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CHAPTER 1: INTRODUCTION AND SUMMARY

The San Diego region is well-known for its unique combination of mild climate, low rainfall, breathtaking shorelines, mountains, and deserts - all in close proximity. Combined with this magnificent diversity of natural environments, the region offers a high quality of life and prosperous economy to its three million residents. Not surprisingly then, the region has also been one of the fastest-growing areas in the nation. It is also a region increasingly under stress. This is not only from population growth, but also the complexity and fragility of the interrelationship between urban and natural systems.

Looking ahead, these stresses will be compounded by climate change. Climate change due to the build up of greenhouse gases from human activities, combined with regional growth, land use policies, economic investments, as well as ecosystem responses will determine what our region looks like into the future. The 2007 report of the Intergovernmental Panel on Climate Change (IPCC) concluded, "…warming of the climate system is unequivocal." The more rapid and intense the climate change, the more severe the local impacts will be, some of which are unavoidable.

This scientific study considers the regional impacts due to climate change that can be expected by 2050, if current trends continue. Higher temperatures, changing precipitation, and a rising sea level will create new issues that will require considerable planning and coordination, as well as exacerbate existing stresses. The extent to which these impacts from climate change affect local communities will depend not only on our ability to change current trends and reduce regional emissions, but also on careful planning in the face of the most serious vulnerabilities.

As the first regional assessment of climate change impacts within California, the following working papers address the likely local impacts on climate, sea-level rise, land use, water, energy, public health, wildfires, biodiversity, and natural ecosystems. It draws upon the most current scientific analysis from over 40 experts from the region's universities, local governments, nonprofits, public sector agencies, and private sector firms. A primary aim of this Focus 2050 study is to provide a scientific basis for local governments and public agencies to develop climate-preparedness plans. To best prepare the region, such planning should include strategies for mitigating the damage from, as well as adapting to, climate change. A key concluding message is that there is no "silver bullet" to deal with these projected impacts. Rather, there is a serious need for continued dialogue and research, as well as coordinated planning among local, regional, and state authorities to determine the best management strategies.

> *No matter what our global society does to mitigate the growth of greenhouse gas emissions, people around the world will have to adapt to climate change; the questions are not whether but who, when, where, and how much. Finding reliable answers to the questions, "What, when, where, who, and how much?" is the goal of climate change impact assessment. It is a key step leading to the capacity to adapt.*
>
> **-- Charles F. Kennel, Former Director, Scripps Institution of Oceanography**

Study Overview

The San Diego Foundation's Regional Focus 2050 Study (Focus 2050 Study) was conceived of and commissioned by the Foundation's Environment Program.[1] The Foundation contracted with UC San Diego's Environment and Sustainability Initiative (ESI) to serve as the project manager for the Focus 2050 study in coordination with Foundation staff. Contributing authors developed each working paper in a coordinated process, and then the combined report was externally peer-reviewed. A workshop was also held in June 2008 to present key findings to the study's stakeholders and to invite final comments and suggestions for the report prior to publication. The Focus 2050 Study for the San Diego region is modeled, in part, on the Focus 2050 study undertaken by King County, Washington.[2] This study also forms the basis for a technical assessment which was developed for inclusion in the 2008 Climate Change Impacts Assessment, Second Biennial Science Report to the California Climate Action Team.[3]

Methodology

The range of impacts presented in this study are based on projections of climate change using three climate models and two emissions scenarios drawn from those used by the Intergovernmental Panel on Climate Change (IPCC). A number of analytical models were developed and used for this study to provide quantitative estimates of the impacts where possible. For example, wave and sea level modeling was used to develop a range of impacts on six low-lying coastal areas in the region. Also, temperature data from the IPCC scenarios was applied to regional ecosystems models to provide information on the migration patterns of species trying to adapt to higher temperatures. These temperature data were also used to extrapolate forecasts of peak electricity demand in the region, which will be exacerbated by higher temperatures as well as the faster inland population growth where the country is hottest.

For some impacts, the study has relied on a literature review and summary of the latest research in the topic of interest. For example, the increased likelihood of regional wildfires as well as the relationship of heat stress illnesses and fatalities due to rising temperatures has been based on these expert reviews. Similarly, the long term supply issues associated with external water deliveries from the Sacramento River Delta and the Colorado River have been based on the conclusions from outside research. These water supply conclusions have been combined with an analytical extrapolation of regional water demand to develop an overall supply and demand analysis for this study. In addition to analyzing the projected impacts, each section of the report offers some insight into potential methods and measures which could be implemented to prepare the San Diego region to be resilient to climate changes.

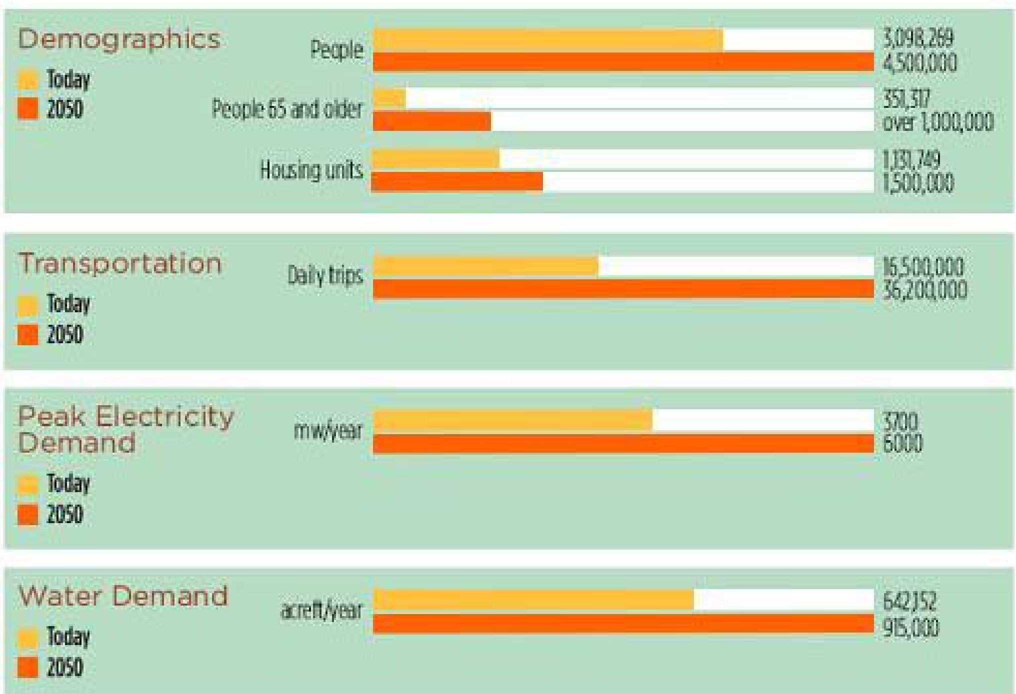
Regional Growth by 2050

By 2050, the population of San Diego County is expected to grow to 4.5 million[4], approximately a 50% increase from the population in early 2007 of 3,098,269 people. In

[1] More information is available at http://www.sdfoundation.org/communityimpact/environment/index.html
[2] More information is available at http://dnr.metrokc.gov/dnrp/climate-change/conference-2005.htm. (Last visited on 06/18/08)
[3] This technical assessment is entitled, *Climate Change-Related Impacts in the San Diego Region by 2050.*
[4] State of California, Department of Finance, Population Projections for California and Its Counties 2000-2050, Sacramento, California, July 2007.

percentage terms, the inland portion of the region shows the fastest change, some areas growing by well over 150 percent. This growing population will not only impact the way in which San Diego adapts to climate change, but will also exacerbate the effects of climate change as well. As the region's population grows, it will also become older. By 2050, almost one quarter of the region's residents (over 1,000,000) will be age 65 and older, with over half being older than age 41. Age groups under 18, and between 18 and 64, will grow more slowly – at around 10 percent each. The aging population of San Diego will be more vulnerable to the public health impacts of climate change, including increased heat waves and air pollution.

