APPENDIX F
CLIMATE CHANGE PROJECTIONS, IMPACTS, AND ADAPTATION

Introduction

This appendix provides background information on global climate change projections, impacts to various resource areas used for the EIR impact analyses, and SANDAG's Climate Action Strategy and example adaptation measures. A discussion of three climate change projections is provided: temperature, sea level rise, and precipitation. Projections for wildfire, a secondary climate variable, are also provided. Potential impacts from these changes are discussed for seven resource sectors: public health, water management, coastal resources, biodiversity/habitat, agriculture, transportation and energy infrastructure, and emergency management. For both projections and impacts, the geographic scale of the discussion begins with the State of California and scales down to the San Diego region, depending on the data available.

Many global climate change projections and impacts are discussed for the year 2100, since many studies and reports use 2100 as an end date. Please note that the proposed Plan's farthest horizon year is 2050 not 2100.

During the timeframe of the proposed Plan, climate change effects likely to exacerbate the proposed Plan's impacts on selected resource areas include, but are not limited to:

- Higher annual average temperature
- More days of extreme high temperatures
- Longer and more humid heat waves
- More intense and frequent drought
- Increased evaporation from soil, surface waters
- More frequent, severe wildfires
- Sea level rise
- Less frequent, more intense rainstorms, more frequent watershed flood events
- More frequent and severe coastal flooding
- Spreading of pests and vector-borne diseases
- Changes in plant and animal species geographic range and distribution
- Increased threats to survival of some plant and animal species, loss of habitat

In general, the effects listed above would increase between 2020 and 2050. Table F-1 below summarizes the linkages among the resources areas addressed in this EIR and projected climate change effects in the San Diego region.

Table F-1: Linkages among Resource Areas Addressed in this EIR and Projected Climate Change Effects in the San Diego Region

Resource Area (EIR Section #)	**Projected Climate Change Effects**										
	Higher annual average temperature	More days of extreme high temperatures	Longer and more humid heat waves	Less frequent, more intense rainstorms, more frequent flood events	More intense and frequent drought	Increased evaporation from soil, reservoirs	Sea level rise, more frequent and severe coastal flooding	More frequent, severe wildfires	Increased threats to survival of some plant and animal species, loss of habitat	Changes in plant and animal species geographic range and distribution	Spreading of pests and vector-borne diseases
Aesthetics and Visual Resources (4.1)							X	X	X	X	
Agricultural and Forestry Resources (4.2)	X	X	X	X	X	X		X			X
Air Quality (4.3)	X	X	X					X			
Biological Resources (4.4)	X	X	X	X	X	X	X	X	X	X	X
Cultural and Paleontological Resources (4.5)							X				
Energy (4.6)	X	X	X	X	X		X	X			
Geology, Soils, and Mineral Resources (4.7)				X	X	X	X	X			
Greenhouse Gas Emissions (4.8)	X	X	X		X			X			
Hazards and Hazardous Materials (4.9)		X	X	X			X	X			
Hydrology and Water Quality (4.10)	X	X	X	X	X	X	X	X			
Land Use (4.11)							X	X			
Noise and Vibration (4.12)											
Population and Housing (4.13)							X	X			
Public Services and Utilities (4.14)	X	X	X	X	X	X	X	X			X
Transportation (4.15)		X	X	X			X	X			
Water Supply (4.16)	X	X	X	X	X	X		X			

Table F-2 summarizes the climate change projections and impacts discussed in greater detail in subsequent sections of the appendix.

Table F-2: Summary of Climate Change Projections and Impacts

Climate Projections	
Temperature	<u>Mid-Century</u> • + 3–4 °F in Coastal San Diego • + 4–5°F in Inland San Diego (Cayan et al. 2014) <u>End-of-Century</u> • + 4–6°F in Coastal San Diego • + 5–8°F in Inland San Diego (Cayan et al. 2014) • Increased frequency, duration, and intensity of heat waves in San Diego region (CEP and SDF 2014) • More humid heat waves with less cooling at night (CEP and SDF 2014)
Sea Level Rise	<u>Mid-Century</u> • Central Estimate(a): 0.9 ± 0.3 feet • Range(b): 0.4 – 2.0 feet <u>End-of-Century</u> • Central Estimate: 3.1 ± 0.8 feet • Range: 1.4 – 5.5 feet (NRC 2012; CO-CAT 2013; SANDAG 2014; CDOT 2013) • Higher storm surges, more extensive inland flooding, and increased erosion during storm events due to higher sea levels (CEP and SDF 2014)
Precipitation	<u>Mid-Century</u> • Up to 16% fewer rainy days per year in San Diego region • Up to 8% increase in avg. maximum daily precipitation in San Diego region (Cayan et al. 2014; CEP and SDF 2014) <u>End-of-Century</u> • Up to 18% fewer rainy days per year in San Diego region • Up to 16% increase in avg. maximum daily precipitation in San Diego region (Cayan et al. 2014; CEP and SDF 2014) • Overall drying trend with longer and more frequent droughts (CEC 2012; CNRA 2014) • More precipitation falling as rain rather than snow (CEC 2012; CNRA 2014; CDOT 2013) • Increase in number and intensity of extreme precipitation events (CEC 2012; CNRA 2014)
Wildfire	• Increase in number of large fires statewide (CEC 2012; Cal OES 2013) • Increase in burn areas statewide (CEC 2012) • Potential for larger fires and longer, less predictable fire season in San Diego (CEP and SDF 2014)
Climate Impacts	
Public Health	• Increased risk of heat-related illnesses and deaths (CalEPA and CDPH 2013; Cal OES 2013; CNRA 2014; CEP and SDF 2014) • Increased health risks for vulnerable populations due to urban heat island effect (CAL EMA and CNRA 2012) • Increased air pollution and associated health impacts due to higher temperatures, wildfires, and increased energy demands (CNRA 2014; CEC 2012; CEP and SDF 2014) • Changes in spread of vector-borne diseases (CNRA 2014) • Increased flooding and wildfire events contribute to injury, death, displacement, mental health burden (CNRA 2014)
Water Management	• Reduced water supply due to reduced mountain snowpack and drought (CalEMA and CNRA 2012, 2014) • Increased risks to water supply from State Water Project and groundwater aquifers due to sea level rise and salinity intrusion (Messner et al. 2009) • Increased water demand due to population growth, higher temperatures, and longer intervals without rain (CEP and SDF 2014)
Coastal Resources	• Increased inundation and erosion of beaches, resulting in loss of public access, tourism, and marine mammal habitat (CNRA 2014; CCC 2015<u>a</u>). • Increased bluff erosion from sea level rise and wave action (CNRA 2014) • Increased inundation, flooding, erosion damage to coastal infrastructure (CNRA 2014) • Increased pollution runoff harming water quality from sea level rise and flooding (CNRA 2014) • Adverse effects to marine chemistry and ecology, with ripple effects to various economic sectors, due to ocean acidification (CNRA 2014)

