20. Southwest

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Key Messages

1. **Snowpack and streamflow amounts are projected to decline, decreasing water supply for cities, agriculture, and ecosystems.**
2. **The Southwest produces more than half the nation's high-value specialty crops, which are irrigation-dependent and particularly vulnerable to extremes of moisture, cold, and heat. Reduced yields from increased temperatures and increasing competition for scarce water supplies will displace jobs in some rural communities.**
3. **Increased warming, due to climate change, and drought 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 is already occurring and is damaging some areas of the California coast during storms and extreme high tides. Sea level rise is projected to increase, resulting in major damage as wind-driven waves ride upon higher seas and reach further 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 percent 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 by 38 million by 2050. Severe and sustained drought will stress water sources already over-utilized in many areas, forcing increasing competition among farmers, urban dwellers, and the region's varied 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 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, such as 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: Forestry).

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 (Ababneh 2008; BCDC 2011; Bonfils et al. 2008; Graumlich 1993; Hoerling et al. 2012; Millar et al. 2006; Salzer and Kipfmueller 2005; Salzer et al. 2009; Stevens et al. 2008; Woodhouse et al. 2010; Ch. 2 Our Changing Climate; Key Message 3). 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 snaps and more heat waves (Hoerling et al. 2012). Compared to temperature, precipitation trends vary considerably across the region, with portions experiencing both decreases and increases (Hoerling et al. 2012; Ch. 2: Our Changing Climate; Key Message 5). There is mounting evidence that the combination of human-caused temperature increases and recent drought has influenced widespread tree mortality (Allen et al. 2010; Van Mantgem et al. 2009), increased fire occurrence and area burned (Westerling et al. 2006), and forest insect outbreaks (Bentz et al. 2010; Ch. 7: Forestry). Human-caused temperature increases and drought have also caused earlier spring snowmelt and shifted runoff to earlier in the year (Barnett et al. 2008).

Regional annual average temperatures are projected to rise by 2°F to 6°F by 2041-2070 if global emissions are substantially reduced (as in the B1 emission scenario) and by 5°F to 9°F by 2070-2099 with continued growth in global emissions (A2), with the greatest increases in the summer and fall. Summertime heat waves are projected to become longer and hotter, whereas the trend of decreasing wintertime cold snaps is projected to continue (Gershunov et al. 2009; Kodra et al. 2011; Ch. 2: Our Changing Climate; Key Message 7). 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. Rising temperatures also have direct impacts on crop yields and productivity of key regional crops, such as fruit trees.

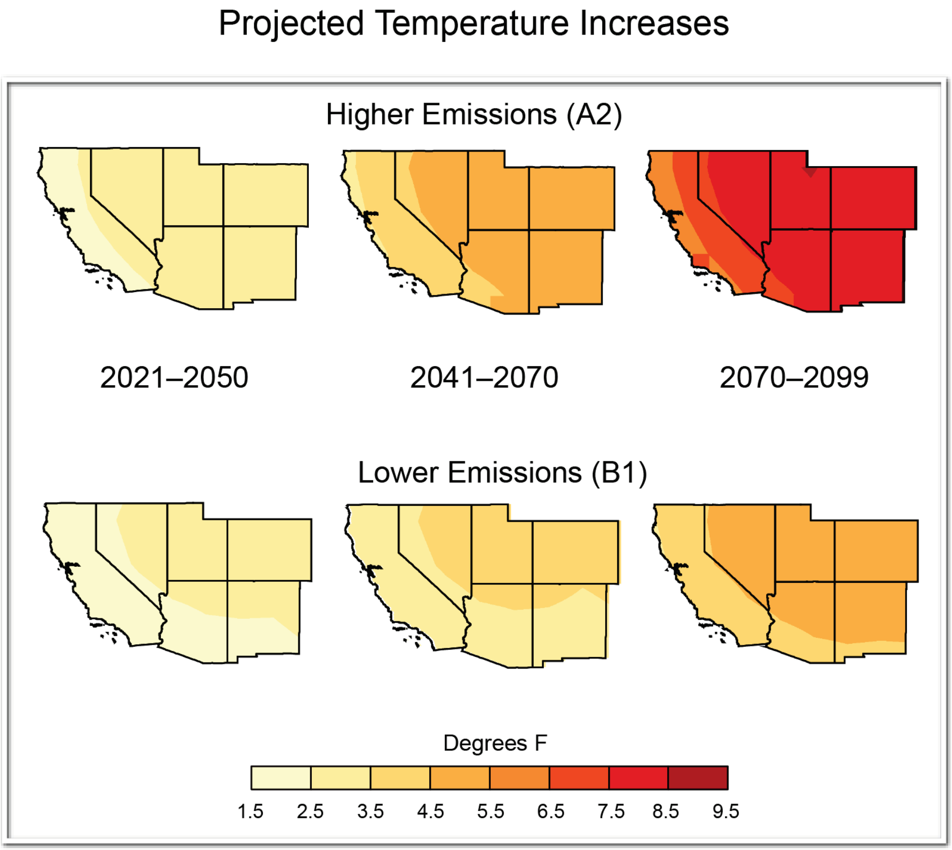

Figure 20.1: Projected Temperature Increases

Caption: Maps show projected changes in average temperature (°F) from observed average temperatures between 1971 and 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: NOAA NCDC / CICS-NC. Data from CMIP3.)