Population trends have connections with regional job growth, housing trends, travel behavior as well as demands for critical resources such as water and electricity. Growing slightly faster than population at 15 percent, the region's employment base will expand by 272,000 jobs by 2050. The figure below summarizes some of the other important patterns of expected growth without consideration for climate change impacts.



KEY CLIMATE CHANGE IMPACTS

Warming

We can already see changes in the Earth's climate system. The Earth is now globally about 1.4 degrees F warmer than in the late 19th century. Warming in the last 50 years has taken place at nearly twice the rate for the last century. Across San Diego County, all six climate model simulations project warming across the region by 2050– ranging from about 1.5 to 4.5 degrees F on average, with variation by season and geographic distribution through the region. While temperature increase in coastal areas will be slightly tempered by the Pacific Ocean, inland areas will be as much as 2 degrees F warmer in comparison. These inland areas are also where the population will be growing most rapidly. There will also be greater warming in summer than in winter, with 0.7 to 2 degrees F additional warming in the summer months.

Heat Waves

Heat waves will increase in frequency, magnitude and duration. For instance, the number of days over 97.3 degrees F in the Miramar area is projected to increase six-fold by 2050. Extreme warm temperatures in the San Diego region today mostly occur in July and August, but as climate warming takes hold, the occurrences of these events will likely begin earlier and continue later into the year.

CURRENT RANGE
OF EXTREME HEAT DAYS

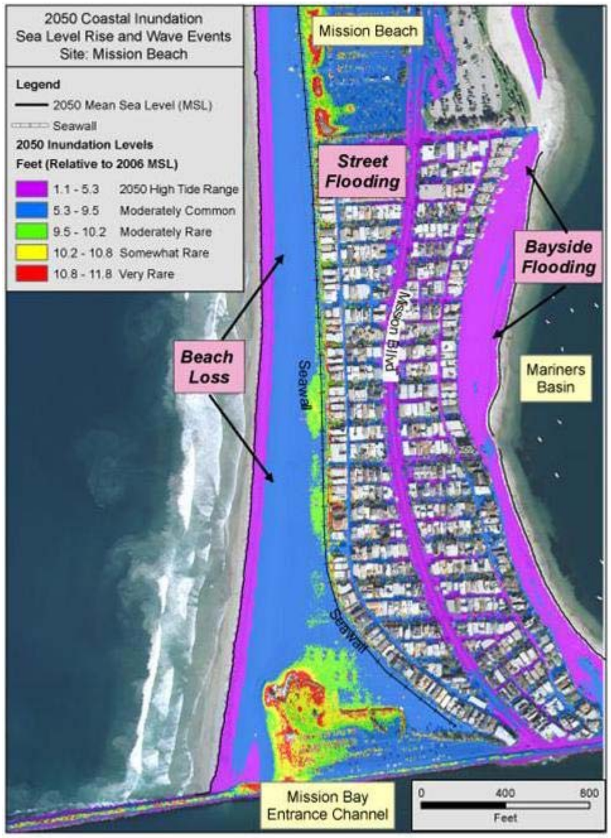
2050 RANGE
OF EXTREME HEAT DAYS

Precipitation

The impact of climate change on precipitation is not entirely clear at this time. Analysis indicates that while San Diego will retain its strong Mediterranean climate with relatively wetter winters and dry summers, projections of future precipitation have mixed results. One important aspect of all model projections, however, is that the high degree of variability of annual precipitation will prevail, suggesting the region will continue to be highly vulnerable to drought.

Sea Level Rise

Sea level rise, averaged globally over the 20th century, has been about 7 inches. By 2050, another 12-18 inches of sea level rise is expected for the San Diego region. This will result in serious flooding in low-lying areas with permanent loss of current sandy beach and increasingly frequent intrusion into near-shore streets, recreational areas, ecosystems and wetlands. There will be an increased incidence of extreme high sea level events which occur during high tides. As the decades proceed, these events will tend to persist longer, likely causing greater coastal erosion and related damage. Serious economic and environmental consequences can be expected, though studies have not yet fully quantified the regional impact. Full page maps of projected inundation in six low-lying coastal areas are provided in Chapter 3, with an example assessment in Mission Beach below.



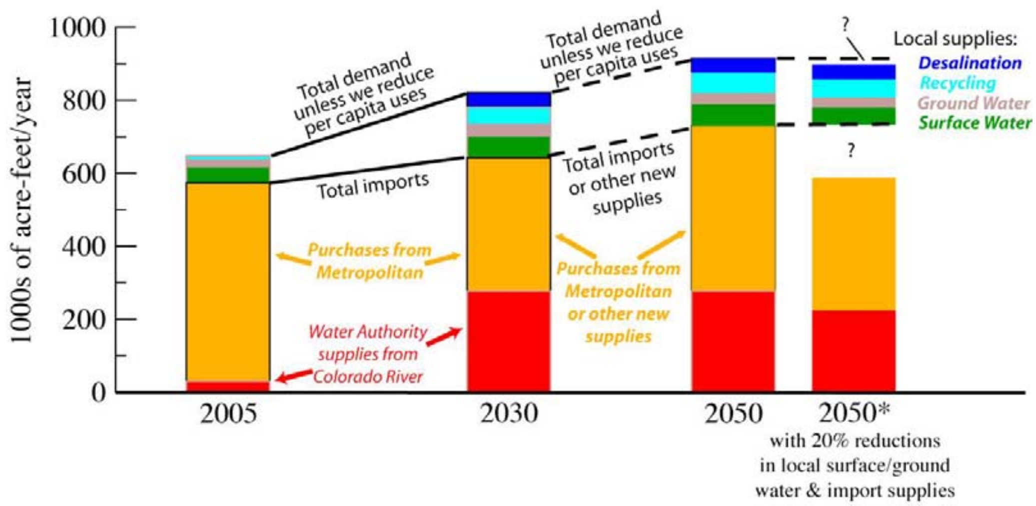
Mission Beach: *Tidal fluctuations alone (purple) appear to inundate portions of sandy beach and streets from bayside flooding. Adding run-up from moderately common wave events (blue) floods majority of sandy beach, streets and parts of Mission Beach Park. Moderately rare wave events (green) appear to breach seawall and inundate streets and sidewalks. Very rare wave events (red) flood sandy beach, surface streets and heavily-used boardwalk in Mission Beach.*

Water Supplies and Demand

Climate change will negatively impact the availability of both imported and local water supplies, while population and economic growth will drive up water demand. If current trends continue, by 2050 regional water demand is projected to increase 37 percent above recent levels. Notably, by 2050 residential demands will comprise 66 percent of the total regional water consumption. This illustrates the continued importance of modifying individual consumer behavior, especially the heavy use of water for residential landscaping, in order to reduce the pressures on regional water supplies.