Climate Impacts (continued)	
Biodiversity/ Habitat	• Migration of some species northward in latitude and/or upward in elevation (CNRA 2009) • Increases in tropical pathogens, parasites, and diseases due to higher temperatures (CNRA 2009, 2014) • Increase in nonnative invasive species (CNRA 2009, 2014) • Increase in species loss and extinction (CNRA 2009, 2014; CEP and SDF 2014) • Increase in mismatches of timing of migration, breeding, pollination, and other ecological processes and interactions (Kadir et al. 2013; CNRA 2009)
Agriculture	• Adverse effects on crop production due to higher temperatures, decreased water availability, and flooding (CEC 2012; CDFA 2013; CNRA 2014) • Adverse effects on agricultural production due to decreases in pollinators, increases in pests, and disruptions to transportation and energy infrastructure (CEC 2012; CDFA 2013; CNRA 2014) • Adverse effects on livestock production due to higher temperatures, decreased water availability (Walthall et al. 2012)
Transportation and Energy Infrastructure	• Increased peak electricity demand due to extreme heat (CEC 2009) • Reduced hydropower output due to precipitation changes and snowpack loss (CEC 2012; CNRA 2014) • Reduced transmission line and power plant efficiency due to higher temperatures (CEC 2012) • Increased wildfire damage to transmission lines (CEC 2012; Sathaye et al. 2011) • Increased flooding damage to coastal energy infrastructure (CEC 2012; Sathaye et al. 2011) • Increased risk of blackouts and power outages (Messner et al. 2009) • Increased damage to coastal transportation infrastructure due to sea level rise and coastal storms (CDOT 2013; CNRA 2014) • Increased damage to roads, highways, and rail due to extreme heat (CDOT 2013; CNRA 2014; FTA 2011)
Emergency Management	• Increased risk to public safety and property (CNRA 2014) • Increased need for emergency management services and capacity (CNRA 2014) • Increased emergency response costs (CNRA 2014)

(a) Central estimate indicates the mean ± standard deviation for the A1B scenario.
(b) Ranges are the means for B1 and A1F scenarios. The lower end of the ranges could only occur under the most optimistic scenarios.

Climate Change Projections

Temperature

California Statewide Projections

The State of California's *Preparing California for Extreme Heat: Guidance and Recommendations* provides a summary of projections for increased temperatures and extreme heat events in California (CalEPA and CDPH 2013). According to the guidance, models have been consistent in projecting increases in annual average temperature of up to 5 degrees Fahrenheit (°F) by the 2030s and up to 10°F by the end of the century.

Temperature projections from Cayan et al. 2012, as referenced in *Addressing Climate Change Adaptation in Regional Transportation Plans* (CDOT 2013), include the following statewide projections:

- Summer temperatures are projected to increase more quickly than winter temperatures.
- Temperatures in inland areas are likely to increase more quickly than in coastal regions.
- Extreme heat events will become more common, last longer, and cover larger areas.
- Temperature changes over the next 30 to 40 years are already determined, due to emissions which have occurred to date. By 2050, temperatures are projected to increase by an additional 1.8 to 5.4 °F, regardless of future emissions.
- After 2050, temperature projections diverge for different emissions scenarios. By 2100, models project temperature increases between 3.6 to 9°F.

San Diego Regional Projections

Temperature varies considerably around the San Diego region due to local geographic characteristics. The Cayan et al. 2014 temperature projections differentiate between coastal and inland San Diego region and predict greater warming inland than near the coast due to the moderating effects of the Pacific Ocean. These projections indicate that annual average temperature in San Diego's coastal areas will increase 3–4 °F by mid-century and 4–6°F by end-of-century, depending on the greenhouse gas emissions scenario. Annual average temperatures in inland areas are projected to increase 4–6°F by mid-century and 5–8°F by end-of-century. The Climate Education Partners and San Diego Foundation's report *San Diego, 2050 Is Calling. How Will We Answer?* (CEP and SDF 2014) projects a 4.8°F increase in annual average temperature by 2050.

Heat waves are also projected to increase in frequency in the San Diego region. While heat wave days have historically occurred twice per year in the San Diego region, by mid-century, the region is projected to see heat wave days occurring 12–16 times per year (Cayan et al. 2014). By end-of-century, heat wave days are projected to occur 17–36 days per year.[1] Heat waves are also expected to increase in duration. Historically, heat waves lasted 2 days on average, but by mid-century, heat waves are projected to last 3–4 days on average (Cayan et al. 2014). By end-of-century, heat waves are projected to last 4–5 days on average. Lastly, heat waves are projected to be more humid with less cooling occurring at night (CEP and SDF 2014).