Projections of precipitation changes are less certain than those for temperature (Cayan et al. 2012; Kunkel et al. 2012). Under a high emissions scenario (A2), reduced precipitation is consistently projected for the southern part of the Southwest by 2100, but there is model disagreement on the direction of change in the northern part of the region. Seasonally, significant decreases in spring precipitation in the south are projected, while a mix of increases and decreases are projected for the other seasons and in the north (Kunkel et al. 2012; Ch. 2: Our Changing Climate; Key Message 5). An increase in winter flood hazard risk is projected due to increases in flows of airborne moisture into California's coastal ranges and the Sierra Nevada (Dettinger 2011; Dettinger et al. 2011). These "atmospheric rivers" have contributed to the largest floods in California history (Neiman et al. 2008), and can penetrate inland as far as Utah and New Mexico.

The region has experienced severe, 50-year-long mega-droughts over the past 2000 years. 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 (Cayan et al. 2012). These drought conditions present a huge challenge for regional management of water resources and natural hazards like wildfire. In light of climate change and water resources treaties with Mexico, discussions are underway, and 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: Tribal Lands and Resources). Historic land settlements and high rates of poverty – more than double that of the general U.S. population (Sarche and Spicer 2008) – constrain tribes' abilities to respond effectively to climate challenges.

Most of the Southwest border population is concentrated in eight 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 (Soden 2006). Border cities concentrate health and safety risks, such as air pollution, inadequate erosion and flood control, and insufficient safe drinking water.

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 all the more daunting for tribes and border populations to address climate change issues.

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Reduced Snowpack and Streamflows

Snowpack and streamflow amounts are projected to decline, decreasing water supply 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 (Hidalgo et al. 2009; Pierce et al. 2008). 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 (Hoerling et al. 2012). Projections of further reduction of late winter and spring snowpack, and subsequent reductions in runoff and soil moisture (Cayan et al. 2008; Cayan et al. 2010; Christensen and Lettenmaier 2007), pose increased risks to the water supplies needed to maintain the Southwest's cities, agriculture, and ecosystems.

