



CALIFORNIA'S FOURTH  
**CLIMATE CHANGE**  
ASSESSMENT

# San Diego Region Report



Coordinating Agencies:



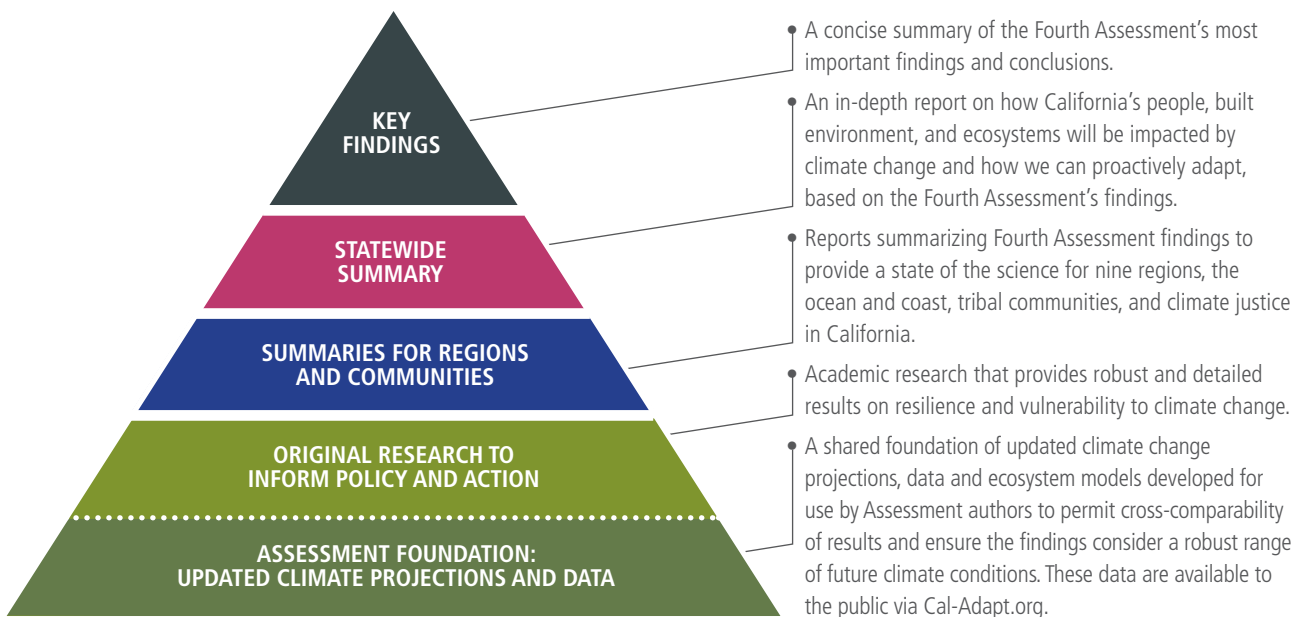




## Introduction to California's Fourth Climate Change Assessment

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

California's Fourth Climate Change Assessment (Fourth Assessment) advances actionable science that serves the growing needs of state and local-level decision-makers from a variety of sectors. This cutting-edge research initiative is comprised of a wide-ranging body of technical reports, including rigorous, comprehensive climate change scenarios at a scale suitable for illuminating regional vulnerabilities and localized adaptation strategies in California; datasets and tools that improve integration of observed and projected knowledge about climate change into decision-making; and recommendations and information to directly inform vulnerability assessments and adaptation strategies for California's energy sector, water resources and management, oceans and coasts, forests, wildfires, agriculture, biodiversity and habitat, and public health. In addition, these technical reports have been distilled into summary reports and a brochure, allowing the public and decision-makers to easily access relevant findings from the Fourth Assessment.



All research contributing to the Fourth Assessment was peer-reviewed to ensure scientific rigor as well as, where applicable, appropriate representation of the practitioners and stakeholders to whom each report applies.

For the full suite of Fourth Assessment research products, please visit: [www.ClimateAssessment.ca.gov](http://www.ClimateAssessment.ca.gov)



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### San Diego Region



The San Diego Region Summary Report is part of a series of 12 assessments to support climate action by providing an overview of climate-related risks and adaptation strategies tailored to specific regions and themes. Produced as part of California's Fourth Climate Change Assessment as part of a pro bono initiative by leading climate experts, these summary reports translate the state of climate science into useful information for decision-makers and practitioners to catalyze action that will benefit regions, the ocean and coast, frontline communities, and tribal and indigenous communities.

The San Diego Region Summary Report presents an overview of climate science, specific strategies to adapt to climate impacts, and key research gaps needed to spur additional progress on safeguarding the San Diego Region from climate change.



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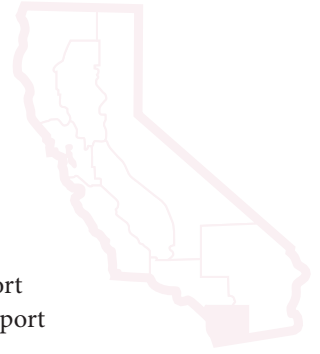
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## Highlights

San Diego County will be increasingly affected by climate change and has begun to prepare on multiple fronts for the panoply of climate change related impacts on San Diego County's residents, development, infrastructure, and ecosystems. In future decades, San Diego County and adjacent regions will be confronted with, among others, increasingly warmer average temperatures, more frequent and likely more intense heat waves, more intense droughts, occasionally increased heavy rainfall events and floods, continuing Santa Ana winds and wildfire threats. The impacts will play out in different ways across the complex terrain and differing climates within San Diego County. Communities along San Diego County's 70 miles of coastline are planning for substantial sea level rise, which will affect beaches, sea cliffs, real estate, infrastructure and other amenities. The region has many unique characteristics, such as narrow beaches backed by sea cliffs, large percentage of conserved lands, highly populated urban and suburban development, small farm dominated agriculture, and large solar power production; these characteristics, among others, all determine vulnerabilities to climate change and related adaptation measures. Below are some highlights of climate impacts, adaptations and gaps.

- Temperature is projected to increase substantially, by 5°F to 10 °F by the end of the 21st century. Along with mean temperature, heat wave frequency will increase, with more intensity and longer duration. Marine layer clouds can help to mitigate the impacts of temperature change in the coastal regions, though these clouds are not well represented in climate models requiring further research.
- Precipitation will remain highly variable but will change in character, with wetter winters, drier springs, and more frequent and severe droughts punctuated by more intense individual precipitation events. Effects of an altered precipitation regime on ecosystems, water demand and supply, water quality and flooding emergencies are incompletely known and will benefit from cross-disciplinary investigation.
- Broadly, wildfire risk will likely increase in the future as climate warms. The risk for large catastrophic wildfires driven by Santa Ana wind events will also likely increase as a result of a drier autumns leading to low antecedent precipitation before the height of the Santa Ana wind season (December and January).
- Sea level along the San Diego County coast is expected to rise approximately 1 ft by mid-21st century, and 3 ft or potentially much higher by 2100. For the next several decades, high tides combined with elevated shoreline water levels produced by both locally and distantly generated wind-driven waves will drive extreme events. Longer-term sea level will increase rapidly in the second half of the century and will be punctuated by short periods of storm-driven extreme sea levels that will imperil existing infrastructure, structures, and ecosystems with increasing frequency. San Diego is testing adaptation approaches, but sustained and improved observations in combination with physics based modeling are needed to evaluate these adaptations measures and guide future planning.
- Development in the San Diego County region is concentrated in the western third of the county with approximately 60% of the land remaining undeveloped. Climate change, along with development and fragmentation, will act as significant stressors to San Diego's natural lands, which are some of the most biodiverse in the United States. San Diego Association of Governments' (SANDAG's) regional planning emphasis on smart growth to concentrate urban development near city and transit centers supports conservation while also mitigating greenhouse gas emissions.

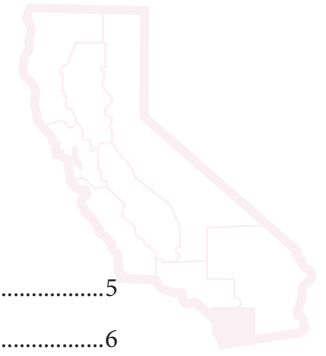




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- The San Diego County Water Authority, the region's water wholesaler, continues to diversify its supply by developing and negotiating local and nearby imported sources, developing more recycled water and encouraging greater water conservation. There are several coordinated efforts in the region to build resilience to climate and wholistic water management adaptations are becoming more prevalent throughout communities. Continued science and regional coordination to evaluate climate change impacts on future water supply, demand and quality are needed in order to inform adaptation to future climate changes.
- San Diego's energy supply is rapidly changing with renewable energy sources, mostly photovoltaic arrays, increasing by more than 30% since 2010, which introduces novel sensitivities to weather variation and evolving vulnerability to climate changes. San Diego Gas and Electric has installed a high density weather station network that provides a more detailed, real time awareness of weather conditions that could damage the energy system and/or produce unusual supply or demand.
- Recent work in San Diego showed that heat-related health impacts are observed at lower temperatures in the coastal region than in the inland and desert regions. This is in part due to coastal residents being less acclimated to heat and less likely to have air conditioning.
- Climate changes felt by San Diego County will also occur in northern Baja, Mexico. Binational coordination of climate adaptation measures present potential for significant benefit to communities on both sides of the border. However, to be effective the approaches must navigate the complexity posed by different governance and community structures.



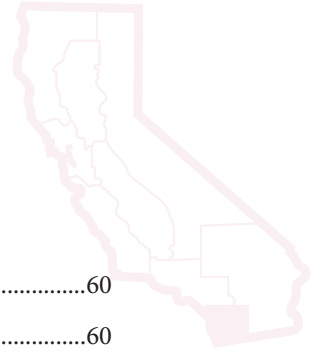
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## Executive Summary

### Climate summary

Over the next several decades, San Diego County and its neighboring California and cross-border regions will very likely experience substantial warming, sea level rise, a precipitation regime with continued mediterranean seasonality but with even greater variability, increasing dryness, and continued dry wind weather episodes that will heighten wildfire danger.

Temperature is projected to increase substantially, increasing by more than 5°F to as much as 10°F by the end of the 21st century, depending on the location and how much greenhouse gases (GHGs) are emitted in the future. Higher amounts of warming are expected in inland areas that do not benefit from the ventilation of marine air which helps to shield the coastal zone. Associated with the anticipated warming trend, heat waves are expected to increase in intensity and frequency—the number of heat wave days is projected to increase between 20-50% under a 6°F temperature increase.

The mediterranean character of wet winters and dry summers in San Diego County is projected to continue and possibly intensify with wetter winters and drier shoulder seasons (spring and autumn). Changes in annual total precipitation are uncertain but most climate models indicate that there will be fewer wet days, but more intense precipitation received when wet days do occur. The reduction in the number of wet days leads to more variable yearly precipitation and consequently, more frequent and intense drought. Longer dry, warm seasons and increasing evapotranspiration due to higher temperature and lower daytime relative humidity will cause stronger seasonal dryness of San Diego County landscapes.

The threat of wildfire may be exacerbated with increasingly warm and dry landscapes and longer dry seasons coupled with the continued occasional dry windy weather patterns. The largest fires occur during strong, dry Santa Ana winds, which occur within a broad season from September through May but most intensely in December and January. Increased drought, deficit moisture for vegetation, and dead fuels are likely to increase wildfire risk during dangerous fire weather extremes caused by Santa Ana winds.

Coastal low clouds and fog, otherwise known as Marine Layer Clouds (MLC), act as a natural air conditioner which moderates daytime heat and dryness in the coastally connected parts of the San Diego region. MLC also provide relief to ecosystems from drying by solar insolation and can also be an important source of water during the dry season. MLC along the West Coast fluctuates greatly from year to year and decade to decade in response to natural climate and weather patterns, but the processes that govern the presence of these low clouds are complex and the net result of climate changes on MLC is still uncertain.

### Coasts

San Diego County has more than 70 miles of coastline. The coastal region includes 10 cities, more than 40% of the County's population, and more than 500,000 employees in the region account for about \$30 billion in wages. The coastal region is a vital resource for recreation and a major attraction for the many tourists who visit the San Diego region.

San Diego has a long history of coastal monitoring and research that have lead to improved wave forecasts, improved





understanding of sediment processes, including beach nourishment (addition of sand to the beaches) and cliff erosion, and improved understanding of local estuarine dynamics and ecosystems. Extensive regional data and multiple studies provided the foundation to augment future research and monitoring under rising sea levels and increasing frequency of extreme events.

In the foreseeable future, sea level rise (SLR) is projected to rise substantially faster than the modest historical rates already observed (about 0.6 ft of rise observed over the last century). Estimates of sea level rise are increases of approximately 1 ft by mid-21st century, so coastal impacts should be intermittent and not catastrophic. Throughout these next several decades, high tides, as well as elevated shoreline water levels produced by both locally and distantly generated wind-driven waves, will be important drivers of extreme water level events at Southern California beaches.

However, as global climate continues to warm, it is estimated that by late-21st century sea levels will likely rise to 3 ft and potentially much higher. This high amount of SLR would exacerbate high sea level extremes and imperil existing infrastructure, buildings, and ecosystems. One study estimates approximately \$400 million of commercial and industrial property could be lost annually in San Diego County with 6.5 ft of sea level rise.

Multiple entities, including San Diego Gas & Electric (SDG&E), the Port of San Diego, California Department of Transportation (Caltrans), and the Cities of Del Mar, Carlsbad, Oceanside, and Imperial Beach, are conducting or have completed vulnerability assessments. Several approaches are being taken to help local jurisdictions prepare for and adapt to climate change. Establishing triggers, which instigate actions when thresholds are crossed, is one recommended strategy that is suited to the high uncertainty in sea level rise projections. While “hard” coastal development protection structures continue to dominate the landscape, San Diego has also been exploring more natural adaptation approaches, often called living shorelines. San Diego County will be confronted with a number of trade-offs and decisions as sea level rises and flooding events become more frequent. Examples of such trade-offs include armoring the coast versus retreating as it applies to both public (state beaches, parks, campsites, etc.) and private lands, or the trade-offs between beach nourishment to mitigate erosion versus potential impacts on flooding and estuary closures. These challenges are not unique to the San Diego region, but these issues may come to a head more rapidly in San Diego than in other segments of the California coast. Continuation of the regional research and monitoring of coastal waves and circulation, beach processes and estuarine dynamics is vital to understand San Diego agencies’ and governments’ vulnerabilities to sea level rise as well as informing current and planned adaptation measures.

## Landscapes: Climate Impacts and Adaptation

Climate changes pose an added complication to land use practices and planning. The impacts of climate change on people and on the environment will vary depending on different types of development (e.g. higher vs. lower density, centralized vs. spread out). San Diego County’s population of 3.3 million people is projected to increase to 4 million or more by 2050. Currently, most residents live in the western third of the County, with large areas of open land in east County. Almost 60% of the lands in San Diego are under public ownership or in conservation status. San



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Diego's natural lands are some of the most biodiverse in the United States and are home to approximately ~200 taxa of plants and animals that are at risk. Reliable and effective water, energy, transportation, and emergency services are climate-affected elements that have factored into SANDAG's (San Diego Association of Governments) regional planning emphasis on smart growth to concentrate urban development near city and transit centers. The location of future development will affect climate vulnerabilities in the region, as will the baseline ecological condition of the landscape. As part of the Fourth California Climate Change Assessment, a group of ecologists and climatologists produced a comprehensive review of climate impacts on ecosystems in San Diego (Jennings et al., 2018; [www.climatealliance.org/sdc-ecosystems-assessment](http://www.climatealliance.org/sdc-ecosystems-assessment)).

Rising temperature and changing precipitation could affect San Diego County's farm economy, ranked 12th largest in the nation with an estimated production value of \$1.7 billion on 251,000 acres in 2016. Nursery and cut flower products are the greatest valued crops at 71%, followed by avocados (9%), citrus (7%), and tomatoes (3%). Carbon farming, or adding organic carbon to soils, has been shown to be an effective way to fertilize crops, reduce greenhouse gases, increase water holding capacity of soils, and mitigate climate change risks.

### Infrastructure and Services: Climate Impacts and Adaptation

The amount of precipitation received in semi-arid San Diego County is insufficient to serve the demands of its current population and infrastructure. Most of San Diego's water originates from the Colorado River basin, augmented by transfers from Northern California and local sources. Provoked by a series of droughts beginning in 1987 and the specter of climate change, the wholesale supplier of water to much of the region, San Diego County Water Authority (SDCWA), has tempered its reliance on these distant sources. SDCWA continues to diversify its supply by developing and negotiating local and near-by imported sources as well as developing more recycled water and campaigning for greater water conservation. Another climate sensitive aspect of the region's water-related infrastructure is its storm water system, whose gravity-driven conveyance of storm water westward to the Pacific Ocean can contaminate ocean water quality by a cocktail of toxins flushed after large events. The recent large storms that have caused sewer spills illustrate another regional water quality vulnerability to climate extremes and future climate change. Several coordinated efforts in the region are working towards enhancing climate resilience in the water sector and holistic water management adaptations are becoming more prevalent throughout communities.

San Diego's energy portfolio is rapidly changing with a more than 30% increase in renewable energy since 2010, mostly in the form of solar photovoltaic arrays. Correspondingly, the energy system's sensitivity to weather variation and vulnerability to climate change has evolved. Under the current energy regime, the days with greatest electrical base load demand are humid, cloud covered days, which provoke high air conditioning usage but also reduce solar electrical generation. Based on temperature projections under RCP 8.5, a business-as-usual greenhouse gas emission scenario, energy use in the San Diego region will increase 6-27% by 2080-2099. San Diego Gas & Electric (SDG&E) has installed a high-density weather station network that provides a more detailed, real time awareness of different forms of weather conditions that could produce unusual energy demand, imperil the power system, or heighten wildfire threats.

San Diego's ongoing effort to expand public transportation has multiple links to climate change but has primarily been tied to reducing GHG emissions. At the same time, transportation-related infrastructure is vulnerable to both flooding and higher temperature, which will likely increase the cost of maintenance. In addition, flooding and





wildfires can lead to major disruptions to the operation of the transportation system. Green streets, designed to help manage storm water and accommodate diverse transportation needs (bikes, buses, pedestrians, etc.) and which often include natural landscapes, have been introduced as an alternative to traditional street design. Green streets are an example of mitigation and adaptation co-benefits by accommodating bicycles and public transit, and by preparing for changes in future precipitation.

Climate-related hazards that confront the San Diego region are projected to feature increasingly intense and possibly longer lasting heat waves and drought, along with floods, wildfire, debris flows, and coastal storms. The San Diego County Office of Emergency Services works closely with regional partners, such as the National Weather Service and the County Health Department to communicate warnings and watches to help mitigate harm to life and property.

The novel High Performance Wireless Research and Education Network (HPWREN), is a non-commercial prototype, high-performance wide-area, wireless network established by University of California, San Diego researchers offering connectivity and data to and from several remote areas across the County, supporting emergency response to fires, extreme weather, flooding, and other public safety conditions where camera images and real-time sensors provide vital information.

## Health and Climate Justice: Climate Impacts and Adaptation

Climate change has been labeled as the greatest public health threat of the 21st century. Human health impacts of climate change would exacerbate existing environmental health impacts (e.g. heat waves, extreme precipitation, wildfires) and could also introduce new ecological challenges (e.g. invasive or changes in relative abundance of species). Recent research indicates that heat-related human health impacts may be felt at lower temperatures at the coast than in the inland and desert regions as coastal residents are not acclimated to heat and humidity and are less likely to have air conditioning. A study of hospitalizations and emergency room visits suggests that the definition of hazardous temperatures is not one-size-fits-all and is dependent on background climatology and sociodemographic composition. Climate change may also increase vector-borne diseases. Populations that are particularly vulnerable to climate changes include those with preexisting or underlying health conditions, with chronic illnesses (e.g. asthma), the elderly, and the uninsured. To help vulnerable communities, Public Health Services has partnered with the Office of Emergency Management in a Partner Relay effort to disseminate messages to vulnerable communities in the event of a natural disaster or public health emergency. To mitigate the impacts of vector-borne disease to the health and well-being on San Diegans, the County has a Vector Control Program.

## Cross Border Climate Impacts and Adaptation

Cross border interactions are an important component to both the County's culture and economy. The climate change impacts that San Diego will experience transcend geopolitical borders and reflect conditions that will likely occur across most of northern Baja, Mexico. Impacts include the previously described increasing temperatures, increasing variability of precipitation, more extreme heat waves and floods, sea level rise, degraded water quality, and more intense wildfires. Flooding and other extremes in the Tijuana River impact both Tijuana and San Diego, producing poor water quality, erosion and sediment transport, and loss or rearrangement of habitats. Binational



coordination of climate adaptation measures is challenging due to the complexity posed by a globalized economy, as well as different governance and community structures. Tijuana River National Estuarine Research Reserve (TRNERR) and the Climate Science Alliance (CSA) are examples of boundary spanning organizations addressing climate change adaptation across the border, with TRNERR facilitating cross-border dialogue about management of the Tijuana River watershed and CSA collaborating with educational programs south of the border for their Climate Kids-Mexico program.

## Key Research Needs and Next Steps

Discussions with experts and stakeholders identified numerous gaps, needs and opportunities to enable the San Diego region to prepare for and adapt to climate changes. Selected examples of these are as follows:

- Knowledge of how San Diego County's highly variable precipitation regime and attendant hydrological balance may be altered by climate change is vital to managing and planning for water supply, flood protection, water quality, and ecosystems.
- Better long-term observations would lead to improved understanding of processes and help to quantify long-term changes in Santa Ana winds. Long-term observations are needed to evaluate the model winds and humidity required to inform future wildfire risks.
- Integrated monitoring and modeling of sea levels, waves, and coastal evolution are needed to understand and plan for shoreline erosion and accretion.
- Engagement across scientific, public agency, private sector and other stakeholders to focus on impacts on the built environment is needed to guide adaptation relating to residential and commercial property and infrastructure such as low-lying streets, sewers and power plants. Shoreline protection approaches including beach nourishment, armoring coastal structures, and living shorelines need to be evaluated and monitored.
- Protection of critical areas and infrastructure along the coast of the San Diego region require careful monitoring and climate change/sea level rise scenario planning. These include San Diego Bay, including the buildings and infrastructure located surrounding the Bay, the estuaries of the region, the coastal rail line, and Highway 101.
- State-of-the-art wildfire behavior modeling that factors in future climate conditions is needed to identify future climate risk and improve understanding of where and when to conduct fire management strategies in order to reduce fire risk and protect biodiversity. Integrate fire hazard maps to identify areas that are most susceptible to wildfire.
- Peak electrical energy supply and demand and impacts on the electrical grid needs to be assessed to ensure demands can be met while increasing reliance on renewable sources.
- This assessment should consider impacts of increasing temperature and effects on photovoltaics of varying or changing coastal clouds.
- A suite of relevant climate changes should be considered in designing requirements for new or renewed transportation infrastructure.



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- More effort is needed to develop improved data and communications for emergency managers and the general public for improved risk preparedness and to provide situational awareness during hazardous events.
- Improved understanding and preparation is needed to cope with diseases burdens and how they may change as climate changes. Predictive models are needed to enable early warning of heat waves, floods, and other extremes.
- Transboundary data sharing between the U.S. and Mexico is needed to enable vulnerability assessments and adaptation planning and to promote urban and economic development strategies, water conservation, and green infrastructure.
- Understand how climate change, along with changing land use, may affect cross-border flows of water, pollutants, sediment, and solid waste.





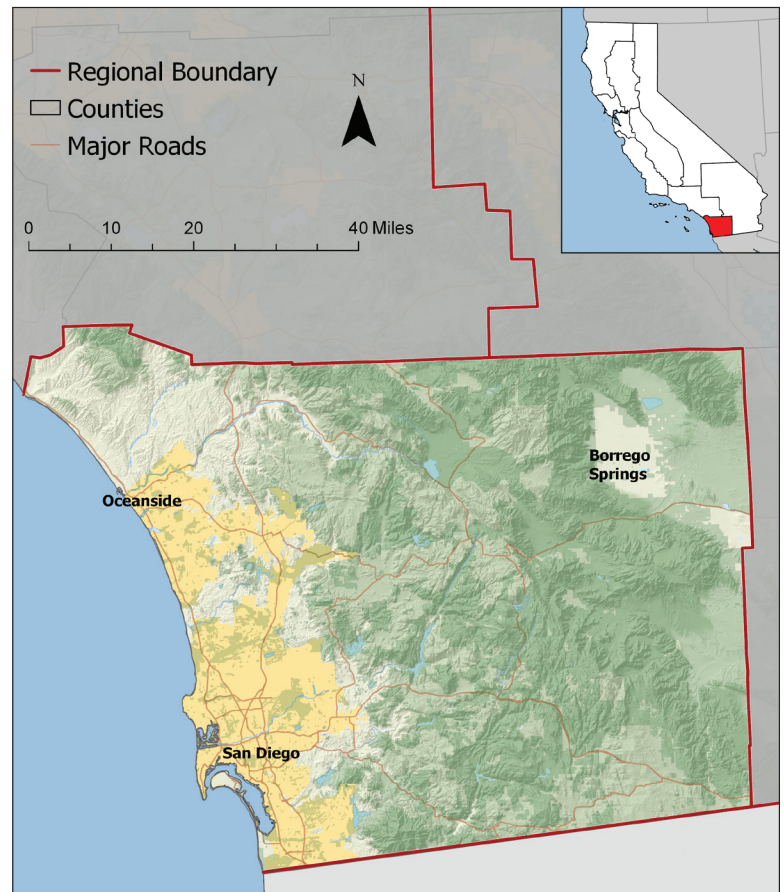
## Introduction

In late 2017, encouraged by organizers of the Fourth California Climate Change Assessment, a team of regional authors was solicited to prepare a Climate Change Assessment for the San Diego Region, the southwestern-most of the nine regions which are included in the regional assessments that are being conducted across California.

Reflecting the rich natural and human landscapes of the San Diego County and cross-border region, the diverse author team includes physical, biological, and social scientists, as well as experts from government agencies and other organizations. The San Diego Assessment structure was framed by discussion and directives at the State level and the detailed assessment content was developed in meetings by authors and other contributors, with additional assistance from authors of assessments of other regions. The target audience for the San Diego Regional Assessment is local and State government agencies and staff and planners, along with interested decision makers in the public and private sectors. To the extent possible, information provided is available from peer-reviewed or readily available online literature and reports. A primary objective of this report is to inform community planning and adaptation to climate change. In addition, it is hoped that this material will provide background for future updates, which will be needed since numerous aspects of climate change and impacts are evolving rapidly, with many trajectories and outcomes still uncertain.

San Diego County is known for its mild year-round climate, beaches, low inland mountains, and deserts. The County of San Diego and its eighteen cities, along with 18 federally recognized tribes, contains 4,530 square miles (almost 3 million acres) with most of the region's population of 3.3 million people having settled within the coastal plain and adjoining valleys in the western third of the region. San Diego County has 70 miles of coastline and a large portion of natural lands, which include over 1.3 million acres (nearly 50%) of highly biologically diverse protected lands. The San Diego region adjoins the Greater Los Angeles metropolitan region (the largest in the United States) to the north, and the Tijuana-Northern Baja California region to the south.

FIGURE 1



San Diego County's complex topography. The thick red lines are county boundaries, yellow areas are developed land and thin red lines are roads. Source: J. Thorne.



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The San Diego region has a vibrant economy with a Gross Domestic Product (GDP) of \$216 billion in 2016, ranked 17th in the US (Bureau of Economic Analysis, 2017). Most economic and population growth in the region has occurred since 1940, the result of a large military presence during World War II and a post-war population boom driven by the aerospace industry through the 1950s and 1960s. Since the 1970s, a more diversified economy has developed, based on services, research and development, manufacturing, agriculture, and tourism. The city of San Diego has grown to be the 8th largest city population in the United States and the 2nd largest in California.

San Diego's mediterranean climate is highly variable, both spatially and temporally. The relatively short distance from coast to mountains to deserts drives the spatial variability through the influence of topography and the locally varying penetration of coastal clouds and fog. Temporally, Southern California has the largest year-to-year precipitation variability in the continental US (Dettinger et al., 2011), which has conditioned the natural and built sectors of the region to be prepared for droughts and extreme precipitation events. The physical characteristics (size, landscapes, climate variability, high biodiversity) offer important opportunities for learning how to adapt, plan, and manage high climate variability and climate change.

Polling data indicates that San Diego has the social and political awareness and will to move climate adaption initiatives forward. In 2017, 87% of San Diegans said they believe that climate change is happening and a majority (52%) believe that climate change will cause them at least moderate harm (Fairbank, Maullin, Metz & Associates, 2017). Further, interviews of over 100 regional leaders who serve in key decision-making roles revealed that all of San Diego's leaders are concerned about climate change. The sentiments of San Diegans toward climate change are in part evident by the many on-going and planned greenhouse gas (GHG) reduction efforts, or mitigation efforts, that agencies and organizations in the San Diego region have initiated.

In 2012, 37% of GHGs in the San Diego region came from passenger cars and light duty vehicles and 23% from electricity, with all other components comprising less than 10% each. Many of the GHG reduction efforts in the region are focused on investments in transportation to reduce vehicle miles traveled and increasing the use of non-polluting vehicles, while at the same time increasing the percentage of electricity that is available from renewable sources. This report is focused on adaptation to climate change, rather than on GHG mitigations; however, many adaptations serve both and are multi-beneficial. Using a "multiple benefit" strategy in addressing climate change impacts allows a project sponsor to qualify for funding and can also lead to participation by multiple agencies and organizations for an integrated approach to build climate resilience.

California is a leader in providing guidance for identifying vulnerabilities and addressing the major impacts of climate change at the state, regional, and local levels, through legally enforceable plans and strategies, as well as regulations and funding programs. San Diego has the potential to become a leader in climate adaptation given the diversity of landscapes, both natural and built, and the belief by residents that climate change is happening. San Diego County also has a history of integrated and cross-jurisdictional planning that will lend climate adaptation planning and execution. This report aims to support planning for climate changes in the San Diego region by describing the region's historical climate and projected climate future, as well as highlighting some ongoing efforts to build resilience, and identifying gaps and needs to move this forward.



## Regional Climate Variability and Change

### Greenhouse Gas Emission Scenarios and Downscaling

**F**uture changes in global and California temperatures will depend on the accumulation in the atmosphere of carbon dioxide and other heat-trapping gases emitted from human activities. The emissions and buildup of greenhouse gases (GHGs) could take a range of pathways, depending on the success of international and combined local efforts to reduce GHG emissions. The warming experienced under different future conditions are projected using Representative Concentration Pathways (RCPs). RCPs do not represent a specific policy, demographic, or economic future, but are instead defined in terms of their total radiative forcing by 2100 (i.e., the net balance of radiation into and out of Earth's surface from human emissions of GHGs from all sources, expressed in Watts per square meter).

The Fourth Assessment uses two RCPs from the Fifth Intergovernmental Panel on Climate Change (IPCC) Assessment Report on Climate Change. The two RCPs represent GHG emissions under a higher emissions pathway (RCP 8.5), commonly understood as a business-as-usual (BAU) scenario, and a more moderate emissions pathway (RCP 4.5). The Department of Water Resources selected ten global climate models (GCMs) from a set of more than thirty as being the most suitable for California water resource climate change studies (Cayan and Tyree, 2015). Many of the figures reference an ensemble average, which is the average of multiple GCMs.