Sea Level Rise

California Statewide Projections

Relative rates of sea level rise vary along the California coast in relation to vertical land movement. The observed rise per century is 8.0 inches in San Diego, 3.3 inches in Los Angeles, and 2.7 inches in Port San Luis; sea level rise is falling in Crescent City at a rate of 2.9 inches per century due to vertical land uplift (NRC 2012). Sea level rise rates are expected to accelerate considerably in the future (CEC 2012; NRC 2012).

San Diego Regional Projections

The California Coastal Commission (CCC) ~~released Draft~~adopted Sea-Level Rise Policy Guidance in ~~October 2013~~August 2015 (CCC ~~2013~~2015b) that recommends steps for addressing sea level rise in CCC planning and regulatory actions. The guidance indicates that, at the time of writing, the 2012 National Research Council (NRC) Report, *Sea Level Rise for the Coasts of California, Oregon, and Washington*, was the best available science on sea level rise in California.

In March 2013, the Coastal and Ocean Working group of the California Climate Action Team (CO-CAT) released updated guidance and policy recommendations for incorporating sea level rise projections into planning and decision making, and also based its findings on the 2012 NRC report (CO-CAT 2013). SANDAG's *Climate Change White Paper* (SANDAG 2014) also references the projections from the 2012 NRC report. At the time of writing, the 2012 NRC report continues to be widely regarded as the best available science for sea level rise projections for the California coast and the San Diego region. The report includes the ranges of three time horizons for the areas south of Cape Mendocino, including San Diego (Table F-3).

California Department of Transportation's 2013 report, *Addressing Climate Change Adaptation in Regional Transportation Plans: A Guide for California MPOs and RTPAs*, (CDOT 2013) references sea level rise projections from State of California Sea-Level Rise Interim Guidance Document (CO-CAT 2010), which has since been updated and revised (CO-CAT 2013).

[1] The definition of a heat wave day in this analysis is the occurrence of the 98th percentile maximum temperature calculated from the historical period of 1970–2000 for at least 1 day.

Table F-3: Sea Level Rise Projections for South of Cape Mendocino

Time Period	Central Estimate	Range
2000–2030	14.7 ± 5.0 cm (0.5 ± 0.2 feet)	4.6–30.0 cm (0.2–2.0 feet)
2000–2050	28.4 ± 9.0 cm (0.9 ± 0.3 feet)	12.7–60.8 cm (0.4–2.0 feet)
2000–2050	93.1 ± 24.9 cm (3.1 ± 0.8 feet)	44.2 –166.5 cm (1.5 – 5.5 feet)

Source: NRC 2012
Note: Central estimate indicates the mean ± standard deviation for the A1B scenario. Ranges are the means for B1 and A1F scenarios. The lower end of the ranges could only occur under the most optimistic emissions scenarios.

Precipitation

California

Although uncertainties exist regarding the precise effects of climate change on precipitation in California, the majority of global climate models predict drying trends across the state (CNRA 2009; Cayan et al. 2012; CEC 2012; Cal OES 2013; CNRA 2014). California's Mediterranean climate is expected to continue through the next century, with warm, dry summers and relatively cooler and wet winters. Despite uncertainty surrounding the amount of precipitation, a larger share of California's precipitation is likely to fall as rain rather than snow because of increasing temperatures (Cayan et al. 2012; CDOT 2013; CNRA 2014). Climate change is also expected to increase the frequency and intensity of large precipitation events in California (Cayan et al. 2012; CEC 2012; CNRA 2014). Cayan et al. 2012 analyzed 3-day accumulations of precipitation to understand the potential for future flooding. This research found that nearly all of California shows striking increases in maximum 3-day accumulations, including many instances of values far outside the historical distribution. Given overall drier conditions, with a higher percentage of precipitation occurring as rain and within large precipitation events, the potential for floods is also expected to increase (CNRA 2014).

San Diego Region

While the region is likely to retain its Mediterranean climate, projections indicate that the San Diego region will likely see drier conditions. Projections indicate that the number of rainy days per year will decrease 8–16 percent by mid-century. At the same time, projections indicate that rainstorms will be more intense, with 8 percent more rainfall during the biggest rainstorms by mid-century (Cayan et al. 2014; CEP and SDF 2014).

Wildfire

California

Wildfire risk in California is anticipated to increase due to earlier snowmelt, higher temperatures, and longer dry periods (CEC 2012; Cal OES 2013; CNRA 2014). The number of large fires statewide is estimated to increase 58–128 percent above historical levels by 2085. Burned areas will also increase 57–169 percent, depending on location (CEC 2012). Wildfire risk will also be indirectly influenced by potential climate-related changes in vegetation and ignition potential from lightning. Nevertheless, human activities will continue to be the biggest factor in ignition risk (CEC 2012). Studies also demonstrate that the distribution and degree of increased wildfire risk in California will also be driven to a large extent by changes in land use and development, including rates of residential and infrastructure expansion into fire prone areas (Bryant and Westerling 2012).

San Diego Region

Southern California already experiences wildfire, and specific increases in the frequency and severity will depend on factors including shifts in vegetation, Santa Ana wind behavior, temperature increases, and decreased soil moisture due to longer periods of drought (CAL EMA and CNRA 2012; SANDAG 2014). Climate change models yield a somewhat different prediction about the frequency, timing, and severity of future Santa Ana wind conditions (Messner et al. 2009).

The wildfires of 2003 and 2007 in San Diego County resulted in more than $4.5 billion in damages, not accounting for indirect costs like interrupted economic activity (CEP and SDF 2014). Hotter and drier climate will alter fuel conditions in ways that promote larger, more catastrophic fires like the ones seen in 2003 and 2007 (CEP and SDF 2014). The fire season is likely to become longer and less predictable (CEP and SDF 2014).