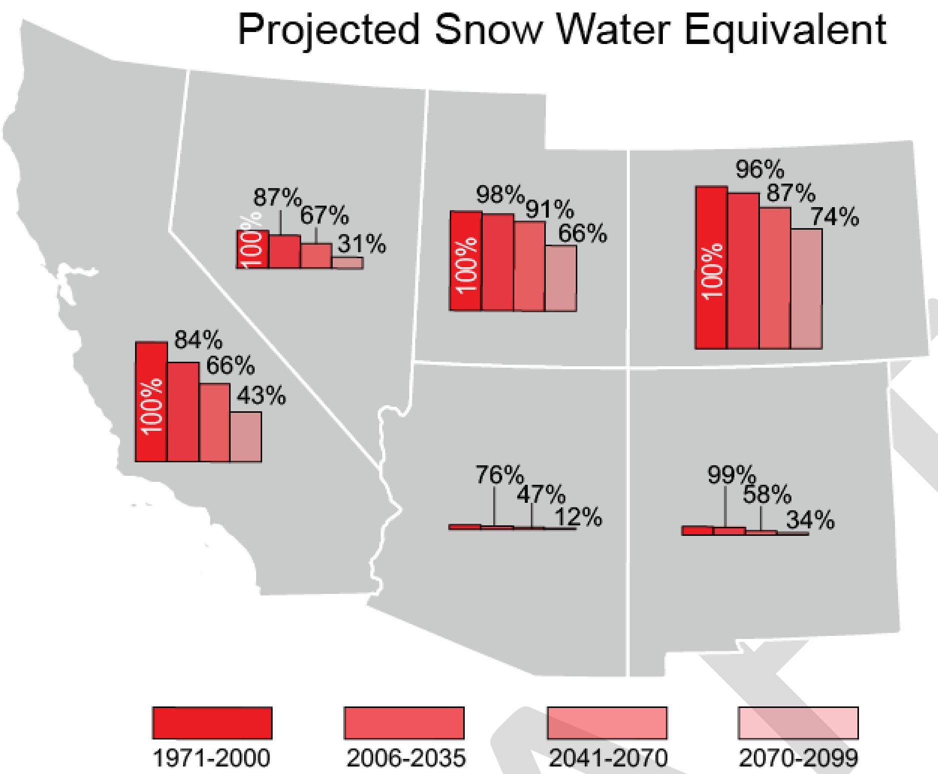

Figure 20.2: Projected Snow Water Equivalent

Caption: Percent changes in statewide snow water equivalent (SWE) accumulation compared to the 1971-2000 modeled average for the first of the month during which the 1971-2000 modeled average modeled peak SWE occurred. Snow water equivalent refers to the amount of water held in a volume of snow, which depends on the density of the snow and other factors. The maps depict the average projections of 16 global climate models for 30-year periods, assuming continued growth in 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. (Source: calculations by Dan Cayan and Mary Tyree (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 (Ault et al. 2011; Painter et al. 2010; Painter et al. 2007; Qian et al. 2009). 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 (ASCE 2012). 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 greenhouse gas (also referred to as heat-trapping gas) emissions to 1990 levels by 2020 (California Energy Commission 2011).

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 (Averyt et al. 2011), which use about 40% of the surface water withdrawn in the U.S. (King et al. 2008). The projected warming of water in rivers and lakes will reduce the capacity of thermal power plants, especially during summer when electricity demand skyrockets (van Vliet et al. 2012). 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 (DOE 2012; Nelson et al. 2012; Wei et al. 2012), and could substantially reduce water withdrawals (Cooley et al. 2011; Halpern and Tramontin 2007; Ch. 10: Water, Energy and Land Use).

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Potential Emissions Reductions in the Electricity Sector

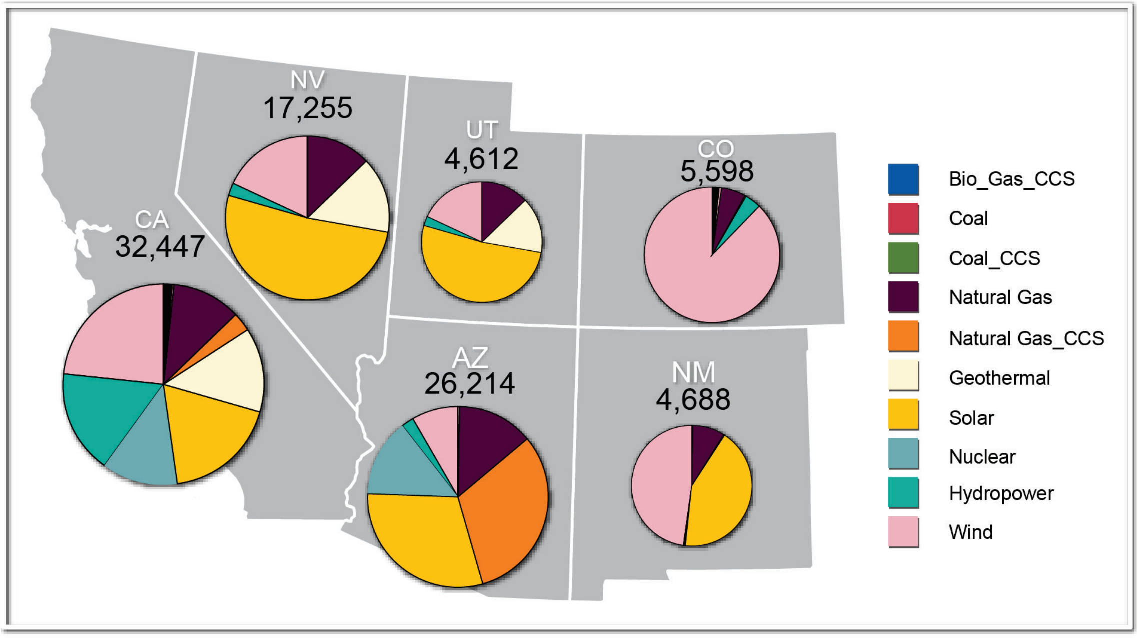

Figure 20.3: Potential Emissions Reductions in the Electricity Sector

Caption: Major shifts in how electricity is produced can lead to large reductions in heat-trapping gas emissions. Many different energy combinations could achieve an 80% reduction of greenhouse gas emissions from 1990 levels in the electricity sector. For each state, that mix varies, with the circle representing the average hourly generation in megawatts (MW; the number above each circle) from 10 potential energy sources. CCS refers to carbon capture and storage. (Source: data from Wei et al. 2012)

Conservation efforts have proven to reduce water use, but are not projected to be sufficient if current trends for water supply and demand continue (Rockaway et al. 2011). 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 (Means et al. 2010; U.S. Bureau of Reclamation 2011a, 2011b).