Most GCMs produce outputs regarding global climate measures (including temperature, precipitation, winds, and other variables) that are rather coarse, typically for 60-120 mi (100-200 km) grid cells. However, regional climate studies typically employ data derived from the global models using a “downscaling” technique to better represent the more detailed variability over an area of interest, so that the results are compatible with regional planning and decision-making. For California's Fourth Climate Change Assessment, selected variables of interest from the coarse-scale global model simulations have been downscaled over California's complex terrain to finer grid cells of approximately 4 mi (6 km) using a statistical technique called “Localized Constructed Analogs”, or LOCA (Pierce et al., 2014, 2018). Additionally, because models are mathematical approximations of the physical, chemical, and biological systems they are aiming to simulate, the results from global and regional models are usually somewhat different from that observed in nature. Because of this, temperature, precipitation, and other variables of interest in California's Fourth Climate Change Assessment's regional projections have been “bias corrected” (Pierce et al., 2015) and a new one developed here, are applied to daily maximum temperature and precipitation from 21 GCMs to investigate how different methods alter the climate change signal of the GCM. The quantile mapping (QM, so that the model-simulated output is adjusted to match the averages and other statistical properties of observations over the historical period.





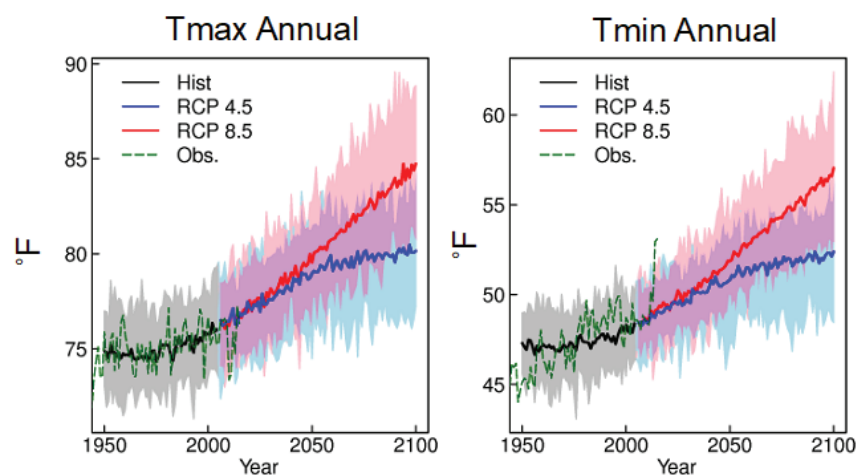
## Temperature

San Diego County contains markedly different climate zones where relatively mild coastal conditions transition rapidly to harsher interior valleys foothills and low mountains. Organisms living within 10 to 20 miles (20-30 km) of the coast are acclimated to a relatively moderate mediterranean-type climate, while those native to inland valleys and higher elevations are acclimated to greater temperature extremes and greater seasonal precipitation amounts. The adjacent ocean gives rise to a relatively shallow, cool, and humid marine layer that can penetrate the coastal land to the point where the foothills or mountains reach an elevation of about 2500 feet. In the marine layer-affected coastal zone, temperatures and humidity are moderated, resulting in relatively cool days and mild nights. During summer, average daily maximum temperatures in the inland valleys average 10-20°F warmer than at the coast. In some parts of the deserts, average summer maximum temperatures exceed 100 °F (38 °C) while average coastal maximum temperatures are below 80 °F (26.6 °C). At night, the dry conditions in the desert promote nighttime cooling, whereas coastal cloud cover helps to keep coastal night temperatures mild. In winter, average coastal and desert temperatures are more similar than in summer. However, there are notable differences in the amount of day-to-day variability. The coldest winter temperatures are observed in the highest elevations, where average nighttime winter temperatures are below freezing.

### INCREASING MEAN TEMPERATURE AND HEAT WAVES

Climate change is expected to raise yearly average temperatures by about 4-6 °F (~2.2-3.3 °C) by the end of the century under the RCP 4.5 scenario or 7-9 °F (3.6-5 °C) under RCP 8.5 (Figure 2). The projected changes between daily maximum temperature (Tmax) and daily minimum temperature (Tmin) are similar, though the projections for Tmin indicate stronger warming in late summer and fall than does Tmax (Figure 3). The pattern of projected temperature change varies smoothly throughout the region, with coastal zone projected to experience less and inland areas greater warming (Figure 4). By mid-21<sup>st</sup> century during summer, the amount of warming in the interior regions of San Diego County is projected to exceed that along the immediate coastal margin by more than 0.5 °C (Figure 5).

**FIGURE 2**

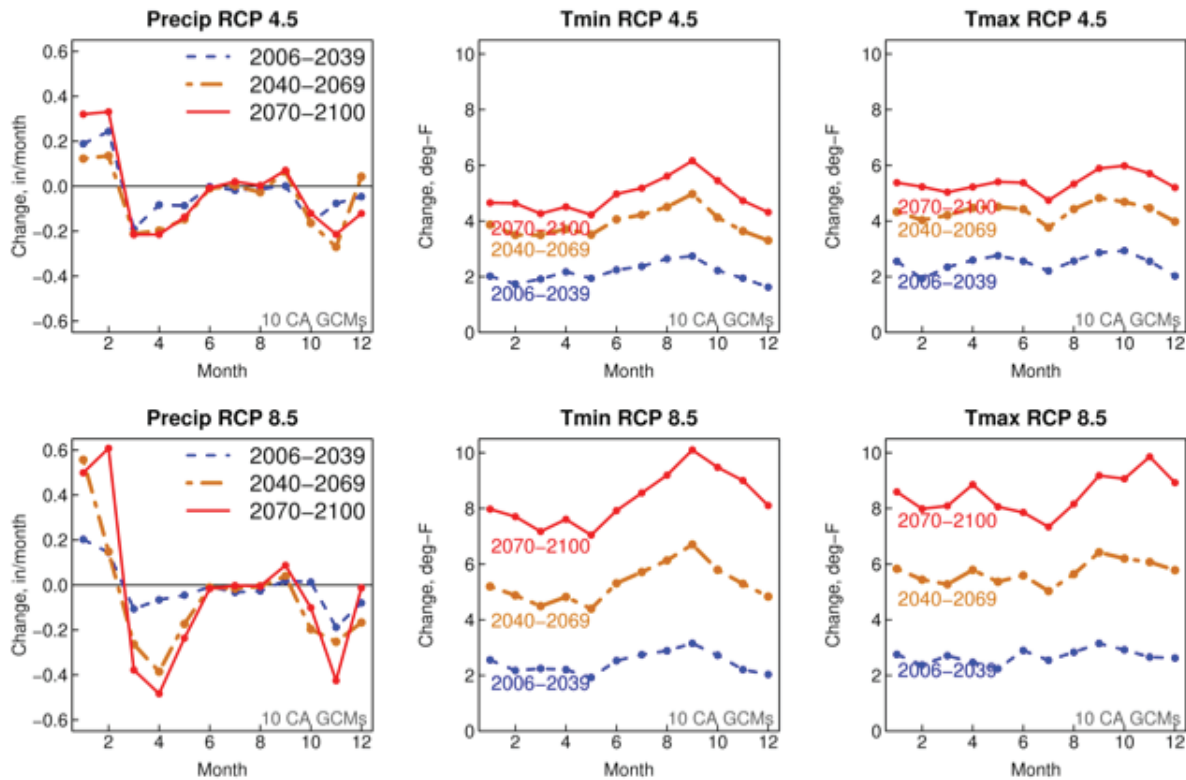


The annual average increase in maximum (Tmax) and minimum temperature (Tmin) averaged over San Diego County from Localized Constructed Analogs (Pierce et al., 2014; Pierce et al., 2018). The shading shows the range of models under historical (black), RCP 4.5 (blue) and RCP 8.5 (red) and the line shows the ensemble mean. The historical observations in the green dashed line are based on the Livneh et al. (2015) gridded data.



**FIGURE 3**

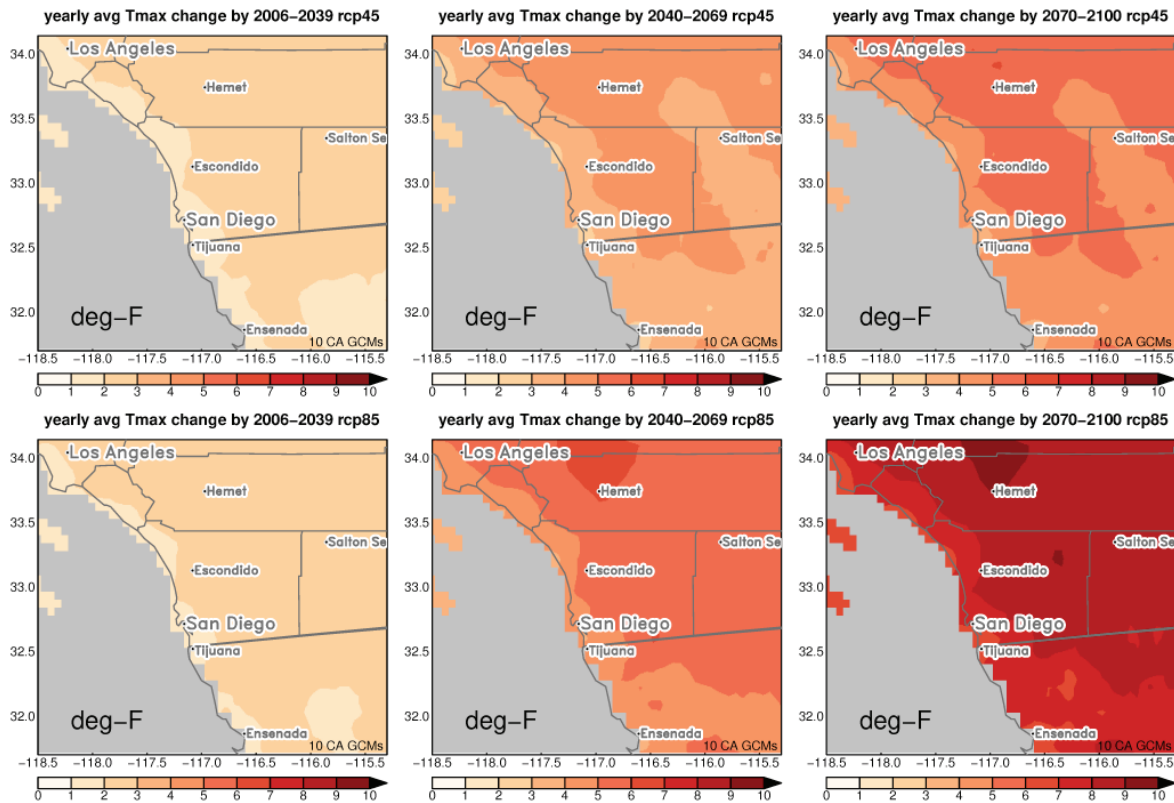
### Annual cycle change, San Diego county



The ensemble average of monthly change of (left to right), precipitation, Tmin, and Tmax for (top) RCP 4.5 and (bottom) RCP 8.5 spatially averaged over San Diego County. The color of the lines indicates the period of time of the averages, early (2006-2039) mid (2040-2069) and late (2070-2100) 21<sup>st</sup> century.



**FIGURE 4**



A map showing the average Tmax increase at early, mid and end of century relative to 1976-2005 climatology for RCP 4.5 (top) and RCP 8.5 (bottom).

The background climate warming will increase the frequency, duration, and intensity of heat waves, as measured against historical thresholds. Historically, the average hottest day per year was in the range of 90-100 °F (32-38 °C) at the coast and 105-115 °F (40.5-46 °C) in the deserts. At the end of the century (2070-2100), under RCP 8.5, the average hottest day per year is projected to increase to 100-110 °F (32-43 °C) and 110-125 °F (43-51.6 °C), at the coasts and in the desert respectively (Figure 6). The probability of a heat waves occurrence however, does not necessarily follow background warming (Kristen Guirguis et al., 2018). In general, locations having temperature probability density functions (PDFs), the distribution of occurrence daily Tmax or Tmin, characterized by shorter warm tails (few very hot days) and smaller variance, will see a greater increase in heat wave probability under the same amount of background warming (Kristen Guirguis et al., 2018). For example, under 6 °F of warming, nighttime

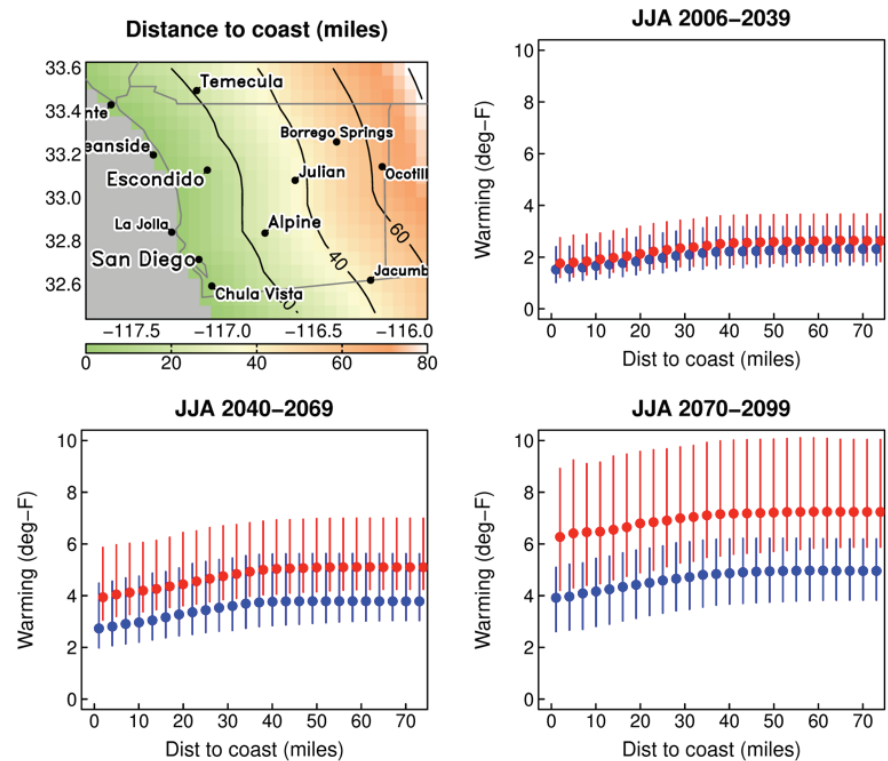




## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT

heat waves are projected to increase by approximately 51% in the coastal zone, while day time heat waves are only projected to increase by 23% (Jennings et al., 2018). This contrast is a result of differences in the shape of the  $T_{min}$  versus  $T_{max}$  temperature PDFs and specifically the number of days at the high temperature (long warm tails). Unlike the coasts, Cuyamaca has a very similar increase (~30%) in the probability of nighttime and daytime heat waves. Our confidence in this result is lowered by the fact that this coastal temperature reflects the cooling effect of coastal low clouds, which strongly modulate heat wave activity at the coast (Clemesha et al., 2017). The sensitivity of coastal low clouds to climate change is complicated and unclear at present.

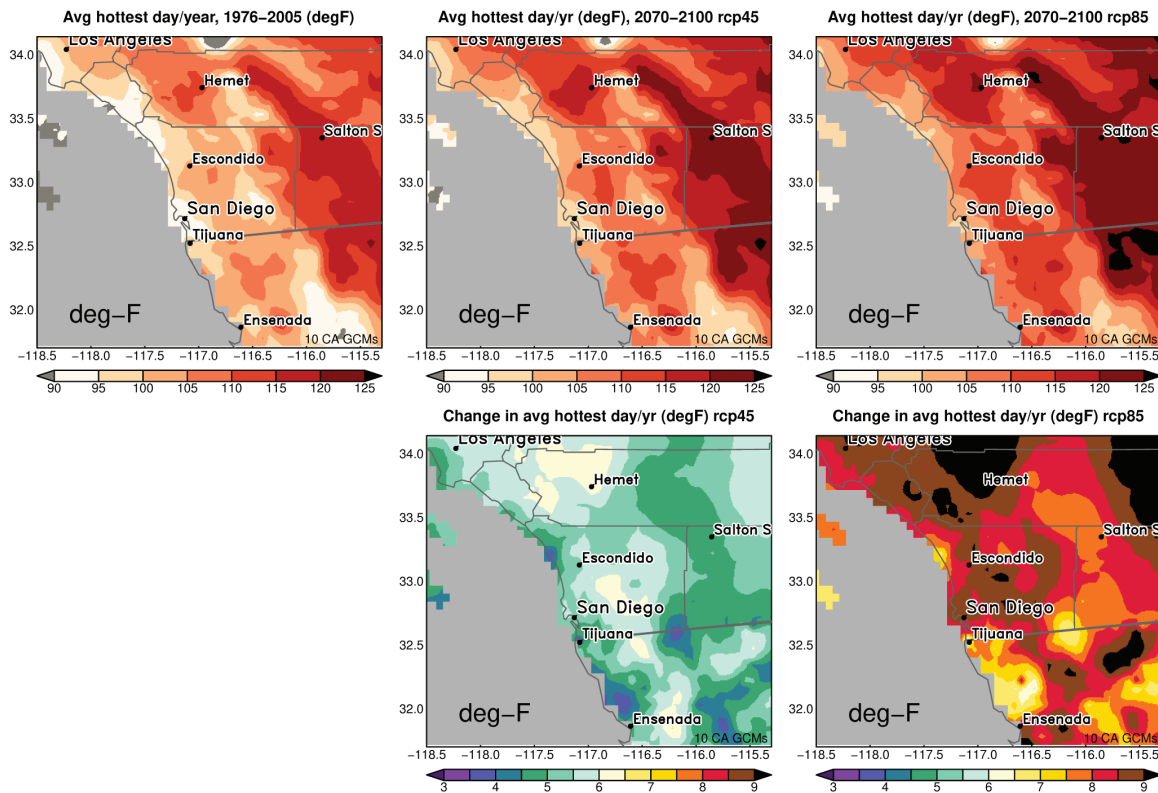
FIGURE 5



Climate warming (°F) from coast to inland of summer (June-August) maximum temperature across San Diego County in early- (2006-2039; left), mid- (2040-2069; center) and late 21<sup>st</sup> century (2070-2099; right) arranged by distance from coast (mi), which is shown in map, upper right. RCP 4.5 is blue and RCP 8.5 is red. The central dots are the median warming across 10 downscaled GCMs, and vertical bars encompass 2/3rds of the range exhibited by the 10 GCMs.



**FIGURE 6**



Top panels show the average hottest day per year for 1976-2005 (top left) and 2070-2100 for RCP 4.5 (top center) and RCP 8.5 (top right). The bottom panels show the degree change for RCP 4.5 (bottom left) and RCP 8.5 (bottom right).

Climate change is already affecting California, and San Diego County, with more frequent and intense heat waves. Heat waves in the region have also become more humid, with warmer nighttime temperatures (Gershunov et al., 2009; Gershunov & Guirguis, 2012). This reduced cooling at night means that humans and animals get less relief from the daytime heat than has been historically experienced. High humidity can exacerbate the impacts of heat on health (Karl & Knight, 1997; Sheridan & Kalkstein, 2004; Steadman, 1984). In California, the strongest health impacts from recent heat waves have been found at the coast (Gershunov et al., 2011; Kristen Guirguis et al., 2014; Knowlton et al., 2009), where residents are used to relatively mild temperatures and are not acclimated to heat.

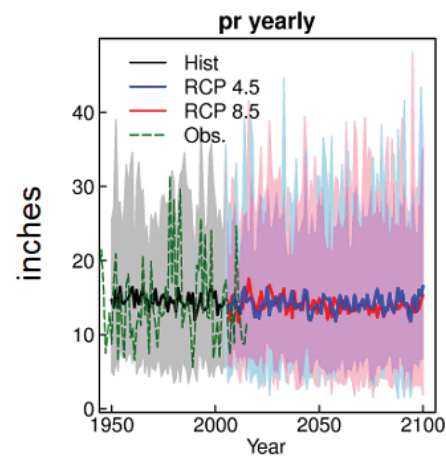


## Precipitation

The unusually wet years of 2005, 2011, and 2017 and the droughts of 2001-2004, 2007-2010 and 2012-2015 exemplify the highly variable climate of the region. Southern California has the highest year-to-year variability of any place in the continental U.S (Dettinger et al., 2011). Annual total precipitation ranges between a low of 5 (120 mm) inches to a high of over 35 inches (900 mm). Similar to other California regions, the high year-to-year variability of precipitation in San Diego County is heavily affected by extreme precipitation events (days have precipitation at or exceeding the 95<sup>th</sup> percentile), which accounts for 80% of the year-to-year variability (Jennings et al., 2018). Most of the heaviest events occur during winter, although the region occasionally experiences a few high rainfall events from tropical storms or convective rainfall patterns during late summer and early fall. Noteworthy seasonal changes in precipitation include increased precipitation in core winter months, a marked decrease of precipitation in the shoulder seasons of autumn and spring, and little change in summer (Figure 3).

Climate models indicate that precipitation volatility will intensify in the future (Figure 7) as global climate continues to warm. While days with measurable precipitation become less frequent in Southern California (Pierce et al., 2013; Polade et al., 2014), extreme precipitation events will intensify (Polade et al., 2017b). Atmospheric rivers, which are transports of moisture from the tropics over the Pacific Ocean in long, thin ephemeral filaments responsible for most extremes, will carry more moisture (Lavers et al. 2015). This trend has recently been detected in observations (Gershunov et al., 2017). By the end of the century, the average wettest day every five years is projected to increase by 10-25% under RCP 4.5 and by 15-30% under the RCP 8.5 (Figure 8).

**FIGURE 7**

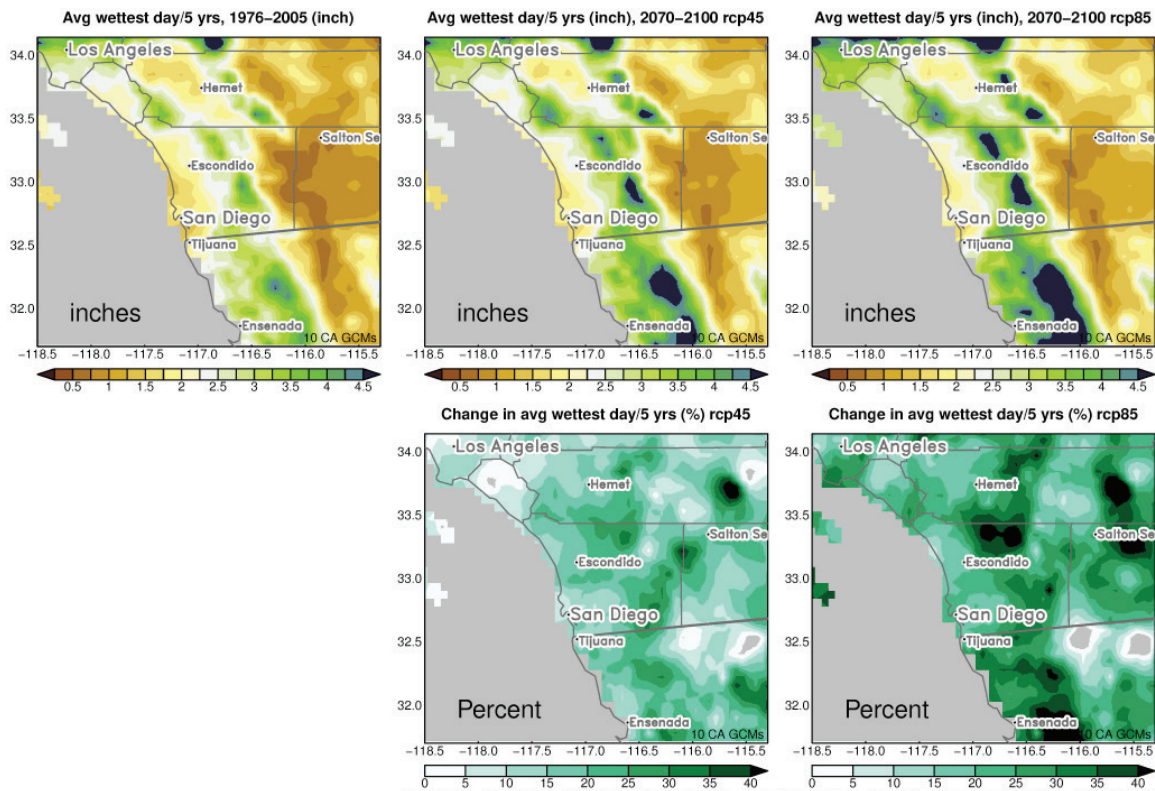


Same as figure 2, but for precipitation.





**FIGURE 8**



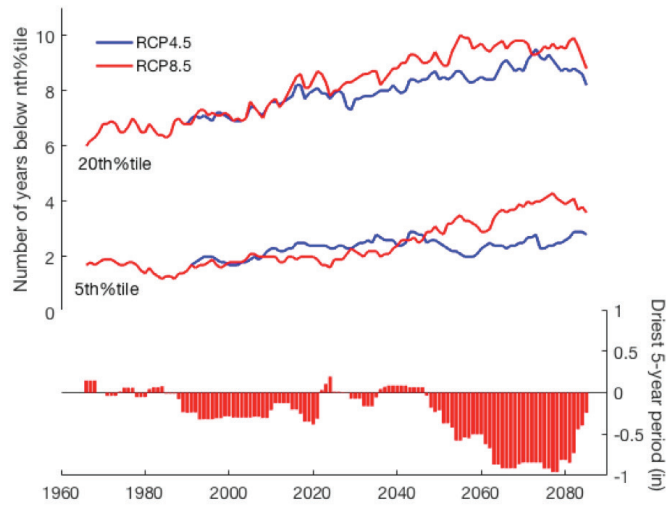
The change in wettest day every five years for 1976-2005 climatology (left) and at the end of the century under RCP 4.5 (middle) and RCP 8.5 (right) in both inches (top) and percent change (bottom) relative to 1976-2005.

Although the region is projected to experience more intense precipitation events, droughts are also projected to become more frequent and intense. The increase in drought is a result of fewer wet days as the subtropical zone expands leading to more dry years (Figure 9). More dry years also lead to an increase in the duration, frequency, and severity droughts in the future. Higher temperatures will exacerbate future droughts leading to larger water deficits across the landscape (Figure 10) (Williams, Seager, et al., 2015). An impact of this is illustrated in an extreme 20-year drought scenario for the Fourth Assessment during which precipitation is 79% of normal but run-off is reduced to 57% of normal (Jennings et al., 2018). The extremely warm dry years of 2014 and 2015 are a harbinger of future droughts given the high temperatures during these drought years (Diffenbaugh et al., 2015).



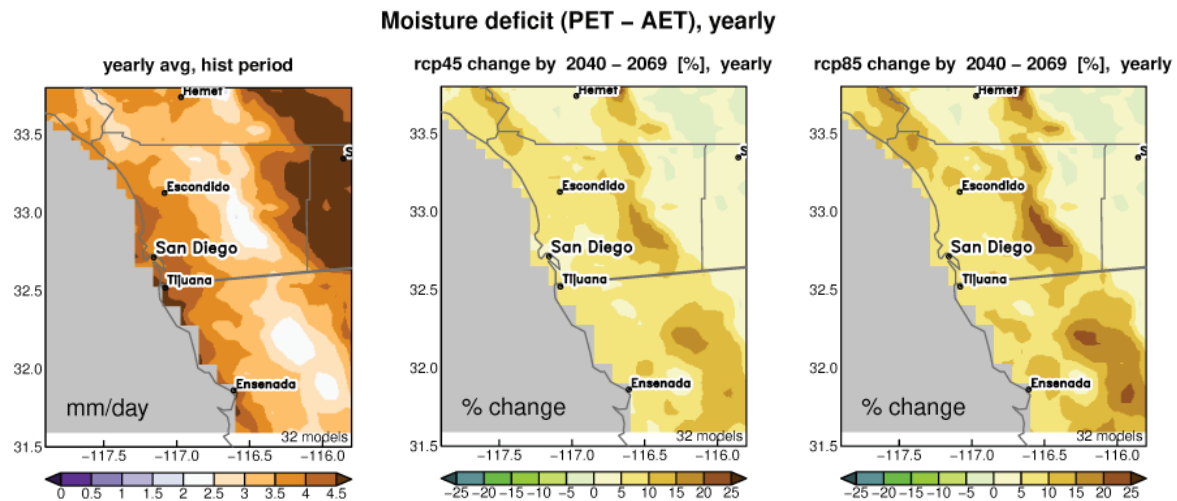
# CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT

FIGURE 9



(Top) The percent of dry years in a 31-year moving window below the indicated historical percentile (5<sup>th</sup> or 20<sup>th</sup>) for RCP 4.5 (blue) and RCP 8.5 (red) from 10 global climate models. (Bottom) Departure from average of the driest 5-years in a 31-year sliding window for RCP 8.5 from the same 10 models. The anomaly is based on the average driest 5 years within in the historical period. Source: Jennings et al., 2018.

FIGURE 10



Moisture deficit, (potential evapotranspiration – actual evapotranspiration) for historical (left) and the percent change in the mid century (2040-2069) under both RCP 4.5 (middle) and RCP 8.5 (right). A positive value indicates increase drying of the landscape.



## Santa Ana Winds and Wildfire

Santa Ana conditions are dry, hot, strong and gusty winds that produce extreme dryness and some of the highest winds in San Diego County. Peaking in winter, Santa Ana winds originate in the elevated Great Basin as cold air masses and pushed southwestward by a synoptic pressure gradient (Hughes et al., 2011). In Southern California's westward and south-westward sloping backcountry, they fan the region's most catastrophic wildfires (Westerling et al., 2004) and can impacting public health in the populate coastal zone by the extreme heat and occasionally smoke (Delfino et al., 2009; Guzman-Morales et al., 2016).

Santa Ana conditions also account for the some of the hottest maximum temperatures along the San Diego County coastal zone. Santa Ana winds can bring very hot temperatures relative to the typical coastal climate. The highest temperatures along the coast generally are associated with Santa Ana winds that occur during the early or late part of the warm season. Nearly 50% of hot days along the coast (days over 85°F [29 °C]) that occur in May are due to Santa Ana events. In October, Santa Ana events account for over 70% of hot days. Early-season heat waves have been shown to be particularly significant in terms of human health because they occur before the population has had a chance to acclimate to warm summer weather (R. Basu & Samet, 2002; Ebi et al., 2004; Kristen Guirguis et al., 2014).