Climate Change Impacts to Resource Areas

Public Health

Climate change poses a variety of public health risks, including risks related to heat, outdoor and indoor air quality, water quality and availability, toxins, extreme weather events, flooding, infectious diseases, limitations on health services, food safety and food security, and cascading impacts from impacts to lifeline infrastructure, including power, water, and transportation (CNRA 2014).Vulnerable populations including the elderly, disabled, or low-income may be more sensitive than others and may have less ability to prepare for, cope with, or adapt to changing conditions. These populations will be impacted disproportionately (CEC 2012).

Extreme Heat

Extreme heat brings greater risk of dehydration, heat stroke, heat exhaustion, heart attack, other heat-related illnesses, and death (CalEPA and CDPH 2013; Cal OES 2013; CNRA 2014).Heat waves do not cause the physical damage that floods, fires, and earthquakes do, but they can be very deadly (Cal OES 2013). For example, a California Department of Public Health study estimates that over 650 deaths occurred in an extended California heat wave in 2006 (Hoshiko et al. 2010).

In highly populated areas within the San Diego region, "urban heat islands" exacerbate the public impacts that heat waves have upon more vulnerable populations (CAL EMA and CNRA 2012). Urban heat islands refer to the phenomenon of temperatures in urban areas being significantly higher than in surrounding, less urbanized areas because pavement and building material absorb sunlight and heat (Imhoff et al. 2010). The most intense urban heat island effects are often seen in neighborhoods where dense land use and impervious, paved surfaces predominate and trees, vegetation, and parks are less common. Access to the cooling effects of urban greening and open space is often most limited for low-income urban communities (CalEPA and CDPH 2013).

Although greater warming due to climate change is anticipated in the region's inland areas, populations in the cooler coastal areas may also be at greater risk because individuals are less acclimatized to heat, people are less aware of behaviors that can reduce exposure or reduce physiologic stress, the built environment is not designed for warmer conditions, and such communities may not have plans for emergency heat mitigation measures (CalEPA and CDPH 2013.)

Increases in Ozone and Particulate Matter Air Pollution

Higher temperatures are expected to increase the frequency, duration, and intensity of conditions conducive to the formulation of ozone (CNRA 2014). An increase in population exposure to ground-level ozone is projected to increase in San Diego in 2050 due to the increase in hot, sunny days (Messner et al. 2009). In addition, wildfires, projected to increase in frequency and size, emit dangerous particulate matter. Particulate air pollution would also increase as a result of increased energy demands due to higher temperatures (CEC 2012). All of these factors would lead to poorer air quality in the San Diego region, exacerbating a range of health issues (CEP and SDF 2014).

Changes in Allergens

Changes in temperature, precipitation, and extreme weather events may also change the production, distribution, and dispersion of air-borne allergens such as pollen, mold, and indoor allergens. Although there are still no definitive conclusions on how climate change will impact air-borne allergens, particularly at the regional level, models indicate that pollen will likely increase in many parts of the United States, seasonal timing of allergen production may shift, and allergen content and potency may increase (CNRA 2014). Long-term studies of plant species have documented earlier flowering in response to increased winter and spring temperatures (Groffman et al. 2014). In addition, as spring is advancing and fall is being delayed, the growing season is lengthening, which exacerbates human allergies (Groffman et al. 2014). For example, a longer fall allows for bigger ragweed plants that produce more pollen later into the fall (Groffman et al. 2014).

Rising pollen levels and longer pollen seasons increase allergic sensitivity and asthma episodes (USEPA 2008), decrease economic productivity, and increase the number of school days missed each year (Staudt et al. 2010). In fact, allergies are the sixth most costly chronic disease category in the United States, collectively costing the health care system approximately $21 billion annually (Gambel et al. 2008).

Flooding and Wildfire

An increase in extreme events like flooding and wildfire would also impact public health. Flooding can lead to loss of life, injury, and increased mental health burden; loss of property and employment; displacement; economic disruptions; interruption of health services and mobility; and toxic or infectious exposures (CNRA 2014). Wildfire may also cause property loss, displacement, injury, and loss of life (CNRA 2014).

Infectious Disease

Changes in temperature and precipitation associated with climate change may lead to changes in the spread of vector-borne diseases (CNRA 2014). Climate change could increase the mosquito population where more standing water occurs, such as after extreme precipitation events (CNRA 2014; CEP and SDF 2014).Higher winter temperatures could also increase the tick population (CNRA 2014). Heavy rainfall and flooding could lead to an increase in water-borne diseases (CNRA 2014).

Water Management

Climate change adds new vulnerabilities and exacerbates historical challenges to California’s water management (CNRA 2014). The major impacts of climate change on the water management sector include changes in the timing, form, and amount of precipitation; changed runoff patterns; increases in the frequency and severity of floods and droughts; and sea level rise. These impacts can negatively affect water supplies, water quality, and water storage and distribution infrastructure (CNRA 2014). Water demand is expected to increase across a range of sectors (CNRA 2014).

Precipitation Changes

Two primary sources of water used by the San Diego region are the State Water Project and the Colorado River, which provide 75–95 percent of the region's water supply, depending on the year (CEP and SDF 2014). In both cases, these water supplies originate in mountain snowpack. Climate change will result in reduced snowpack due to drier conditions and warmer conditions, (CalEMA and CNRA 2012; CNRA 2014). The state's current water management system relies on mountain snowpack acting as a huge winter and spring reservoir, with snow at some altitudes not melting until well into June. Mountain regions will experience less precipitation overall. Even as precipitation decreases, warmer temperatures will result in a higher percentage of annual precipitation falling as rain, and in an earlier spring melt of the remaining snowpack. Existing reservoirs will be filled to capacity earlier in the year, and no longer replenished in late spring. As a result, the total annual stored water volume will decrease, resulting in a reduced water supply during dry seasons (CNRA 2014). Scientists are expecting a 12 percent decrease in the runoff and streamflow that is replenishing San Diego's major water sources (CEP and SDF 2014).