Regional water demands will continue to be met primarily by importing water, with imports from the Sacramento Delta and the Colorado River comprising about 80 percent of total supplies in 2050. Climate change threatens the reliability of both of these sources, however. Significant reductions in Colorado River flows are expected, with projections ranging anywhere from 6 to 45 percent declines. Freshwater available to San Diego from the Sacramento River Delta will be less certain by 2050 due to Sierra snowpack reductions of at least 25 percent, as well as the need for authorities to manage the fragile balance between the Delta's ecosystem health, water quality, and water demands from the burgeoning statewide population. Blank areas in the rightmost column of the figure below illustrate potential shortfalls in water supplies for the San Diego region by 2050 due to the estimated 20 percent reductions in the volumes of available imported water and local surface and ground water supplies. This figure, and related conclusions, are described further in Chapter 4.

Projected Water Demand and Supply in 2005, 2030, and 2050 under "Normal Year" and Climate Change Conditions.



Managing and acquiring adequate water resources for the San Diego region will continue to be a complex and increasingly difficult challenge in the upcoming decades. Local supplies of water will play an important role in sustaining demand, but are projected to reach foreseeable limits by 2015 unless less-traditional sources, such as water recycling or desalination, are employed. There is much reason for concern that even with creative and innovative arrangements among competing water interests, with concerted conservation measures, and with enhancement of identified supply sources, the combined effects of regional growth, water use practices, and climate change will expose the region to greater risk or water shortfalls even before 2050.

Wildfires

San Diego County already has among the worst fire conditions in the country, and the situation is likely to worsen with climate change. Historically, wildfire frequency has increased in direct proportion with population growth, portending a hazardous trajectory of the future fire regime given the expected human growth by 2050. Different climate change models yield somewhat different predictions about the frequency, timing, and severity of future Santa Ana wind conditions, leading to uncertainty regarding how San Diego regional fire regimes may differ in the future due to climate change. Preliminary research by the California Climate Change Center suggests that such wind conditions may increase earlier in the fire season, and continue later into the year. Furthermore, the spread of invasive species that are more fire-prone, coupled with more frequent and prolonged periods of drought, also increase the risk of fires.

While fire is a key ecological process regionally, and our native species are well-adapted to the long-term *natural* fire regime, the changes to this regime may be faster than many species can adapt to. Research has shown that of the eight megafires (affecting more than 50,000 hectares) recorded for the region, half have occurred in the past five years. The implications to San Diego of an increase in fires go beyond impacts on biodiversity and ecosystems however, and represent risks to public safety, human health, the built environment, air and water quality.

Ecosystems

As a global biodiversity hotspot, the biological richness of the San Diego region is difficult to overstate, and is already under stress from population growth and habitat fragmentation through land use changes. A changing climate will add to the stress on ecological systems in ways that may create feedback cycles with significant and cascading consequences. Plant and animal species will each differ in their sensitivity to a changing climate, but the fact that they depend on each other increases the overall effects. Additionally, with climate change, the "climatic envelopes" where species need to make their habitat will move due to increasing temperatures and more frequent fires. Their likelihood of surviving such a shift may be limited through the speed at which they are forced to do so, as well as the increasing conversion of land for human use, habitat degradation by non-native grasses, unsuitable soils, or other physical limitations.

Thorne's Hairstreak butterfly is a highly restricted species that had all known occupied patches burn in a single fire in 2003.

Forest ecosystems will be substantially affected by temperature rise and indirect climate change affects in California. Extended drought can stress individual trees, increase their susceptibility to insect attack and result in widespread forest decline. Stressed trees have less resistance to insects, such as bark beetles that girdle and kill the trees. More indirectly, warmer winter temperatures projected regionally can increase such insect survival and populations.

Coastal ecosystems are particularly vulnerable to the combination of climate change and population growth. Intertidal and subtidal habitats along San Diego's coastline contain a large diversity of marine algae, invertebrates and fish. Sea level rise and ocean acidification, coupled with more intense storms may wipe out certain habitats altogether. For instance, two intertidal marine reserves, Cabrillo National Monument and Scripps Coastal Reserve, are bordered by steep cliffs and will almost certainly lose much of their intertidal habitats. Predicting which species will persist or not, and how changes in species composition and abundance may affect local productivity and fisheries remains a complex challenge.

Public Health

Climate change effects on human health will be both direct, with temperature and extreme weather-related illness and death; as well as indirect, with air pollution-related harm, wildfire injuries and deaths, and vector-, rodent-, and water-borne disease. The aging population in San Diego will likely face more mortality events associated with such extreme heat events and the increase in temperature due to climate change. Notably, heat waves in California have claimed more lives over the past 15 years than all other declared disaster events combined, indicating the level of vulnerability in San Diego due to such projected increases.

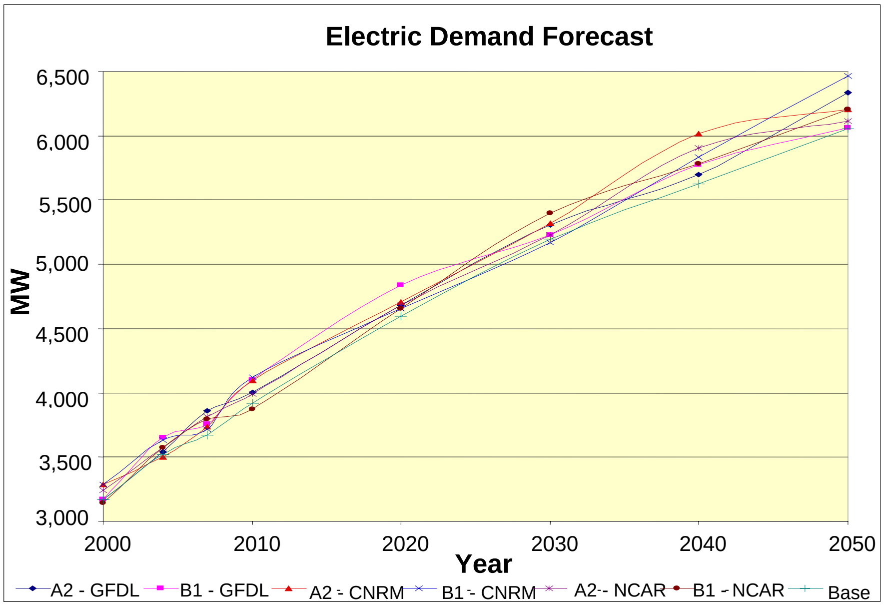
Already, Californians experience the worst air quality in the nation. San Diego County is currently out of compliance with the federal ozone standard, and the Environmental Protection Agency (EPA) has projected that this will still be the case by 2020 despite current regulatory efforts. High ozone levels have been definitively associated with adverse human health effects, including exacerbation of asthma and other respiratory diseases, cardiac effects, and mortality. The number of hot, sunny days that are conducive to ground-level ozone formation is likely to rise due to climate change by 2050.