Threats to Agriculture

The Southwest produces more than half the nation's high-value specialty crops, which are irrigation-dependent and vulnerable to extremes of moisture, cold, and heat. Increased temperatures threaten to reduce yields, and increasing competition for scarce water supplies will affect rural livelihoods.

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 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. A warmer, drier climate is projected to accelerate current trends of large transfers of irrigation water to urban areas (Frisvold et al. 2012; Pritchett et al. 2011), 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 (Beach et al. 2010). Drought and extreme weather affects the market value of fruit and vegetables more than other crops, because they have high water content and because sales depend on good visual appearance (Hatfield et al. 2008). The combination of a longer frost-free season, less frequent cold snaps, 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 (Baldocchi and Wong 2008; Battisti and Naylor 2009; Lobell et al. 2006; Purkey et al. 2008). 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 (Jackson et al. 2012a; Medellín-Azuara et al. 2012).

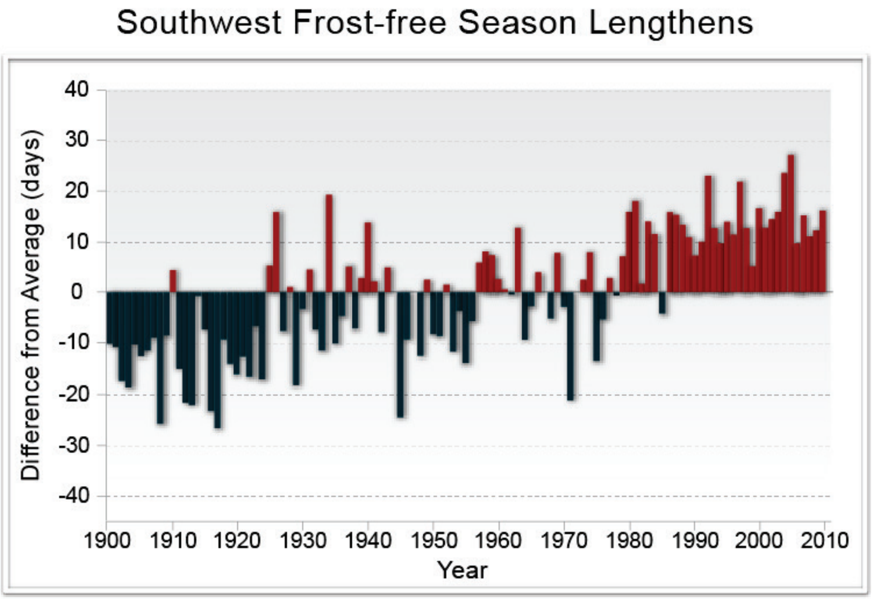

Figure 20.4: Southwest Frost-free Season Lengthens

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. (Figure source: modified from (Hoerling et al. 2012),)

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 (Luedeling et al. 2011). Warm-season vegetable crops grown in Yolo County, one of California's biggest producers, may not be viable under hotter climate conditions (Jackson et al. 2012a; Jackson et al. 2012b). 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, due to climate change, and drought 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 (Bowman et al. 2009; Keeley and Zedler 2009). Excessive wildfire destroys homes, exposes slopes to erosion and landslides, threatens public health, and causes economic damage (Frisvold et al. 2011; Morton and Global Institute of Sustainable Forestry 2003; Richardson et al. 2011;

WFLC 2010). The $1.2 billion in damages from the 2003 Grand Prix fire in southern California illustrates the high cost of wildfires (WFLC 2010).

Beginning in the 1910s and 1920s, the federal government developed a national policy of extinguishing every fire, which, in hindsight, allowed wood and other fuels to over-accumulate (Hurteau et al. 2008) and urban development to encroach on fire-prone areas. Recent policies that allow some wildfires to burn naturally have increased burned area back to the levels seen before the strict fire controls.

Increased warming due to climate change (Bonfils et al. 2008), drought, insect infestations (Williams et al. 2010), and fuel accumulation make the Southwest vulnerable to increased wildfire. Climate outweighed other factors in determining burned area in the western U.S. from 1916 to 2003 (Littell et al. 2009), a finding confirmed by 3000-year long reconstructions of southwestern fire history (Marlon et al. 2012; Swetnam 1993; Swetnam et al. 2009; Taylor and Scholl 2012; Trouet et al. 2010). Between 1970 and 2003, warmer and drier conditions increased burned area in western U.S. mid-elevation conifer forests by 650% (Westerling et al. 2006).