Groundwater/Drought

Groundwater supplies are less plentiful in the San Diego region than elsewhere in California due to lack of storage capacity in local aquifers, availability of groundwater recharge, and degraded water quality (SDCWA 2015a). As a result, only about 3 percent of regional supply comes from groundwater (SDCWA 2015a). During droughts, groundwater use will likely intensify, potentially resulting in increased overdraft and subsidence, which can result in permanent loss of storage and damage to overlying infrastructure, and further stress groundwater-dependent ecosystems (CNRA 2014).

Sea Level Rise

Sea level rise, coastal storm surge, sea level-driven increases in ground water levels, and salinity intrusion pose threats to San Diego's water supplies imported from the Sacramento-San Joaquin Delta via the State Water Project (Messner et al. 2009). As seas rise, and freshwater flows decrease, the salinity influence of the Pacific Ocean moves deeper into the California Delta, threatening the water quality of this major source of freshwater to the state (SDCWA 2015b). Over the 5-year period 2009–2013, 19 percent of the San Diego County Water Authority's (SDCWA) supply came from the State Water Project. Further threatening the State Water Project is the vulnerability of the levees protecting the California Delta to damage and failure from flooding (Messner et al. 2009; DWR 2009).

In addition, coastal groundwater aquifers are already vulnerable to salinization, which will be exacerbated by rising sea levels (Heberger et al. 2009). While only 3 percent of San Diego's regional supply comes from groundwater, in 2014, that roughly corresponded to 19,000 acre-feet of water (SDCWA 2015a). As each single acre-foot is approximately 325,900 gallons, this is a non-negligible amount of water that may be threatened by increased salinity.

Changing Water Demand

SDCWA analyzed climate change impacts on water demand and found that, in 2035, the impact would range from a 0.63 percent increase in demand under a B1 emissions scenario to a 1.8 percent increase under an A2 emissions scenario. While potable water use has decreased more than 20 percent since 2007, SDCWA also notes that high temperatures in 2015 have made it difficult to reduce water use compared to the same months a year earlier (SDCWA 2015c).

Coastal Resources

Three-quarters of California's population lives near the coastline, living, commuting, working, and recreating along the shorelines. Downtown San Diego, and commercial and residential portions of Pacific Beach, Encinitas, and Oceanside are only a few feet above existing sea level. Rising sea levels, coastal storms, and erosion put infrastructure and natural assets at risk (CNRA 2014). Ocean acidification threatens the health of ocean ecosystems and ocean-based activities, including commercial fishing and coastal recreation (CNRA 2014).

Beaches and Bluffs

Sea level rise will result in the inundation of some beaches; for gently sloping beaches, a general rule of thumb is that approximately 50 to 100 feet of beach width will be lost for every foot of sea level rise (CNRA 2014). Beaches and bluffs also will be exposed to greater and more frequent wave action, due to the elevated seas as well as to a possible increase in the frequency and severity of storm waves, resulting in more erosion (CNRA 2014). When the means of protecting existing structures involves building sea walls or other "hard armoring" of the coast, there will be an inevitable additional loss of beaches as a result (CNRA 2014). The loss of beaches due to armoring and sea level rise will in turn result in loss of public beach access, tourism losses, losses of marine mammal haul-out area and sandy beach habitat, and loss of beach buffering capacity against future bluff erosion (CCC 2015a; Pendleton et al. 2009).

Sea level rise can also result in loss of intertidal zones, where they are bordered by cliffs or man-made structures. Loss of this habitat is of particular concern because these zones nurture an incredible diversity of marine wildlife and act as important nursery habitat for many marine species. The two primary intertidal marine reserves in San Diego, Cabrillo National Monument and Scripps Coastal Reserve, are both bordered by steep cliffs and will lose much of their intertidal habitats (Messner et al. 2009).

Infrastructure

Sea level rise and coastal erosion threaten coastal infrastructure, including transportation assets (ports, airports, roads and highways, bridges, transit systems, and fueling infrastructure), water supply and delivery infrastructure, and wastewater and storm water infrastructure (CNRA 2014). Rising sea levels will significantly increase the challenge to transportation managers in ensuring reliable coastal transportation. Erosion, permanent inundation, and temporary flooding from sea level rise can cause roadway, rail, and airport washout and damage, route closures, travel delays, and disruption of transit services (CDOT 2013). Inundation of even small segments of the intermodal transportation system can render much larger portions impassable, disrupting connectivity and access to the wider network (CDOT 2011). Bridges can also be vulnerable to sea level rise. A North Coast Corridor study found that multiple bridges along the railroad, Interstate 5, and State Highway 101 corridors may be vulnerable to high water in the future (SANDAG and CDOT 2013).

The *Sea Level Rise Adaptation Strategy for the San Diego Bay* found that the storm water, wastewater, transportation facilities, and commercial buildings sectors in the San Diego Bay are particularly vulnerable to sea level rise and coastal flooding (ICLEI 2012). For example, parts of the San Diego International Airport were found to be vulnerable to future localized flooding from blocked storm outfalls in the bay and, in 2100 scenarios, airport operations will be vulnerable to Bay flooding and inundation, particularly from impacts on access roads, future terminal areas, and portions of the runway/airfield (ICLEI 2012).

A range of climate change impacts to energy and transportation infrastructure is discussed further below.