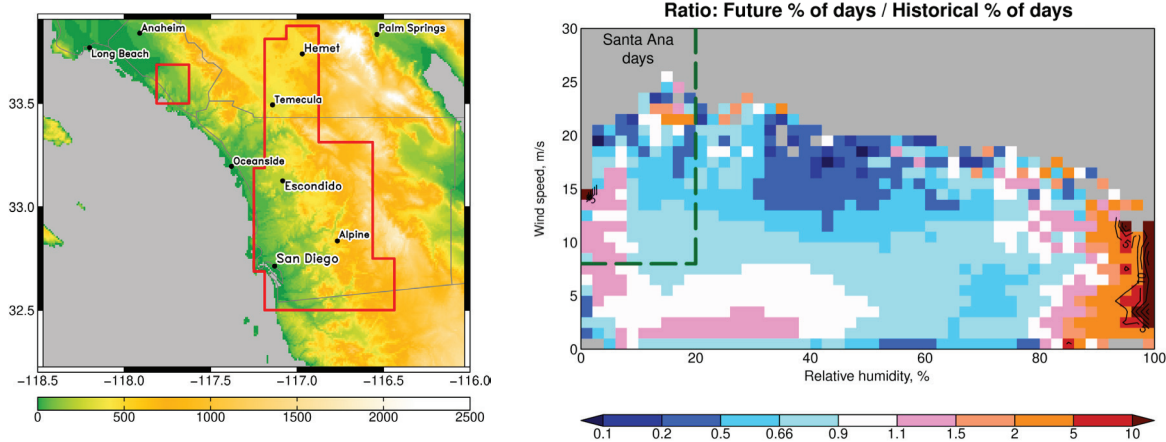
Recent results from a report of the scenario developed for the California Fourth Climate Change Assessment examined changes in Santa Ana winds by defining these events as wind greater than to equal to 8 m/s with relative humidity less than or equal to 20% (Pierce et al., 2018). Results for the San Diego region (Figure 11, left) are similar to the result for the entire Southern California region presented in Pierce et al. (2018). Specifically, for the San Diego region, the projections at the end of century (2070-2100) under RCP 8.5 suggest there will be a modest decrease in percent of days with relative humidity between 10-20% and wind speeds above 8 m/s; however, there is an modest increase in percentage of days with the lowest relative humidity (10% or less) and with wind speeds between 5 and 17 m/s (Figure 11, right). Also notable is a decrease in the percentage of days with wind speeds above 17 m/s at almost all relative humidity levels. Therefore, the future projections indicate an increase in the driest of Santa Ana days, although the number of Santa Ana days and the days with the strongest winds are projected to decrease.

Fire weather conditions, such as Santa Ana winds, have flamed the most catastrophic wildfires in San Diego, however other factors, such as development, are important in determining fire risk. In recent years, wildfires in much of San Diego have occurred significantly more frequently than historical fire return intervals (Safford & Van de Water, 2014). Since human ignitions sources are the primary cause of fires in the region, the shorter intervals between fires is attributed to development and population increases in the region (Syphard et al., 2007). In San Diego County, the two ignition sources that are associated with the largest area burned are from sparks from equipment, such as power saws or machine with gas or electric motors, and power lines (Syphard & Keeley, 2015a). Structure density has the largest influence on fire risk, with medium to low density housing being the most at risk (Syphard et al., 2012). Other important variables for San Diego include road length, elevation, slope, distance from the coast, and fuel type. Syphard et al (2012), developed empirical maps of fire hazards with the intent of informing fire mitigation efforts and planning (Figure 12).





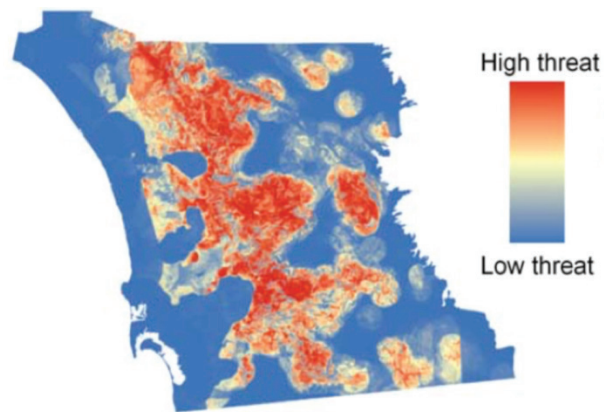
**FIGURE 11**



Map of the San Diego Ana wind region (left). The ratio of the occurrence of days within a specific wind speed and relatively humidity bin in the future relative to the historical (1976-2005) occurrence of days within the same bin. Future refers to 2070-2099 under RCP 8.5 conditions. The green box indicates the Santa Wind criteria (wind speed over  $>+ 8$  m/s, and relative humidity  $\leq 20\%$ ) used in the analysis of Pierce et al. (2018) (right). Source D. Pierce. For more information on the analysis, please see Pierce et al. (2018).

Future wildfire risk will be dependent upon both development and climate risk. Santa Ana Winds will continue to be a key driver of San Diego wildfires, and they will likely become hotter even relative to background warming (Pierce et al., 2018). Thus, the projected changes in the precipitation regime, with increasing drought and drier autumns, will increase wildfire risk during the dangerous fire weather conditions that Santa Ana winds create especially during the peak season in December and January. The increase in fire risk is illustrated in the results of Westerling (2018), who produced fire scenarios for the Fourth Assessment. The statistically based model shows an increase in area burned by up to 61 acres (0.25 square km), or up to 50%, under RCP 8.5 at the end of the century (2070-2100) as compared to the historical simulations. There is little difference

**FIGURE 12**



Map of fire hazard (threat) in the San Diego region based on an empirical model. Source: Syphard et al. (2012), figure 6D.



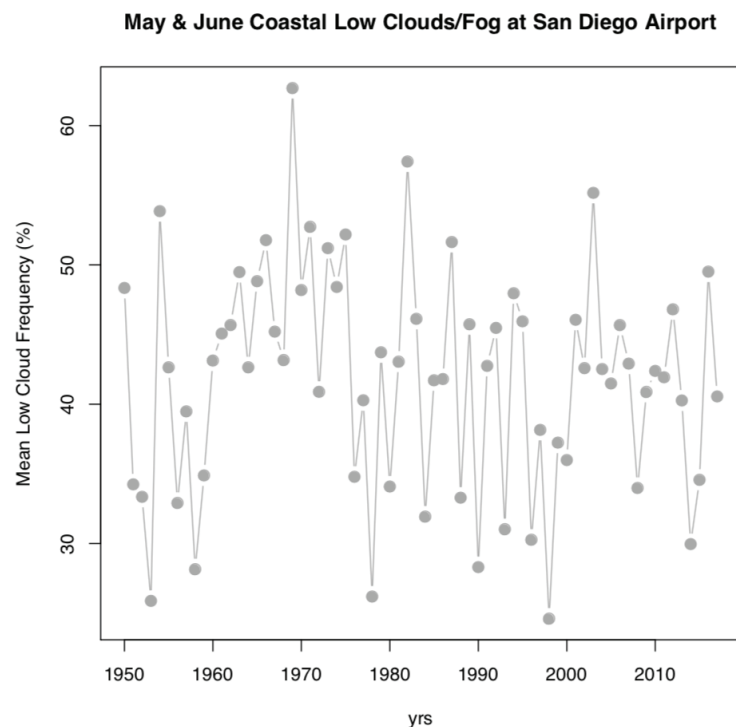
between the two GHG scenarios and mid century (2035-2064) and end of century. The similarities between the GHG scenarios and time periods are primarily due to the model's response to precipitation which is highly variable and has a minimal long-term trend in the annual precipitation totals.

The changes in the precipitation regime and the increased fire risk create higher potential for cascading impacts that can culminate in dangerous post-fire debris flows. This sequence of events was realized in Montecito in January 2018 when a deadly post-fire debris flow occurred from intense precipitation after the Thomas fire, the largest fire in California's history (Oakley et al., in review). There are several on-going efforts to map potential post-fire debris flow hazards including proposed methodology by California Geological Survey (Lancaster et al., 2014) and a mapping tool by the USGS ([https://landslides.usgs.gov/hazards/postfire\\_debrisflow/](https://landslides.usgs.gov/hazards/postfire_debrisflow/)), which has maps for the recent Lilac fire and Gate fire.

## Marine Layer Clouds (MLC)

Coastal low stratus clouds colloquially known as Marine Layer Clouds (MLC), or in Southern California as "May gray" and "June gloom," are a defining, persistent, and highly variable aspect of coastal California summer climate (Figure 13). MLC in San Diego are common in late spring and early summer when cool moist air near the ocean surface and sinking warm air above cause a temperature inversion which traps low level moisture and creates optimal conditions for these blanket-like stratiform clouds.

**FIGURE 13**



Monthly mean of low clouds at San Diego International Airport (KSAN) as defined in Schwartz et al. (2014). Cloud base height is at or below 1 km, cloud cover 0.75 or greater and time are 7, 10, 13, 16 PST for data record consistency. Source R. Clemesha.



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MLC are a poorly predicted aspect of coastal weather and climate. Although its seasonal coherence is organized by large-scale North Pacific sea surface temperature (SST) variability (Schwartz et al., 2014), its structure on fine spatial and temporal scales is extremely complex. This is readily apparent from a satellite-derived data set that was recently created at Scripps Institution of Oceanography (Clemesha et al., 2016). Iacobellis and Cayan (2013) demonstrated that summertime MLC cover is strongly associated with coastal California surface temperature variations. An estimate of the sensitivities of coastal daily maximum temperatures to changes in cloud cover yields a decrease of approximately 1°F for an increase in daily average cloud cover of 12%. When present, MLC shield the coast from summertime heat, but they may be absent during severe heat wave events which have inflicted public health impacts (Gershunov et al., 2009, 2011; Kristen Guirguis et al., 2014). The complex mix of larger scale atmospheric circulation and ocean temperature influences and their interactions need to be better understood to provide credible predictions of any future changes in MLC along San Diego County's coastal zone under future climate changes.





## San Diego Coasts

### State of the Science

#### COASTAL STORMS, WAVES AND EXTREME WATER LEVELS

Much of what we know and understand about coastal storms, swell predictions, and extreme water levels is a result of continued monitoring, study, and modeling throughout the region. This includes the 100-year long ocean temperature record and nearly as long tide gauge record from the Scripps Institution of Oceanography pier in La Jolla. Widespread nearshore wave observations and modeling offer a key example of the value of such efforts. These data enabled development of reliable swell hindcasts, nowcasts, and forecasts with international benefits for storm preparedness, boating safety, and ocean recreation, notably surfing (O'Reilly & Guza, 1998). Observations provide information on the connections between tides, sea level, and wave run-up that leads to coastal erosion, flooding, and damages. In the context of climate change, this provides guidance on how these interactions will evolve in the future at short (daily to annual), medium (annual to decadal), and century time scales.

Along the open coast, wave run-up combined with high water levels causes flooding and erosion events leading to the largest impacts on exposed natural and built environments. High water levels are a combination of several factors, including mean sea level, which will rise due to climate change, but also natural climate fluctuations such as multi-year and decadal enhancements from El Niño and large-scale ocean wind and circulation changes, extreme astronomical tides, and storms (Bromirski et al., 2017; Graham et al., 2013). For the next several decades, the confluence of natural processes will continue to trigger the worst coastal flooding, erosion, and damages, yet these processes will become ever more frequent and destructive as the background sea level rises due to the Earth's warming.

High tides are an important component of extreme sea level events; short-term sea level enhancements combined with peak tides contribute about 55% to annual maximum sea level events (Serafin et al., 2017). The next period of unusually high tides will occur in 2021 from 16.8 and 4.4-year lunar tidal cycles, and will produce peak monthly tides about 0.5 ft (0.15 m) higher than years in between cycle peaks (Cayan et al., 2008; Zetler & Flick, 1985). The most damaging sea level events involve storm surge and wave run-up that occur during peak high tides with a background of elevated water levels, for example from El Niño events.

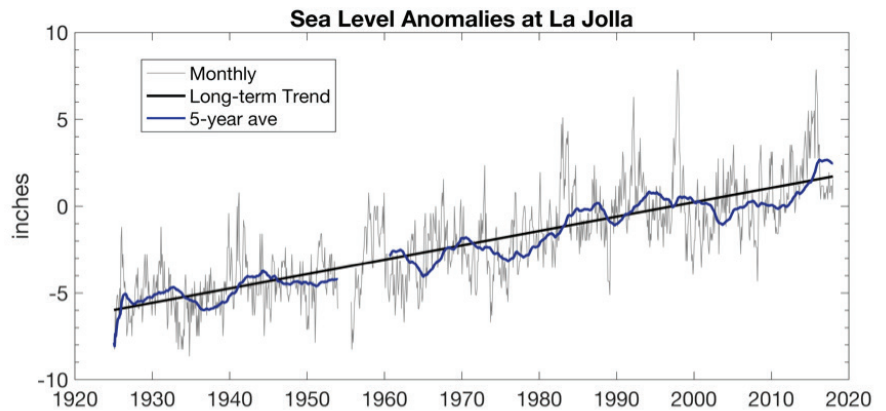
Since the beginning of the record in 1924, the tide gauge at La Jolla has measured an increase in sea level at a rate of  $0.08 \pm 0.01$  in/year ( $2.1 \pm 0.27$  mm/year) (Figure 14). Overlaid on this long-term mean sea level increase are multi-decadal fluctuations attributable to slowly-varying Pacific basin winds, temperature, and ocean circulation (Bromirski et al., 2011, 2012; Merrifield, 2011). Between 1980 and 2000, sea level along San Diego was relatively stable, even decreasing slightly as stronger wind stress gradients over the eastern Pacific suppressed the global rise along North America. Since 2000, sea level has been increasing rapidly as the wind systems relaxed once again (Bromirski et al., 2011, 2012; Hamlington et al., 2016). Within these multi-decadal fluctuations, interannual variability is largely attributed to the El Niño Southern Oscillation (ENSO), with higher sea levels occurring during El Niño events (Figure 15). The El Niño winters of 1982-1983 and 1997-1998 were the most destructive in modern memory, largely because storm waves coincided with peak high tides, especially in January 1983 (Flick, 1998). The La Jolla tide gauge recorded its highest still water level on November 25, 2015 during the confluence of a 6.8-ft King Tide and a 0.36-ft storm surge riding on background sea level enhanced by 0.67 ft from the strong 2015-2016 El Niño (Flick, 2016).



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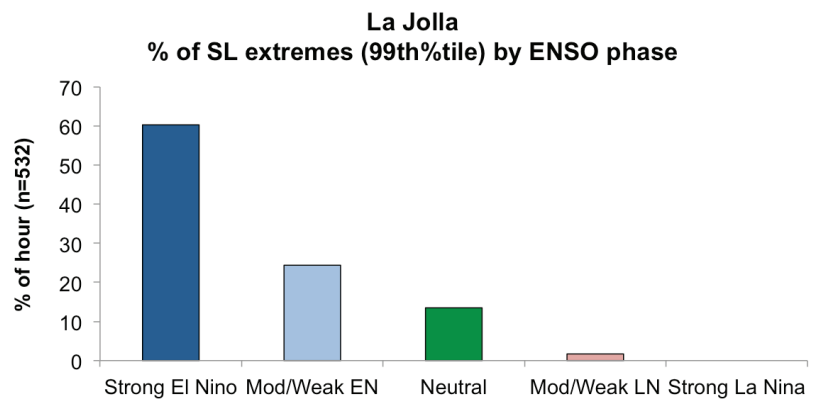
Flooding, erosion, and damages in Southern California were relatively modest in 2015-2016, however, owing to peak tide heights being lower and occurring earlier in the winter season, and the asynchrony of storm waves and high tides (Flick, 2016). Further information on impacts to California's ocean and coast, both statewide and in Southern California, may be found in Fourth Assessment companion report that explores the physical, ecological, social, and political changes climate change will have on these important features of the California landscape (California's Ocean and Coast Summary Report, 2018).

**FIGURE 14**



La Jolla tide gauge monthly sea level anomaly (light line), 5-year running average (blue) illustrating multi-year variability, and linear trend (black) 1925-2016.

**FIGURE 15**



Percentage of the 532 extreme (99 percentile) sea level (SL) hours that occurred during strong (dark blue), moderate to weak (light blue) El Niño events, neutral (ie neither El Niño or La Niña) (green), and moderate/weak La Niña events (pink), as ranked by the Multivariate ENSO Index. The index is based on observed tropical Pacific sea level pressure, surface wind (E-W; N-S), sea surface temperature, air temperature, and total cloudiness fraction.



## **SEDIMENT BUDGETS AND BEACH PROCESSES**

Beaches and beach culture contribute significantly to the quality of life in the region. Geologically speaking, the San Diego coastline is relatively young and naturally eroding. Similar to observations of waves and extreme sea level events, observations of the beaches and sea cliffs are critical for understanding how the regional beaches evolved naturally and how they respond to armoring and/or nourishment. Over the last several decades, beach monitoring has provided data to enhance the understanding of processes at the regional beaches, as well as more wide-scale beach processes that apply to much of the California coast.

Beach processes and sediment budgets are typically characterized within a particular littoral cell. The littoral are geographically limited and consist of a series of sand sources (such as rivers, streams, and eroding coastal bluffs) that provide sand to the shoreline, sand sinks (such as coastal dunes and submarine canyons) where sand is lost from the shoreline, and alongshore transport that moves sand along the shoreline. The littoral cell is a useful concept for analyzing sediment budgets and organizing regional sediment management plans because exchanges of sediment across littoral cells tend to be inhibited. The San Diego County shoreline comprises three littoral cells: the Oceanside, Mission Bay, and Silver Strand cells. Sources of beach sand into the littoral cell include: discharge from rivers and gullies, offshore deposits, nourishment placed by humans, and erosion from coastal cliffs. Damming in Southern California has reduced river sediment input to beaches (Flick, 1993; Flick, 1994; Willis & Griggs, 2003). In addition to damming of the watershed, much of the adjacent watershed has been urbanized, further reducing natural sediment yield. For example 60% (40% dammed and 20% urbanized and not dammed) of the Oceanside Littoral Cell watershed no longer generates beach sand (Young et al., 2010).

Actively eroding coastal cliffs comprise the majority of the California (and San Diego County) coast and threaten development throughout the State. Episodic cliff failures have caused human injury and several deaths in recent years. Seawalls and rock armoring are increasingly used to prevent erosion, but eroding coarse-grained coastal cliffs can be an important source of sediment to San Diego beaches (Young & Ashford, 2006). Cliff stabilization to protect coastal development has largely eliminated 42% of sea cliffs in the Oceanside Littoral Cell as a potential beach sand source. For the remaining sea cliffs, 0.4 in (1 cm) of average cliff retreat yields approximately 13,000 cubic yards (10,000 cubic meters) of beach sand (Young et al., 2010).

Coastal cliff erosion is broadly attributed to marine and terrestrial erosion mechanisms. Wave erosion acts directly at the cliff base only when tides and other water level fluctuations are high enough for waves to reach the cliff. Wide and elevated beaches can help reduce wave-driven erosion (Young et al., 2016; Young et al., 2014). Elevated rainfall and groundwater can trigger landslides and are often well correlated with cliff erosion events in Southern California (Young et al., 2009, Young, 2015). While these processes drive the erosion, geologic conditions dictate the cliffs resistance to erosion and control the cliff failure modes. The relative importance of the different erosion processes varies in space and time and can cause feedback mechanisms that work synergistically to cause erosion (Young et al., 2009).

San Diego cliffs are usually between 65 -115 ft (20 - 35 m) high and reach over 325 ft (100 m) in Torrey Pines. Estimated long-term cliff retreat rates vary widely between 0.1 and 5.6 ft/yr (2 and 170 cm/yr) (Benumof et al., 2000; Everts, 1990; Hapke, C.J. and Reid, 2007; L. J. Moore et al., 1999; Adam P Young, 2018), with average rates of about 0.2 to 0.7 ft/yr (5-20 cm/yr) (Young et al., 2010). Between 1998 and 2009, the mean cliff top retreat was 0.46 ft/yr (14





cm/yr), and the mean cliff face retreat averaged over the entire cliff height was 0.1 ft /yr (2 cm/yr) (Young, 2018). Recent cliff erosion hot-spots in San Diego County include extensive deep-seated landsliding at San Onofre State Beach (Young, 2015, 2018).

Studies over the past 40 years have defined how the offshore islands and complex topography off Southern California shelters and focuses long-period Pacific swell in different sectors of the coastline (Pawka 1982). Specifically for San Diego, waves approach the coast from three different sources: Pacific Ocean swell from both the northern and southern hemispheres, regional wind waves generated inside the islands, and local sea breeze chop arising nearshore. Wave energy is generally higher at the southern beaches in San Diego due to the islands sheltering the northern San Diego beaches from Pacific swells. Current research focuses on the regional and local wind-generated short-wave portion of the spectrum, which turns out to be crucial for sand transport calculations because they can cause a reversal of the alongshore sediment transport.

Beach nourishment, or the addition of sand, has been part of the sediment supply to beaches throughout San Diego since the end of World War II. The effect of beach nourishment on the San Diego shoreline is most dramatic in the Silver Strand littoral cell comprising the beach from Coronado to Imperial Beach. About 26 million cubic yards of sand greatly widened the sand spit beach beginning in 1946 as a by-product of San Diego Bay naval base dredging to accommodate the returning Pacific Fleet. This sand spit includes Coronado, Silver Strand, and Imperial Beach, and is a relatively thin strip of sand that separates San Diego Bay from the ocean. There have been many other opportunistic beach nourishment projects, such as the placing of sand from the dredging of Oceanside Harbor and during the construction of the San Onofre Nuclear Powerplant (Flick & Wanetick, 1989). Beach nourishment is a method of mitigating coastal erosion and helps counter-act decreases in sediment supply from the damming of rivers, which traps sediment behind the dam, and cliff armoring, which prevents sediment from bluff erosion from reaching the beach (Young et al., 2010). To help mitigate erosion, in 2001 and 2012, San Diego Association of Governments' (SANDAG) spent \$44 million dollars on non-opportunistic nourishment by placing 3.5 million cubic yards of sand on beaches throughout the County (Smith, 2016) and north San Diego County has developed a 50-year, \$160 million plan for beach nourishment (Diehl, 2015). The impacts of beach nourishment are complex as there are several physical processes that interact to determine the impacts on flooding, erosion, and ecosystems.

Close monitoring of four San Diego beaches by Scripps Institution of Oceanography has shown varying impacts of beach nourishment. At Torrey Pines, a nourishment constructed in 2001 with a sand grain size similar to native material was washed offshore in a single storm and partially returned to the beach the following summer (Seymour et al., 2005; Yates et al., 2009). In contrast, nourishments built with coarser than native grain size at Imperial, Solana,



and Cardiff beaches helped widen beaches for several years. In the past decade, North Pacific waves during El Niño winters 2009-10 and 2015-16 were the most energetic and had similarly extreme erosive power. The monitored beaches nourished with coarse grain sand remained 33 ft (10 m) wider in the 2015-16 winter than in the unnourished winter of 2009-10. In Imperial Beach, the sand nourishment helped protect low lying homes from flooding by wave over-topping, but elevated the water table leading to groundwater flooding (Ludka et al., 2018). Additional unintended consequences of beach nourishment include impacts on neighboring estuary mouths with negative ecosystem impacts (discussed below) and potentially negative impacts to intertidal invertebrates (Wooldridge et al., 2016).

### ESTUARIES, LAGOONS AND BAYS

The San Diego County coastline has several estuaries, formed where rivers meet the sea (Zedler, 1982). These range from the as six lagoons in northern San Diego County between Oceanside and Torrey Pines, to large embayments, such as San Diego Bay. Each of the estuaries, and the salt marsh wetlands they contain, are unique (Beller et al., 2014) and are temporally variable ecosystems that perform many ecosystem services (Levin et al., 2001; Zedler & Kercher, 2005). These benefits include supporting rare species, offering nurseries for fish and birds, absorbing nutrients and pollutants from rivers, trapping atmospheric carbon, and providing popular recreational opportunities. San Diego's coastal wetlands are highly urbanized, being impacted by extensive habitat loss and degradation, particularly the salt flats and upland wetlands (Beller et al., 2014). The wetlands that remain, however, are prized, and substantial effort is aimed at their conservation and restoration (e.g., the Southern California Wetlands Recovery Project).

All of San Diego County estuaries are classified as low-inflow estuaries (LIEs) because the region's mediterranean climate leads to low and intermittent inflow from creeks and rivers (Largier et al., 1997). However, as a result of development, most of the San Diego County estuaries have year-round inflow of freshwater from local runoff (from lawns, agriculture, etc., i.e., urban-drool) (Greer & Stow, 2003; White & Greer, 2006). Due to the low freshwater input, the dynamics of San Diego estuaries can differ substantially from estuaries with more persistent and larger freshwater inflow (Largier, 2010).

San Diego County estuary inlets that are minimally armored can naturally close when large waves move beach sand and cobbles into sandbar sill near the mouth (Behrens et al., 2013; Jacobs et al., 2010). These inlets can re-open naturally when large river flow events scour river mouths (Elwany et al., 1998; Webb et al., 1991). The frequency and duration of closures affect the habitat diversity at the various lagoons in San Diego (Beller et al., 2014). Sill height and location can have large impacts on circulation, inundation, stratification, and dissolved oxygen (Elwany et al.,



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1998; Ranasinghe & Pattiaratchi, 2003), and mouth closure is a characteristic, episodic event that influences the physics, chemistry, and biology of LIEs in Southern California (Webb et al., 1991). In particular, the potential for closure makes San Diego County LIEs particularly susceptible to hypoxic events and creation of breeding grounds for mosquitos. Hypoxia, vector control, and a risk of upstream flooding often drive mouth management. Inlet dredging to alleviate these problems can be costly, ranging from ~\$100K to over \$1M per system annually (Hastings & Elwany, 2012; Jenkins & Wasyl, 2006).

As seas rise, which has been the trend since the last Ice Age, wetlands tend to migrate upstream and inland. In heavily urbanized San Diego, however, this migration space is often limited by development (Figure 16). Coastal wetlands are prime examples of “living shorelines,” and can keep pace with some amount of sea level rise by trapping and depositing sediment in the water. The rate of sediment accretion and whether it can keep up with sea level rise is an active area of research in the region.

**FIGURE 16**



Tijuana River National Estuarine Research Reserve, illustrating coastal wetlands in an urban setting.  
Source: Jeff Crooks.



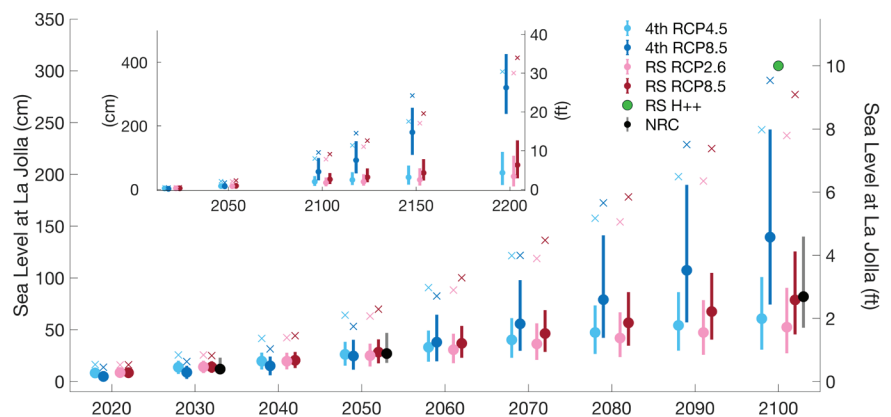


## Future Vulnerabilities to Sea Level Rise

### SEA LEVEL RISE PROJECTIONS

The Fourth Assessment sea level rise projections employ input from multiple global climate model simulations and are contingent upon the business-as-usual GHG emissions RCP 8.5 scenario and a more moderate emissions RCP4.5 scenario. Sea level rise projections use the 50<sup>th</sup>, 95<sup>th</sup>, and 99.9<sup>th</sup> percentiles; the 99.9<sup>th</sup> percentile is considered the maximum possible. The Fourth Assessment sea level rise projections use methodology developed by Kopp et al. (2014) (Pierce et al., 2018). The Kopp et al. (2014) method incorporates projections of all the major contributors to sea level (thermal expansion, Greenland, land glaciers, water use, Antarctica) in a model to make a projection of sea level rise at a given location. This model is run thousands of times to develop probabilistic projections. The sea level rise projections from Kopp et al. (2014) use the IPCC report and expert elicitation to estimate Antarctica's contribution to sea level rise. The Fourth California Climate Change Assessment sea level rise scenarios substitute in results from DeConto and Pollard (2016) (DP 2016) for Antarctica's contribution to sea level rise in the Kopp et al., 2014 method. DP2016, using new ice sheet modeling, suggests that Antarctica might contribute as much as 2.3 ft (70 cm) of sea level above what is used in the Kopp et al. (2014) projections. The California Ocean Protection Council (OPC) guidance presented in the Griggs et al. 2017 *Rising Seas* document uses RCP 2.6 and RCP 8.5 projections from Kopp et al., 2014 and does acknowledge DP2016 in an extreme of 10 ft by 2100, the H++ scenario (Figure 17; Table 1). A limit on the Kopp et al. (2014) method is that, given the high uncertainty in the projections in the latter half of the century, the probabilistic approach cannot represent the full uncertainty in sea level rise at these later periods (Behar et al., 2017). The sea level rise projections are similar until 2050, when there is much less uncertainty, but uncertainty grows rapidly in the latter half of the century (Figure 17). Similarly, sea level rise accelerates significantly in the second half of the century and continues past 2100 (inset in Figure 17).

**FIGURE 17**

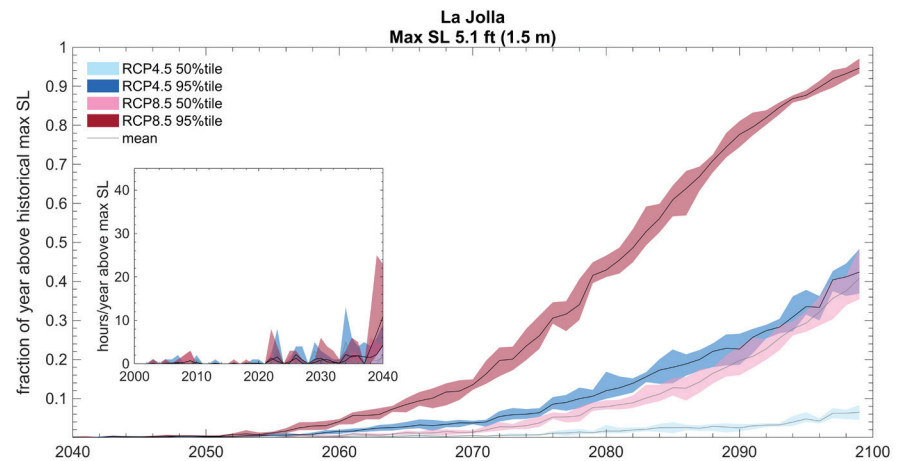


Sea level rise (SLR) estimates for La Jolla from three different publications and two different greenhouse gas scenarios. These include SLR projections made for the Fourth Climate Change Assessment (Pierce et al., 2018) for RCP 4.5 (light blue) and RCP 8.5 (dark blue) for each decade over the 21st century. The California Ocean Protection Council Rising Seas projections are shown for RCP 2.6 (pink), RCP 8.5 (red), and the extreme scenario H++ (green dot). The National Research Council (NRC, 2012) sea level estimates for all of California are shown by the black dots and grey lines. Each decade's estimate is shown as a range from the 5th to 95th percentile with the circle representing the 50th percentile and the x representing the 99.9th percentile. Inset shows projections carried out to 2200.



Similar to historical extreme sea level events, in the future, extreme events will occur in short bursts as a result of high astronomical tides and storms, usually during winters having El Niño conditions. However, as sea levels rise, current thresholds of extremes will occur more frequently and with longer durations because they will occur on top of higher water levels. As part of the Fourth Assessment, hourly sea level projections (still water level, not including wave run-up) were calculated to better understand the impacts of extreme events on long-term sea level rise (Pierce et al., 2018). As previously mentioned, the record high sea level recorded in one hour's measurement at the La Jolla tide gauge in November 2015 was 5.1 ft (155 cm), representing an occurrence of one hour in almost 100 years. By 2050, the number of hours per year projected to exceed this threshold ranged from 2-45 hours, depending on the sea level rise scenario (Figure 18). After 2050, the number of hours per year above this historical threshold increases significantly until 2100, when, depending on the RCP scenario and percentile, half the year to almost the entire year will exceed the historical maximum (Figure 18). The amplitude of extreme events will also increase with the maximum sea level extreme in 2050 estimated to be approximately 6 ft (1.8 m) and the maximum estimate to be 13.5 ft (4.1 m) by the end of the century (not shown).