Analysis of climate change impacts on regional fine particulate matter ($PM_{2.5}$) concentrations is less certain than that of ozone levels. Modeled results indicate that particulate matter air pollution levels move in different directions under different climate models and emissions scenarios. Thus, effects on mortality from this type of air pollution are not definitive at this time.

The incidence and spread of a number of infectious diseases can be affected by climate change. By 2050, the potential for waterborne diseases will increase in San Diego County as population increases, water becomes scarcer, and the ecosystems which provide natural purification services decline and become more stressed. In coastal waters, conditions are likely to favor more frequent “red tides” or harmful algal blooms, which could interact with increased incidence of pathogens from runoff and sewage outfalls, resulting in increased health risk. Additionally, climate change in San Diego County could increase the risk of certain vector-borne diseases while decreasing the risk of others. Modeling the occurrence of vector-borne diseases is difficult however, because they are influenced by a variety of factors which interact in ways that are complex and poorly understood.

Electricity

Coupling projected growth in the population and economy, total electricity demand by 2050 is projected to increase by approximately 60 percent, and peak loads by 70 percent. Climate change accounts for approximately 2 percent of the expected rise in electricity consumption by 2050, and up to 7 percent of the increase in peak demand. Additional peak demand will be primarily due to the need for more cooling in the summer, especially in inland areas where both regional population growth and temperature increases will be highest. Additionally, the possible implementation of seawater desalination to diversify water supplies is likely to boost overall electricity use in the region by 1-1.5 percent by 2030.



Climate change will have also an impact on system reliability unless adequate planning and investments are made, and consumers modify their consumption patterns. Peak demand will be even more challenging to deal with due to higher frequency of heat waves. Summertime, when demand is highest, is also the time when electric utility operating efficiency is lower and line losses increase—both due to temperature effects.

Conclusions

Despite not fully knowing all the details, it is abundantly clear that climate change, coupled with significant population growth, poses serious threats to the region's resources and welfare. While climate change is a global issue, a key message of the analysis in this study is that the San Diego region is uniquely threatened. Some impacts do not necessarily represent new challenges to the region, but it is the extent and intensity of these changes due to climate change which will be novel and unlike that which we've had to manage before.

The San Diego region, by 2050, will have to concurrently deal with the major challenges of protection against sea level rise, increased risk of large wildfires, increasingly uncertain water imports from the Sacramento Delta and Colorado River, increased electricity demands, and public health issues associated with heat waves and an increase in some infectious disease. Our ecosystems are also already a unique hot-spot for endangered and threatened species and climate change will place even greater adaptation stresses on these species.

An overarching recommendation is that public decision makers and agencies keep moving in a common direction on understanding the climate forecasts for the region, which in turn should facilitate better joint planning. For example, fire protection agencies, utility planners, and public health planners should have a common understanding of temperature increase expected for the region to plan effectively.

Likewise, water agencies and fire prevention agencies should have a uniform understanding about the likelihood of droughts and precipitation patterns.

Though this Focus 2050 study does not definitively project all the economic, social, and environmental costs associated with the outlined risks, a heavy price for continuing "business as usual" is anticipated. Shoreline protection and modification or relocation of critical facilities will need to be addressed. Investment will be required to ensure adequate water and power to meet the growing population's demands and to protect our endangered ecosystems and unique biological diversity. Additionally, this study focuses on the adaptation needs of our region to climate change, but it is important to recognize the need to reduce local emissions as a way to reduce the seriousness of these impacts of climate change before we face them in 2050. Through sensible adjustments, forward-thinking policy making and coordinated action, we can prepare our communities and enhance the region's capacity for resilience to climate change.

In adaptation to climate change, many of the actions to be taken will be local, where the greatest complexity of interaction between human society and natural systems is often found. The response will have to be adaptive and incremental. Each region and locality has its unique combination of environmental, economic, and social factors, its own ways of reaching decisions; each will have to monitor, model, assess, and decide... and monitor, model, assess, and decide… again and again.

-- Charles F. Kennel, Former Director, Scripps Institution of Oceanography

CHAPTER 2: POPULATION, TRANSPORTATION, & LAND USE

Introduction

This chapter provides an overview of the San Diego region's geography, demographic trends, economics and governance structure in order to provide a foundation for the assessment of climate change risks. The region is growing, and this growth is projected to continue. The percentage of population over 65 years is growing and increasingly will live inland and drive more. The way we grow will determine how we experience climate change. The decisions we make today may ensure greater resilience to, or greater risk from, climate change. This report helps to paint a picture of how current growth trends will affect our ability to adapt to climate change in the future. The choices we make today – and the extent to which we decide to act now – can mitigate future risks.

SAN DIEGO TODAY	SAN DIEGO IN 2050	% CHANGE
Demographics	**Demographics**	**Demographics**
3,098,269 people	4,500,000 people	46.19%
351,317 people 65 and older	Over 1,000,000 people 65 and older	> 184.64%
1,131,749 housing units	1,500,000 housing units	32.54%
Transportation	**Transportation**	**Transportation**
16.5 million daily trips	36.2 million daily trips	119.39%
Peak Electricity Demand	**Peak Electricity Demand**	**Peak Electricity Demand**
4,500 MW/year	7,000 MW/year	55.56%
Water Demand	**Water Demand**	**Water Demand**
642,152 acre-feet/year	915,000 acre-feet/year	42.49%
CO_2 Emissions	**CO_2 Emissions**	**CO_2 Emissions**
17,593,000 tons CO_2 from road transportation	Business as usual projection for 2030 from road transportation: 24,425,800 tons[1]	38.84%

Table 2 -1. San Diego regional changes.

Geographic Profile

San Diego is highly diverse in its geography and biology. San Diego County covers approximately 4,255 square miles, including 70 miles of coastline, bordered on the south by Mexico. The region is situated in the rolling hills and mesas that rise from the Pacific shore to join with the Laguna Mountains to the east. Its bay is one of the country's finest natural harbors. The region covers a large area of vastly different terrain: miles of ocean

[1] This projection is for the year 2030 because the regional transportation plans only go out to the year 2030, limiting the ability to estimate emissions from road transportation out to 2050.

and bay shoreline, densely forested hills, fertile valleys, as well as mountains, canyons and desert. The seasonal precipitation for San Diego is roughly 10 and a half inches depending on which series of seasons that are used for the average. La Mesa and El Cajon receive roughly 12 inches and Palomar Mountain receives roughly 40 inches.