Hazardous Materials

The presence of facilities or land containing hazardous materials in coastal areas susceptible to flooding presents toxic exposure risks for human communities and ecosystems. Hazardous materials can be spread by flood waters to contaminate drinking water supplies, buildings and property, and ocean-based food sources (CNRA 2014). A 2009 study evaluated sites containing hazardous materials at risk from sea level rise in California. In 2009, no such sites were located in high flood risk areas (100-year floodplain) in San Diego County, but with a 55-inch sea level rise, the high risk flood area along the San Diego County coast will expand and the number of hazardous waste sites at risk will increase to 13 (Heberger et al. 2009).

Extreme Weather and Pollution Runoff

Sea level rise and extreme storm events may lead to increased flooding, which may result in water pollution from nonpoint sources of contaminants (e.g. oil, pesticides, litter, nitrogen fertilizers, etc.) (CNRA 2014). Polluted storm water runoff in coastal waters can cause serious public health problems as well as illness, death, and reproductive failures in marine species (USEPA 2015). Extreme storm events may also increase releases of raw sewage into marine environments, due to accidental spills from aging, cracked, and leaking sewer systems or due to overflows of untreated or partially treated wastewater from combined sewer systems (State Water Board 2015).

Ocean Acidification

The chemistry of the world's oceans is changing as increasing carbon dioxide is absorbed into the surface water. This results in a decrease in pH, a process known as ocean acidification. Ocean acidification is considered a global threat to marine ecosystems and has the potential to impact various economic sectors (e.g., fisheries, aquaculture, tourism) and coastal communities in California, and may also have indirect effects on food security and biodiversity (CNRA 2014). While oceanic uptake of carbon dioxide from the atmosphere provides some mitigation of greenhouse gas emissions, it is having a profound long-term impact on marine ecosystems (Kelly and Caldwell 2012).

Biodiversity/habitat

Climate change is adding pressure to ecosystems already stressed by habitat loss and fragmentation, pollution, disease, population growth, and other human-related impacts. This added pressure is significantly increasing the risk of biodiversity loss and species extinction (CNRA 2014). There is evidence that changes to air and water temperatures, changes to water quality and availability, sea level rise, ocean acidification, and altered wildfire regimes are already affecting biological systems in California (Kadir et al. 2013). The 2009 California Climate Adaptation Strategy (CNRA 2009) provides detailed information on projected impacts and risks to biodiversity, and includes the impacts described below.

Species Migration

The population distributions of some North American species are expected to move northward in latitude and upward in elevation. While this means a range expansion for some species, for others it means a range reduction, movement into less hospitable habitat, or increased competition. Some species have nowhere to go because they are already at the northern or upper limit of their habitat or because there are impediments to migration, such as natural landscape features or human development (CNRA 2009). Modeling by the Center for Conservation Biology at UC Riverside has shown that, in response to higher temperatures and reduced precipitation, vegetation types in Southern California will tend to move to higher elevations. Suitable environmental conditions for coastal sage scrub are predicted to decrease between 10 percent and 100 percent under altered climate conditions (Messner et al. 2009).

Chaparral responded in a manner similar to coastal sage scrub, although higher percentages of suitable habitat remain under altered conditions. However, elevation shifts in San Diego County are substantially constrained as a result of population growth and development, habitat degradation, unsuitable soils, or other physical limitations (Messner et al. 2009). In addition, current high altitude habitats are not able to migrate to higher elevations and are particularly vulnerable to species loss and extinction (CNRA 2014).

Pathogens, Parasites, and Disease

Climate change and shifts in ecological conditions could support the spread of pathogens, parasites, and diseases, with potentially serious effects on human health, agriculture, and commercial fishing (CNRA 2009, 2014). For example, projected warmer winter temperatures may increase insect survival and populations, including pest species such as bark beetles that kill trees and impact habitat in San Diego County forests (Messner et al. 2009).

Invasive Species

Climate change may aid or accelerate the spread of invasive species that pose additional threats and stress to native fish, wildlife, and plants (CNRA 2009, 2014). Extreme weather events projected to increase due to climate change generally benefit invasive species given their tolerance to a wide range of environmental conditions. Invasive species often have greater flexibility and can survive under variable and extreme conditions, such as flood events or drought (CNRA 2009).

Extinction Risks

Climate change, along with habitat destruction, pollution, and other human-related impacts, can act as a stressor that contributes to species loss and extinction (CNRA 2014). The Intergovernmental Panel on Climate Change estimates that 20–30 percent of the plant and animal species evaluated so far in climate change studies are at risk of extinction if temperatures reach levels projected to occur by the end of this century (Fischlin et al. 2007). While natural systems have some adaptive capacity to respond to change, many ecosystems may lack the ability to survive the rate and scale of predicted change, threatening the survival of some species (CNRA 2009, 2014; CEP and SDF 2014).

San Diego County is located in a biodiversity hotspot, which refers to a region that is both a significant reservoir of biodiversity and is threatened with habitat destruction (Messner et al. 2009). San Diego has a large convergence of fish, mammal, and plant hot spots all coinciding (Messner et al. 2009). At the same time, land use changes have impacted biodiversity across San Diego County (Messner et al. 2009). As a result, San Diego County is one of two counties with the most plants and animals at risk for extinction in the continental United States (Messner et al. 2009).

Changes in the Timing of Seasonal Life-Cycle Events

Climate changes can lead to mismatches in the timing of migration, breeding, pollination, and food availability. Warming has already impacted the seasonal timing of biological events in California, including flowering times, leaf emergence, fall bird migration, and insect emergence (Kadir et al. 2013). A change in climate can disrupt biological interactions and impact ecosystem dynamics by displacing existing biological interactions. For example, an earlier occurrence of flowering may result in lack of pollination and plant reproduction if pollinators have not yet emerged from dormancy or arrived from winter migration sites (CNRA 2009).