**FIGURE 18**



The projected fraction of year the exceeds the historical maximum at the La Jolla tide gauge, which is 5.1 ft. The thin black line is the multi-model ensemble of the 8 models that were used to create hourly projections (Pierce et al., 2018). The sea levels are still water levels and do not include wave heights or wave run-up. Inset shows results from 2000-2040 with an adjusted scale (hours per year).



TABLE 1

	2030 (5TH-50TH-95TH) (FT)	2050 (5TH-50TH-95TH) (FT)	2100 (5TH-50TH-95TH) (FT)
NRC	0.2- <b>0.4</b> -0.8	0.6- <b>0.9</b> -1.7	1.7- <b>2.7</b> -4.6
RS (RCP 2.6)	0.3- <b>0.5</b> -0.7	0.5- <b>0.8</b> -1.2	0.9- <b>1.7</b> -3.0
RS (RCP 8.5)	0.3- <b>0.5</b> -0.6	0.6- <b>0.9</b> -1.3	1.5- <b>2.6</b> -4.1
4th Assessment (RCP 4.5)	0.1- <b>0.3</b> -0.5	0.3- <b>0.7</b> -1.1	1.2- <b>2.5</b> -4.7
4th Assessment (RCP 8.5)	0.1- <b>0.3</b> -0.5	0.4- <b>0.8</b> -1.3	2.5- <b>4.6</b> -8.0

Sea level rise projections for CA (NRC) and for La Jolla (*Rising Seas* and Fourth Assessment) for the different RCPs. Similar to figure 17, the NRC is the committee value and the range while *Rising Seas* (RS) and Fourth Assessment are the 5<sup>th</sup>, 50<sup>th</sup> (in bold) and 95<sup>th</sup> percentiles. All values are in ft above 2000 level.

### SAN DIEGO SEA LEVEL RISE ASSESSMENTS

San Diego agencies and governments are aware of the region's vulnerability to sea level rise and have begun to make an effort to understand potential exposures and begin considering adaptations. The regional coordination has been led in large part by the San Diego Regional Climate Collaborative (discussed in more detail below) under a NOAA grant for regional coastal resilience. The current efforts in the region are briefly described in Table 2 and the sea level projections different regions are using are shown in Figure 19.

Recent vulnerability assessments and the USGS Coastal Modeling System (CoSMoS) tool have shown that high sea levels combined with the aforementioned extreme events have the potential to cause significant flooding in the region particularly in the low lying areas in around San Diego, such as San Diego Bay (Figure 20), Mission Bay, Imperial Beach, and La Jolla Shores. San Diego Bay is particularly vulnerable to sea level rise due to the core location of several important transportation hubs, the airport, naval base, and port, as well being a business and population center. A recent study of economic impact of sea level rise commissioned by the San Diego Regional Climate Collaborative indicates that the largest economic vulnerabilities (not including residential losses) are in and around San Diego Bay. Throughout San Diego County, the analysis estimates that between \$395-451 million of commercial and industrial property could be lost annually with 6.6 ft (2 m) of sea level rise and the sector most affected would be tourism followed by ship building and professional and technical services (Colgan et al., 2018). The analysis looked at each of these as singular events; however, it is noted that the cumulative effects of flooding on the region's economy may hinder its ability to recover, which is an important consideration for overall impacts to regional GDP and economic resilience. Similarly, a recent sea level rise vulnerability assessment of SDG&E's electrical infrastructure showed the highest vulnerabilities are around San Diego Bay (Bruzgul et al., 2018). The majority of SDG&E vulnerabilities under 1.6 ft (0.5 m) of sea level rise are from damage to distribution lines from corrosion from more frequent flooding, though with a 100-year storm event on top of a modest 1.6 ft (0.5 m) of sea level rise, 4 substations, which are critical infrastructure for energy transmission and distribution, could be affected.





Currently, the Port of San Diego is conducting a sea level rise vulnerability assessment to better understand areas and infrastructure which may be vulnerable to flooding and inundation, while simultaneously highlighting how multiple jurisdictions and agencies are connected through regional vulnerabilities to sea level rise. The Port of San Diego is in a unique position to examine vulnerability across many sectors as the Port is a land manager of over 34 miles of waterfront property in San Diego Bay including sensitive tideland habitat. The Port's land management portfolio consists of a wide array of businesses including hotels, marinas, restaurants, ship building and repair services, boatyards, and maritime commerce, as well as public parks and other public spaces that allow for access and recreation along San Diego Bay. This vulnerability report is due in the summer of 2019.

In northern San Diego County, both Del Mar and Carlsbad have completed coastal vulnerability assessments. Del Mar identified the Coastal Rail Corridor tracks that run parallel to the coasts as being vulnerable, even under relatively low levels of sea level rise, in addition to the city's firehouse (ESA, 2016b). Carlsbad sea level rise vulnerability assessment identified over 500 parcels of land and over 1,000 acres of natural lands (largely lagoons) vulnerable to flooding at 1.6 ft (0.5 m) of sea level rise. If sea level was to increase to 6.6 ft (2.0 m), vulnerability throughout Carlsbad would increase such that six times the amount of beach would be affected, and almost four times the amount of key roadways in the city would be vulnerable including, Highway 101 (Carlsbad, 2017). Additionally, each of the Caltrans District offices (including San Diego Region 11) will be preparing Climate Change Vulnerability Assessments, which are scheduled to be completed in 2018.

The Department of Defense commissioned a report on sea level vulnerabilities in Southwest which focused on the Naval Base Coronado and Marine Corps Base Camp Pendleton (Chadwick et al., 2014). The 600 page report provides a detailed examination of the vulnerabilities and estimates the replacement costs which ranged from several \$100s of million of to over \$1 billion for 6.6 ft (2.0 meters) of sea level rise. Naval Base Coronado is particularly vulnerable to inundation and flooding in water front properties due to the low-lying nature of the base. The training areas at Marine Corps Base Camp Pendleton are particularly vulnerable to SLR. The report also examined the impact of seawater intrusion on groundwater as a result of sea level rise at Marine Corps Base Camp Pendleton, making it one of the few pieces of research that have examined this potential impact for the San Diego region. The intrusion was highly dependent of the amount of groundwater pumping, but under most scenarios chloride concentrations decreased by about 1.5 miles (2.5 km) from the coast.

The response of estuaries and coastal wetlands to sea level rise and other climate impacts have been the subject of increasing scientific investigation. A recent study (Thorne et al., 2018) on wetlands along the US West Coast identified accretion rates and available upland migration space as key characteristics for wetland adaptation to sea level rise. Different estuary settings affect how these two variables interact to determine adaptability. For example, Sweetwater River Estuary has more space to migrate inland though lower sediment accretion rates than the Tijuana River Estuary wetland, indicating that the mechanism of adaption between the two estuaries will be different. Nonetheless, both of these wetland systems are projected to become largely mud flats by 2110 under 5.4 ft (1.7 m) of sea level rise (Thorne et al., 2018). Other studies have demonstrated that sea level rise might lead to decreases in plant diversity in the salt marsh plain through competition (Noto & Shurin, 2017), but that at higher elevations native species might have a competitive advantage over non-natives, which typically have lower salt tolerances (Uyeda et al., 2013).

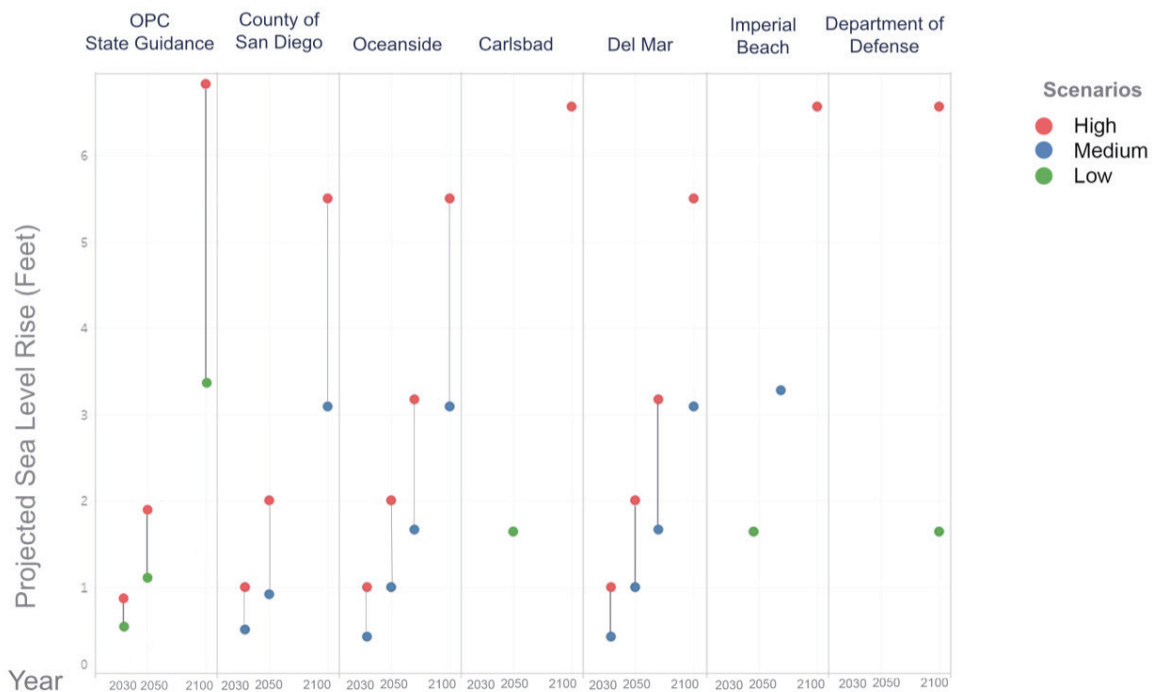


## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT



As climate is expected to affect not only sea level, but also waves and river flow (the latter driven by the size and intensity of precipitation events), it is likely that the dynamic nature of estuarine tidal inlets subject to accretion and closure will change as well. Potential changes in inlet closure patterns would have cascading impacts on both ecosystems and humans (Harvey et al., 2015). For example, recent studies during the 2015-2016 El Niño suggest that more frequent extreme water level events may lead to inlet closures (which in turn lead to hypoxia (low oxygen), vector control problems, and the potential for upstream flooding) becoming more frequent and/or lasting longer in duration; however, additional research is needed to understand the response of these systems given their heavily managed nature (Harvey et al., n.d.). Importantly, the interaction between estuaries and their neighboring environments is critical to fully understand estuarine vulnerability. For example, large waves along with beach nourishment at Imperial Beach contributed to the closing of the neighboring Tijuana River Estuary (Ludka et al., 2018) during the 2015-2016 El Niño, creating anoxic conditions in the estuary which killed many organisms and led to upstream flooding as river flow raised water levels inside the closed lagoon (Baker, 2016).

FIGURE 19



The sea level rise scenarios that cities and agencies in San Diego are using for planning. The figure shows the sea level projections that are being used at different time horizons and for some a low and high scenario. Source: Laura Engeman and Laura Walsh of the San Diego Regional Climate Collaborative.



## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT



TABLE 2

LOCATION	LOCAL/REGIONAL COASTAL RESILIENCE EFFORT	STATUS
Oceanside	City Local Coastal Program (LCP) update to include SLR Vulnerability Analysis, adaptation planning, and a Land Use Plan (LUP) update.	Ongoing
Carlsbad	City Local Coastal Program (LCP) update to include SLR Vulnerability Analysis, adaptation planning, and a Land Use Plan (LUP) update.	Ongoing
Solana Beach and Encinitas	Coastal Storm Damage Reduction Project, undertaken by The U.S. Army Corps of Engineers (ACOE), that includes a SLR white paper and associated technical analyses for the cities of Encinitas and Solana Beach.	Complete
Encinitas	Cardiff Beach Living Shoreline Project, managed by the City and State Parks Department, to create a dune system on the seaward side of Coast Highway 101 on Cardiff State Beach. The project serves as a natural SLR adaptation approach to protect a vulnerable segment of the roadway while providing native dune habitat.	Construction in 2018
Solana Beach	Updated Local Coastal Plan (LCP), Land Use Plan (LUP), and Mitigation Fee Study for land lease/recreation fees that are designed to compensate the public for potential loss of recreation use of the public beach due to shoreline protective devices such as sea walls.	Ongoing
Solana Beach	LiDAR bluff survey to help determine how quickly the coastal bluffs are eroding now and in the future.	Complete
Del Mar	City Local Coastal Program (LCP) update to include SLR Vulnerability Assessment, adaptation planning, and a Land Use Plan (LUP) update.	Ongoing
City of San Diego	Synthesis of City SLR Vulnerability Information and integration into the City's Climate Adaptation Plan.	Ongoing
County of San Diego	County Local Coastal Program (LCP) update for unincorporated coastal property as well as an updated 2015 Multi-Jurisdictional Hazard Mitigation Plan to include climate impacts such as coastal flooding due to SLR and extreme weather events.	Complete
San Diego Bay	Sea Level Rise Adaptation Strategy for San Diego Bay that evaluates where and when SLR impacts may occur, as well as the extent to which exposed community assets would be impaired by an impact and whether they may be able to cope or adapt on their own.	Complete
San Diego Bay	The San Diego Bay Native Oyster Restoration Project to integrate intertidal shoreline stabilization with restoration of native oyster beds as a living shorelines demonstration project.	Planning & Design complete.
Imperial Beach	City Local Coastal Plan (LCP) update to include SLR Vulnerability Assessment, adaptation planning, and a Land Use Plan (LUP) update.	Ongoing
Chula Vista	Chula Vista Bayfront Master Plan	Complete





## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT

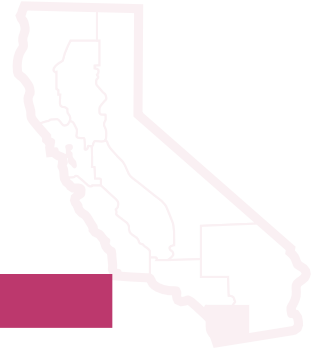


TABLE 2 - CONTINUED

LOCATION	LOCAL/REGIONAL COASTAL RESILIENCE EFFORT	STATUS
<b>Port of San Diego</b>	SLR Vulnerability Assessment and planning as part of the Port Master Plan Update and requirements of AB 215.	Ongoing
<b>San Diego International Airport</b>	SLR Vulnerability Assessment and strategies designed to help improve the Airport's resilience to flooding and sea level rise incorporated into a Water Stewardship Plan, which takes a holistic approach of simultaneously addressing water conservation, water quality, and flood resilience efforts at the San Diego International Airport.	Complete
<b>Tijuana River National Estuarine Research Reserve</b>	As part of the Climate Understanding & Resilience in the River Valley (CURRV) project, future scenarios were developed, outlining the Tijuana River Valley's vulnerabilities to sea level rise and riverine flooding. The results are informing the Reserve's Comprehensive Management Plan and the Tijuana Estuary Tidal Restoration Program.	Complete
<b>Tijuana River National Estuarine Research Reserve</b>	A large multi-phased wetland restoration program involving up to 250 acres. A primary goal is to design the restoration projects to naturally adapt to changing environmental and climatic conditions.	Ongoing
<b>SANDAG</b>	Regional synthesis of regional transportation infrastructure to SLR and update to the regional beach nourishment and sand retention policies.	Ongoing
<b>US Navy</b>	Framework for the Southwest Installations Naval Base Coronado and Marine Corps Base Camp Pendleton to assess the impacts of local SLR and associated impacts to natural and built infrastructure along coastlines.	Complete
<b>San Diego Gas &amp; Electric</b>	Evaluation of SLR vulnerabilities to the region's natural gas and electricity infrastructure.	Ongoing

The Coastal Resilience Activities occurring in the San Diego Region (Courtesy of the San Diego Regional Climate Collaborative). Note sea level rise abbreviated SLR.



## San Diego Sea Level Rise Adaptation and Planning

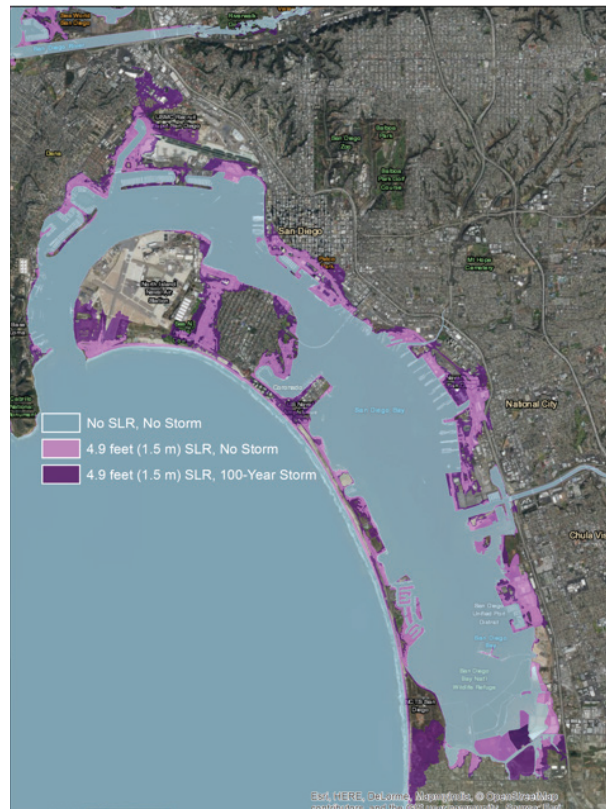
### ADAPTIVE PLANNING

The recent Ocean Protection Sea Level Rise Guidance (Ocean Protection and California Natural Resources, 2018) recommends using adaptive management in planning, allowing the plan to adapt as needed as the threat from sea level evolves. One such approach is a trigger-based approach in which an adaptation action will be taken only once a threshold has been reached. This approach is recommended largely due to the uncertainty in sea level rise projections and these projections, which will continue to evolve with more observations, modeling, and scientific understanding. The City of Del Mar's coastal adaptation plan uses triggers. One example from the plan identifies the magnitude of SLR and the summer and winter beach width as triggers that provoke progressive phases of adaptation, including beach nourishment, improving sea walls, installing sand retention structures, raising structures, and eventually removing structures (ESA, 2016a). More about Del Mar's sea level rise planning experience is presented in the text box below.

### LIVING SHORELINES AND OTHER ADAPTATIONS

Public agencies in the San Diego region have begun adapting to sea level rise, and, in particular, exploring more natural adaptation approaches (living shorelines) through several demonstration projects. One such project is the Cardiff Beach Living Shoreline project, a \$2.1 million dollar project to construct a sand dune that will be seeded with native plants on Cardiff State Beach to protect Highway 101 from flooding. The Port of San Diego has received funding to design an oyster reef of native Olympia oysters (*Ostrea lurida*) in 2.5 acres of intertidal zone near the Sweetwater Marsh with the goal of restoring native oyster habitat, providing forage for birds and aquatic species, and slowing shoreline erosion by reducing wave energy and promoting sediment accretion in the coastal marsh.

FIGURE 20



A Map of San Diego Bay showing the current sea level (blue), 1.5 M of sea level (light purple) rise with and with a 100-year storm (dark purple) using CoSMoS. Source: J. Finzi Hart from USGS.



Communities are also examining the potential to protect resources through beach nourishment and armoring, (i.e., sea walls). Beach nourishment was discussed above, and a wider, more elevated beach can help promote recreation and tourist economies, protect the back beach from erosion (Young et al., 2014) and guard coastal infrastructure from flooding. Nourishment can also have negative consequences on the groundwater table (causing groundwater flooding at Imperial Beach) and local ecosystems (potentially smothering invertebrates, or clogging estuary mouths). Impacts (positive and negative) influence both the localized region of the sand placement and beaches throughout the littoral cell as nourishment sand moves alongshore. Continued monitoring of beach nourishment is important for understanding how these sand placements evolve and impact the region under different climate and wave conditions.

Sea walls are a highly controversial topic and have resulted in several recent legal cases in San Diego County (Brennan, 2017). Currently, 31% of San Diego coastline is armored (Young, 2018). Sea walls inhibit coarse sediment from cliff erosion from entering the littoral cell and becoming part of the beach. Although comparative studies between the presence and absence of sea walls have shown differences in active erosion, it is not conclusive that sea walls affect the long term active erosion rate (Griggs, 2005). Seawalls can also cause beach width reduction through passive erosion and placement loss (structural footprint). Saving infrastructure and development at the expense of the beach dramatically illustrates one of the trade-offs that is expected to become more acute in a future of rapid sea level rise.

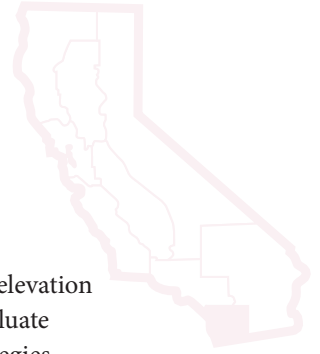
The Climate Understanding and Resilience in the River Valley (CURRV) Initiative, led by the Tijuana River National Estuarine Research Reserve (TRNERR), is using scenario planning to inform on-the-ground management and restoration decisions, based on careful analysis of trajectories from the past to the present and into the future (Boudreau et al., 2017). The future scenarios were based on changes in an ocean driver of change (increases or decreases of tidal prism) and a watershed driver of change (increased or decreased extreme flow events from the watershed). Sea level rise was taken as a given across all scenarios. This planning tool is being used to challenge assumptions about future states, foster dialogue about cross-sector adaptation responses, inform adaptation strategies in the update of the TRNERR's Comprehensive Management Plan, and steer design of the Tijuana Estuary Tidal Restoration Program. Since the development of the Tijuana River Valley scenarios, TRNERR has implemented the scenario planning process in several geographically distinct areas with different local conditions and climate impacts.

The first regional coordination and collaboration around sea level rise in San Diego was around the Sea Level Rise Adaptation Strategy for San Diego Bay (2012). The effort included the cities located around San Diego Bay, the Regional Airport Authority, the Port, California state agencies, the US Navy, SANDAG, Federal Emergency Management Agency (FEMA), and several academics from the region. In 2015, the Climate Collaborative, in partnership with the Climate Science Alliance, South Coast and the TRNERR, launched a Resilient Coastlines Project (<http://www.resilientcoastlines.org>) designed to support community based coastal hazard planning across San Diego County. The project has successfully engaged local government, scientists, and the community with fourteen various sea level rise planning and adaptation initiatives in the County, primarily through a regional working group. This group represents every coastal city in the County, as well as significant regional, state, and national entities that have assets on the coast such as the Airport, Port of San Diego, TRNERR, US Navy, California State Parks, and California Department of Transportation. Central to this group is also participation from scientists at Scripps Institution of Oceanography, and from local consulting firms providing additional data and analysis to the region's jurisdictions. The group is invested in understanding the use of "triggers" by local government whereby certain coastal





## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT



observations may invoke city land use policies such as increased setbacks, development restrictions, or the elevation of structures. The regional group also began exploring legal risks, cost-benefit frameworks, and ways to evaluate regional economic impacts. These tools help communities prioritize financial resources for adaptation strategies which are often costly and require several years of lead time. Through this cross-jurisdictional collaboration, local entities are exploring how to integrate sea level rise adaptation into hazard mitigation planning, capital infrastructure planning, and community revitalization programs.

As these examples highlight, there is a need to consider the trade-offs between what is being protected and what is being put at risk while planning for adaptations. These trade-offs do not exist in isolation; rather a decision on one can require additional decisions. Many of the trade-offs and decisions that San Diego is facing are similar to the trade-offs that will be considered all along the California coast; however, given the geological setting of the region, San Diego may have to make many difficult decisions around these issues before other regions.



## CASE STUDY | THE CITY OF DEL MAR

**T**he City of Del Mar is a small coastal city in the San Diego region that is actively planning to protect its beach, coastal bluffs, and coastal resources, and minimize impacts from projected storms, flooding, erosion, and sea level rise. The City is working with technical consultant, Environmental Science Associates (ESA) and a Sea Level Rise Technical Advisory Committee (11 members appointed by the City Council) to address State law requirements.

The City completed its Coastal Hazards, Vulnerability and Risk Assessment (ESA 2016) which identified properties vulnerable to sea level rise, storm surge, coastal flooding, river flooding, and erosion along the entire western boundary of Del Mar, including properties on coastal bluffs, at beach level, and adjacent to the San Dieguito Lagoon. Vulnerable City facilities/infrastructure include the fire station, public works yard, sewer lift station, beach access points, public roads, sewer lines, and storm water systems.

In 2016, the City began preparation of an Adaptation Plan using best available science, State guidance, and context-specific, local data and technical studies. Extensive outreach and public discussion has occurred. Key resources relied upon include a cost benefit analysis prepared by Nexus Planning & Research (2017) and a legal risk analysis prepared by the Environmental Law Institute (2017). The Nexus Planning & Research study evaluated the cost of “no action” versus scenarios to protect, adapt, or abandon vulnerable properties; and concluded that the highest return on investment may be realized if beach nourishment is used in the near term and paired with sand retention, and that the highest cost to Del Mar would likely be a choice to take no action at all, followed by the high cost for planned retreat of the City’s North Beach neighborhood. The Environmental Law Institute’s report also concluded there are risks if the City takes no action. These studies reinforced the importance of adaptation planning, especially when certain stakeholders requested to slow or stop the process.

The Adaptation Plan was adopted in May 2018. Del Mar is taking a phased, long term approach to help owners (public and private) plan ahead and help the City manage its coastal resources for future generations. The City’s preferred approach at this phase is to complete a Sediment Management Plan and pursue a combination of beach nourishment and sand retention strategies accordingly with a goal to maintain the existing high quality walkable beach and public access currently enjoyed in Del Mar.

The main point of contention with the planning effort continues to be managed retreat. Del Mar identifies retreat as an option to reduce risk (i.e. setbacks adjacent to flood or erosion hazards), to accommodate migration of wetland habitat, and to remove/relocate public facilities and infrastructure. However, retreat of private property (beyond the use of setbacks) is not a desired strategy in Del Mar and should not occur until other alternatives have been exhausted.





## Climate Impacts and Adaptations on Lands

### Land Use and Change

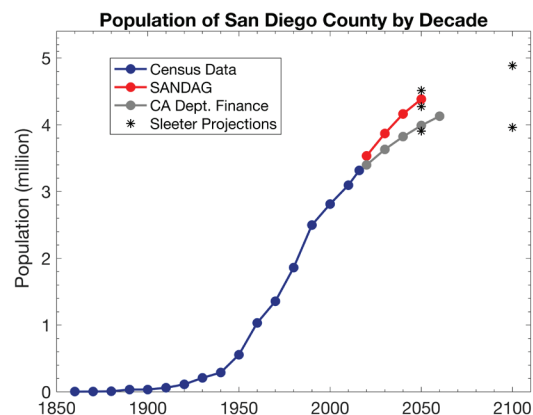
**T**he ways in which climate variability and climate change impacts will be felt on humans and natural systems in San Diego County will be strongly affected by Land Use/Land Change (LULC). Changes in land use from natural and rural environments to urban can cause changes in temperature patterns, particularly the diurnal temperature range, often causing an increase in daily minimum temperatures (Kalnay & Cai, 2003).

These types of shifts increase the coverage of impervious surfaces such as asphalt and concrete, which can increase stream flows in urban stream segments. Such a shift was documented in Los Peñasquitos Creek, in San Diego, where increased minimum, medium, and dry day stream flows resulted from an increase in impervious surfaces (White & Greer, 2006). Development in San Diego also leads to increased fires because most fires are caused by anthropogenic ignition sources and are more common in low- to medium-range developments (Syphard et al., 2013; Syphard & Keeley, 2015a). More frequent fires shorten fire-return intervals which can cause land cover changes and lead to the invasion of non-native grasses in native ecosystems (Jennings et al., 2018). Urbanization has also been implicated in reducing coastal low level clouds and fog, which in turn could lessen the mitigating features provided by low coastal clouds on high daytime temperatures and summer dryness (Williams et al., 2015).

### POPULATION CHANGES

LULC is driven strongly by population growth, which is linked to job growth and the additional housing and services needed to support an increasing population. In San Diego County, the population has more than doubled since 1970 to a total of 3.3 million people in 2016 (U.S. Census Bureau, 2017), making it California's second most populous county and 5<sup>th</sup> most populous in the U.S (Figure 21). The San Diego Association of Governments (SANDAG) projects that the future population of San Diego will be 4.4 million by 2050 whereas the California Department of Finance puts the 2050 estimate at 4 million. Extending out to 2100, the Department of Finance estimates the population in San Diego will be between 3.9 and 5.5 million people (Figure 21).

**FIGURE 21**



The population in San Diego County by decade as estimated by the US Census Bureau (blue), projected populations estimated by SANDAG (red) (San Diego Association of Governments, 2015), and California Department of Finance (grey) (Projections, 2017). The black asterisks are the low, middle, and high estimates used for the California Department of Finance and used the Sleeter et al. (2017) land use study.





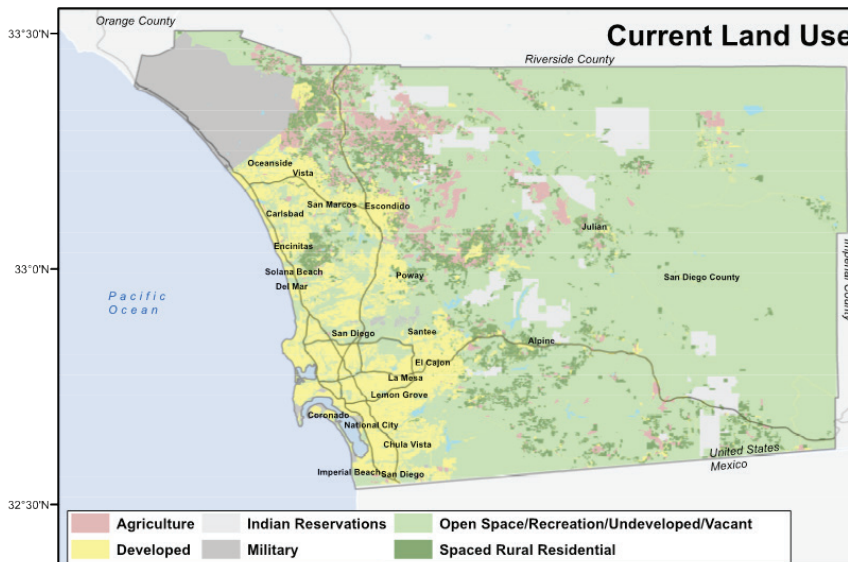
## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT



### SAN DIEGO LANDS OWNERSHIP, MANAGEMENT AND CONSERVATION

As population has increased, urban development in San Diego County has primarily remained in the western third of the County (Figure 22), in part due to the land conservation in the County over last 100+ years. San Diego County is considered a biodiversity hotspot including approximately ~200 at risk taxa of plants and animals (Rebman and Simpson, 2014; Tremor et al., 2017; California Department of Fish and Wildlife 2017). The lands in San Diego County include thirty different vegetation types, with the largest percentage being chaparral followed by Desert scrub and Coastal scrub (Table 3). San Diego has been able to maintain the high biodiversity as a result of multiple agencies working to protect lands since the early 1900s. Protected lands in San Diego began with the US Forest Service designation of the Cleveland National Forest (1908), followed by several California State Parks (Anza Borrego Desert State Park, 1932; Cuyamaca Rancho State Park 1933; Torrey Pines State Natural Reserve, 1956) and, more recently, city and County parks as well as land trusts and public agencies (1960-1970s). Currently, almost 60% of the lands in San Diego are public owned or in conservation status with the largest land owners being the US Forest Service, Bureau of Land Management, Department of Defense, and State Parks (Table 4). Integral to the land management in San Diego are the 18 federally recognized tribes. San Diego has 19 reservations, more than any other county in the US, making up almost 5% of the total area (Table 4).