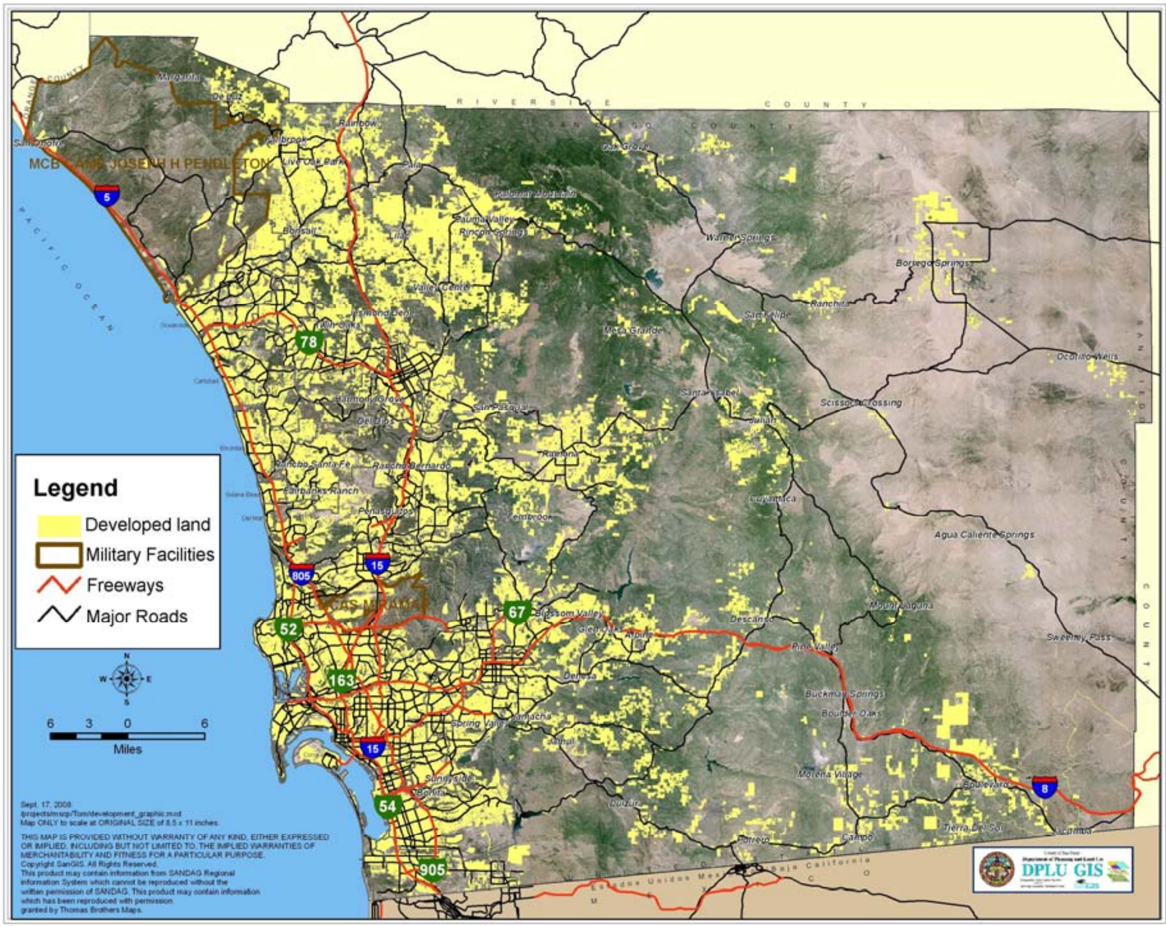


Figure 2-1. Overview of San Diego land use[2]

This study uses San Diego County and the term "San Diego region" interchangeably. It includes 18 incorporated cities, 18 federally-recognized tribal reservations, and the unincorporated communities with a combined population of over three million people. The region is one of the fastest-growing areas in the country. Its combination of high biodiversity, large numbers of rare and unique species, and rapid urbanization has created stresses on the economy and the ecosystem. This chapter describes current and projected demographic and economic activity.

[2] San Diego County Department of Planning and Land Use Geographic Information System Division.

Demographic Trends Through 2050

Population Trends

The population of San Diego County in January 2007 was 3,098,269 people living in 1,131,749 housing units.[3] The San Diego Association of Government (SANDAG) Regional Growth Forecast (RGF) projects that between 2004 and 2030 the region will add about one million more people. By the early 2020s, the region's annual growth rate will fall below one percent and be slightly above that expected for the U.S. overall (see Figure 2-2). Currently, Riverside County, Imperial County, and Tijuana are all growing at faster rates than San Diego.

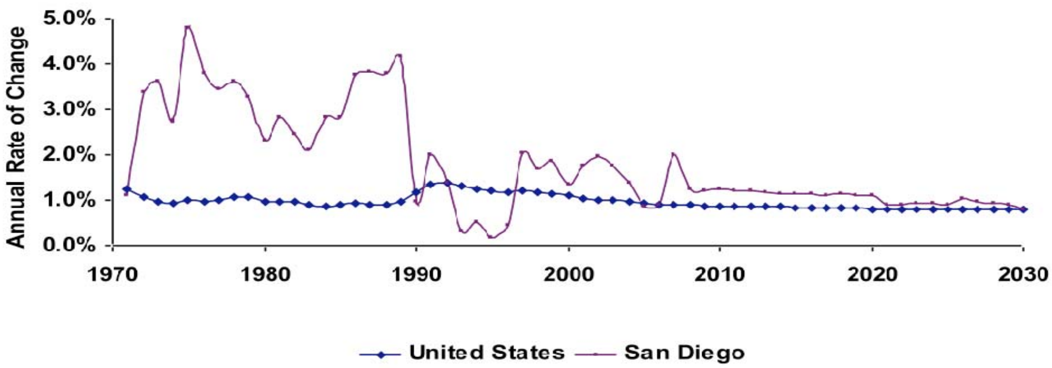


Figure 2-2. Population growth slows in the San Diego region. [4]

Trends beyond 2030 are examined using a population forecast developed by the California Department of Finance (DOF).[5] The region's population is projected to reach 4.5 million in 2050, an increase of 524,000 persons beyond the 2030 projections.[6] Population growth continues to slow beyond 2030.[7] On average the region's population increases by 0.7% per year, which matches the increase in the U.S. population between 2030 and 2050. This growing population will not only impact the way in which San Diego adapts to climate change impacts, but also exacerbate the possible effects of climate change.

SANDAG's population growth projections are driven by fertility and mortality levels, immigration policy and local economic conditions. They assume that housing patterns will permit this growth according to current land-use plans and policies as well as

[3] SANDAG. 2007.

[4] 2030 Regional Growth Forecast, SANDAG, September 2006; U.S. Census Bureau, 2004, "U.S. Interim Projections by Age, Sex, Race, and Hispanic Origin," Internet Release Date: March 18, 2004.

[5] State of California, Department of Finance, 2007.

[6] To judge the reasonableness of the DOF 2050 forecast, an independent forecast was prepared based on the average of different extrapolation trends, including an ARIMA (0,2,2) model with no constant. This forecast showed a population of 4.7 million for the region in 2050, 4.4% higher than the DOF forecast. This suggests that the DOF forecast may be conservative, but this difference is well within the expected error of a forecast this far into the future.

[7] Average annual increase of 28,000 persons between 2030 and 2050 compared to average of 37,400 persons between 2004 and 2030.

increased commuting by people willing to drive long distances from outside the area to work in San Diego. Between 2004 and 2030, it is estimated that 99,000 more households will have residents living in Imperial, Riverside, and Orange counties or in Baja California while working in the San Diego region. Long-distance commuting, both interregional and from within the region, has a tremendous impact on transportation facilities and on greenhouse-gas emissions. Researchers suggest that over the long term, sizable levels of long-distance commuting tend to lead to the development of secondary employment centers to reduce commuting times. This is already happening in Riverside County.