Drought and increased temperatures due to climate change have caused extensive tree death across the Southwest (Breshears et al. 2005; Van Mantgem et al. 2009). 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 (Raffa et al. 2008). Wildfire and bark beetles killed trees across 20% of Arizona and New Mexico forests from 1984 to 2008 (Williams et al. 2010).

Numerous fire models project more wildfire as climate change continues (Gonzalez et al. 2010; Krawchuk et al. 2009; Litschert et al. 2012; Westerling et al. 2012). Models project a doubling of burned area in the southern Rockies, (Litschert et al. 2012) and up to 74% more fires in California (Westerling et al. 2012). Fire contributes to upslope shifting of vegetation and conversion of forests to woodland or grassland (Allen and Breshears 1998; Keeley and Brennan 2012). Historical and projected climate change make 42% 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 (Gonzalez et al. 2010).

Prescribed burning, mechanical thinning, and retention of large trees can help forest ecosystems adapt to climate change (Finney et al. 2005; Stevens et al. 2008; Swetnam et al. 2009). These adaptation measures also reduce emissions of the heat-trapping gases that cause climate change because long-term storage of carbon in large trees outweighs short-term emissions from prescribed burning (Hurteau and Brooks 2011; Hurteau et al. 2008).

Sea Level Rise and Coastal Damage

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

In the last 100 years, sea level has risen along the Southwest coast by 6.7 to 7.9 inches (NRC 2012). 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 (Bromirski et al. 2011; NRC 2012; Parris et al. 2012; Romanovsky et al. 2011). 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 (Bromirski et al. 2012; Cayan et al. 2012; Kildow and Colgan 2005; Revell et al. 2012; Storlazzi and Griggs 2000).

The result will be impacts to the nation's largest ocean-based economy, estimated at $46 billion annually (Cooley et al. 2012; Pendleton 2009). 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 (BCDC 2011), an amount consistent with the 1 to 4 feet of expected global increase in sea level (Ch. 2: Our Changing Climate, Key Message 9). In Los Angeles, sea level rise poses a risk to groundwater supplies and estuaries (Bloetscher et al. 2010; Heberger et al. 2009), by potentially contaminating groundwater with seawater, or increasing the costs to protect coastal freshwater aquifers (Webb and Howard 2011).

Coastal Risks Posed by Sea Level Rise and High Tides

1 February 2011: 16:51 -0.47 ft MLLW

20 January 2011: 11:32 7.20 ft MLLW

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

Caption: 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, range from four to nine feet, providing a preview of what California coasts may look like in the future. 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. (Photo credit: Mark Johnson).

Projected increases in extreme flooding in addition to sea level rise will increase human vulnerability to coastal flooding events. Currently, 140,000 people are at risk from what is considered a once-in-100-year flood. With a sea level rise of about three feet (in the range of projections for this century (NRC 2012; Parris et al. 2012; Ch. 2: Our Changing Climate; Key Message 9), 420,000 people would be at risk from the same kind of 100-year flood event (Cooley et al. 2012). 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 (Cooley et al. 2012; Cutter et al. 2003; Ch. 25: Coastal Zone).

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.

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 percent 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 (U.S. Census Bureau 2012). 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 (California Department of Water Resources 2009; Gleick 2010; Ray et al. 2008). 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 (Min et al. 2007; NRC 2002; Rinaldi et al. 2001). 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 (Federal Energy Regulatory Commission and North American Electric Reliability Corporation 2012); the outage disrupted pumps and water service, causing 1.9 million gallons of sewage to spill near beaches (Medina 2011). 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 (Hayhoe et al. 2010; Mazur and Metcalfe 2012; Miller et al. 2008).