FIGURE 22



The current land use in San Diego County using data available from SANDAG (top). Rural residential are single-family homes located in rural areas with lot sizes greater than 1 acre. Source: Laura Hampton.



# CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT



TABLE 3

VEGETATION CLASS	TOTAL LAND AREA (ACRES)	PERCENT LAND AREA	PROTECTED LAND AREA (ACRES)	PERCENT PROTECTED
Agriculture	139,474	5.11%	9,958	7.14%
Chaparral	877,146	32.17%	527,687	60.16%
Coastal scrub	267,407	9.81%	100,953	37.75%
Coniferous Forest	128,049	4.70%	90,410	70.61%
Desert scrub	467,126	17.13%	407,821	87.30%
Hardwood Forest	126,817	4.65%	38,337	30.23%
Herbaceous/Grassland	162,550	5.96%	43,802	26.95%
Riparian	70,079	2.57%	34,743	49.58%
Sparse/Disturbed	79,247	2.91%	51,298	64.73%
Water/Wetland	37,264	1.37%	15,165	40.70%
Unvegetated/Urban	371,773	13.63%	5,990	1.61%
<b>TOTAL</b>	<b>2,726,933</b>		<b>1,326,165</b>	<b>48.63%</b>

The total acres of land by vegetation class and the protected lands in the vegetation class. The values were calculated using the Countywide vegetation layer provided by SANDAG and were updated in 2017. Table provided by Megan Jennings



# CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT



**TABLE 4**

OWNER TYPE			LAND AREA (ACRES)	LAND AREA (%)
<b>PUBLICLY-OWNED LANDS OR LANDS IN CONSERVATION STATUS</b>				
<b>City</b>			77,192	2.83%
<b>County</b>			32,588	1.20%
<b>Federal</b>	Bureau of Land Management	185,961		6.82%
	Department of Defense	174,843		6.42%
	National Park Service	82		0.00%
	U.S. Fish and Wildlife Service	13,272		0.49%
	U.S. Forest Service	286,380		10.51%
	Other Federal lands	155		0.01%
			660,692	24.25%
<b>Tribal</b>			129,514	4.75%
<b>Home Owners Association</b>			3,840	0.14%
<b>Joint</b>			7,154	0.26%
<b>Non-Profit</b>			29,114	1.07%
<b>Private</b>			13,332	0.49%
<b>Special District</b>			39,664	1.46%
<b>State Lands</b>	California State Parks	581,339		21.33%
	California Department of Fish and Wildlife	48,288		1.77%
	Other State lands	9,783		0.36%
			639,410	23.46%
<b>Total</b>			1,632,499	59.91%
<b>PRIVATELY OWNED AND UNCONSERVED LANDS</b>				
<b>Total</b>			1,092,560	40.09%
<b>Total area of County</b>			<b>2,725,059</b>	<b>100%</b>

Land ownership by agency or sector in San Diego County. The is from the SANDAG Conserved Lands layer as well as the California Protected Areas Database (2017) and was calculated based on publically owned conserved lands, lands owned by other agencies and communities (tribal and Department of Defense) and then all remaining lands (Privately Owned and Unconserved Lands). Table is provided courtesy of Megan Jennings.





## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT



SANDAG, the regional planning authority in San Diego County, makes strategic plans, obtains and allocates resources, plans and builds public transportation and provides information pertinent to the region's quality of life. SANDAG began in 1966 when the local governments created the Comprehensive Planning Organization within the San Diego County government and then four years later was designated as the Metropolitan Planning Organization. An early milestone was adoption of the first comprehensive regional transportation plan in 1975. In 1987, there was a turning point in San Diego's development history when voters passed Proposition A, a local 0.5% sales tax that funded *TransNet*, a \$3.3 billion program for highways, transit, and local roads and bike paths.

An extension to *TransNet* was passed by voters in 2004 that included funds for the Environmental Mitigation Program for habitat-related environmental mitigation activities, including purchasing, conserving, and restoring native habitats as offsets to disturbances caused by transportation projects. Over the past decade, the \$850 million program has helped acquire and/or restore more than 8,600 acres around the region with a total value of about \$150 million, in part by leveraging \$27 million from conservation partners. In 2008, SANDAG set aside funds for the regional monitoring and management of natural habitats and sensitive species over a 10 year period, forming the San Diego's Monitoring and Management program (SDMMP). SDMMP completed the *Management Strategic Plan (MSP) for Conserved Lands in Western San Diego County*, providing a comprehensive approach for management of multiple plant and animal species. A component of the MSP addresses regional threat and stressor management, including fire, invasive species, urban edge, habitat fragmentation, human use of preserves, nitrogen deposition, and cumulative stressors.

*TransNet* has also guided development in San Diego through grant opportunities for Smart growth development. Smart growth development brings people closer to more destinations and supports low-carbon travel choices (public transit, carpooling, walking, and biking). Mixed use, compact developments also result in reduced per capita demand for electricity, heating, and cooling. There are also co-benefits of these land use and transportation strategies beyond GHG reductions, including preservation of agricultural land, open space, and habitats, improved water quality from reduced development-related pollutant sources, positive health effects, and the reduction of smog forming pollutants. SANDAG provides planning and financing tools to local jurisdictions to encourage smart growth development in areas on the Smart Growth Concept Map through the *TransNet* Smart Growth Incentive Program, the *TransNet* Active Transportation Grant Program, and transportation investments. The impacts of these efforts are illustrated by the update to local general plans over the last 14 years, which now concentrate growth to a greater degree than before with previous plans. These land use changes are collectively moving the region toward more compact development, more open space preservation, and reduced GHG emissions.



## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT

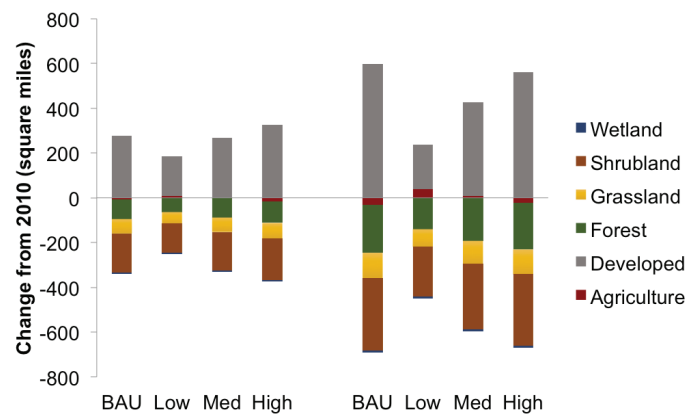


### FUTURE LAND USE PROJECTIONS

As the regional planning authority, SANDAG has the most up-to-date projections on LULC changes in the region based on local general plans. These plans show the projected changes in San Diego County developed lands out to 2050 (Figure 23). Many of the areas of anticipated new development is located next to already developed land, representing an addition of approximately 29 square miles of urbanized areas. Other aspects of land use, such as agriculture and working lands, are not modeled in the same way, making it difficult to incorporate how agricultural land uses will change in the future.

As part of the Fourth California Climate Change Assessment, a very different methodology was developed to model how land use may change in the future (Sleeter et al., 2017). The method used California Farmland Mapping and Monitoring program for baseline information on development and agriculture and then models were developed to examine the probability of land use transitions. This approach is more theoretical than the work SANDAG does and does not account for land use plans, but does provide estimates on land use changes under different population scenarios. These model projections suggest that the amount of developed land in San Diego County will increase by 180-280 square miles (4-6% of County area) in 2050 relative to 2010, which is approximately 5-10 times greater than the SANDAG estimates in 2050. By 2100, Sleeter et al. (2017) estimates an increase of 200-600 square miles (4-13% of County area) of developed lands (Figure 23). Agricultural land use classes show relatively small changes, while other types of non-developed lands are projected to decrease in the area. San Diego's long history of conservation will continue to play an integral role in mitigating GHG emissions, preserving biodiversity, and supporting the region's quality of life.

FIGURE 23



The land use change projected from a model that is informed by four population change scenarios from California Department of Finance: business-as-usual (BAU), low, medium, and high. The first set of data is the projected land use change in 2050 from 2010 and the second set of data is the projected changes in 2100 from 2010. Source: Sleeter et al. (2017).



## Natural Lands and Ecosystems

San Diego has a diversity of ecosystems in the region resulting in large biodiversity (Figure 24). In order to address the climate impacts and vulnerabilities to many of the ecosystems in San Diego, climatologists and ecologists under the umbrella of the Climate Science Alliance, South Coast developed a report that critically examines the potential impacts of climate change on the ecosystems in the San Diego region as part of the Fourth California Climate Assessment (Jennings et al., 2018). The report also includes adaptation approaches that will likely be effective in managing natural lands under climate change and knowledge gaps and recommendations on how best to approach these gaps. This section will be a brief summary of the report and only include a few of the references. If the reader is interested in the topic, we encourage them to a condensed version ([www.climatesciencealliance.org/sdc-ecosystems-assessment](http://www.climatesciencealliance.org/sdc-ecosystems-assessment)) or the full report, depending on depth of interest.

**FIGURE 24**

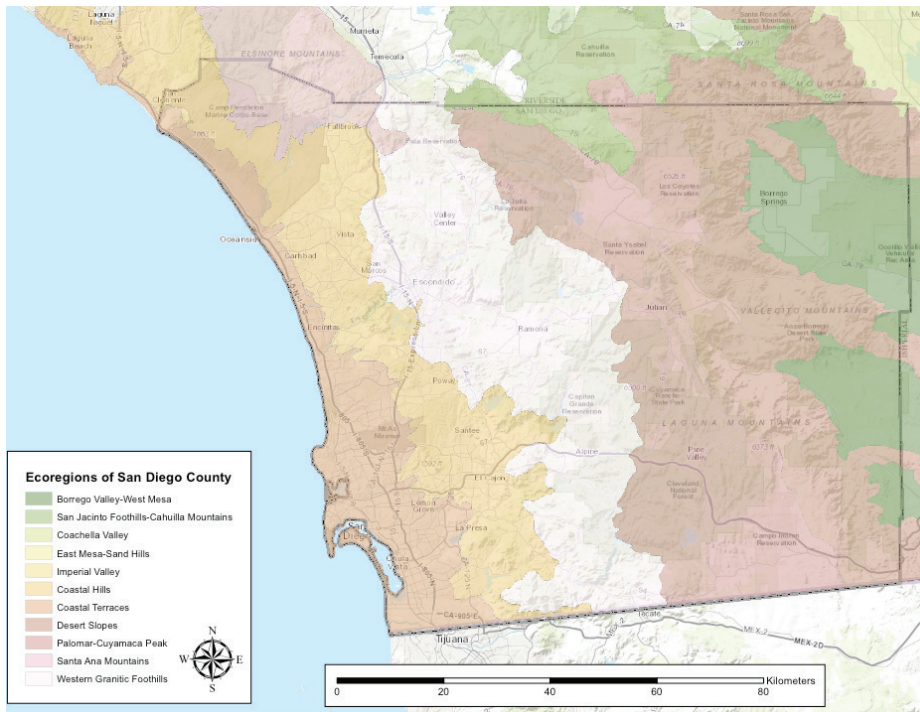


Figure 24. Map of the ecosystems in San Diego County. Source: M. Jennings.





## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT



### ECOSYSTEMS CLIMATE VULNERABILITIES

Primary climate variables that are important to San Diego ecosystems include temperature, precipitation, fire, and marine layer clouds and fog (MLC). Changes in temperature have the potential to impact species distribution; mean minimum temperature of the coldest month and the warmest month are important for shrubland community species (Riordan & Rundel, 2009). Temperature changes may also alter the timing of ecological phenomenon such as flowering and the onset of breeding. One of the many implications for aquatic species, such as the federally endangered arroyo toad (*Anaxyrus californicus*), is breeding may correspond to more extensive algae blooms or emergence of insect larvae, both of which can affect stream productivity (Hamilton et al., 2008; Poff et al., 2002). Temperature also exacerbates drought, which is projected to become more frequent and severe under an even more variable precipitation regime. Increased duration, frequency, and intensity of droughts have the potential to lead to structural changes in ecosystems as it may not impact all species equally. The 2012-2016 drought provided a glimpse of future droughts in that it was intense, long, and was coupled with unusually warm temperatures. Mortality of shrubs in the chaparral ecosystems was greater for the drought “tolerators” than the drought “avoiders”, species with deeper root systems (Venturas et al., 2016). Drought also makes plants more susceptible to pests. This was observed in Camp Pendleton when there was increased oak mortality that was thought to be caused by drought weakening and then secondary attack by pest (Lawson, Marschalek, et al., 2017; Lawson, Ordonez, et al., 2017).

Oak death not only impacts ecosystems, but has potential cultural impacts as well. California Indians venerate the oak tree because it is the very basis of their survival. For Tribal communities, oak trees provided an extraordinarily abundant and nutritious source of food in the form of acorns, allowing California Indian tribes to develop complex economies and political structures. Oak trees are also a symbol of life, growth, and the cycle of the seasons. San Diego's tribal and indigenous populations will also experience several other disproportionate impacts from climate change. More details can be found in a companion Fourth Assessment report which explores how tribal communities – both in San Diego and statewide – are threatened by and adapting to the threats posed by climate change (Tribal and Indigenous Communities Summary Report, 2018).



## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT



Fire and MLC are both extremely important to San Diego's biodiversity, but interactions between these climate drivers and ecosystems are complex. Fire return intervals are important for ecosystem evolution and the ability to regrow after a fire; however, much of San Diego burns too frequently (Safford & Van de Water, 2014). As discussed previously, although humans will remain the primary driver of fires in San Diego, climate will likely cause increase fire risk by extending the fall dry season further into the Santa Ana wind season, which is when the largest fires typically occur. The impacts of increased fire frequency can lead to vegetation type conversation, particularly from shrub-dominated systems to non-native grasses, which is exacerbated by drought conditions (Jennings et al., 2018). Similar to fire, MLC are critical to the biodiversity in San Diego and are just beginning to be understood. MLC are important for the water cycle balance and the moisture from fog supports a wide range of taxa. MLC support higher growth rate and overall population size (Baguskas et al., 2014, 2016). MLC can help offset future increases in temperatures and drying, thus reducing fire risk; however the projections of MLC are uncertain (Jennings et al., 2018).

### ADAPTIVE MANAGEMENT UNDER CLIMATE CHANGE

Some aspects of climate change may exacerbate the effects of land use changes in stressing habitats and species. Management approaches that allow flexibility are important, as are efforts that emphasize maintaining functional diversity at the community or ecosystem level. There are three primary categories of adaptation: resistance, accommodation, and transformation (Fisichelli et al., 2016). Resistance and accommodation focus on ameliorating compounding stressors that may impact habitats and populations. One example of this is habitat connectivity, which strengthens ecosystem resilience to stressors such as habitat fragmentation (Beier & Gregory, 2012). Transformation may focus on novel states that can be maintained in future climate. Many trade-offs regarding climate stressors will have to be considered (and periodically re-evaluated) going forward with the recognition that single-species management may hamper the ability to build resilience into vulnerable ecosystems (Boitani et al., 2007). Adaptation and scenario planning are the primary approaches in managing the natural systems under climate change and will require active monitoring program to inform the process.



## CASE STUDY | USFS CLIMATE CHANGE IMPACTS, MONITORING AND ADAPTATIONS

**T**he United States Forest Service (USFS) issued new regulations in 2012 that require National Forests to monitor for changes related to climate change and other stressors. USFS has documented two changes: shrublands have converted to non-native annual grasslands on a widespread scale across the Cleveland National Forest, and coast live oak mortality has been rising dramatically over the past several years. Because these effects result from multiple factors other than climate change, such as fire and invasive species, it is difficult to discern how much of the change is directly attributable to climate change.

For fire management, the Cleveland National Forest integrates research and monitoring, has extensive outreach, and works closely with partners. This includes the suppression of nearly 100 fires each year, vegetation management of over 2,500 acres each year, and regular prevention patrols. Outreach efforts are via media, events and focus on communication with neighboring landowners, and coordination with other agencies. In particular, partnerships with CalFire, municipal fire departments, fire safe councils, and the County of San Diego are crucial to successful fire management. With climate change, more resources will be needed for all aspects of fire management.

For natural resource management, the focus of efforts to adapt to and mitigate for climate change is ecological restoration to render ecosystems more resilient for the future. There are several projects listed below.

- Because the San Diego River Gorge burned in both 2003 and 2007, it is being restored through active revegetation of the coastal sage scrub plant community to benefit species such as the threatened California gnatcatcher. The site will be monitored for establishment and invasive weed retreatment as necessary over the next few years.
- Unauthorized vehicle routes that degrade habitats and cause soil erosion are being restored to natural condition and monitored for five years.
- Trees are being planted where they are dying, and their survival rates are monitored over several years. Aerial mapping of tree mortality occurs annually. Forest stands are being managed to improve forest health and reduce the risk of stand-replacing fires using mechanical thinning and prescribed fire, with pre-treatment conditions compared with post-treatment outcomes.
- Invasive species are being eliminated where possible, such as large-scale tamarisk removal along Cottonwood, La Posta, Pine Valley, and Santa Ysabel Creeks and the San Diego River. Sites are monitored for treatment effectiveness and retreated as necessary.
- Endangered species habitats and riparian areas are being protected and restored, with field surveys conducted to confirm that protections are functioning.
- San Diego Gas and Electric is currently fire-hardening its power lines across the Cleveland National Forest to reduce the likelihood of wildfire ignition.
- Due to the extensive replanting that is occurring in the region, seeds can become limited. CalFire has been working with Mexico partners on the possibility of using seeds from Mexico, as ecosystems cross national borders.





## Agriculture

San Diego is the 12<sup>th</sup> largest farm economy in the nation with an estimated total value production of \$1.7 billion on 251,000 acres in 2016 (Department of Agriculture Weights and Measures, 2016). Nursery and cut flower products are the largest crops economically at 71%, followed by avocados (9%), citrus (7%), and tomatoes (3%) (Department of Agriculture Weights and Measures, 2016). San Diego County has more small farms than any other county in the United States, with a median size around 4 acres.



Photo Credit: Geoffrey Plagemann

than avocados (Lobell et al., 2006). Research more broadly has shown that the extreme flooding, which is projected to become more frequent and more extreme in the future, will delay the harvesting of citrus and strawberries (Pathak et al., 2018).

Other future climate impacts of more frequent and intense drought combined with warmer temperatures will lower soil moisture and increase the evaporative demand in the region (Jennings et al., 2018). This will increase irrigation demand. Although the economic impacts due to increased water demand have not been quantified, during the period from 2005-2015, 25%, or approximately 1 million orchard trees, were removed from production due, in large part, to the rising costs of water. Carbon dioxide emissions and lost sequestration resulting from this tree removal is conservatively estimated to be over 300,000 MTCO<sub>2</sub>e over the 15 year period, not accounting for below-ground tree biomass, loss of soil carbon, or post-removal emissions (Batra, 2017). Drought and higher temperatures also increases the susceptibility of plants to pest infestation (Pathak et al., 2018), though there are not specific examples of this for crops that are most important in San Diego.

### CARBON FARMING: ADAPTATION AND MITIGATION

Agriculture is part of San Diego Climate Action Plan (CAP) to reduce GHG emission, and is estimated to contribute 5% of current baseline emissions (County of San Diego, 2017), accounting for livestock, agricultural machinery, and fertilizer use. Sequestration by permanent crops, which comprise almost 70% of cropland acreage (Department of Agriculture Weights and Measures, 2016) is, however, not included in baseline emissions estimates, so the estimate for agricultural emissions in San Diego is likely to be inaccurate. As part of the CAP, San Diego County plans to

### CURRENT AND FUTURE IMPACTS

There is surprisingly little research on the impacts of climate change on nursery and cut flowers, however, there is more information on food crops. An assessment of impacts of climate change on California agriculture showed that avocados are sensitive to climate change with an approximate 15-45% decrease in crop yields by 2050 (Lobell et al., 2006). Avocados are most sensitive to maximum daily temperature in August the year prior to harvest and May minimum temperatures and October precipitation during the year of harvest (Lobell et al., 2007). Oranges are also projected to see a decline with increased temperature, though less so



acquire 4,430 acres of agriculture easements between 2021-2030 that will extinguish future development potential, thereby reducing a portion of projected transportation emissions estimated in the CAP baseline. This is part of the Purchase of Agricultural Conservation Easements program that was established in San Diego in 2011. CAP strategies that aim to reduce agricultural emissions focus on conversion of agricultural machinery from fossil fuel burning to engines and motors that use renewable energy.

Recent attention on agricultural practices that build soil carbon has gained momentum in San Diego, as well as other parts of the state. These practices, known as “carbon farming,” include a suite of farming practices that reduce the GHG emissions that result from soil erosion, fertilizer use, and agricultural machinery use, and instead sequester carbon in soil and vegetation over decades and centuries. Long lived plants, such as the permanent crops (trees, bushes, vines) that comprise the majority of San Diego’s croplands, are among the most climate-beneficial species. Other important carbon farming practices include composting, riparian restoration and the use of perennial vegetation in windbreaks, filter strips, and hedgerows; cover cropping; reduced or zero-till methods; silvo-pasture (combining of trees and the grazing of domesticated animals in a mutually beneficial way); mulching; and compost application, along with several others.

New research suggests that the addition of composted organic material to range and croplands, and the resulting increase in carbon sequestration by soils and vegetation holds great promise for climate mitigation. A single one-time addition of ¼ inch of compost to a rangeland plot in Santa Ysabel in San Diego County (1,135 m elevation) showed a maximum greenhouse gas reduction of 5.90 Mg\*CO<sub>2</sub>e per hectare (1 megagramme (Mg) is equivalent to 1 metric tonne (MT), and is the standard unit for measuring soil carbon sequestration), decreasing to zero approximately 75 years after the addition (Silver et al., 2018). Additionally, 2- to 3-fold increases were seen in plant productivity in the first year after compost application (J. Borum, unpub. data, 2017).

Increased soil organic carbon also provides nutrients and serves to increase the water holding capacity of the soils, potentially reducing the irrigation necessary for the plants (Rawls et al., 2003) and alleviating drought stress. Increases in soil water holding capacity will provide important climate resilience benefits such as storm water reduction, water quality improvements, deep soil infiltration, and potential groundwater recharge in the areas of the County where groundwater is important. Carbon farming practices can also benefit habitat connectivity in riparian, rangeland, and other areas with natural or structurally complex stands of vegetation. Using California Department of Food and Agriculture’s modeling tools for carbon sequestration that result from different carbon farming practices, Batra (2017) estimates that if 25% of riparian areas in the unincorporated County were restored, and all of the County’s current green waste were composted and applied to crop and rangelands within the appropriate slope range, these two practices could achieve around 25% of the County’s needed emissions reductions.

There is currently a collaborative multi-stakeholder effort underway to scale up the adoption of carbon farming in San Diego County by developing incentives for farmers and ranchers to implement carbon farming practices (Batra, 2017). The current generation of farmers’ average age in San Diego County is 62; therefore, enabling the younger generation of farmers, many of whom are new to the profession, to successfully learn and establish carbon farming practices presents an opportunity, over the next two decades, to scale up climate-smart agriculture and transform farming into a formidable solution to our growing climate impacts. By recognizing the mitigation and resilience-building ecosystem services that carbon farming can provide to the entire region, progress can be made towards the climate action targets while also building regional resilience and alleviating increasing economic burdens on farmers.



## Climate Change Impacts on the Infrastructure and Services

### Water

#### CURRENT WATER SUPPLY AND INFRASTRUCTURE

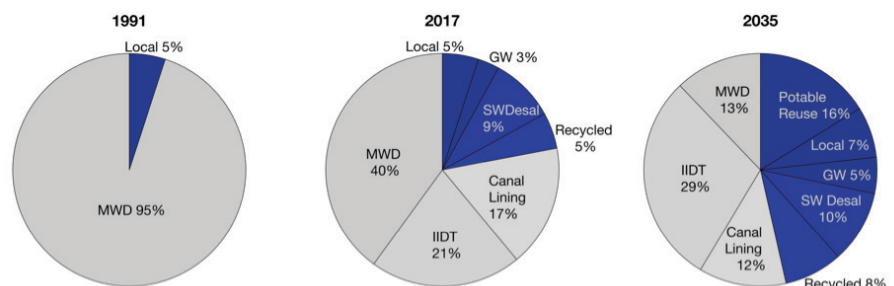
##### Water Supply

In San Diego, local water supplies are limited due to the generally arid climate, seasonal availability of surface supply, the relatively shallow aquifers, and lack of permeable soils (San Diego County Water Authority, 2016).

The San Diego County Water Authority (SDCWA) is the wholesale supplier and provides the vast majority of water to the region's users. The largest percentage of water in SDCWA service area is from Northern California and the Colorado River via Metropolitan Water District. This percentage has been decreasing since a statewide drought in 1987-1992 led to severe shortages in San Diego's imported water sources, causing SDCWA and its member agencies to initiate a progressive strategy to diversify its supplies, which has become an ongoing SDCWA program. As part of this strategy, in 1998 SDCWA signed an initial Water Conservation and Transfer Agreement with the Imperial Irrigation District for conserved agricultural water. With the 2003 Quantification Settlement Agreement (QSA), transfer water started to flow to the San Diego region - an initial delivery of 10,000 AF in 2003, increasing to 100,000 acre-feet of transferred water to San Diego in 2017 (this amount is scheduled to ramp up to 200,000 acre-feet per year by 2021). In 2006, SDCWA also began receiving conserved water from the All American and Coachella canal linings, the beginning of an arrangement that was instated for 110 years. Additionally, in late 2015, SDCWA began receiving water from the Claude "Bud" Lewis Carlsbad Desalination Plant, the largest seawater desalination facility in North America, through a long-term public/private partnership with Poseidon Water. Together, these three supply sources comprised 47%, of the 477,00 acre-feet per year of water supplies in of SDCWA's service territory in 2017 (Figure 25). The total supply is currently divided amongst residential (64%), commercial and industry (17%), agriculture (10%), and public (9%) use (San Diego County Water Authority, 2018).

Local supplies from SDCWA member agencies have historically constituted a small (under 20%) but growing portion of the region's water supply, and are largely comprised of surface water, groundwater, and recycled water (San Diego County Water Authority, 2016). Seven major streams and other local sources supply 24 reservoirs that have a combined capacity of about 744,000 acre feet per year, much of which is used for emergency storage (San Diego County Water Authority, 2016). Although regional groundwater is generally considered limited, groundwater constitutes a greater portion of supplies in localized areas such as the

**FIGURE 25**



Percentage of total regional water supplies in 1991, 2017 and 2035 (via projections by SDCWA). Blue are local supplies while grey are imported supplies. Metropolitan Water District (MWD); Imperial Irrigation District Transfer (IIDT); Seawater Desalination (SW Desal); groundwater (GW); local for 2017 and 2035 refers to local surface water. Source: Sleeter et al. (2017).





community of Lakeside, the Marine Corps Base at Camp Pendleton, Pauma Valley, the San Luis Rey River Area, and National City (San Diego Regional Integrated Water Plan, 2013). In the late 1950s, the first recycled water system in the County was built by the Padre Dam Metropolitan Water District and today still delivers recycled water to Santee Lakes Recreation Preserve, as well as other customers. Since the 1990s, a significant expansion of recycled water occurred in the region through collaboration and agreements between water suppliers and wastewater agencies. Today this collaborative effort has resulted in the delivery of approximately 30,000 acre feet per year of non-potable recycled water in the San Diego Region with the possibility of as much as 100,000 acre feet per year of potable water by 2035.

Tribal lands, which account for ~130,000 acres in San Diego County, often rely on their own groundwater sources or purchase their water from adjacent districts not associated with SDCWA (San Diego Regional Integrated Plan, 2013). Distinct tribes have vastly different sources of water and capacity to manage it. A general concern of the tribes regarding climate change is the availability of groundwater supplies and the impact of future projects on water quality and runoff (San Diego Integrated Regional Water Management Plan, 2013.)

### Infrastructure and Water Quality

Regional storm water infrastructure consists of conveyance pipes using gravity to direct water westward to the Pacific Ocean. Regional storm water systems discharge untreated water from large precipitation events that contain oil, pesticides, metals, pathogens, and bacteria from numerous sources into the ocean negatively affecting coastal water quality (Semenza et al., 2012). Between 2006-2017, Imperial Beach experienced 437 beach closures and the San Diego Bay experienced 141 beach closures (Smith, 2017). Further, a recent study showed that surfers are more likely to suffer from acute illness after wet weather (Arnold et al., 2017) likely as a result of toxins being flushed to the ocean.

The San Diego Regional Municipal Storm Water Permit regulates the conditions under which storm water and non-storm water discharges into and from municipal separate storm water systems (MS4s) are prohibited or limited. The 18 cities, County of San Diego government, County of San Diego Regional Airport Authority, and San Diego Unified Port District each owns or operates an MS4, through which it discharges storm water and non-storm. These agencies identify the highest priority water quality conditions within each watershed and specific goals, strategies, and schedules to address those priorities, including numeric goals and action levels, and requirements for water quality monitoring and assessment. They also consider the hydrologic control measures so that post-project runoff flow rates and durations do not exceed pre-development flow rates and durations that could result in an increased potential for erosion or significant impacts to beneficial uses (SANDAG, 2015).

To help mitigate some of these impacts and improve water quality, the region has begun to opportunistically restore and implement natural systems that provide flood control, water quality functions, and other community co-benefits — these are referred to as green infrastructure projects. Green streets incorporate storm water capture and filtration elements in addition to other community co-benefits and, are a project type of regional interest that are discussed more in the Transportation section of this report.

Similar to many areas of California, wastewater and storm water systems in the region are not combined. Wastewater in San Diego discharges into the Pacific Ocean at two major outfalls: the Point Loma outfall and the South Bay



outfall. The Point Loma Treatment Facility is the largest facility in the country exempt from secondary treatment standards due to longstanding agreements to reduce inputs upstream. The South Bay outfall discharges regional wastewater as well as water from the International Wastewater Treatment Plant. The region has experienced recent major sewage spills associated with rain events, including a January 2016 Tecolote Canyon Spill in San Diego that released 109,000 gallons of sewage into Tecolote Creek and Mission Bay, and a Los Coches Creek spill in March 2017 in El Cajon that released 900,000 gallons of sewage into Los Coches Creek and the San Diego River (San Diego Union Tribune, 2016; Winkley, 2017).

## **VULNERABILITIES TO CLIMATE CHANGE**

### **Supply and Demand Vulnerabilities**

Climate change will likely reduce water supply from current resources, both imported and local, while increasing demand. Reductions of 10% or more by mid-21<sup>st</sup> century (Wang et al. 2018) are expected from the State Water Project, which exports water from the Sierra Nevada and other northern California sources via the Sacramento-San Joaquin Delta. These reductions would result from changes in operations caused by higher rain/snow elevations, earlier snowmelt and flashier winter and early spring runoff. The Colorado Basin, being even more arid than Sierra Nevada catchments, has a smaller portion of precipitation that results in runoff, so increased evaporation demand leaves proportionately less runoff. Thus, climate warming is projected to take a high toll on Colorado River streamflow, with estimated reductions in flow from the Upper Colorado Basin at Lees Ferry ranging from 10-45% by mid-21<sup>st</sup> century (Vano et al., 2014; Udall and Overpeck, 2017).