Along with the current population and its characteristics, future population dynamics will also be influenced by wages (the nature of employment opportunities), housing prices and the level of amenities in the region. Improving job opportunities and the level of amenities in the region relative to other competing regions will drive up housing prices.[8] SANDAG's modeling structure, with its limited linkages to areas outside San Diego County, has some serious limitations when looking as far out as 2050. Thus, while these projections are the best available for San Diego, the region would benefit from more sophisticated modeling to address the more complex dynamics described.[9]

Trends in Age Structure

As the region's population grows, it will become older. Approximately one quarter of the region's current population are baby-boomers, the large cohort born between 1946 and 1964. Their presence helps increase the median age in the region from 33.7 years in 2004 to 39 years in 2030, an increase of 16 percent. Dynamic changes in the region's age structure will continue to occur from 2030 and 2050, albeit at a slower pace than seen in the 2030 forecast. Between 2030 and 2050, the number of people age 65 and older is estimated to increase by 35 percent, compared to an increase of 14 percent for the overall population. Age groups under 18, and between 18 and 64, will grow more slowly – at around 10 percent each. ***By 2050, almost one quarter of the region's residents (over 1,000,000) will be age 65 and older, with over half being older than age 41.*** The aging population of San Diego will be more vulnerable to the public health impacts of climate change, including increased heat waves and air pollution (see Chapter 7).

Subregional Population

The region's neighborhoods and communities show significant variation in their population change going forward. Population is expected to grow more rapidly in the outer areas of the region, and at a slower pace along the coast. High population growth cities include Chula Vista (52 percent), San Marcos (43 percent) and the unincorporated area (55 percent). Figure 2-3 provides a more geographically-focused look at future population change within the region, focusing on census tracks that typically average between 4,000 and 8,000 people.

In percentage terms, the far eastern half of the region shows the fastest change, with all areas increasing faster than the region, some by well over 150 percent. Relative to the

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[8] This view has been well accepted in the economics literature (Blomquist, Berger, and Hoehn, American Economic Review, 1988) for some time.

[9] SANDAG has embarked on a multi-year effort to upgrade its modeling system centered on a complex spatial economic framework and direct linkages to areas outside the region. This modeling system is known as PECAS, which stands for the Production, Exchange, Consumption, Allocation System.

existing population in these areas, this future growth is significant and has important implications for infrastructure and other services, but represents only roughly four percent of the region's future population growth.

Growth along the coast, including the jurisdictions of Coronado and Imperial Beach, is generally slower than the region as a whole. Other urban areas in the central and eastern parts of the region experience relatively slow growth, with the notable exceptions of the San Diego State area, downtown San Diego and pockets of National City.

There are no official forecasts of the geographic distribution of the projected population growth during the period 2030-2050. However, in the absence of changes in land use and other policies and plans, we assume that the patterns of growth described above will continue, and we have used that assumption in our assessment of climate change impacts.

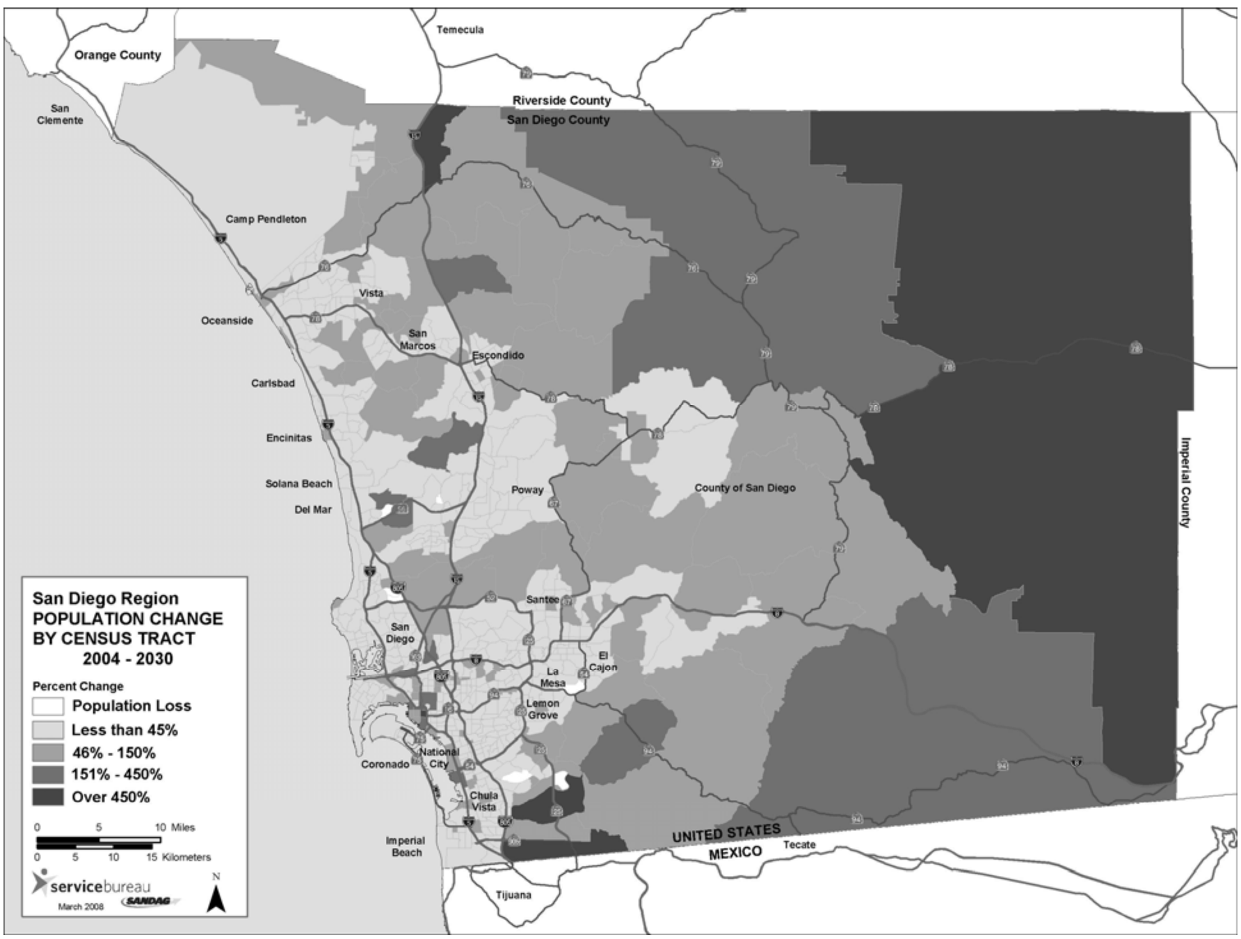

Figure 2-3. Future population growth clustered throughout the San Diego region. [10]

Employment and Housing Trends

As noted above, population growth is directly linked to job growth. The 2030 SANDAG forecast predicts that the region will add 465,000 new jobs by 2030, bringing the

[10] SANDAG. 2006.

employment base to 1.9 million. Jobs are created across all industry sectors. However, the largest gains will be seen in the relatively low-paying services sector, which is expected to grow by roughly 40 percent. The effects of the disparity between local wages and housing costs are already noticeable. More and more people, particularly those employed in lower-paying sectors, are choosing to keep their jobs in the region, but live in more affordable homes in Imperial County, Riverside County and northern Baja California, Mexico.