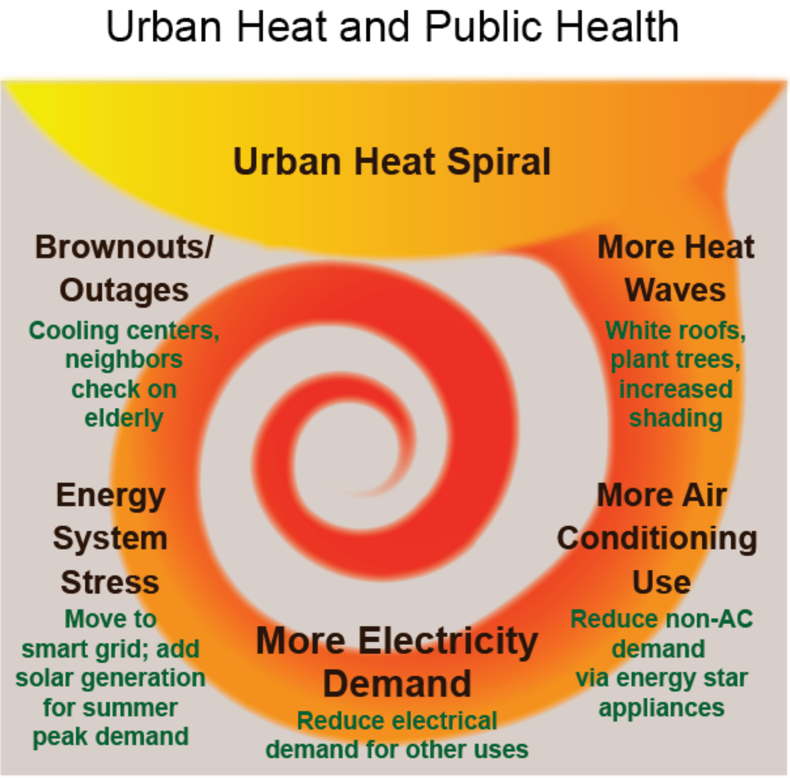

Figure 20.6: Urban Heat and Public Health

Caption: Description of a "vicious spiral" of warming in Southwest cities that could lead to serious increases in illness and death due to heat stress. This spiral shows how more heat waves can lead to increased occurrence of electric power brownouts and outages, which in turn reduce the availability of life-saving air conditioning. Shown in green above are various response options, such as increased use of more efficient architectural practices, more reflective building and paving materials, low water-use landscaping for shading, alternative energy, smart electric grid technologies, and improved public awareness, which can reduce vulnerability.

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 (NWS 2012) – and the highest rates nationally are found in Arizona (Brown et al. 2012). 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 (Gershunov et al. 2009; Sheridan et al. 2011), become more humid (Gershunov et al. 2009), and cause a greater number of deaths (Ostro et al. 2011). Already, severe heat waves, such as the 2006 ten-day California event, have resulted in high mortality, especially among elderly populations (Ostro et al. 2009). In addition, evidence indicates a greater likelihood of impacts in less affluent neighborhoods, which typically lack shade trees and other greenery (Grossman-Clarke et al. 2010; Harlan et al. 2006; Pincetl et al. 2012).

Exposure to excessive heat can also aggravate existing human health conditions, like for those who suffer from respiratory or heart disease. Increased temperatures can reduce air quality, because atmospheric chemical reactions proceed faster in warmer conditions. The upshot is that heat waves are often accompanied by increased ground-level ozone, which can cause respiratory distress (Brown et al. 2012). Increased temperatures and longer warm seasons will also lead to shifts in the distribution of disease-transmitting mosquitoes (Brown et al. 2012).

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 that began the process leading to a foundational TIR report (Garfin et al. 2012). The report 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 townhall meeting at the American Geophysical Union meeting in 2011, and feedback collected and incorporated into the draft.

The chapter author team engaged in multiple technical discussions via over 15 biweekly teleconferences that permitted a careful review of the foundational TIR (Garfin et al. 2012) 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, wherein each message was defended before the entire author team before this key message was selected for inclusion in the Report; 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”.

Key message #1/5	**Snowpack and streamflow amounts are projected to decline, decreasing water supply for cities, agriculture, and ecosystems.**
Description of evidence base	The key message was chosen based on input from the extensive evidence documented in the SW Technical Input (Garfin et al. 2012) 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 Kunkel et al. (2012) discuss regional outlooks and trends for the Southwest. Historical changes over the past 50 years have shown a reduction in the amount of snow in the total annual precipitation and the associated streamflow timing of snowfed rivers (Hidalgo et al. 2009; Pierce et al. 2008). For the “recent decade” (i.e., 2001-2010), snowpack evidence is from USDA-NRCS snow course data, updated through 2010. Streamflow amounts are for the four major river basins in the region, the Colorado, Sacramento-San Joaquin, Great Basin (Humboldt River, NV), and the Rio Grande; data are from Reclamation, California Department of Water Resources, USGS, and International Boundary and Water Commission (U.S. Section), respectively as analyzed by Hoerling et al. (2012). These data are backed by a rigorous detection and attribution study conducted by Barnett et al. (2008). Projected trends are from Cayan et al. (2012), and make use of downscaled climate parameters for 16 GCMs, and hydrologic projections for the Colorado River, Rio Grande and Sacramento-San Joaquin River System. When combined with temperature projections, there are likely reductions in spring snow accumulation and water supply for much of the Southwest, with enhanced impacts occurring in later time periods (Cayan et al. 2008; Cayan et al. 2010; Christensen and Lettenmaier 2007). Future flows in major Southwest rivers will 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	Uncertainty in climate change warming and precipitation response due to differences between GCMs, regional downscaling, uncertainty in hydrological modeling, and differences in emissions, aerosols, and other forcings, and internal climate variation produces different levels of snow loss in different model simulations. In addition to the aforementioned uncertainties pertaining to projection of regional climate and hydrology, projection of future water supply includes at least the following additional uncertainties: a) changes in water management, which depend on agency resources and leadership and cooperation of review boards and the public; b) management responses to non-stationarity; c) legal, economic, and institutional options for augmenting existing water supplies, adding underground water storage and recovery infrastructure, and fostering further water conservation; d) adjudication of unresolved water rights; e) local, state, regional and national policies related to the balance of agricultural, ecosystem and urban water use.
Assessment of confidence based on evidence	There is **high** confidence in the continued trend of declining snowpack and streamflow given the evidence base and remaining uncertainties. For the impacts on water supply, there is **high** confidence that reduced water supply will affect the region.