San Diego County's native surface water, which constituted 5% of overall water supply in fiscal year 2017, will be impacted by climate change because precipitation variability in particular will affect seasonal availability (San Diego County Water Authority, 2016). The impacts to groundwater from a changing precipitation regime, higher temperature, and rising sea level are poorly understood. However, the degree to which climate change impacts the region's water supply is dependent on the continued use of regional climate-resilient supplies such as Quantification Settlement Agreements (means to implement water transfer between agencies in CA that use Colorado water), desalination, and potable reuse that reduces dependence on climate vulnerable imported supplies. SDCWA has plans to increase these more resilient supplies in the future (Figure 25). By 2040, forecasted total water demand is expected to increase by approximately 30 % compared with demand in 2015 (San Diego County Water Authority, 2016, figure 2-2). The increase in demand is based on historical normal hydrology and is driven by a combination of population and economic growth and savings from conservation.

Flood control facilities in San Diego have faced challenges in the past due to overflowing drainage channels, low lying areas with poor drainage, and debris build-up in basins (San Diego Integrated Regional Water Plan, 2013). More intense rain events occurring over short periods of time will exacerbate flood risks, putting watersheds in foothill areas (where water collects) and unincorporated areas (where there is less robust storm water infrastructure) especially at risk.



Wastewater infrastructure is vulnerable to future climate extremes. This has been illustrated recently by aforementioned large sewage spills in Tecolote Canyon and Los Coches Creek after large storms. Projected increase in the most extreme precipitation events may increase the severity or frequency of these types of spills. Additionally, the region has miles of sewage pipelines and treatment facilities located within canyons that will face increased risk from flooding or erosion (Haas personal com, 2017).

The infrastructure itself is also vulnerable to coastal flooding and can be particularly impactful when are also associated with a large storm. Storm water pipes can become submerged under high sea level events, as was shown during the 2011 king-tide event (San Diego Union Tribune, 2011), potentially causing flooding issue upstream. Based on the USGS Coastal Storm Model System (CoSMoS) maps, some pump stations are relatively more vulnerable, with one pump station in Otay Mesa being affected by a 20-year flood with 1.6 ft (50 cm) of sea level rise.

Integrated into the San Diego regional water infrastructure is the military bases in the region. Vulnerabilities of Naval Base Coronado (NBC) are similar to those of the entire region. Specifically, NBC identified six top risks that were directly related to water and both lack of water supply and flooding threats to infrastructure are primary areas of concern (Garfin et al., 2017).

### **Water Quality Vulnerabilities**

The impact of climate change on water quality in the region is complex. In Southern California, there is a positive association between measured precipitation and observed coastal water contamination (Semenza et al., 2012). An overall decreased precipitation frequency could have potentially beneficial implications for public health in that less rain would mean less frequent flushes of microbiological contamination to coastal waters. In contrast, the first precipitation event of the rainy season, often referred to as the “first flush,” may result in a larger and therefore more dangerous flush of contaminants accumulated after long dry spells. A potential decrease in gastrointestinal illnesses due to less frequent rain events could also be offset by an increase in exposures of a larger population or greater recreation at the beaches, lagoons, and waterways (Semenza et al., 2012).

Rising temperatures in local lagoons and waterways and the near shore ocean could increase disease risks from exposure to harmful algal blooms (red tides), microbes (*Vibrio* spp., *Listeria monocytogenes*, *Clostridium botulinum*, *Aeromonas hydrophila*), and other waterborne agents (S. K. Moore et al., 2008; Tamplin, 2001). Impacts of harmful algal blooms can have a human health impact due to increased levels of exposure to water-borne diseases and contaminants through fish and shellfish harvested for personal consumption (Feldhusen, 2000).

### **ADAPTATION APPROACHES**

San Diego is pursuing options to adapt to a climate change future that includes strains on water resources and challenging flooding scenarios.

#### **Water Efficiency and Conservation Adaptation**

San Diego has a track record of successfully conserving water and has invested in water shortage and drought response plans. Regional water use efficiency has consistently met or exceeded the state's goals and continues to offer a robust selection water conservation programs to the region. Between fiscal years 1990 and 2017, total potable per





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capita water use within the SDCWA service area dropped by 47%. With respect to water shortage planning, in 2017, SDCWA's board approved the Water Shortage Contingency Plan to ensure that SDCWA continues to proactively plan for future water supply shortages. The plan incorporates elements of the state's long-term framework in Making Water Conservation a California Way of Life, Implementing Executive Order B-37-16. The plan also incorporates the evaluation criteria and the process that will be used to conduct an annual water supply reliability analysis, as well as elements of SDCWA's 2015 Urban Water Management Plan's shortage contingency analysis. The plan will be reviewed and potentially updated at least every five years in coordination with preparation of SDCWA's urban water management plan.

### **Collaborative Management and Planning**

SDCWA collaborates with its 24 member agencies and regional partners on a variety of planning related items. This coordination includes supporting its member agencies in developing resilient local supply projects as part of the region's diversification strategy, as well as assisting with the implementation of cost-effective programs to promote water use efficiency. Additionally, water demand projections contained in SDCWA's Urban Water Management Plan are based on demographic and economic forecasts generated by SANDAG (using local jurisdictions' general plans).

The San Diego Integrated Regional Water Management Program (IRWM) is an initiative aimed at developing long-term water supply reliability, improving water quality, and protecting natural resources. The San Diego IRWM Program is implemented and administered by the Regional Water Management Group (RWMG), which is comprised of three entities: City of San Diego, County of San Diego, and the SDCWA. The establishment of the RWMG has allowed the region to secure substantial funding from Proposition 50, Proposition 84, and Proposition 1. To date, 67 local water projects have received funding through the IRWM Program totaling \$96.4 million. Climate change is incorporated into the program's 2013 IRWM plan, and a climate change framework is being created for its 2019 plan update. The San Diego IRWM Program is advised by stakeholders and regularly convenes a Regional Advisory Committee (RAC), which was established to provide recommendations on key issues related to IRWM planning and funding applications.

The San Diego Regional Water Quality Control Board is also working to incorporate climate change considerations into planning. Via Resolution R9-2018-0051 (tentative as of March 2018), the San Diego Water Board resolved to implement a Climate Change Readiness Work Plan that outlines actions to achieve these goals, which include increasing local water supply via water recycling, identifying and remedying vulnerable wastewater infrastructure, and protecting and restoring natural flow regimes, among other commitments.

The City of San Diego is currently (2014-2019) collaborating with the U.S. Bureau of Reclamation on the San Diego Basin Study, using up-to-date modeling tools to analyze climate change impacts and associated uncertainties on local and imported fresh water supplies in the San Diego Basin. An important goal of the Study is to provide a meaningful analysis of various water management strategies that may address the impacts of climate change and increasing demands on water supply. The City of San Diego is also procuring an agreement for the preparation of 2020 Long-Range Water Resources Plan and the 2020 Urban Water Management Plan, both of which will update demand forecasting projects that are based on modeled scenarios that incorporate a variety of climate change impacts.



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### Holistic Water Management

The San Diego region is proactively exploring opportunities to supply water more efficiently, capture storm water using climate-smart tactics, and streamline water management goals and resources. Low impact development and green infrastructure projects are being implemented opportunistically throughout the region. Water capture, filtration, and reuse can be a component of green street projects. An example is National City's Avenue Green Street and Pedestrian Pathway Improvement project, which paired a green street with a 30,000-gallon cistern to capture and direct water to the Sweetwater Reservoir (Walsh, 2017). Other examples include the City of Chula Vista's Water Stewardship Plan which links GHG mitigation efforts with adaptation efforts for managing storm water and the San Diego County Regional Airport Authority's Water Stewardship Plan, which links aggressive goals for storm water management and water supply (see callout box.)

### CASE STUDY | COMPREHENSIVE PLANNING FOR HOLISTIC WATER MANAGEMENT AT THE SAN DIEGO INTERNATIONAL AIRPORT

**T**he San Diego International Airport (SAN) covers 661 acres of land and receives more than 22 million passengers annually. Because SAN is located alongside San Diego Bay, the San Diego County Regional Airport Authority (Authority) is proactively addressing water conservation, water quality, and flood risk considerations while accommodating passenger growth, new airport developments, and a changing climate. In 2016, the Authority developed a Water Stewardship Plan to guide this holistic water strategy. One major component of the plan includes the installation of smart air conditioning condensate water capture systems on airside passenger boarding bridges. Beginning in 2017, condensate that would otherwise drip from AC units onto the tarmac began to be captured and stored in barrels. Sensors installed on both pre-conditioned air units and the barrels provide real-time data on water volume and allow maintenance teams to match available AC condensate water with usage opportunities including sidewalk cleaning, dust control, and the cleaning of vehicles. Other completed initiatives include the installation of 6 acres of permeable pavement, 2.75 acres of bioretention swales, and 14 modular wetland treatment systems. A new parking plaza under construction will feature a storm water capture and treatment system capable of storing 100,000 gallons and capturing two million gallons of storm water annually. This water will be reused at the Central Utility Plant to offset potable drinking water that is used to regulate air temperature in terminals. A current expansion of Terminal 2 will also include low-flow water fixtures, drought tolerant landscaping, and a 15th modular wetland system in a new Federal Inspection Station.



## Energy

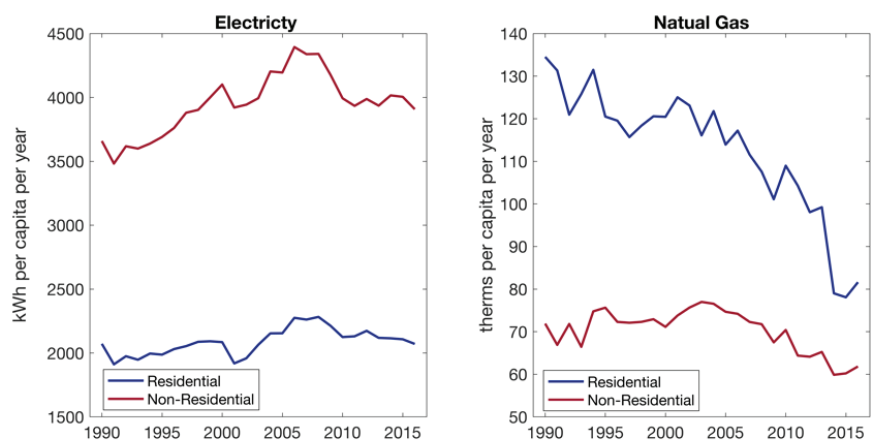
### CURRENT ENERGY CONSUMPTION AND SUPPLY

The energy sector includes fuels, energy carriers, and infrastructure which includes lighting, heating and cooling, water purification, industrial heat, electricity generation and transportation. In San Diego, electricity and natural gas are provided by San Diego Gas and Electric (SDG&E), part of Sempra Energy. The energy landscape has changed dramatically in the last decade, with a stark increase of renewables into the electricity portfolio, a trend that will continue to evolve and be influenced by the electrification of the energy sector (Mahone et al., 2018).

Historically, annual energy use per capita has remained relatively constant since 1990, with peaks in 2006-2009 (Figure 26). On average, non-residential energy use is a little less than double that of residential energy use in the County. August is the month with highest electricity demand, followed by July and September (Figure 27); these months are the warmest in San Diego. Air conditioner use often causes an increased electricity load on the system in San Diego. Although there are a large number of air conditioners in the eastern part of the County (K. Guirguis et al., 2018), the highest electricity demand days are driven when there are high temperatures near the coast where the majority of the population lives and businesses are located. Natural gas consumption is greater in residential buildings than in non-residential buildings and has experienced a slow decline since 1990 (Figure 26). In 2013 the residential gas use dropped by approximately 20 therms per person and has remained lower since this drop.

San Diego has seen significant changes in the electricity portfolio, with a noticeable increase in renewables. As part of SDG&E's sustainability efforts, which are aligned with California's renewable legislation (Senate Bill 1078), the agency's renewable portfolio has increased from 11.9% in 2010 to 43% in 2017 (SDG&E). Renewables include solar (~60% of renewable portfolio), wind (~20%), and biomass/waste (17%) (California Energy Commission, 2017). The addition of renewables is changing energy demand trends, which has been highlighted by California Independent System Operator's (CAISO) publication of the "duck curve" (CA Independent System Operator, 2016). The duck curve illustrates that energy demand drops during the day when solar energy is generated, and then rapidly increases once the sun sets; this has the potential to lead to over-generation of electricity during mid-day hours (CA Independent System Operator 2016).

**FIGURE 26**



The annual per capita electricity and natural gas use in San Diego County broken down as residential and non-residential. Source: energy data from California Energy Commission ([ecdms.energy.ca.gov/electricbycounty.aspx](http://ecdms.energy.ca.gov/electricbycounty.aspx); [ecdms.energy.ca.gov/gasbycounty.aspx](http://ecdms.energy.ca.gov/gasbycounty.aspx)) and population data from the U.S. Census Bureau.



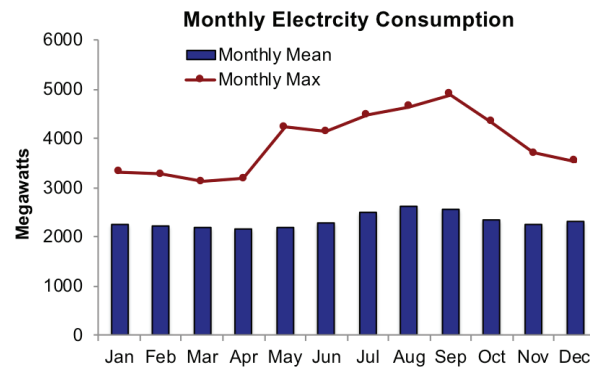


## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT

The addition of local roof-top solar generation has also changed peak electricity demand. Previously, some of the highest electrical demand days were associated with early season Santa Ana wind days when high temperatures were experienced along the coast. Since the significant addition of rooftop solar, the peak demand during these very hot days can be offset by high solar production due to the clear skies that typically occur under Santa Ana conditions. More recently, the largest peak demand days are associated with hot, humid days with significant cloud cover. This is because there is limited solar production due to cloud cover, but humidity and high temperatures lead to increased use of air conditioners throughout the region. A recent example of this circumstance occurred during San Diego's September 2014 heat wave. In September 2014, SDG&E had the highest energy use with a maximum of 4900 megawatts per month (Figure 27). This was largely driven by a multiday heat wave that showed higher dew points (an indicator of the moisture in the air) than average and more clouds than average, which reduce the electricity from roof-top solar in the area. The base electricity load (or nighttime load, when most appliances are turned off) was 670 MW (~33%) above the monthly average during the peak of the event. Recent efforts have been made to improve solar forecasting to help manage the system and prepare for days like these. Advancements include using a camera to capture clouds for nowcasts (forecasts in the 10-30 mins range) (Chu et al., 2017) and cloud data assimilation into regional numerical weather models to improve forecasts for 6-hour to multiple day lead times (Sahu et al., 2018).

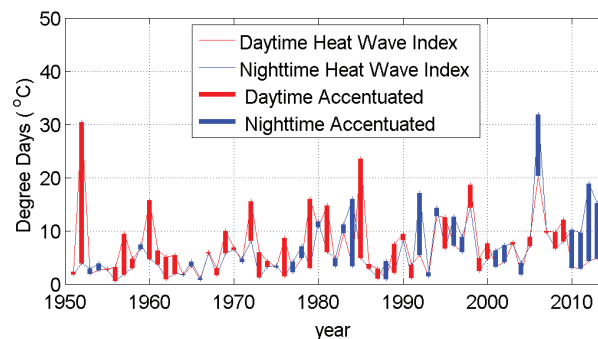
The September 2014 heat wave was nighttime accentuated heat wave, meaning that the nighttime temperature did not cool off much relative to daytime temperature indicating higher humidity. Nighttime accentuated heat waves have increased in San Diego since 1980 (Figure 28). The warmer nighttime

FIGURE 27



Historical monthly mean and max electricity use in SDG&E service area. Data provided by SDG&E.

FIGURE 28



The graph shows heat wave activity in San Diego County since 1950. The red line is based on maximum temperatures and the blue line is based on minimum temperatures. Degree days are the sum of degrees that exceed the 95<sup>th</sup> percentile of daily temperatures during June, July and August. The bold parts of the graph indicate when the heat wave activity is accentuated in minimum or nighttime temperatures (blue) or during the day (red), predominantly humid or dry days respectively. Source: K. Guirguis, adapted from Gershunov et al. (2009).



temperatures are significant because when temperatures do not cool off at night, people are more likely to run air conditioners all night increasing the electricity during a time when solar production is limited.

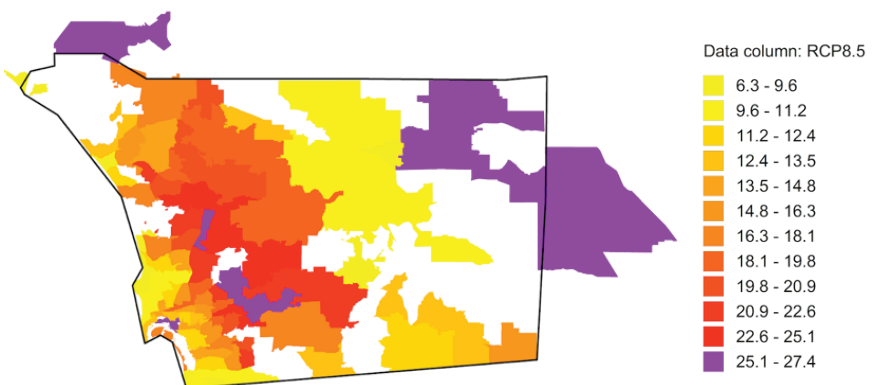
### FUTURE ENERGY USE AS RELATED TO CLIMATE

California's recent laws require that California reduce GHG emissions 40% by 2030 and 80% by 2050, relative to 1990 levels. Recent reports show that for California to achieve this goal, the energy system must be electrified and clean renewables must contribute more than 90% of electricity generation by 2050 (Mahone et al., 2018). Because of the electrification of the energy sector, electricity demand will likely increase in the future.

In addition, higher temperatures will likely increase electricity demand, in large part due to increased air conditioning use. Recent work by Auffhammer (2018) examines electrical billing data narrowed to the zip code level to determine how energy use responds to temperature. He showed that in warmer regions, electricity consumption increases more rapidly in response to higher temperatures than it does in cooler regions once temperatures go above site-specific thresholds. Based on temperature projections under RCP 8.5, the San Diego region will see an increase in energy use of 6-27% in 2080-2099, with non-coastal communities seeing the largest increases (Figure 29). These increases are attributed to both the increased frequency of air conditioner use and the increased installation of air conditioners. A Los Angeles-based study showed that peak energy demand will increase 10-80% by 2040 and is impacted by population growth and the type of development (multifamily or single family), with multifamily homes reducing demand by up to 50% (Burillo et al., 2018). Although the report does not directly examine the population and development dynamics for San Diego County, the similarities in climate and future temperature projections provide a method to consider how peak energy demand may change in San Diego. Further, the report shows that transmission lines decrease in their efficiency by 0.27% to 2.1% amps per 1°C, depending on other weather variables, further adding to the complicating factors of temperature increases on the electricity system (Burillo et al., 2018).

The above studies only consider the impacts of temperature on electricity demands, but not how other weather variables, such as cloud cover (solar production potential) and humidity, impact the electricity demand from the grid. Based on LOCA projections over the San Diego, surface solar radiation will potentially decrease slightly (-2-0%) during summer and increase slightly (0-2%) in the fall by the end of century (2070-2100) (Pierce et al., 2018). The 90thile heat index, which is affected by both relative humidity

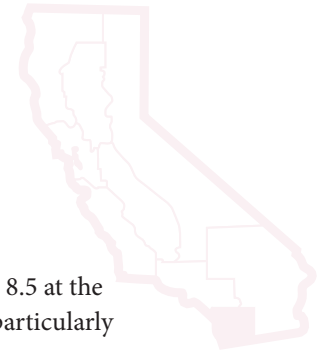
**FIGURE 29**



The projected percent increase in average household electricity consumption in 2080-2099 relatively of 2000-2015 under RCP 8.5. The percentages include the impact of temperature only and are averaged over 18 GCMs (Global Climate Models). Areas with insufficient data to generate future projections are in white. Source: M. Auffhammer



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and temperature, is projected to increase by 5-7°F (3-4°C) under RCP 4.5 and 9-12°F (5-7°C) under RCP 8.5 at the end of the century (Pierce et al., 2018). How these changes will impact the region electricity is uncertain, particularly given the evolution of the grid and electricity portfolio in San Diego.

### ENERGY VULNERABILITIES

Electricity is critical for emergency management during extreme weather scenarios as well as day-to-day life; thus, understanding vulnerabilities to climate change and adapting to these vulnerabilities is crucial for quality of life in the region. In collaboration with SDG&E, an assessment of SDG&E's electricity infrastructure vulnerability to sea level rise was completed as part of the Fourth Climate Change Assessment (Bruzgul et al., 2018). The most vulnerable areas are in San Diego Bay, where a modest sea level rise scenario (1.6 ft; 0.5 meters) and a 100-year storm event could render four substations out of service for up to two weeks. Electricity distribution will also be impacted by sea level rise due to more disruptions from more frequent flooding and corrosion of lines. A similar report was completed for the natural gas system which showed that most natural gas infrastructure is not likely to experience many impacts from future climate hazards, but will experience increased maintenance and repair costs (Bruzgul et al., 2018). The most vulnerable natural gas infrastructure is located near water such as bays, floodplains, and water crossings (Bruzgul et al., 2018).

In addition to sea level rise, the other major climate-related vulnerability of the energy sector relates to wildfire risk. In San Diego County, downed powerlines are the second leading cause of fire damage based on area burned (Syphard & Keeley, 2015b). SDG&E has a detailed fire prevention plan (more information below) which incorporates the increased length of the fire season in the future (San Diego Gas and Electric, 2017).

### CONSERVATION AND ADAPTATION

SDG&E's has built what is arguably the nation's largest utility-owned weather network. The 170 stations transmit temperature, humidity, and wind speed data every 10 minutes, providing unprecedented situational awareness of potential weather threats on the electric system. This weather system informs day-to-day operational decision-making at all levels of the company and is integral to the safe and reliable operation of the electric system. Operational products include solar forecasts that are directly integrated into the Network Management System, the Santa Ana Wildfire Threat Index (SWATI), the Fire Potential Index (FPI), outage prediction modeling, load forecast modeling, and the Wildfire Risk Reduction Model. More information on this can be found in the Emergency Management section in a text box. Additionally, the network provides an immense amount of regional data to understand how climate is changing in a non-stationary regime.

A microgrid is an energy system that is capable of operating in parallel or independently from the main power grid, which can help communities keep power during extreme events. Borrego Springs was one of the first communities to have a microgrid. With an \$8 million energy grant from the U.S. Department of Energy, SDG&E built a microgrid for Borrego Springs. The benefit of the microgrid was illustrated during severe thunder storms in 2013 that took out the main transmission line in the community. The microgrid was isolated from the main grid and was able to supply electricity to essential locations, including a gas station (so people could fuel up and leave for cooler climates), a library serving as a cool zone for people experiencing heat stress, and an elderly community. Microgrids are being explored in other locations as a way to minimize electrical outages during extreme weather conditions.





## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT



Another example of a planned microgrid is the Carlsbad Emergency Services Advanced Microgrid (CESAM). SANDAG's Energy Roadmap Program, which is funded through San Diego Gas and Electric's Local Government Partnership, provides no-cost energy engineering services to member jurisdictions to assist in saving energy in government operations and in the community. Through that program, Carlsbad studied the feasibility of a microgrid at its Safety and Service Center complex. The complex contains the city's Emergency Operations Center, police and fire headquarters, a fire station, fleet operations center, and a safety training center that also serves as a regional command center and overflow field hospital during regional emergencies. A microgrid at this location would allow all facilities to operate fully during a power outage or grid interruption and would provide critical community service benefits. Because of these benefits, the Carlsbad City Council authorized the complex to be an advanced microgrid demonstration site under the California Energy Commission's (CEC) Electric Program Investment Charge (EPIC) program grant funding opportunity. With SANDAG's Energy Roadmap Program and the grant funding opportunity, the city explored the feasibility of climate change resiliency in its emergency services.

Smart Cities San Diego, managed by Cleantech San Diego, is an alliance between public, private, and academic organizations working together to deploy IoT technologies (Internet of Things, a system of interrelated computers, machines, and people) to advance urban connectivity, reduce greenhouse gas emissions, increase water and energy efficiency, and drive economic growth in the San Diego region. Through the Smart Cities San Diego collaborative, ([cleantechsandiego.org/smart-city-san-diego/](http://cleantechsandiego.org/smart-city-san-diego/)), regional agencies, including the Port of San Diego, the City of Chula Vista, and the City of San Diego are deploying technology for the benefit of the economy and the environment. Projects include solar powered electric vehicle charging stations at the San Diego Zoo and the deployment of the world's largest city-based IoT platform using smart streetlights.



## CASE STUDY | WATER ENERGY NEXUS

**T**he City of San Diego's Climate Action Plan (CAP) covers community-wide emissions, and aims to reduce emissions from sources within the ownership or control of the various City departments, as well as those within the ownership and control of businesses and the public. The Public Utilities Department (PUD) plays an important role in helping the City achieve the City's overarching goal of sustainability in two key areas: water and energy. PUD's water conservation efforts include the development of alternative water supplies, changes in water and wastewater treatment, and use of digester biogas. PUD also seeks to reduce GHG emissions and limit consumption of vehicle fuel, space heat, and electricity via the purchasing of materials, hiring of contractors, designing of infrastructure, and greening of facilities.

City/PUD is also developing a 500 MW bulk energy storage facility at its San Vicente Reservoir in collaboration with the San Diego County Water Authority and a private development partner. As envisioned, the San Vicente Energy Storage Facility could store 4,000 megawatt-hours of energy (500 megawatts of capacity for eight hours) via a closed-loop pumped storage hydroelectric system. This project would have a small new footprint, but it would be able to store more megawatt-hours than all the batteries currently operating in the state combined. Pumped storage can play a critical role in integrating renewables into the grid because it is extremely efficient (about 80 percent of the energy used to pump water is regenerated) and it operates on a large scale with long duration. Batteries, improved grid control technologies, and better markets all have a role to play as well, but pumped storage is unique in its ability to operate at full power for many hours. A well-designed pumped storage project also provides other critical grid benefits like firm capacity, frequency regulation, up and down ramping, fast-start, inertia, and voltage support. Traditionally, those services that are vital to keeping the grid reliable came from the spinning turbines in large fossil and nuclear plants. As those facilities close, pumped storage can help fill the gap and make a clean energy revolution feasible.



## Transportation

Transportation infrastructure is an essential component of the overall fabric of the San Diego region. Changes to transportation primarily affect climate change through mitigation, or the reduction of GHG emissions. This has implications because the concentration of GHG drives future climate change (IPCC, 2014). At the same time, one important aspect of climate change impacts is its effect on the life span of transportation infrastructure (Chinowsky et al., 2017; Sias-Daniel et al., 2014). “Green streets,” an alternative to traditional street design which incorporates more natural elements, are an example of transportation infrastructure that can serve to mitigate climate change by facilitating the use of bicycles and public transit, as also serve as a climate change adaptation by preparing for future precipitation changes.

### CURRENT AND FUTURE SAN DIEGO TRANSPORTATION

Every four years, SANDAG develops a detailed transportation assessment and prepares a long-range regional transportation plan (RTP) for the San Diego region. Much of the information presented here is a very brief summary of the information from that plan, which is contained in San Diego Forward: The Regional Plan (San Diego Association of Governments, 2015).

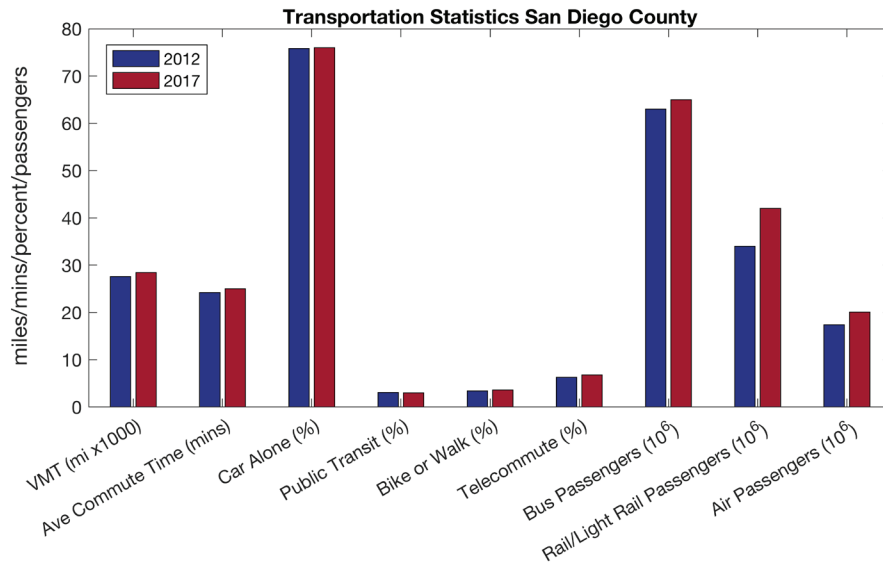
The regional transportation system includes interstate and state highways, local arterial roadways, public transportation systems, nonmotorized transportation facilities, maritime and aviation facilities, and land ports of entry. The regional roadway system is an interconnected network of interstates, freeways, highways, toll roads, arterial streets, and local streets. The regional public transit system includes local and regional bus operations, regional and interregional commuter rail services, and light rail service. The freight railroad network includes three freight rail lines serving cargo and goods services. Nonmotorized transportation facilities generally include walkways and bikeways. Often, facilities such as bikeways share space with roadway facilities. The airport system consists of commercial, general, and military aviation facilities serving passenger, freight, business, recreational, and military needs (San Diego Association of Governments, 2015).

The three largest categories of transportation-related GHG emissions (passenger vehicles, aviation and heavy-duty trucks,) accounted for ~45% of the region's GHG emissions in 2012 (San Diego Association of Governments, 2015). Regional transportation habits have not changed significantly since 2012, suggesting that emission levels are similar today. Of available transportation statistics for the time period, the most notable change from 2012 to 2017 is an approximately 7% increase in rides on public transit (Figure 30).





**FIGURE 30**



Transportation statistics for San Diego County for the 2011-2012 and 2016-2017 fiscal years. Units and magnitude (10<sup>3</sup> or 10<sup>6</sup>) are indicated along the bottom. Data from the figures is from CalTrans California County Quick Facts (Caltrans, 2017)

To help reduce GHG emissions, SANDAG and local agencies are working to expand the public transit system and increase ridership. SANDAG estimates annual transit boarding to increase threefold to 300 million in 2050. Public transit in San Diego includes the rail line (Coaster, Amtrak, and Metrolink), Sprinter (diesel powered light system), trolleys, and buses. Currently, new trolley lines and rapid transit options are being built throughout San Diego, which include lines between Downtown and University City, San Ysidro and Carmel Valley, and Pacific Beach and El Cajon Transit Center. In addition, SANDAG is planning to increase the number of managed lanes (express lanes, carpool lanes, transit only lanes) on highways to help reduce congestion. The last major component of this regional plan is to increase bike ridership. Currently there are ~1340 miles of bikeways, and the regional plan will connect more bike corridors. Many cities have also incorporated plans to increase ridership in their Climate Action Plans. With this breadth of transportation improvements, SANDAG estimates that San Diego region can reduce GHG emission by 21% by 2035 (San Diego Association of Governments, 2015).



## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT



### CLIMATE IMPACTS ON TRANSPORTATION

Research on climate impacts on the transportation system in San Diego is nascent. However, some recent findings from relevant studies and literature are worth noting. Roads will potentially be impacted through flooding and increased temperatures. Flooding, whether from coastal flooding or extreme precipitation events, increases moisture content of streets, weakening the pavement base and ground below, which can cause increased cracking and rutting of the pavement. A significant flooding event can also cause failure or washout (Sias-Daniel et al., 2014). Asphalt grades are designed to perform adequately between a high and low temperature, and the increased temperatures associated with climate change can decrease the stiffness of asphalt and increase its susceptibility to rutting (Sias-Daniel et al., 2014). Historical climate, which is often used to determine the grade, will likely not be appropriate given the projected temperatures. Recent results suggest that the impact of asphalt decline could be \$150 million in Phoenix under RCP 8.5 by 2100 (Underwood et al., 2017). Early adaptation of the asphalt grades in San Diego may have long term benefits in the durability of the roadways. Similar to asphalt, temperature impacts on rail are design dependent, but more extreme temperatures have been found to make the rail susceptible to buckling. A recent study estimates that the delays due to heat will range between \$103--\$138 billion throughout the US, with Southern California experiencing some of the highest impacts; however, through proactive adaptation of sensor technology rather than broad speed reduction technology, significant reduction in delay costs are estimated (Chinowsky et al., 2017). Like roads, railways (both light rail and trains) are also vulnerable to sea level rise if they are in a coastal flooding zone. The city of Del Mar in San Diego County has identified the Coastal Rail Corridor tracks as being one of its most vulnerable assets (ESA, 2016b).



### MITIGATION AND ADAPTATION CASE STUDY: GREEN STREETS

“Green streets” is a street design concept that combines more multiple features to capture and treat storm water while also providing other community co-benefits. Elements of a green street in San Diego may include porous pavement with biofilters and or retention soils to reduce urban run-off, widened sidewalks to accommodate bike and pedestrian traffic, and improved connectivity to bike corridors. Several examples of green street projects throughout San Diego were compiled in a recent San Diego Regional Climate Collaborative report, with one example described in full in the call-out box below.

#### CASE STUDY | A AVENUE

**A**venue links major cornerstones of National City and runs parallel to a main boulevard making it a preferred walking path for pedestrians. Awarded \$2.5 million in California Proposition 84 funding in 2013, the ‘A Avenue Green Street and Pedestrian Pathway’ project incorporates low impact development and educational elements into an eight-block avenue that has created a new gateway entrance to Kimball Park, where incidents of crime have since been reduced. An educational pedestrian pathway with a creek-themed mural and design elements, augmented with curb extensions and other improvements to walkability, runs through the project area. To reduce flooding, the project incorporated bioretention basins, a nutrient separator baffle box, and infiltration elements like decorative permeable cobble. These elements also help to capture and filter storm water, which is stored in a 30,000-gallon cistern for use in the park to irrigate a new garden. The project supports sustained, long-term water quality improvement of a nearby watershed by retaining, filtering, and infiltrating urban runoff before it enters the existing storm drain system, and has resulted in a 40% reduction in discharged pollutant load for all pollutant types. Additional elements include upgraded LED street lighting for way finding, enhanced crosswalks with pedestrian refuge islands and corner bulb-outs for traffic calming, pedestrian actuated flashing crosswalk signs, and high intensity signing and striping (see Figure 31). Project construction went out for bid in 2014 and was completed in 2015.

**FIGURE 31**



A photo of Avenue A green street showing the permeable cobble, the improved lighting, and enhanced pedestrian walkway. Source: City of National City.





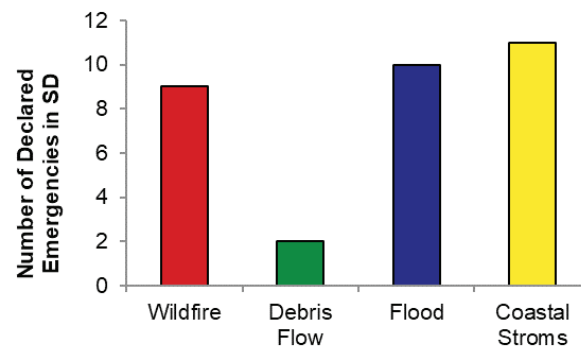
## Emergency Management

### CURRENT STATE OF EMERGENCY MANAGEMENT IN SAN DIEGO

The Unified San Diego County of Emergency Services Organization is governed by the Unified Disaster Council (UDC), which is chaired by the County Board of Supervisors and includes representatives from 18 of the incorporated cities. San Diego County Office of Emergency Services (SDOES) works for the UDC and coordinates between the California Governor's Office of Emergency Services, Federal Emergency Management Agency (FEMA), and non-governmental agencies such as the American Red Cross. SDOES is responsible for alerting and coordinating agencies' response in case of an emergency, developing emergency response plans, ensuring adequate resources are available, and developing preparedness material for the public. A primary task the SDOES facilitates is the County's Multi-Jurisdictional Hazard Mitigation Plan, which requires pre-disaster planning to facilitate coordination and effective risk mitigation.

The 2017 San Diego Multi-Jurisdictional Hazard Mitigation Plan, which is an update of the previously adopted 2010 plan, was approved by FEMA on October 20, 2017. The 22 jurisdictions and special districts have until October 2018 to adopt the plan. Once the plan has been adopted by all participating jurisdictions, it will be posted on the SDOES website. Until then the 2010 mitigation plan is available at <https://www.sandiegocounty.gov/content/dam/sdc/oes/docs/2010-HazMit-Final-August-2010.pdf>. The 2017 plan sites the following as hazards: coastal storms, erosion and tsunamis, dam failure, drought, earthquakes, extreme weather, floods, hazardous material release, debris flows (including landslides), nuclear material release, terrorism, and wildfire/structure fire. Of these the events, the hazards that are most likely related to climate include coastal storms, erosion, floods, debris flows and wildfires, drought, and extreme weather. In previous plans, extreme weather and drought were not considered hazards, while each of the other hazards have had emergency proclamations in the past (Figure 32).

FIGURE 32



The number of Emergencies declared in San Diego County for each weather/climate related hazard type. Period of record is from 1950-2016 for wildfire and 1960-2009 for debris flow, flood and coastal storms.



## CLIMATE IMPACTS TO EMERGENCY MANAGEMENT

The revision to the 2010 plan examined the impacts of climate change to the region's hazards. Drought and extreme weather were added to the Multi-Jurisdictional Hazard Mitigation Plan as a result. The projected frequencies of these extreme weather events that can cause hazards (see climate summary) are of concern. Heat waves are of significant concern as they will become more frequent in the future and have potential public health impact of (see section on public health). A heat wave is defined as the occurrence of the 98<sup>th</sup> percentile maximum temperature calculated from the historical period of 1970-2000 for at least one day. Another concern is coastal flooding, as sea level extremes will become more frequent, particularly in the later half of the century, as sea level rises. Sea level vulnerability assessments have also shown some transportation routes, emergency services stations, evacuation routes to be vulnerable to sea level rise impacts potentially hindering the ability to respond to coastal flooding in the future.

## ADAPTATIONS TO IMPROVE EMERGENCY MANAGEMENT IN THE REGION

Improved communication is an important adaptation to keep residents aware of emergency situations. In San Diego, OES has several partners to help alert and educate the public about hazards and potential hazards. These agencies facilitate communication during an emergency and alert the public of potential hazards to build preparedness. The National Weather Service (NWS) is the official source for public warnings and disseminates information through FEMA and the Wireless Emergency Alerts as well as the legacy Emergency Alert System. NWS provides public forecasts and maintains official climate records at the National Center for Environmental Information. NWS disseminates forecast and warning alerts through FEMA IPAWS (common alert protocol or Wireless Emergency Alerts) and the Emergency Alert System, as well as on numerous social media platforms, NOAA weather radio, and official web pages and wires. NWS also participated in nearly 100 annual meetings, workshops, briefings, and visits, and collaboration exercises are conducted each year with local partners. These strong relationships allow for more effective delivery of critical weather and climate information towards building a Weather Ready Nation. San Diego County Public Health also has the Relay system which works with community organizations to alert minority and non-English speaking residents of risks associated with weather events (see public health section for more information).

Improved monitoring and understanding of extreme weather events can support climate hazard warning. One such example is the High Performance Wireless Research and Education Network (HPWREN; [hpwren.ucsd.edu](http://hpwren.ucsd.edu)), a University of California, San Diego partnership project led by the Scripps Institution of Oceanography and the San Diego Supercomputer Center. HPWREN functions as a collaborative, internet-connected cyber infrastructure that supports a high-bandwidth wireless backbone and access data network in San Diego, Riverside, and Imperial counties in areas that are typically not well-served by other technologies to reach the internet. This includes locations, typically sited on mountain tops, to connect often hard-to-reach areas in the remote Southern California back country. With greater instrumentation throughout the region, forecasters can ascertain and verify exact weather conditions much more thoroughly despite the geographic diversity of the region. As a result, more accurate forecasts and warnings can be issued. With archive and animation capabilities provided by HPWREN, research on particular weather phenomena, such as cloud formation and dissipation, heavy rain events and flooding, wildfires, and wind patterns is possible. With greater knowledge and understanding of these phenomena, forecasters can receive training that will enable greater accuracy and utility of future forecasts and warnings.



## CASE STUDY | SDG&E EFFORTS TO MITIGATE WILDFIRE RISK

**S**an Diego Gas and Electric (SDG&E) has taken significant steps to mitigate fire risk in San Diego. Over the last decade the company has spent over \$1 billion to enhance grid resiliency, modernize energy assets and reduce climate and weather-related vulnerabilities like wildfire. Below are several steps SDG&E has taken.

- The weather network of 170 stations (please see Energy Section for more information).
- SDG&E accelerated a wood-to-steel pole program replacing 69 kilovolt (kV) transmission and 12 kV distribution wooden poles located in these areas, with fire- and wind-resistant steel poles.
- SDG&E collaborated with the USFS and the University California Los Angeles (UCLA) to develop the Santa Ana Wildfire Threat Index (SAWTI). The SAWTI calculates the potential for large wildfire activity based on the strength, extent, and duration of the wind, dryness of the air, dryness of the vegetation, and greenness of the grasses.
- SDG&E's uses a Wildfire Risk Reduction Model (WRRM), which integrates the latest weather and GIS technology, to understand wildfire growth patterns across the region. WRRM assesses the areas of highest fire danger before a blaze begins so preventative measures can be taken to enhance public safety and ensure the reliable operation of the electric system. This model uses simulations generated from weather conditions, historical fire and outage history, and vegetation data to evaluate the wildfire risk on every component of the electric system. In one night, WRRM can simulate 10 million fires.
- SDG&E's has one of the largest deployments of state-of-the-art pulse reclosers, focusing heavily on areas of high fire threats. When the Fire Potential Index is elevated, SDG&E proactively turns off all power line reclosing switches. They remain off until the fire potential index returns to normal for an extended duration. Reclosers are annually turned off during high fire season in the Fire Threat Zone to prevent electrical devices from automatically reenergizing lines that have detected a fault.



## Climate Impacts on Health and Vulnerable Communities

### Public Health and Climate

Climate change is expected to be the greatest public health threat of the 21<sup>st</sup> century. This growing challenge amplifies the need for an open, collaborative, dedicated climate and health infrastructure, with robust research and predictive capacity (Watts et al., 2017; World Health Organization, 2017). The impact of climate change on health in San Diego is mainly through the exacerbation or modification of existing environmental health impacts (e.g. heat waves, extreme precipitation, wildfires) but also the introduction of new ecological challenges (e.g. invasive or changes in relative abundance of species).

Current data to inform predictions of disease burden, evaluate health-related climate interventions, and support the development of a regional adaptation plan has notable gaps and is siloed within different sectors. The County of San Diego, local universities, community-based organizations, non-profit organizations, local governments, and other stakeholders are willing to work together to identify and address gaps in the region's adaptation effort going forward toward making San Diego the most resilient community in the U.S.

#### **MOST VULNERABLE POPULATION AND COMMUNITIES**

Vulnerabilities to climate extremes are spatially variable. Inland communities are most vulnerable to the impacts from wildfire, though the region as a whole (including the coast) is at risk from smoke exposure and poor air quality resulting from fires. Heat will likely affect the entire region with coastal populations experiencing a higher level of vulnerability due to lack of air conditioning while inland populations will be vulnerable through exposure to dangerously hot temperatures. Coastal areas and areas prone to flooding, including Tijuana River watershed, San Diego River, Imperial Beach, and Mission Valley, will be at risk of both the direct effects (evacuations and damages) and indirect effects of flooding. Indirect events include enhanced exposure to vector borne diseases and to pollutants flushed into the watershed.

Generally, the most vulnerable populations from extreme events are those who lack resources, are socially isolated, or whose health is already compromised. People with preexisting or underlying health conditions, with chronic illnesses (e.g. asthma), and the uninsured are especially vulnerable to the impacts of climate change (Benmarhnia et al., 2015; Reid et al., 2009). For example, cardiovascular and respiratory illnesses are exacerbated by heat and air pollution (Analitis et al., 2014). Lessons learned from past natural disasters demonstrate that people with preexisting conditions are not always able to obtain needed medications and access medical equipment and/or devices during and following a natural disaster for a variety of reasons, including power outages, transportation, and insurance issues. Depending on their health status, senior citizens may be especially vulnerable (Figure 33) resulting from the combination of chronic health problems, limited mobility, and social isolation. This is true for elderly living alone or in skilled nursing facilities.

Further, socioeconomic disadvantages also restrict the capacity of individuals to avoid the negative health impacts of climate change, to mitigate those impacts, or cope with them as they become threat multipliers. This is particularly true for the unsheltered or homeless. Flash floods, vector borne disease, mudslides, and extreme heat are just a few of the elements that would be experienced more profoundly by someone who is unsheltered living in areas directly affected by these extremes. For example, the risk factors for morbidity and mortality from heat correlate closely





## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT

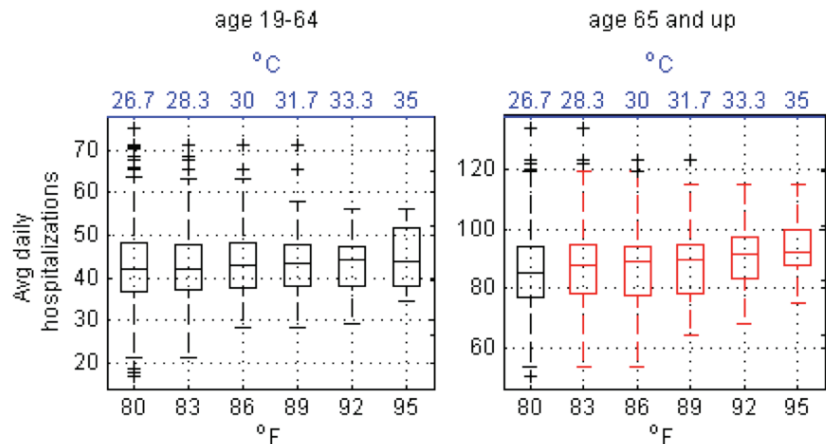
with the characteristics of homeless individuals. One such characteristic is pre-existing psychiatric illness which has been shown to triple the risk of death from extreme heat (Bouchama et al., 2007). Reaching the unsheltered with key messages about risk and adaptation also presents a challenge, as seen in the 2017 hepatitis A virus outbreak. A lack of a permanent address creates additional challenges for both the individual and the agencies seeking to provide help or response.

San Diego's proximity to the busiest land border crossing in the world makes it a likely region for asylum seekers, migrants, and immigrants from all over the world. San Diego has been the foremost receiver in California for the resettlement of refugees (43% of state total). These groups may be isolated geographically, socially, linguistically, and politically, making them more vulnerable to the impacts of climate change and natural disasters. Migrant workers may also be more reluctant to evacuate from a wildfire or remain inside in air-conditioned spaces due to limited means or concerns over lost wages or deportation. For example, three states (Arizona, California, and Texas) accounted for 94.5% of non-citizen heat deaths, and the risk was greatest among Hispanic immigrants between the ages 18 and 24 (Taylor et al., 2017). As a result, researchers are urging tailored heat prevention messages for people at greatest risk.

### CLIMATE CHANGE IMPACTS ON PUBLIC HEALTH IN SAN DIEGO COUNTY

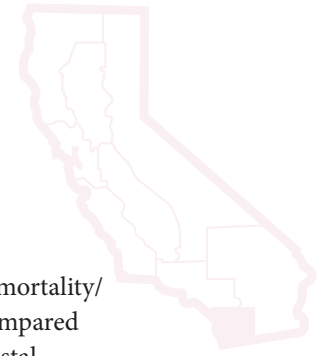
Human health effects associated with extreme heat are expected to increase significantly, including heat-related illness and cardiovascular failure (Mora et al., 2017). The National Weather Service (NWS) reports that between 1987 and 2016, heat was the number one weather-related killer in the United States and claimed more lives on average than floods, lightning, tornadoes, and hurricanes or other weather-related events (National Weather Service, 2017). For example, the July 2006 heat wave in California, which exhibited unprecedented magnitude and unusually high humidity levels (Gershunov et al., 2009), resulted in over 600 excess deaths (Ostro et al., 2009), over 1200 excess hospitalizations for cardiovascular and other diseases (Kristen Guirguis et al., 2014), and over 16,000 excess emergency-department visits (Knowlton et al., 2009), with disproportionate effects along the coast relative to inland locations. The effect of high apparent temperature, a combination of hot temperatures and high humidity, can have a greater impact in mortality (heat-related deaths) in coastal areas than inland areas (Rupa Basu, 2009). Observed trends and our analyses of climate-model projections suggest that heat waves are becoming more common, stronger, longer lasting and, importantly, more humid in California (Gershunov et al., 2009; Gershunov & Guirguis, 2012).

FIGURE 33



Daily average hospitalizations for zip codes in San Diego County within the coastal region for days exceeding a given Tmax temperature threshold for different age categories. Red indicates results are significantly different from a reference taken as days cooler than 75°F. Data is from 1999-2013.

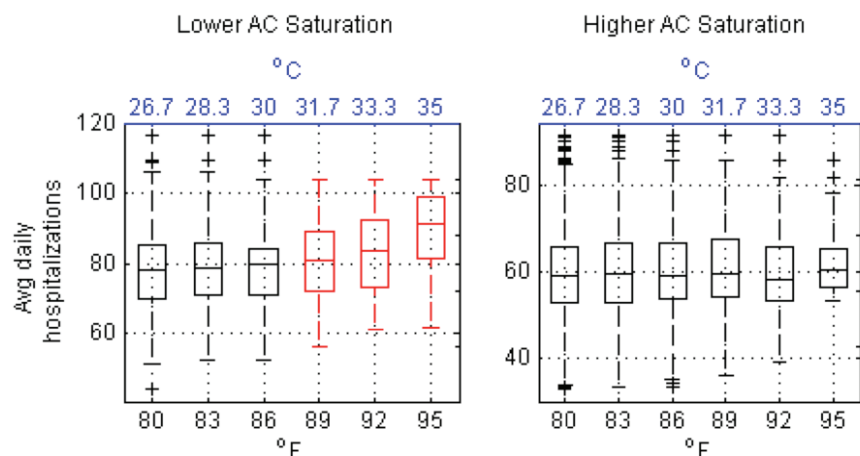
Source: Figure 7 from Guirguis et al. (2018a), provided by K. Guirguis.



A recent scientific review found people living in hotter areas within cities had an overall 6% higher risk of mortality/morbidity compared to those in cooler areas, and those living in less vegetated areas had 5% higher risk compared to those living in more vegetated areas (Schinasi et al., 2018). In parallel, differences may exist between coastal and inland zones. Recent work in San Diego showed that heat-related health impacts are observed at lower temperatures in the coast than in the inland and desert regions (K. Guirguis et al., 2018). This is in part due to coastal residents being less acclimated to heat and less likely to have air conditioning (Figure 34). However, a challenge for implementing policy to protect human health is that there is no standard definition for a heat wave. Definitions can vary according to the specified high-end temperature threshold (e.g., 95th or 99th percentile), the number of consecutive days (e.g., 2, 3 or more) or the temperature metric that is used (e.g. maximum, minimum, or diurnal temperatures) (Kent et al., 2014; Xu et al., 2016). An ongoing study at UC San Diego by Benmarhnia (unpublished) compared different heat wave definitions (~30) within the County of San Diego and found the definition to be important for identifying local thresholds at which the highest number of attributable emergency room visits occurred. While the definition of a heat wave does not, of course, cause the illness, different characteristics of the heat wave, such as nighttime temperature, duration, or maximum temperature, affect how heat waves impact health. Thresholds varied within the city, due to differences in microclimate conditions and sociodemographic composition. These findings highlight the importance of considering different heat wave definitions for intervention purposes even within a single city. The Western Region of the National Weather Service recently developed a health-focused heat warning system that accounts for local variation in climatology and has begun to issue tiered heat alerts using different temperature thresholds for different locations and for different levels of vulnerability (National Weather Service, <https://www.wrh.noaa.gov/wrh/heatrisk/?wfo=sgx>).

The projected increase in wildfire risk directly relates to an increase health risk from the fires and the smoke produced by the fires. Smoke contains particulate matter, ozone, carbon monoxide, and nitrogen dioxide, all of which are associated with respiratory and cardiovascular negative health impacts. A recent study of health impacts from wildfires smoke in exposure in 2015 showed that wildfires smoke increased cardiovascular and respiratory health risk as a result of medium and high smoke density exposure (Wettstein et al., 2018). The study showed that most significant health impacts were to people over 64 years old and the largest increases in relative risk were for dysrhythmia,

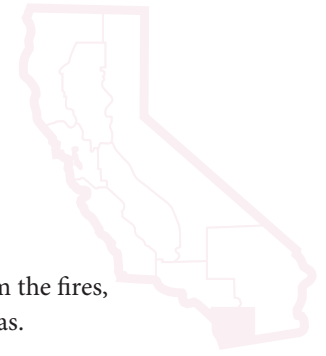
**FIGURE 34**



Same as figure 33 but for different saturations of air conditioning. Source: Figure 4 from Guirguis et al. (2018a), provided by K. Guirguis.



## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT



heart failure, and chronic obstructive pulmonary disease (COPD). As smoke can travel large distances from the fires, the health impacts of smoke is a vulnerability to all of San Diego County, not only regions in fire prone areas.

In general, climate change is expected to increase vector borne diseases (Campbell-Lendrum et al., 2015), though the factors involved are complex and the incidence of disease will depend on both environmental and demographic factors. A potential precursor to changes in vector-borne disease is the recent massive expansion of invasive mosquito species, *Aedes aegypti* and *Aedes albopictus* (Figure 35), which have the potential to transmit infectious diseases such as chikungunya, dengue, and the Zika virus. Temperatures and pooling water are two

critical factors in a mosquito's life cycle and, subsequently, their potential to spread disease. At warmer temperatures, mosquitos lay eggs more frequently, feed more frequently, and the incubation period of viruses they carry decreases, allowing mosquitos to transmit viruses more quickly after becoming infected. Also, at higher temperatures, some highly virulent genotypes of West Nile virus replicate more efficiently than low pathogenic genotypes. Research suggests this has contributed to the emergence of pathogenic strains (Reisen, 2013). Increased flooding due to higher increased extreme precipitation events can flush out immature mosquito stages but leave behind pools of water in natural and man-made structures throughout the region which provide abundant habitat for mosquitos to breed. Rising seawater levels and high tides can also create brackish water habitat in coastal areas in which certain adapted mosquitos can breed. Aided by increasing temperatures, the time it takes for a mosquito to complete its life cycle is shortened in these new water pools, which can yield many thousands of new, adult mosquitos. On the other hand, the mosquito life cycle is shortened by high temperature and low humidity, which could decrease their ability to spread disease. Thus, there is a balancing act. In general, though, it is largely thought that vector borne diseases will increase with climate change (Campbell-Lendrum et al., 2015).

FIGURE 35



*Aedes aegypti* and *Aedes albopictus*.

### COLLABORATION AND ADAPTATIONS

The County is working towards communicating health risks associated with excessive heat. Below is an example of the region's adaptation to excessive heat taken from the County's updated Excessive Heat Response Plan (Table 5; EHRP, 2017). In San Diego County, the Plan is in effect from May 1 to September 30 each year, and at other times during the year if unusually high heat events occur. The activation of the EHRP by the County's Public Health Services (PHS) occurs when the NWS issues a heat alert product indicating a heat event in one or more areas of San Diego County. PHS informs all stakeholders of the appropriate preventive action. The County Health Officer determines that a Heat Emergency exists based on the threat to public health and safety. The designated staff in the Public Health Preparedness and Response (PHPR) branch of the PHS serves as the EHRP Coordinator when the plan is activated. The County Communications Office issues standardized health and safety messages to the public via the press and social media as well as working with external partners to disseminate key information.





## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT



Public Health Services (PHS) also has partnered with the County Office of Emergency Services (OES) in a Partner Relay effort to disseminate messages to vulnerable communities in the event of a natural disaster or public health emergency, such as the during heatwaves as mentioned above. Other disasters include the recent Lilac fire and Hepatitis A outbreak. The County has established networks and action plans to address any emergency; however, this valuable information is less likely to reach the over 400,000 non-English speaking individuals that live in the region. The Partner Relay improves the communication with communities that speak languages other than English, by establishing relationships with community leaders to understand the best method to communicate emergency information. Through ongoing discussions and meetings with leaders representing eight language groups (Spanish, Tagalog, Chinese, Korean, Arabic, Vietnamese, Somali, and Karen), they determined that the best method of communication was to use existing networks and phone trees/partner relays to disseminate emergency information. Over 300 individuals representing non-profit organizations, houses of worship, and refugee resettlement agencies have agreed to partner with the County in disseminating information to their communities during emergencies. The OES maintains the Ready San Diego app providing access to an online communication platform where information is shared with trusted partners and they in turn share the information with their community in various languages. In preparation for adaptation planning, it also co-developed a Climate and Profile Report and Vulnerability Assessment in collaboration with the CalBRACE Project in the California Department of Health Office of Health Equity. Both of these adaptations also help promote climate justice (see next section), by ensuring climate hazard communication reaches the most vulnerable communities.

TABLE 5

MONTH	COASTAL	VALLEYS	MOUNTAIN REGIONS	DESERT REGIONS
Oct - May	100	105	95	113
June	100	105	100	115
July	100	105	100	117
August	100	105	100	117
September	100	105	100	115

Excessive Heat Warning Criteria (°F) in San Diego

### CLIMATE & CHILDREN'S HEALTH

During a heat wave in October 2017, 85 schools in San Diego had to close early due to extreme heat. Children, especially those under age 5, are particularly vulnerable to heat, poor air quality, and UV radiation, including having reduced ability to regulate body temperature compared to adults. Research shows that children also perceive thermal environments differently than adults (Mors et al., 2011) and may not recognize the early signs of heat stress. San Diego Unified School District is the first district in the County to adopt a climate action plan, with plans to install air conditioning in all schools. Design interventions, such as shade for reduced radiation and evaporative cooling through misters and vegetation/natural surfaces, are also well-known to reduce overheating (Brown et al., 2015), with the added benefit that certain trees/plants are able to absorb air pollutants.





## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT



The County Vector Control Program (VCP) mitigates the impacts of vector-borne diseases to the health, well-being, and economy of the County by: 1) limiting mosquito numbers in critical areas; 2) educating residents on how to prevent mosquitos from breeding on their property in open containers or other water sources, and protect themselves from getting bitten, and; 3) mobilizing residents to report mosquito breeding sites and sentinel dead bird species to the VCP. The Department of Environmental Health utilizes an in-house molecular diagnostic laboratory to provide highly sensitive and rapid disease test results so that informed, data-driven control measures can be quickly instituted. It also works closely with local and state agencies, universities, research centers, and private foundations to find new ways to control mosquitos and prevent the spread of disease.

A multi-beneficial adaptation approach to improve health as climate changes at the city level is the City of San Diego's Urban Forestry Program. As mentioned above living in vegetated areas reduce health risks (Schinasi et al., 2018). The Urban Forestry Program supports climate adaptation in many ways, and by providing cooler green space and improved air quality the Program supports improved community health now and in the future.

## Climate Justice

### VULNERABLE COMMUNITIES

San Diego County is one of five counties in California with a high percentage of socially vulnerable populations to climate change impacts, according to a study funded by the California Energy Commission in 2012. Social vulnerability is defined as the susceptibility of a given population to harm from exposure to a hazard, directly affecting its ability to prepare for, respond to, and recover. Social vulnerability is a function of diverse demographic and socio-economic factors that influence a community's sensitivity to climate change. Understanding vulnerability factors and the populations that exhibit these vulnerabilities is critical for crafting effective climate change adaptation policies and disaster response strategies. This is also important to achieving climate justice, which is the concept that no group of people should disproportionately bear the burden of climate impacts or the costs of mitigation and adaptation (Cooley et al., 2012). To better understand climate justice issues statewide, the Fourth Assessment includes a report on climate and environmental justice issues facing California due to projected impacts from climate change. More information on climate justice issues for both the San Diego region and statewide may be found in this report (Climate Justice Summary Report, 2018).

In the San Diego region, city and County health and emergency management agencies, the non-profit community, faith-based organizations, and others support programs address climate justice directly or indirectly through delivery of public health services, infrastructure development, and advocacy and empowerment projects with a focus on vulnerable and disadvantaged communities. Primary climate impacts in the region disproportionately affecting these populations include increasing temperatures, particularly relative to air quality and heat waves. Increased frequency and intensity of heat waves will exacerbate already existing challenges such as air pollution and associated public health risks including asthma, cardiovascular and respiratory disease, and related conditions. Warmer temperatures year-round could lead to growing mosquito populations, increasing the regional occurrence of West Nile virus and potentially introducing tropical diseases such as chikungunya, dengue, and the Zika virus (see previous section).

In San Diego, disadvantaged communities such as Barrio Logan, Logan Heights, and National City already have the highest rates of child asthma hospitalization, breathe polluted air from trucks, freeways and industrial sources, live in homes lacking energy affordable energy bills, and lack access to safe, affordable, and convenient transit to jobs,



## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT



health care, parks, and cooling centers. In January 2017, California released the updated version of its pollution-screening tool, CalEnviroScreen. The data indicate that these same communities in San Diego remain among the top 5-10% of communities in the state most impacted by pollution. CalEnviroScreen combines environmental, health, and socioeconomic information to identify communities most affected by pollution. Since the last version, released in 2014, the state has added new factors to measure cardiovascular disease and housing cost burden, as well as incorporated air-monitoring data from the border region to more thoroughly evaluate air quality in border communities.

