, it is difficult as yet to locate a best-estimate of water transfers between zero and the upper bound. Water scarcity may also be a function of trade-offs between economic returns from agricultural production versus returns for selling off property or selling water to urban areas (for example, Imperial Valley transfers to San Diego). Given the evidence base and remaining uncertainties, confidence is **high** in this key message.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter 20: Southwest

Key Message Process: See key message #1.

Key Message #3/5	**Increased warming, drought, and insect outbreaks, all caused by or linked to climate change, have increased wildfires and impacts to people and ecosystems in the Southwest. Fire models project more wildfire and increased risks to communities across extensive areas.**
Description of evidence base	Increased warming and drought are extensively described in the foundational Technical Input Report (TIR).[103] U.S. temperatures have increased and are expected to continue to rise (Chapter 2: Our Changing Climate, Key Message 3). There have been regional changes in droughts, and there are observed and projected changes in cold and heat waves and droughts (Ch. 2: Our Changing Climate, Key Message 7) for the Nation. A study for the Southwest[17] discusses outlooks and trends in both cold waves and heat waves. Analyses of weather station data from the Southwest have detected changes from 1950 to 2005 that favor wildfire, and statistical analyses have attributed the changes to anthropogenic climate change. The changes include increased temperatures,[2] reduced snowpack,[27] earlier spring warmth[30] and streamflow.[10] These climate changes have increased background tree mortality rates from 1955 to 2007 in old-growth conifer forests in California, Colorado, Utah, and the northwestern states[7] and caused extensive piñon pine mortality in Arizona, Colorado, New Mexico, and Utah between 1989 and 2003.[69] Climate factors contributed to increases in wildfire in the previous century. In mid-elevation conifer forests of the western U.S., increases in spring and summer temperatures, earlier snowmelt, and longer summers increased fire frequency 400% and burned area 650% from 1970 to 2003.[8] Multivariate analysis of wildfire across the western U.S. from 1916 to 2003 indicates that climate was the dominant factor controlling burned area, even during periods of human fire suppression.[65] Reconstruction of fires of the past 400 to 3000 years in the western U.S.[66] and in Yosemite and Sequoia National Parks in California[67,68] confirm that temperature and drought are the dominant factors explaining fire occurrence. Four different fire models project increases in fire frequency across extensive areas of the Southwest in this century.[71,72,73,74] Multivariate statistical generalized additive models[64,72] project extensive increases across the Southwest, but the models project decreases when assuming that climate alters patterns of net primary productivity. Logistic regressions[74] project increases across most of California, except for some southern parts of the state, with average fire frequency increasing 37-74%. Linear regression models project up to a doubling of burned area in the southern Rockies by 2070 under emission scenarios B1 or A2.[73] The MC1 dynamic global vegetation model projects increases in fire frequencies on 40% of the area of the Southwest from 2000 to 2100 and decreases on 50% of the areas for emissions scenarios B1 and A2.[71] Excessive wildfire destroys homes, exposes slopes to erosion and landslides, and threatens public health, causing economic damage.[59,60] Further impacts to communities and various economies (local, state, national) have been projected.[74]
New information and remaining uncertainties	Uncertainties in future projections derive from the inability of models to accurately simulate all past fire patterns, and from the different General Circulation Models (GCMs), emissions scenarios, and spatial resolutions used by different fire model projections. Fire projections depend highly on the spatial and temporal distributions

	of precipitation projections, which vary widely across GCMs. Although models generally project future increases in wildfire, uncertainty remains on the exact locations. Research groups continue to refine the fire models.
Assessment of confidence based on evidence	There is **high** confidence in this key message given the extensive evidence base and discussed uncertainties.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter 20: Southwest

Key Message Process: See key message #1.