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 the nation's high-value specialty crops, which are irrigation-dependent and particularly vulnerable to extremes of moisture, cold, and heat. Reduced yields from increased 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 Garfin et al (2012). Evidence of increased temperatures is brought out in the Urban impacts key message, and in Chapter 2: Our Changing Climate, Key Message 3 for the Nation. Chapter 2 also discusses extremes of moisture, cold and heat (Key Message 7). Kunkel et al. (2012) discusses the outlooks and trends both variables in the Southwest. There is abundant evidence of **irrigation dependence and vulnerability of high value specialty crops to extremes of moisture, cold, and heat**, including, prominently, the 2009 National Climate Assessment and Garfin et al. (2012). Southwest agricultural production statistics and irrigation dependence of that production is delineated in the USDA 2007 Census of Agriculture, the USDA Watersheds study (derived from the Census) and the USDA Farm and Ranch Irrigation Survey (FRIS). **Reduced Yields.** Even under the most conservative emission scenarios evaluated, Luedeling et al (2011) found that required winter chill periods are projected to fall below the hours that are necessary for many of the nut and fruit bearing trees of California, and yields are projected to decline as a result. Also Jackson et al. (2012a) found that California wheat acreage and walnut acreage will decline, due to increased temperatures. Drought and extreme weather are more likely to affect the market value of fruit and vegetables, as opposed to other crops, because they have high water content and because consumers expect good visual appearance and flavor (Hatfield et al. 2008). 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 (Battisti and Naylor 2009). **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, impacting local agriculturally dependent economies (Medellín-Azuara et al. 2012). 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 (Pritchett et al. 2011). 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 (Frisvold et al. 2012). The economic impacts of climate change on Southwest fruit and nut growers are likely to be substantial and will result in a northward shift for production of these crops, displacing growers and impacting communities.
New information and remaining uncertainties	Competition for water. The extent to which water transfers take place depends on whether complementary investments in conveyance or storage 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 institutional innovations facilitating transfers will

	develop. Institutional barriers will be greater if negative 3rd-party effects of transfers are not adequately addressed. Research to improve information base include (a) estimates of 3rd party impacts, (b) assessment of institutional mechanisms to reduce those impacts, (c) environmental impacts of water infrastructure projects, and (d) options and costs of mitigating those environmental impacts, would inform future water transfer debates. **Extremes and phenology.** A key uncertainty is the timing of the 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. In particular, the ability of conventional breeding and biotechnology to keep pace with crop plant and animal genetic improvement 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. Because net reductions in the costs of water shortages depend on multiple institutional responses, it is difficult as yet to locate a best-estimate water transfers between zero and the upper bound. Water scarcity may also be a function of trade-offs between economic returns for agricultural production versus returns for selling off property or selling water to urban areas (for example, Imperial Valley transfers to San Diego). Therefore 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, due to climate change, and drought 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 Garfin et al. (2012). Evidence of increased temperatures is brought out in Chapter 2: Our Changing Climate, Key Message 3 for the Nation. Chapter 2 also discusses extremes of moisture, cold and heat (Key Message #7). Kunkel et al. (2012) discusses the outlooks and trends both variables in the Southwest. 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 (Bonfils et al. 2008) , reduced snowpack (Pierce et al. 2008), earlier spring warmth (Ault et al. 2011) and streamflow (Barnett et al. 2008). These climate changes have increased background tree mortality rates from 1955 to 2007 in old-growth conifer forests in California, Colorado, Utah, and the Northwest (Van Mantgem et al. 2009) and caused extensive piñon pine mortality in Arizona, Colorado, New Mexico, and Utah between 1989 and 2003 (Breshears et al. 2005). Climate factors have contributed to increases in wildfire in the 20th 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 (Westerling et al. 2006). 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 (Littell et al. 2009). Reconstruction of fires of the past 400 to 3000 years in the western U.S. (Marlon et al. 2012; Trouet et al. 2010) and in Yosemite and Sequoia National Parks, California (Swetnam 1993; Swetnam et al. 2009; Taylor and Scholl 2012) 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 the 21st century (Gonzalez et al. 2010; Krawchuk et al. 2009; Litschert et al. 2012; Westerling et al. 2012). Multivariate statistical generalized additive models (Krawchuk et al. 2009) project extensive increases across the Southwest, but the models project decreases when assuming that climate alters patterns of net primary productivity. Logistic regressions (Westerling et al. 2012) 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 scenarios B1 or A2 (Litschert et al. 2012). 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% for IPCC emissions scenarios B1 and A2 (Gonzalez et al. 2010). Excessive wildfire destroys homes, exposes slopes to erosion and landslides, and threatens public health, causing economic damage (Frisvold et al. 2011; Morton and Global Institute of Sustainable Forestry 2003; Richardson et al. 2011; WFLC 2010). Further impacts to communities and various economies (local, state, national) have been projected (Westerling et al. 2012).