### SAN DIEGO EFFORTS IN SUPPORT OF CLIMATE JUSTICE

San Diego County's draft Climate Action Plan largely focuses on GHG emissions reduction plans and strategies, some of which will have co-benefits for disadvantaged communities (County of San Diego, 2017). The Plan includes a section on adaptation and resilience that references the adaptive capacity of the County to address climate impacts and outlines strategies such as cooling centers for underserved communities in the face of increasing and more intense heat waves. The City of San Diego Climate Action Plan includes reference to City Council Policy 800-14, which prioritizes capital improvements in under-served communities and points to the use of the CalEnviroScreen to identify these communities and prioritize projects in census tracts ranking in the top 30% of CalEnviroScreen scores. This policy also prioritizes projects located in areas eligible for the Community Development Block Grant funds, and projects located within a half mile of affordable housing. The assumption is that co-benefits in adaptive capacity to climate impacts will be realized through these projects.

The Single-family Affordable Solar Homes Program (SASH) program is structured to provide qualifying single-family homeowners with access to solar technology while also providing green jobs training, employment, and community engagement opportunities. GRID Alternatives is the non-profit organization responsible for administering the program and has installed systems on 885 homes in San Diego County. These SASH funds enabled communities that have been historically left out of the renewable energy market to become integral partners in building a sustainable solar industry.

Current solar photovoltaic systems on affordable housing properties have historically been used to offset electricity costs in common areas, benefiting property owners instead of tenants. California's newest solar program for low-income renters, the Solar on Multifamily Affordable Housing (SOMAH) program (Assembly Bill 693 2017), will bring \$1 billion in rooftop solar to low-income renters over 10 years. The new program, anticipated for launch in August of 2018, is intended to fund 300 megawatts of new solar projects with the potential to serve over 150,000 low-income renters at over 2,000 affordable housing properties across the state. Low-income tenants will receive credits on utility bills through tariffs, namely virtual net metering (VNEM) tariffs. VNEM tariffs provide a mechanism for allocating bill credits from system generation among the property occupants, including both common area electric accounts and the accounts of tenants. Under SOMAH, tenants receive at least 51% of the VNEM credits from any solar project.



## Cross Border Climate Interaction and Adaptations

Cross border interactions are an important component to San Diego's culture and economy. The climate change impacts that San Diego will experience transcend geopolitical borders, especially those occurring across most of northern Baja. Border region climate adaptation planning is challenging due to the complexity posed by a globalized economy with increasing food-energy-water security problems, as well as different governance and community structure. By overcoming these obstacles, cross-border climate adaption planning has the potential to build resilience throughout the border region bringing a higher quality of life to the region.

### Cross-Border Region

In 2010, the population of the San Diego-Tijuana border region was 4.8 million, making it the largest binational metropolitan area shared between the United States and Mexico (Al-Delaimy et al., 2014). The border region is home to San Ysidro, the busiest land border crossing in the world. In 2017, almost 14 million personal vehicles and buses crossed into the US at San Ysidro and over 900,000 trucks crossed into the US through Otay Mesa (Bureau of Transportation Statistics, 2017). The region is at the forefront of cross-border development due to a history of innovation across numerous industries in California; a large, diverse local economy; the scale of crossborder human mobility; successive waves of crossborder advanced manufacturing development; and an urban/civic renaissance in Tijuana (Wilson Center, Wash DC, 2015). A recent cross-border development project for large-scale infrastructure improvements includes a \$741 million renovation of the San Ysidro Port of Entry, a unique crossborder air terminal, Otay Mesa East, a new port of entry currently under construction, and other improvements.

The border region of San Diego County is a highly diverse area with a large proportion of economically disadvantaged residents. Geographically, the region covers 155 square miles of urban, suburban, and rural areas. The region includes the cities of National City, Chula Vista, Imperial Beach, Coronado, and three communities of the City of San Diego: Otay Mesa, Nestor and San Ysidro. As of 2013, over 60% of the population of San Diego's border communities was Hispanic and approximately 20% was white. Household income levels were generally lower in the border communities than San Diego County overall; about 44% of these households earned incomes less than \$50,000 a year (Live Well San Diego Demographics, 2017).

Tijuana is the sixth largest and fastest growing city in Mexico, reaching the one million milestone between 1995 and 2000, with a current population of 1.7 million people. The city continues to grow at double-digit rates and has become a national leader in economics, culture, politics, education, and industry. However, rapid and unplanned growth has resulted in economically distressed colonias (rural communities) lacking in infrastructure in Tijuana (Wilder et al., 2013). Generally, there are higher levels of social sensitivity for the Tijuana populations when compared to San Diego; thus, different vulnerabilities emerge as a result of the dynamics of social and biophysical processes and the socioeconomic and environmental condition.





## CASE STUDY | TWO EXAMPLES OF ADAPTATION PLANNING IN TIJUANA

1. Due to rapid urbanization, flooding has become an urban dilemma in the City of Tijuana. Nuisance flooding, or flooding which causes public inconveniences such as frequent road closures, is common in the urban center of Tijuana and poses risk to urban infrastructure. Citizen scientists have documented and shared photographs of these damages caused by the rains. Directed to estimate rainfall runoff in streams, canyons, and streets, notate water levels in storm drainage, and document debris in flood channels, this data has been used directly in informing climate change impact assessments in the City.
2. A social vulnerability analysis and the development and of short-, mid-, and long-term adaptation strategies were funded by the Instituto Nacional de Ecología y Cambio Climático (INECC). This effort examined the sociodemographics, knowledge, and perception of risk, and conducted a neighborhood characterization that identifies support networks and services upon which the neighborhood relies. An inventory of social organizations was developed as a tool for engagement in future development projects related to climate change and social vulnerability in Tijuana (Goodrich et al. in press).

## Cross-Border Climate Planning

Although substantial climate change adaptation planning is underway at various scales and among various sectors, few measures have been implemented across international borders and steps forward may be out of sync when looking across communities that span national boundaries (Bierbaum et al., 2013). Governance, planning, and communication are complicated by the asymmetries between the U.S. and Mexico sides of the border (Wilder et al., 2013). The border region is significantly influenced by the increasing globalization of markets, trade and industry, intensified negative impacts of urbanization, and complex and often fragmented institutional landscapes. Societal responses will differ across the border region but regionalizing adaptive responses may increase resilience (Wilder et al., 2010). Below are some examples of climate planning across the US-Mexico border.

Boundary-spanning organizations and initiatives are key to progress in better understanding impacts of climate change and in the process of identifying mitigation and adaptive solutions. Binational, or transboundary, vulnerability assessments and adaptation planning, although difficult, are occurring across regions that span the U.S.-Mexico border. The National Oceanic and Atmospheric Administration (NOAA), for example, funded an interdisciplinary assessment of adaptation strategies in the Arizona – Sonora region of the U.S.-Mexico border through its Climate and Societal Interactions Program. This study was launched as a result of an assessment that indicated that there was a lack of studies related to adaptation and its implementation.

Two binational agencies, the Border Environment Cooperation Commission (BECC), and the North American Development Bank (NADB), are supporting initiatives across the broader border region to increase solar photovoltaic and wind projects as well as climate change action planning in Mexico's northern border region.



## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT



NADB has provided loans that finance almost \$500 million for nine solar and wind projects within Arizona and California, totaling about 271 megawatts generated. BECC facilitated the Baja California Climate Change Action Planning process, which resulted in an estimate of costs and benefits of different mitigation and adaptation options. BECC has supported broader border efforts to address air pollution risks posed by climate change. For example, BECC collaborated to help the Mexican border states develop GHG emissions inventories and forecasts in 2010. The resulting state climate action plans developed by the Mexican states of Baja California, Sonora, Chihuahua, Coahuila and Tamaulipas identified mitigation policies and the economic impacts of implementing these public policies. In Baja California, Coahuila, and Chihuahua, the action plans also include socioeconomic micro- and macro analyses of mitigation policies, as well as the quantification of reduction and costs and the cost savings of the GHG inventory (Good Neighbor Environmental Board 2017).

An on-going, two-year project, funded by California Office of Environmental Health Hazard Assessment (OEHHA), has the primary objective of understanding the air pollution health risks faced by communities, specifically from exposure to air pollution from idling vehicles at the port of entry and from the migration of pollutants from Tijuana. The project is implemented by Casa Familiar, San Diego State University, and the University of Washington. A collaborative process with community leaders resulted in an increased understanding of vulnerability and plans for the placement of air quality sensors in San Ysidro to monitor pollutants. The long-term goal is that collected data may inform future solutions to environmental justice problems within the area, including reducing vehicle emissions at the port of entry, as well as outreach and education programs to at-risk groups in the community on ways to reduce their exposure to harmful air pollutants.

Such examples illuminate that shared understanding of regional vulnerabilities through cross-border collaboration can enhance the border region's adaptive capacity. This is especially true of data sharing and the conditions that foster use of the information (Feldman et al., 2008; Wilder et al., 2010). For example, regional Climate Action Plans with a primary focus on GHG reduction have links to regional, state, and federal efforts regarding climate change within the United States. CAP outcomes could benefit from an expansion of climate action efforts in Tijuana through increased cross-border collaboration. A co-benefit is GHG reduction at the two ports of entry on both sides of the border that would benefit both the San Diego region and Tijuana and provide air quality co-benefits for the residents and workers in the area.

At the same time, alternative approaches to climate mitigation and adaptation planning in binational settings can assist in overcoming binational barriers. One such example is connecting to economic development efforts. With strong cross border collaboration around economic activity already in place, the San Diego region can work to bring climate change considerations into partnerships and joint efforts with Tijuana. With fewer financial resources, this multi-benefit approach is likely to yield successful outcomes for Tijuana as well.



## Tijuana River Watershed

### ECOSYSTEM AND CURRENT VULNERABILITIES

Geographically, the Tijuana River Watershed is an approximately 1750-square mile binational area that includes a diverse and complex drainage system ranging from 6000-foot pine forest-covered mountains to the tidal saltwater estuary at the mouth of the Tijuana River in the United States (Figure 36). The Tijuana River originates at the confluence of Arroyo del Alamar and Río de las Palmas in Mexico (TRNERR, 2010). A wide variety of land uses are present in the watershed, from largely undeveloped open space in the upper watershed to highly urbanized, residential, commercial, military, industrial, and agricultural areas in the lower watershed. Nearly three-quarters of the watershed is located in Mexico, as the Tijuana River drains to the Pacific Ocean through an approximately 8-square mile area called the Tijuana River Valley that is located adjacent to the border. Despite intense pressure from development associated with the area being situated on an international border between two major metropolitan areas, San Diego and Tijuana - the Tijuana River Valley contains the largest intact coastal wetland system in Southern California.

The Tijuana River flows during rain events, and is subject to flooding during major storms; however, typical of a mediterranean system, it is relatively dry most of the year (Nordby et al., 1992). Powerful floods have in the past shaped and will continue to shape much of the area (Safran et al., 2017). Historical ecology studies, photographs, and records from the last 150 years show shifts in the course of the river and several major floods, inundating large sections of Tijuana, as the River can swell up to two miles in width (Safran et al., 2017). In steep, narrow canyon communities such as Los Laureles Canyon, adjacent to and uphill from the Tijuana River Valley, flooding presents more life-threatening circumstances. A storm with heavy rain can create running rivers of mud and debris that can scour and erode unpaved roads and hillsides and destabilize already tenuous slopes resulting in landslides, destruction of homes, and human injury and loss of life (Goodrich et al. in press). Further, the proliferation of sediment in these events can fill and overtop sedimentation retention basins, compromise flood conveyance channels, and choke natural systems downstream across the border in the Tijuana River Valley (Goodrich et al. in press).

**FIGURE 36**



Map of the Tijuana River Watershed

TRNERR Management Plan





## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT



Storm events also produce water quality issues. During large precipitation events the Tijuana River Valley is exposed to various contaminants conveyed by the River in storm events from sewage runoff and spills, urban runoff, and illegal dumping. Past storms have resulted in bacteria, chemical, and heavy metal levels exceeding water quality standards (Nordby et al., 1992). Since 2006 there have been almost 2,000 days of beach closures at the two beaches closest to the border (Border field State Park and Imperial Beach) caused by poor water quality (Smith, 2017). In addition to riverine flooding, flooding is also experienced on the western (Pacific Ocean) edge of the River Valley from tidal waters being pushed inland and is expected to increase due to sea level rise from climate change (see Coasts section for more information) (Goodrich et al. in press).

Various public agencies have jurisdictional and management authority over land and facilities, TRNERR, a Federal-State entity, the United States Border Patrol, US Navy, Fish and Wildlife Service, San Diego County, City of San Diego, California State Parks, and the International Boundary and Water Commission (Goodrich et al. in press)

### CLIMATE UNDERSTANDING AND RESILIENCE IN THE RIVER VALLEY

TRNERR, part of the NOAA's National Estuarine Research Reserve System, is a boundary spanning organization that plays a large role in facilitating cross-border dialogue and collaboration. TRNERR provides a unique venue to support binational education, training, research, and stewardship as it collaboratively manages large portions of the Tijuana River Valley directly adjacent to the border. Since 2012, the *Climate Understanding and Resilience in the River Valley* (CURRV) Initiative has built upon California's statewide support to prepare for climate change and an articulated need by communities for targeted support to advance regional resilience planning. CURRV leverages TRNERR's capacity as a boundary organization to do climate scenario planning, interfacing with communities on both sides of the border (See Section 3.3 for more information).

An emphasis was put on transferability of the process, including a bi-directional science transfer between individuals planning for climate change in Southern California and Tijuana. As such, a binational exchange of information and ideas focused on better understanding of regional climate change impacts, building skills in assessing vulnerabilities to climate variability and change, and evaluating adaptation strategies.

### CLIMATE KIDS – MEXICO

Climate Kids-Mexico is a collaborative partnership in Tijuana and Northern Baja focused on youth education on climate change through science activities, storytelling, and art. In partnership with Profesora Escalante, an environmental leader in region, the Climate Science Alliance launched Climate Kids Mexico in 2015. This program piloted a unique approach to training high school students to deliver the Climate Kids program in elementary and middle school classes in Tijuana, Baja Mexico. Since the program started Climate Kids-Mexico has reached more than 6,000 students a year with climate change science, art, and storytelling. In 2016 a series of binational events were implemented for students from Climate Kids-Mexico and Climate Kids-San Diego to meet and learn together.

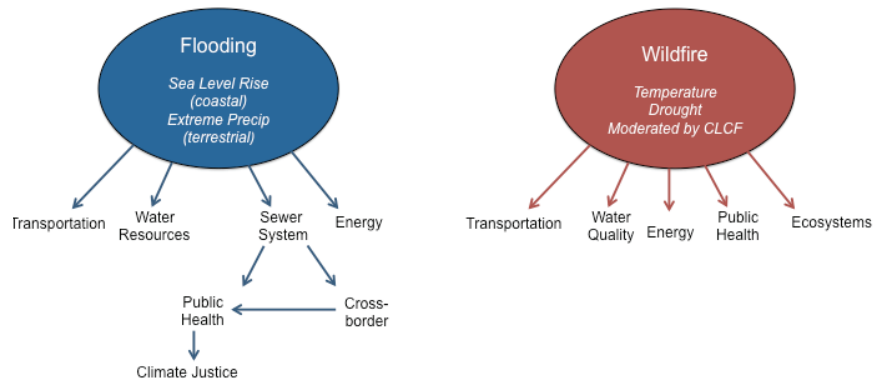


## Cross-Jurisdictional & Cross-Sector Climate Change Issues

California passed SB 379 in the fall of 2015, which requires that all cities and counties integrate climate adaptation into their general plan processes. This builds on previous bills that require flood protection and fire protection to also be considered (AB 162 and SB 1241 respectively), as well as AB 32 requiring the statewide reduction of GHGs. Although these are separate bills, there are significant synergies among them in that climate change in San Diego is projected to increase flooding (both coastal and riverine) as well as increase fire risk due to an extended fire season, particularly when Santa Ana Winds are present. These hazardous events will impact multiple sectors (Figure 37). A wildfire can cause large public health concerns with injuries from the fire and air quality, close roads, and disrupt energy transmission and distribution. After the fires, ecosystems need to regrow, the loss of habitat may impact water quality due to erosion, and the filter capacity of the landscape may be altered. Flooding impacts are primarily immediate and include road closures, electricity disruptions, and sedimentation and water quality issues, as well as impacts to waste water systems which can cause public health concerns, particularly in the cross-border regions (see previous section).

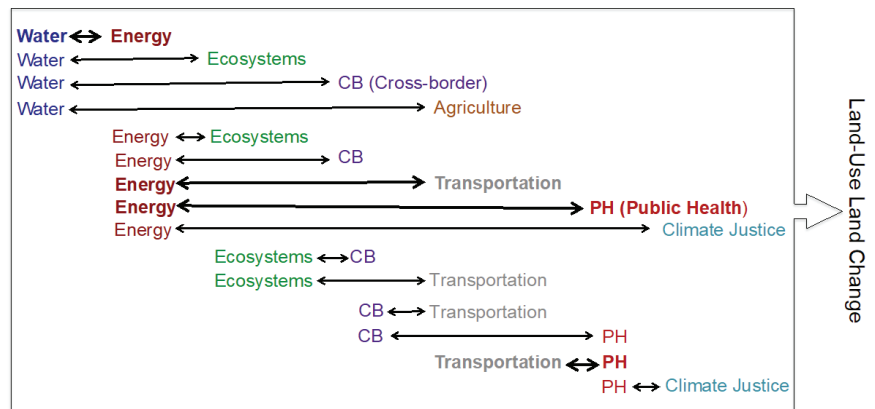
Because of the large spatial scale of climate change and the range of sectors impacted by it, climate adaptation can act as an integrator between multiple jurisdictions and multiple sectors. Climate change impacts thus present cross-jurisdictional and cross-sector issues (Figure 38), and consideration of the climate change vulnerabilities between

**FIGURE 37**



Examples of hazards from climate change and the sectors that the hazard impacts. The climate variables that contribute to the hazard are indicated in the circle below the hazard.

**FIGURE 38**



The arrows between sectors show the sectoral impacts are related under climate change. The sector linkages in bold indicate that climate impacts on these can lead to emergencies and required emergency services. All sector impacts act synergistically with land use land change.



sectors can produce multi-beneficial adaptation measures. This is particularly true for adaptation measures that also reduce GHG, such as carbon farming, green streets, water conservation, and land use planning, amongst others. Given the intersections of many sectors, a truly multidisciplinary approach that brings experts from multiple fields together is important for developing multi-beneficial approaches. Further, multi-beneficial adaptation approaches provide opportunities for multiple funding sources to complete projects.

### Coordination Opportunities: Boundary Spanning Organizations, Universities, and Non-Profits

As discussed above, the impacts of climate change are not isolated and building resilience requires a coordinated approach. The use of consistent scientific information, models, climate projections, and terminology is central to enabling cross-sector and inter-jurisdictional adaptation strategies. This consistency is key to providing elected leaders, policymakers, and stakeholders the confidence to make commitments to tackling climate change risks.

In order to advance co-production of research that informs management and policy actions, researchers, managers, and decision makers must invest and participate in building strong partnerships that bring together different perspectives and expertise, drawing on advances from across the scientific spectrum. However, the science does not always reach decision makers and research is often not coordinated or integrated into planning actions. Fortunately, these barriers can be overcome by identifying boundary-spanning organizations that can help translate the science in real time, build trust among partners, and have enough influence to garner support for action. An example of barriers to local adaptation planning and how the support of boundary organizations helped support adaptation planning in Carlsbad is highlighted below. San Diego has several organizations that have taken on this role which include the Climate Science Alliance, South Coast (The Alliance), the San Diego Climate Collaborative, the San Diego Foundation, and academic research teams.

The Alliance brings together more than 200 organizations to support, promote, and connect climate adaptation activities with natural resource and local government planning and projects from Santa Barbara, California through Baja California, Mexico. The Alliance's network offers the opportunity to leverage costs and complementary efforts, forge new and expanded climate adaptation partnerships, and serve as a catalyst for the kind of innovative and large-scale actions necessary to build long-term resilience to climate change. The Alliance is divided into Working Groups' whose activities and programs are divided into three focus areas: Science Focused Partnership, Climate Smart Conservation, and Innovative Community Engagement. The over 300 individuals participate in one or more Working Groups. In 2017, these collaborative programs and activities resulted in 6 research projects; 37 local case studies; 28 capacity building trainings, workshops and conferences that reached over 1,000 professionals; school programs that reached over 9,000 students; and 21 community events that reached over 91,000 community members.

The San Diego Climate Collaborative (Collaborative) is a member-based organization created to facilitate partnerships between public agencies, academic institutions, non-profits, philanthropy, and businesses in a collective effort to advance climate action planning in the San Diego region. Currently the Collaborative has 27 members which represent 80% of San Diego County. The Collaborative's key focus areas are: Resilient Coastlines, Energy Efficiency, and Climate-Smart Water, with major accomplishments pertaining to building local capacity, providing technical and grant assistance, and coordinating research projects. In 2015, the Climate Collaborative, in partnership with the





## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT



Alliance and the TRNERR, launched a Resilient Coastlines Project designed to provide a multi-faceted approach to building resiliency in the coastal communities of San Diego (see Coast section for more details). Notably, the project also created a Sea Level Rise workgroup that convened a diverse set of stakeholders once monthly for two years. This working group continues to meet even after the end of the grant highlighting the value of it.

The San Diego Foundation (TSDF), through their Climate Initiative, is committed to providing critical leadership to catalyze greater regional action to address climate change. TSDF does so by investing in locally-based research, nonprofit climate action, community-based leadership, technical assistance, and peer-to-peer networking and collaborative projects among our region's local governments and public agencies. Through the support of our donors and other local, regional, and national funding partners, the Climate Initiative works to catalyze greater regional action to reduce polluting emissions, facilitate and strengthen collaborative efforts to prepare for climate change, and build public awareness and engage regional leaders around local solutions to climate change.

These boundary-spanning organization and local agencies have the support of regional climate researchers at Scripps Institution of Oceanography, UC San Diego. CNAP, California-Nevada Applications Program ([cnap.ucsd.edu](http://cnap.ucsd.edu)), is a NOAA Regional Integrated Assessment Team (RISA) that has been engaging with local stakeholders for almost 20 years to integrate climate science into decision-making. Scripps Institution of Oceanography's new Center for Climate Change Impacts and Adaptation (CCCCIA) serves as an interface between academia and the community to foster interdisciplinary research, data, and applications to inform adaptation strategies that target impacts from sea level rise and extreme weather events.



## **CASE STUDY | CITY OF CARLSBAD - CLIMATE CHANGE ADAPTATION THROUGH THE LENS OF SUSTAINABILITY AND REGIONAL AND STATE PARTNERSHIPS**

**T**he challenges presented to local jurisdictions by climate change are daunting. In coastal San Diego County, sea level rise, increased fire risk, droughts, and water and energy shortages all pose serious threats to the existing quality of life. Significant barriers thwart local decision makers' efforts to address these threats, most notably institutional and financial barriers (Kay et al., 2018; Moser et al., 2018). Local jurisdictions typically lack the staffing, expertise, funding, and other resources needed to engage in climate adaptation policy derivation that would guide future activities. Also, the magnitude, timing, and results of climate change impacts are uncertain and more immediate and familiar needs can take priority.

The City of Carlsbad shares these common institutional and financial barriers to comprehensive climate adaption planning. The city's Climate Action Plan (CAP) is a GHG emission reduction plan intended to mitigate impacts associated with implementation of the recently updated General Plan. The CAP does not contain any climate adaptation strategies. The Sustainability and Safety elements of the General Plan contain only limited mention of climate adaptation and no comprehensive policies. Without expressed policies to guide decision-making and budgeting, successful implementation of climate adaptation initiatives and projects requires a different approach.

The City of Carlsbad is leveraging its existing Community Vision of Sustainability and regional partnerships to overcome these barriers and pursue climate change adaptation projects in the areas of natural resource resiliency, energy, and sea level rise. The city has also found, as noted in recent research, that by employing a project-level approach, the city can begin its path to climate adaptation with successes that can gain community momentum for future adaptation efforts (Lyles & Berke, 2017). Despite its lack of climate adaptation policies, programs, or comprehensive plans, Carlsbad has been able to pursue climate adaptation projects by translating the issues into the existing policy language of sustainability and leveraging the San Diego Region's many climate related partnerships.



## Moving Forward; Research and Coordination Gaps

**T**he San Diego region faces numerous challenges imposed by climate change. The writing of this report brought together a diverse group of stakeholders to discuss climate vulnerabilities and adaptation in the region. The group identified research and coordination gaps and opportunities that, if addressed, will help build climate resilience in the region.

Feedback from stakeholders clearly highlighted the need for improved cost-benefit analyses that examine the financial benefits and risks of decisions made in the near-term that include climate change impacts in the analysis. Such analyses includes costs of development in areas that present high wild-fire risk as a way to provide more affordable housing, the costs of beach nourishment (including the impacts of flooding and ecosystems to offset beach erosion), and the cost of moving or redesigning infrastructure in the next couple of decades versus to later in the century. More specific research needs are identified below.

### Research Needs and Next Steps

#### CLIMATE

- Improved understanding and modeling to determine how San Diego County's highly variable precipitation regime and attendant hydrological balance may be altered due to climate change to support management and planning for water supply, flood protection, water quality, and ecosystems.
- Better long-term observations should help to investigate processes and track changes of Santa Ana winds. A reliable, long-term wind record is needed to more reliably downscale winds while humidity projections would help evaluate and inform wildfire risks and out-of-season season (early spring or fall) heat waves.
- Assess the state of wildfire behavior modeling and apply future conditions to identify future climate risk. Integrate fire hazard maps for the region to identify areas that are most susceptible to wildfire.
- Marine Layer Cloud (MLC) is an important determining factor of the climate of the coastal margin in San Diego County but is difficult to resolve at the scale of global climate models (GCMs). Methodologies to better understand how GCM-projected impacts translate into changes in MLC has large implications for the future climate and impacts to public health (heat waves), energy (solar energy production), water demand, and ecosystems.

#### COAST

- Wave forcing of beach erosion and accretion and wave-cliff interaction are poorly understood. Coordinated monitoring of waves and coastal change measurements and modeling are just beginning and must continue in order to enable reliable prediction of future influences of sea level rise on beach and cliff erosion, and especially to inform beach nourishment decisions.
- Wave and storm surge flooding processes and exposure of open coast and urban infrastructure such as low-lying streets, roads, homes, businesses, sewers and power plants, and other facilities are poorly understood and quantified. Monitoring and modeling have recently begun, but intensive research is critical.





## CALIFORNIA'S FOURTH CLIMATE CHANGE ASSESSMENT



- There is a need for additional pilot and demonstration living shoreline projects to broaden expertise and encourage regional leaders to integrate these strategies into long-term planning. Specifically, there is a need for additional research on the efficacy and costs and benefits of nature-based strategies (e.g., living shorelines), and their connection to community resilience.
- San Diego Bay, whose shoreline area is highly developed and populated and a vital element of the San Diego economy, will be exposed to sea level rise impacts, but there are limited studies and insufficient monitoring in the bay.
- Integration of the latest science on sea level rise, coastal and estuarine circulation, sediment transport, and sea cliff dynamics.
- Evaluation of adaptation measures including both living shorelines (dune restoration and oyster reefs) and less natural approaches (sea walls, groins, offshore breakwaters, and beach nourishment) or some combination of multiple approaches to inform local government adaptation policies that include science-based thresholds for triggering various adaptation strategies.
- Similar to the “Great Shake-Out” or “ArkStorm,” integrated scenario planning under extreme conditions sea level conditions with and without sea level rise to help inform planning and hazard preparedness.
- Develop real-time forecasts for response to extreme sea level events.
- Improve understanding of how sea level rise impacts groundwater salinity and sustainability in the region.

### LANDSCAPES

- Vegetative modeling to understand how climate change may affect native vegetation may change impacting ecosystem function and fuels and wildfire risk.
- A cost-benefit analysis and prioritization is needed to better understand where and when to conduct fire management strategies to optimally reduce fire risk and protect biodiversity.
- Possible thresholds or triggers for changes in management action associated with various forms and magnitudes of climate change should be evaluated. In concert, an assessment of attendant monitoring programs should be conducted to deliver the necessary data to inform management actions.
- Climate change impacts, including economic impacts, on nursery and cut flower operations, a major portion of San Diego’s agriculture, should be investigated.
- The benefits of carbon farming and how it can best be implemented could be more broadly explained to agriculturalists in the region.

### INFRASTRUCTURE AND SERVICES

- Work to better understand how higher temperatures and a changing precipitation regime will impact regional hydrology and water demand as well as supply, both local and non-local.



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- Understand how increased temperature will impact harmful algal blooms and the potential impacts to fisheries and riparian ecosystems.
- Continue to explore linkages between water and energy, and how conscious use and management of each of these resources with regard to the other can provide multiple benefits to the region.
- Assessment of energy demand in the San Diego region under climate change that includes an assessment how the grid will respond to higher temperatures. Analyses should include scenarios when coastal clouds are present and absent and the associated energy produced by photovoltaics and how this impacts the overall grid response.
- Improved ability to simulate hot, humid and cloudy events with weather forecast models and climate models.
- Understand and assess how smart meters can be integrated in decision making at the local, regional, and state level.
- Determine transportation infrastructure impacts from climate change and integrate climate change considerations into material requirements, infrastructure design, and improvements.
- Develop strategies and infrastructure to improve data flow and communications for emergency managers and the general public to provide situational awareness and risk preparedness during hazardous events.

### HEALTH

- Increased mechanisms to share climate and human health data across the various sectors to better understand how climate changes may inflict health problems and how to mitigate and adapt to them.
- Identify the trajectory of disease burden under climate projections through the use of calibration of predictive models.
- Improved understanding of heat health-related impacts to the outdoor work force and recreation and the resulting impacts to the economy.
- Improved assessments of public health interventions to determine if interventions have and will reduce mortality and morbidity, especially among the most vulnerable. Best practices and related research in adaptation pertaining to public health interventions should also continually be explored, communicated, and adapted for the region.
- Identify the potential mental health impacts from heat and prepare first responders.
- The region needs more engagement of the general public and community stakeholders to discuss potential threats to human health, promote preparedness, and discuss what individuals can do to protect themselves and others.

### CROSS BORDER

- Binational and transboundary data sharing, vulnerability assessments, and adaptation planning through strong border collaborations and promotion of urban and economic development strategies, water conservation, and green infrastructure.



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- Understand drivers and more accurately quantify cross-border flows of water, pollutants, sediment, and solid waste, especially as related to changing land use patterns in Tijuana.
- A regional social vulnerability study that outlines impacts to communities on both sides of the border and also identifies opportunities for San Diego and Tijuana to work together to reduce socioeconomic vulnerabilities and increase local resilience to climate change.

The generation of this report has already contributed to the regional momentum to build climate resilience in the San Diego region. By identifying and addressing the gaps listed above, and through coordination with regional boundary organizations and on-going efforts, the San Diego region can carry the momentum forward to address the many challenges presented by climate change. The efforts in San Diego also promote improved resilience statewide by sharing lessons learned and providing examples of hurdles and successes.





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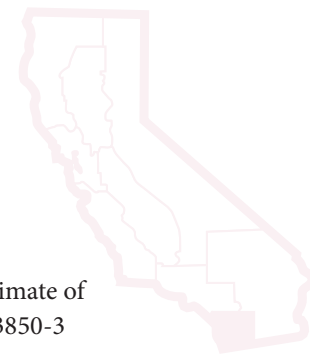
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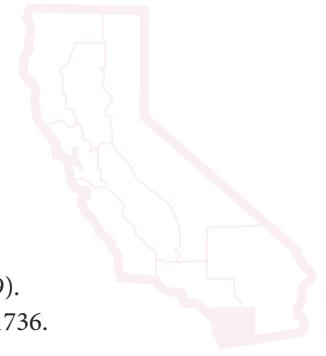


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