Key message #4/5	**Flooding and erosion in coastal areas are already occurring even at existing sea levels and damaging some California coastal areas during storms and extreme high tides. Sea level rise is projected to increase as Earth continues to warm, resulting in major damage as wind-driven waves ride upon higher seas and reach farther inland.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the Technical Input Report.[103] Several studies document potential coastal flooding, erosion, and wind-driven wave damages in coastal areas of California due to sea-level rise (for example,[81,82]). Global sea level has risen, and further rise of 1 to 4 feet is projected by 2100 (Chapter 2: Our Changing Climate, Key Message 10). All of the scientific approaches to detecting sea-level rise come to the conclusion that a warming planet will result in higher sea levels. In addition, numerous recent studies[78,80] produce much higher sea level-rise projections for the rest of this century, compared to the projections in the most recent report of the Intergovernmental Panel on Climate Change[83] for the rest of this century.
New information and remaining uncertainties	There is strong recent evidence from satellites such as GRACE[110] and from direct observations, that glaciers and ice caps worldwide are losing mass relatively rapidly, contributing to the recent increase in the observed rate of sea level rise. Major uncertainties are associated with sea-level rise projections such as the behavior of ice sheets with global warming and the actual level of global warming that the Earth will experience in the future.[78,80] Regional sea-level rise projections are even more uncertain than the projections for global averages because local factors such as the steric component (changes in the volume of water with changes in temperature and salinity) of sea level-rise at regional levels and the vertical movement of land have large uncertainties.[78] However, it is virtually certain that sea levels will go up with a warming planet as demonstrated in the paleoclimatic record, modeling, and from basic physical arguments.
Assessment of confidence based on evidence	Given the evidence, especially since the last IPCC report,[83] there is **very high** confidence the sea level will continue to rise and that this will entail major damage to coastal regions in the Southwest. There is also **very high** confidence that flooding and erosion in coastal areas are already occurring even at existing sea levels and damaging some areas of the California coast during storms and extreme high tides.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter 20: Southwest

Key Message Process: See key message #1.

Key message #5/5	**Projected regional temperature increases, combined with the way cities amplify heat, will pose increased threats and costs to public health in southwestern cities, which are home to more than 90% of the region's population. Disruptions to urban electricity and water supplies will exacerbate these health problems.**
Description of evidence base	There is excellent agreement regarding the urban heat island effect and exacerbation of heat island temperatures by increases in regional temperatures caused by climate change. There is abundant evidence of urban heat island effect for some Southwest cities (for example,[98]), as well as several studies, some from outside the region, of the public health threats of urban heat to residents (for example, Ch. 9: Human Health,[99,100]). Evidence includes observed urban heat island studies and modeling of future climates, including some climate change modeling studies for individual urban areas (for example, Phoenix and Los Angeles). There is wide agreement in Southwest states that increasing temperatures combined with projected population growth will stress urban water supplies and require continued water conservation and investment in new water supply options. There is substantial agreement that disruption to urban electricity may cause cascading impacts, such as loss of water, and that projected diminished supplies will pose challenges for urban cooling (for example, the need for supplemental irrigation for vegetation-based cooling). However, there are no studies on urban power disruption induced by climate change. With projected surface water losses, and increasing water demand due to increasing temperatures and population, water supply in Southwest cities will require greater conservation efforts and capital investment in new water supply sources.[92] Several Southwestern states, including California, New Mexico and Colorado have begun to study climate impacts to water resources, including impacts in urban areas.[91] The interdependence of infrastructure systems is well established, especially the dependence of systems on electricity and communications and control infrastructures, and the potential cascading effects of breakdowns in infrastructure systems.[16] The concentration of infrastructures in urban areas adds to the vulnerability of urban populations to infrastructure breakdowns. This has been documented in descriptions for major power outages such as the Northeast Power Blackout of 2003, or the recent September 2011 San Diego blackout.[94] A few references point to the role of urban power outages in threatening public health due to loss of air conditioning[14] and disruption to water supplies.[94]
New information and remaining uncertainties	Key uncertainties include the intensity and spatial extent of drought and heat waves. Uncertainty is also associated with quantification of the impact of temperature and water availability on energy generation, transmission, distribution, and consumption – all of which have an impact on possible disruptions to urban electricity. Major disruptions are contingent on a lack of operator response and/or adaptive actions such as installation of adequate electricity-generating capacity to serve the expected enhanced peak electricity demand. Thus a further uncertainty is the extent to which adaptation actions are taken.
Assessment of confidence based on evidence	The urban heat island effect is well demonstrated and hence projected climate-induced increases to heat will increase exposure to heat-related illness. Electricity disruptions are a key uncertain factor, and potential reductions in water supply not

	only may reduce hydropower generation, but also availability of water for cooling of thermal power plants. Based on the substantial evidence and the remaining uncertainties, confidence in each aspect of the key message is **high**.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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