By assuming the same relationships with population seen in the 2030 forecast, regional employment and housing are forecast to the year 2050. The region's housing stock is estimated to increase by 157,000 units or 11 percent, reaching just over 1.5 million by 2050. Growing slightly faster than population at 15 percent, the region's employment base will expand by 272,000 jobs – making the region home to 2.2 million jobs by 2050.

Land Use and Transportation Trends

One of the main determinants of travel behavior is the pattern of land use in the region. Much of the region's growth has occurred during the past 50 years, a time when automobiles became the travel mode of choice, and land use patterns reflect this trend. The flexibility and speed of the automobile allowed development to be scattered throughout the western areas of San Diego County, a departure from earlier land use patterns that clustered development in neighborhood centers and downtowns. In addition to the wide dispersion of development, individual uses (such as residential, commercial, and institutional) are segregated into single-use zones. This low-density, segregated, land use pattern is what is colloquially known as "sprawl." This distribution of land uses—made possible by the automobile—now *requires* the automobile as well. Most destinations are a considerable distance from one another, discouraging non-motorized modes such as walking and biking. Many types of transit service are uneconomical in sprawling areas, because too few routes can be operated to serve low-density areas and too few riders live or work near existing routes. Consequently, current land use in the region leaves residents with few alternatives to driving.

The historical trend described above has begun to change, as denser, mixed-use projects that enable walking, biking, and transit are being developed in cities throughout the region. Land use authority lies with local governments, some of which have begun establishing these "smart growth" land use policies in their General Plans and implementing them through their Zoning Codes. SANDAG also encourages these policies through its Regional Comprehensive Plan and Smart Growth Toolkit for Local Governments. However, the larger trend going forward continues to be characterized by auto-oriented land use, and, given existing plans and policies, land use will continue to be a prime contributor to vehicular travel demand and accompanying greenhouse gas emissions.

Travel Behavior

Travel behavior is influenced by many factors, including demographics, land uses, lifestyles, the economy, the location of jobs and work practices. Like most major metropolitan areas around the country, the San Diego region has seen a gradual decline in commuting by carpool and transit in favor of driving alone. There is active effort to reverse the trend through changes in policy and infrastructure. As Figure 2-4 shows, while the great majority are work trips, the share of work trips by solo drivers declines by four percentage points, which is accompanied by increasing shares in carpooling and transit. The 2030 Regional Comprehensive Plan and Regional Transportation Plan (both prepared by SANDAG) include policies and improvements that better integrate land use and the transportation system, enhance the public transportation system and carpooling options, and facilitate the use of these alternatives to solo commuting.

The most recent update to the 2030 Regional Transportation Plan (RTP), which was adopted by the SANDAG Board of Directors in 2007, included an analysis of climate change impacts from forecasted regional growth and associated transportation system development. However, the State Attorney General wrote a letter to SANDAG indicating that the draft plan and associated Environmental Impact Report did not fully address impacts of the project on climate change. A number of environmental and community planning advocacy groups submitted similar comments to SANDAG regarding the inadequacy of the climate change analysis in the documents. As a result, SANDAG entered into a settlement agreement with these groups. The agreement calls for SANDAG to undertake additional studies and to give more attention to greenhouse-gas mitigation strategies in the next RTP.[11]

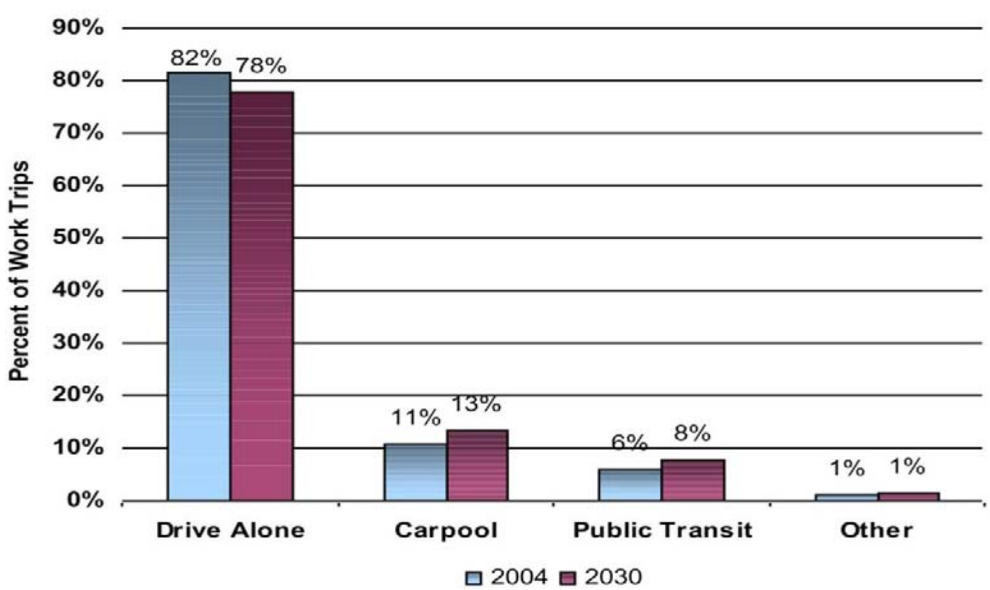

Figure 2-4. Transit and carpooling capture more of work trips in San Diego region.[12]

<u>Increasing Daily Trips</u>

The region's current population makes an estimated 16.5 million daily trips by motorized and non-motorized travel. ***Travel demand is projected to increase by 66 percent to 27.8 million daily trips by 2030, and to 36.2 million daily trips in 2050***. This increase could be offset to some extent by increased fuel prices. It is unclear how fuel prices will influence Vehicle Miles Traveled (VMT) in the future, but the most recent data from the

[11] See Appendix C for Settlement Agreement.
[12] SANDAG. 2007.

Federal Highway Administration shows a significant decrease in early 2008. Nationally, VMT declined by 4.3% compared with March 2007.[13]

Growth in travel consistently outpaced growth in population and employment during the past two decades. Throughout the 1980s, travel as measured in VMT, grew about twice as fast as population, primarily because of growth in two-worker households and longer commute distances. In 1990, daily travel demand was nine million trips. During the 1990s, growth in VMT was 50 percent higher than population growth. This trend is projected to continue through 2030 as vehicle miles traveled would be three times higher than 1980 levels.

With population and employment forecast to increase by 113 percent and 150 percent respectively over the same period, the region faces a large increase in vehicle miles traveled during the next two decades. Between 2030 and 2050, VMT could increase twice as fast as population at 30 percent – adding 8.4 million vehicle miles to the region's transportation system.