Agriculture

Climate change is expected to exacerbate stresses on the agricultural sector. Changes in air, soil and water temperature, soil moisture content, invasive pests, native pollinators, and water availability affect crop yield and quality, crop species, and livestock management, making the agricultural sector highly sensitive to climate change (CEC 2012).

Crops

Crops are sensitive to the availability of water, the quality of water, and the timing of water application (CDFA 2013; CNRA 2014). In general, water resources available for agricultural irrigation are expected to decrease, and become less predictable, while risks of flooding also expected to increase (CNRA 2014). Both of these factors could take a toll on crop production (CDFA 2013).

Crops are also sensitive to the magnitude of change in temperature, extreme temperature, and the timing of temperature changes (CDFA 2013). Higher temperatures due to climate change are likely to result in the reduction in yield of some of California's most valuable specialty crops (CDFA 2013).Many of California's crops require distinct seasons, including specific chill temperatures and durations, and inadequate winter cold can cause late or irregular blooming that decreases yields (CDFA 2013). Extreme summer temperatures can burn crops, and by increasing evaporation, decrease soil moisture, causing and exacerbating drought conditions (CDFA 2013)

Indirect impacts could also take a toll on crop production, including decreases of pollinators and increases of pests, disease, and invasive weeds, and disruptions to the transportation and energy infrastructure supporting agricultural production (CEC 2012; CDFA 2013; CNRA 2014).

The combined effect on agriculture from multiple changing climate variables is complex and difficult to predict, and can be a mix of positive and negative impacts (e.g., longer growing periods, but more pests); however, by midcentury and beyond, climate change is projected to have overall detrimental impacts on most current crop production (Walthall et al. 2012; CDFA 2013). San Diego County's highest revenue crops include ornamental trees and shrubs, indoor flowering and foliage plants, bedding plants, avocados, tomatoes, lemons, herbaceous perennials, strawberries, and cactus and succulents (Farm Bureau 2015). Perennial crops, like avocados, lemons, and strawberries, are semipermanent and therefore potentially more vulnerable to climate change than are annual crops (Lobell et al. 2006). For example, research has found that climate change will likely put downward pressure of yields of avocados by 2050 and San Diego County is one of the nation's leading avocado producers (Lobell et al. 2006; Farm Bureau 2015). A study of annual crops in California, including tomatoes, found that climate change will decrease crop yields in the long term (Lee et al. 2009).

Studies have established that many impacts on perennials (such as peaches, strawberries, and almonds) vary by crop, while nearly all annual crops (such as wheat and sunflowers) are expected to decline in the future (CEC 2012).

Livestock

Increasing air temperatures can also affect livestock production when temperature exceeds optimal levels. Heat stress in livestock can result in reduced pregnancy rates, longer time needed to reach market weight, and reduced milk production (Walthall et al. 2012).

Agricultural Workers

Higher temperatures and extreme heat could lead to increased incidences of heat stress in agricultural workers, which may reduce productivity, and lead to illness, disability, or death in extreme exposures (CNRA 2014).

Energy and Transportation Infrastructure

California's economy and its residents' quality of life depend on safe and reliable energy and transportation services. The energy sector provides services through a complex, integrated system involving generation, transmission, distribution, and consumption in homes, businesses, and other facilities (CNRA 2014). California's transportation infrastructure includes extensive roads and highways, railways, ports, airports, transit systems, and a variety of supporting fueling systems (CNRA 2014). While both of these sectors are primary contributors to greenhouse gas emissions, both are also vulnerable to climate change impacts, including extreme heat, sea level rise, changes in precipitation, and wildfire (CNRA 2014).

Energy

California's energy systems are vulnerable to a variety of climate stressors as reported in the California Climate Change Third Assessment (CEC 2012). The primary climate stressors to the energy system in California are warmer temperatures, less snowpack, more frequent extreme weather events, and sea level rise. Expected impacts include higher energy demand, decreased production efficiency, and physical damage to power infrastructure from floods, wildfire, and sea level rise.

Higher temperatures, especially during more frequent and intense heat waves, stress the electricity generation and distribution system as cooling needs cause electricity demand to spike. A 2009 study estimates a 60–70 percent increase in peak electricity demand by 2050 (CEC 2009). Without adequate planning, hotter summers and more intense heat waves could result in rolling blackouts and power outages (Messner et al. 2009).

While higher temperatures lead to higher electricity demand, higher temperatures could also lead to reductions in electricity supply. Higher temperatures reduce the efficiency of thermal power plants, such as natural gas, solar thermal, nuclear, and geothermal. Power plant cooling is less efficient at higher air temperatures and this, in turn, reduces overall efficiency and the amount of energy generated (CNRA 2014).Transmission of electricity is also impacted by higher temperatures as transmission lines experience lower efficiencies in high heat (CEC 2012).

Hydroelectric power, a key source of electricity during the summer peak demand period, will likely see reduced capacity due to the loss of mountain snowpack and potential reductions in annual precipitation (CEC 2012; CNRA 2014). Alternative generation would need to be procured, likely at a higher cost (CNRA 2014).

Furthermore, transmission lines are vulnerable to damage by wildfires, which are likely to occur more frequently in the coming decades (CEC 2012). The probability of exposure to fire of some transmission lines is expected to increase by as much as 40 percent by end-of-century (Sathaye et al. 2011).

Sea level rise threatens about 20 existing coastal power plants in California (CNRA 2014; Sathaye et al. 2011). These low-lying power plants face the risk of flooding or partial flooding due to sea level rise and increased storm surges. While none of these facilities are located in San Diego County, the interconnectivity of the grid means that their impairment could impact the San Diego region.