New information and remaining uncertainties	Uncertainties in future projections derive from the inability of models to accurately simulate all past fire patterns, and 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.

1

CONFIDENCE LEVEL			
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2

Chapter 20: Southwest

Key Message Process: See key message #1.

Key message #4/5	**Flooding and erosion in coastal areas is already occurring and is damaging some areas of the California coast during storms and extreme high tides. Sea level rise is projected to increase, resulting in major damage as wind-driven waves ride upon higher seas and reach further inland.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the Technical Input (Garfin et al. 2012). Evidence for sea level rise across the U.S. is discussed in Chapter 2 (Our Changing Climate, Key Message 9) and its Traceable Accounts. 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 (NRC 2012; Parris et al. 2012) produce much higher sea level-rise projections than what the IPCC reported in 2007 (IPCC 2007) for the rest of this century.
New information and remaining uncertainties	New information: There is strong recent evidence from satellite's such as GRACE, and from direct observations, that glaciers and ice caps worldwide are losing mass faster than expected, accounting for the recent increase in the rate of sea level rise that was not accounted for from temperature increase alone. 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 (NRC 2012; Parris et al. 2012). The NRC report indicates that regional sea level rise projections are even more uncertain than the projections for global averages because local factors such as the steric (changes in the volume of water with changes in temperature and salinity) component of sea level-rise at regional levels and the vertical movement of land have large uncertainties (NRC 2012). 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, there is **high** confidence the sea level will continue to rise and that this will entail major damage to coastal regions.

CONFIDENCE LEVEL			
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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 percent 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 urban heat islands and exacerbation of heat island temperatures by climate change-caused increases in regional temperatures. There is abundant evidence of urban heat island effect for some Southwest cities (e.g., Sheridan et al. 2011), as well as several studies, some from outside the region, of the public health threats of urban heat to residents (e.g., Ostro et al. 2011; Ostro et al. 2009). Evidence includes observed urban heat island studies and modeling of future climates, including some climate change modeling studies for individual urban areas (e.g., Phoenix, 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 can cause cascading impacts, such as loss of water, and that projected diminished supplies will pose challenges for urban cooling (i.e., need for supplemental irrigation for vegetation-based cooling). However, there are no studies on urban power disruption induced by climate change and the emerging studies on power blackouts since 1984 do not identify high temperatures/heatwaves as a separate cause triggering blackouts. 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 (Gleick 2010). Several Southwestern states, including California, New Mexico and Colorado have begun to study climate impacts to water resources, including impacts in urban areas (Ray et al. 2008; California Department of Water Resources 2009). The interdependence of infrastructure systems, especially the dependence of systems on electricity and communications and control infrastructures, and the potential cascading effects of breakdowns in infrastructure systems are well established (Min et al. 2007; NRC 2002). The concentration of infrastructures in urban areas adds to the vulnerability of urban populations to infrastructure breakdowns. This has been documented in descriptions of major power outages such as the Northeast Power Blackout of 2003, or the recent September 2011 San Diego blackout (Federal Energy Regulatory Commission and North American Electric Reliability Corporation 2012). A few references point to the role of urban power outages in threatening public health (loss of air conditioning) (Hayhoe et al. 2010; Miller et al. 2008)and water supplies (Federal Energy Regulatory Commission and North American Electric Reliability Corporation 2012).
New information and remaining uncertainties	Key uncertainties include the intensity and spatial extent of drought/heat waves. Uncertainty is associated with quantification of the impact of temperature and water availability on energy generation, transmission, distribution, and consumption – which have an impact on possible disruptions to urban electricity. Major disruptions are contingent on a lack of operator response and/or adaptive

	actions.
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. Disruptions are a key uncertain factor. Based on the substantial evidence and the remaining uncertainties, confidence in each aspect of the key message is **high**.

CONFIDENCE LEVEL			
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