Just as the electrical grid is vulnerable to climate change, the transportation fuel infrastructure and associated facilities (e.g., refineries) that support transportation are vulnerable to extreme events, sea level rise, and coastal inundation or levee failure (CNRA 2014).The infrastructure that provides natural gas to homes, industries, and power plants is also vulnerable to indirect impacts of climate change. Vulnerability assessments and adaptation studies for these parts of the energy system, however, have yet to be examined in more detail (CNRA 2014).

Transportation

Major transportation infrastructure, such as ports and airports, roads, highways, bridges, transit systems, and energy and fueling infrastructure, faces increased risks of flooding and erosion due to sea level rise and extreme precipitation events (CNRA 2014; CDOT 2013). The resulting damage to transportation infrastructure would lead to service interruptions, route closures, travel delays, and impaired goods movement (CDOT 2013).

Extreme heat associated with climate change also threatens highways and railways as it may damage road materials and other transportation infrastructure (CDOT 2013). High temperatures cause deformation of asphalt, including buckling (CDOT 2013). Rail lines are also vulnerable to heat as metal rail lines kink under extreme heat conditions, which can lead to rail breakage and train derailment (FTA 2011; CDOT 2013; CNRA 2014).

Emergency Management

Emergency management is a comprehensive system of policies, practices, and procedures designed to protect people and property from the effects of emergencies or disasters. It includes programs, resources, and capabilities to mitigate, prepare for, respond to, and recover from effects of hazards (CNRA 2014). Disaster risks typically associated with the San Diego region include earthquake, flood, and wildfire. However, the San Diego region also faces emergency risks associated with landslides, dam failures, tsunami, and man-made hazards (SDC OES 2010).

More extreme weather events, sea level rise, changing temperature and precipitation patterns, and more severe and frequent wildfires will affect all aspects of emergency management. Climate stressors will affect existing emergency management capabilities and increase needs for emergency management services (CNRA 2014). Without appropriate preparation in the emergency management sector, climate change will increase risks to public safety and property, and increase emergency response and recovery costs to government and taxpayers (CNRA 2014).

Climate Change Adaptation

Climate change adaptation is the process of adjustment to reduce the negative impacts of climate change (IPCC 2014). Adaptation seeks to moderate or avoid harm or exploit beneficial opportunities (IPCC 2014). The 2010 SANDAG Climate Action Strategy states that adaptation will be critical to protecting the region from the impacts of climate change. The strategy includes adaptation goals, objectives, and measures to protect transportation and energy infrastructure. A 2014 North Coast Corridor study included a Coastal Sea Level Rise Analysis that provides recommendations of future ocean water levels for consideration in the design of transportation improvements (SANDAG and CDOT 2014). The 2015 update to the San Diego County Multi-Jurisdictional Hazard Mitigation Plan will also include climate change risks and strategies to mitigate those risks (ICLEI 2015). Local jurisdictions are also planning for climate change impacts. For example, in 2011 climate adaptation measures were added to Chula Vista’s Climate Action Plan (City of Chula Vista 2011). The cities around the San Diego Bay, the Port of San Diego, and San Diego Airport also developed a sea level rise vulnerability assessment and strategy in 2012 (ICLEI 2012).

Below are examples of adaptation measures found in these local and regional plans and studies:

Transportation Sector Adaptation Measures (SANDAG 2010)

- Conduct research aimed at developing transportation infrastructure materials better suited to withstand high temperatures
- Accelerate inspection schedules and prepare for increased maintenance costs
- Address adaptation issues in the design and location of new projects, and when improvements are made to existing infrastructure
- Modify standards for the design, location, and construction of infrastructure to account for areas potentially subject to storm surge, sea level rise, and more frequent flooding
- Reduce building in floodplains and areas subject to storm surge or sea level rise

Energy Sector Adaptation Measures (SANDAG 2010)[2]

- Support the rollout of advanced metering infrastructure that enables electric vehicles, distributed generation systems, and electricity consumption to be accurately monitored by end-users and the utility
- Participate in peak demand reduction programs and undertake peak demand measures at local government facilities
- Support a regional building retrofit program that can reduce overall and peak energy and water use in older structures
- Exceed Title 24 energy requirements for new construction through policy or incentives that work toward an overall goal of zero net energy new homes by 2020 and net energy new commercial buildings by 2030
- Request periodic briefings from utilities, the California Public Utilities Commission, and the California Energy Commission on long-term adaptation issues regarding energy infrastructure

Water Management Adaptation Measures

- Evaluate and propose new ordinances to incorporate gray water plumbing (all residential properties) and dual plumbing for indoor recycled water use (commercial properties in eastern area) for new development projects (City of Chula Vista 2011)
- At the subarea plan stage, development projects with 50 or more dwelling units (or equivalent) must complete Water Conservation Plans to outline their strategies for maximizing indoor and outdoor water use efficiency (City of Chula Vista 2011)

Coastal Resources Adaptation Measures

- Institutionalize or mainstream sea level rise adaptation by incorporating sea level rise and associated impacts into relevant local and regional plans and projects (ICLEI 2012)
- Perform more detailed vulnerability assessments at a site-specific level as significant plans or capital projects are undertaken (ICLEI 2012)
- Update the grading ordinance to require that all "tidally influenced" projects account for anticipated sea level rise for the next 50 years into their project development and grading plans (City of Chula Vista 2011)
- Update the Subdivision Manual to add requirements for development projects within "tidally influenced" areas to demonstrate that the storm drain system is designed to prevent any property damage with a 100-year storm occurring at the highest high tide with a projected 1.5 feet of sea level rise (City of Chula Vista 2011)

[2] Strategies that reduce energy use, whether used to reduce peak or overall demand, limit the potential for energy infrastructure overload and associated brownouts or blackouts. Reduction of greenhouse gases is a co-benefit of these infrastructure protection measures.

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