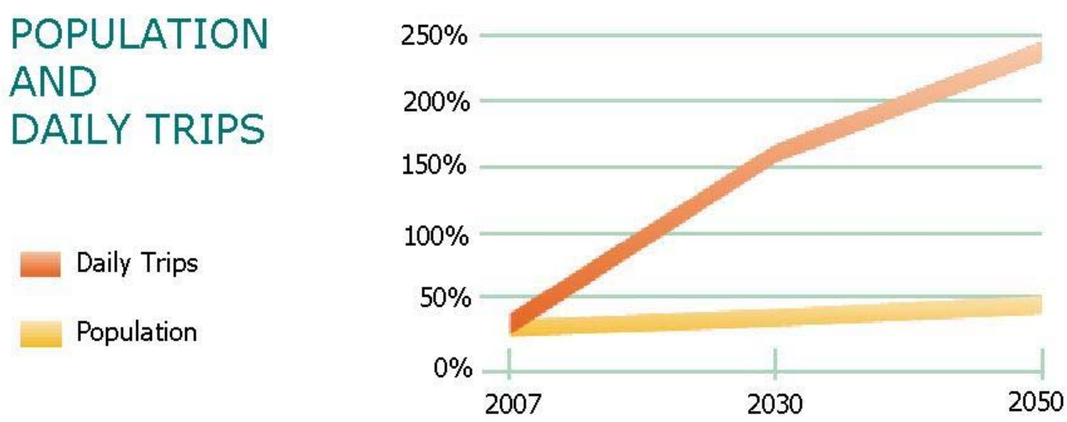

Figure 2-5. Increasing population and daily trips through 2050. [14]

With an increase in traffic and daily trips, there will be an increase in carbon dioxide (CO2) emissions. The San Diego Foundation, SANDAG, and NRG Energy recently funded the University of San Diego's Energy Policy Initiatives Center to conduct the first-ever regional inventory of greenhouse-gas (GHG) emissions for San Diego County.[15] SANDAG is using this inventory to develop a climate action plan with targets for reducing GHG emissions along with strategies to achieve those targets. Examples of strategies include changes in transportation planning and enhancement of traffic demand management (e.g., telecommuting, flexible hours and mandatory ride-sharing).[16]

[13] See U.S. Dept. of Transportation, Federal Highway Administration. http://www.fhwa.dot.gov/ohim/tvtw/08martvt/08martvt.pdf.
[14] SANDAG. 2007.
[15] University of San Diego Energy Policy Initiatives Center. 2008. An Analysis of Regional Emissions and Strategies to Achieve AB 32 Targets. Available at: www.sandiego.edu/epic/ghginventory
[16] See Appendix D.

Economics of San Diego County

The value of total goods and services produced in San Diego County in 2005 was $146.3 billion dollars. While the production of goods is vital, San Diego's economy relies heavily on the service sector for the majority (72.2%) of its output. Major service-sector industries include financial, trade, professional and technical services, communications, high-technology and hospitality. With respect to the production of goods in San Diego County, manufacturing, construction and agriculture are the largest industries, accounting for 7.3 percent, 5.3 percent and 1 percent of total output respectively.

Over the last 50 years, San Diego's economy has changed from one reliant on the military, naval shipping, agriculture and fisheries, to a more diversified economy including manufacturing, scientific research, communications technology and tourism. Future economic growth in the San Diego region will most likely continue to diversify and continue to move toward human capital-intensive industries, such as research, due to San Diego's relatively educated workforce. Additionally, as international trade continues to increase as a percentage of global production, San Diego's export and import industries should continue to grow.

Agriculture

Figure 2-6 shows the real value of San Diego agricultural output as calculated by the San Diego Farm Bureau for the last 20 years. Ornamental plants are the main component of San Diego County's agricultural production. Avocados and tomatoes (reported as fruit/nuts and vegetables respectively) are also important. Recent trends show a movement away from food production and into ornamental products, reducing the capacity of the region to provide for its own food needs. In fact, since the 1960s San Diegans have imported almost all of their food from outside the County.

Increased reliance on food production from outside San Diego County is cause for concern for some from the perspective of sustainable agriculture and community farming.[17] From an economic standpoint, it creates more wealth to put resources, land and water toward their most productive use and then trade that output for food, which can be produced more cheaply outside of San Diego County. As long as trade between food producers can continue to be secured into the future, it will lead to a higher standard of living to import food and the food supply will be secure as well. However, when the full life cycle implications of reduced food production and alternative land use is considered, there may be non-market social and ecological losses that offset direct economic gains. In developing climate mitigation and adaptation strategies, it may be appropriate to give consideration to broader issues related to the overall food system, nutrition and health, as well as ecosystem services associated with choices in land use.

[17] For discussion of food security issues, see for example, Food and Justice: Policy Initiatives for Community Food Security in California, http://www.foodsecurity.org/california/CA_Policy_Platform.pdf.

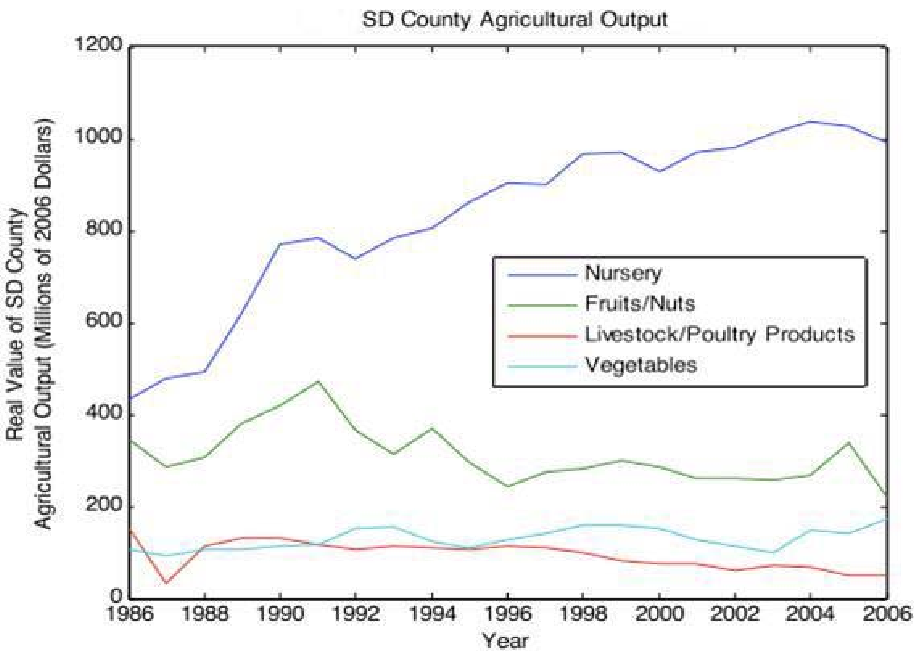

Figure 2- 6. San Diego county agricultural output.

San Diego Regional Governance Related to Climate Change Activities

A number of local, regional and state agencies have jurisdiction (sometimes unclear and/or overlapping) over climate change activities in the San Diego region. Figure 2-7 illustrates the relationship between these agencies. (For a full description of local and regional agencies, see Appendix D.) Much current attention is focused on the state mandates contained in AB32, the Global Warming Solutions Act of 2006. In addition, the state Attorney General has interpreted the California Environmental Quality Act (CEQA) as including greenhouse-gas emissions and is pressing local and regional jurisdictions to measure and reduce greenhouse emissions in their planning and development policies and practices. Thus, climate action plans and supporting analyses are beginning to command attention from local- and county-level entities. Seven cities in San Diego County have signed the US Mayor's Climate Protection Agreement, and two others have joined the California Climate Action Registry. Of these nine cities, two have already developed greenhouse gas inventories and adopted reduction strategies.
Most are struggling with internal coordination challenges, because the climate issue cuts across many, if not most, departments, and rarely has a dedicated staff position been assigned to it. In some cases, non-profit organizations are working with municipal employees to provide assistance and support in climate mitigation and adaptation strategies.

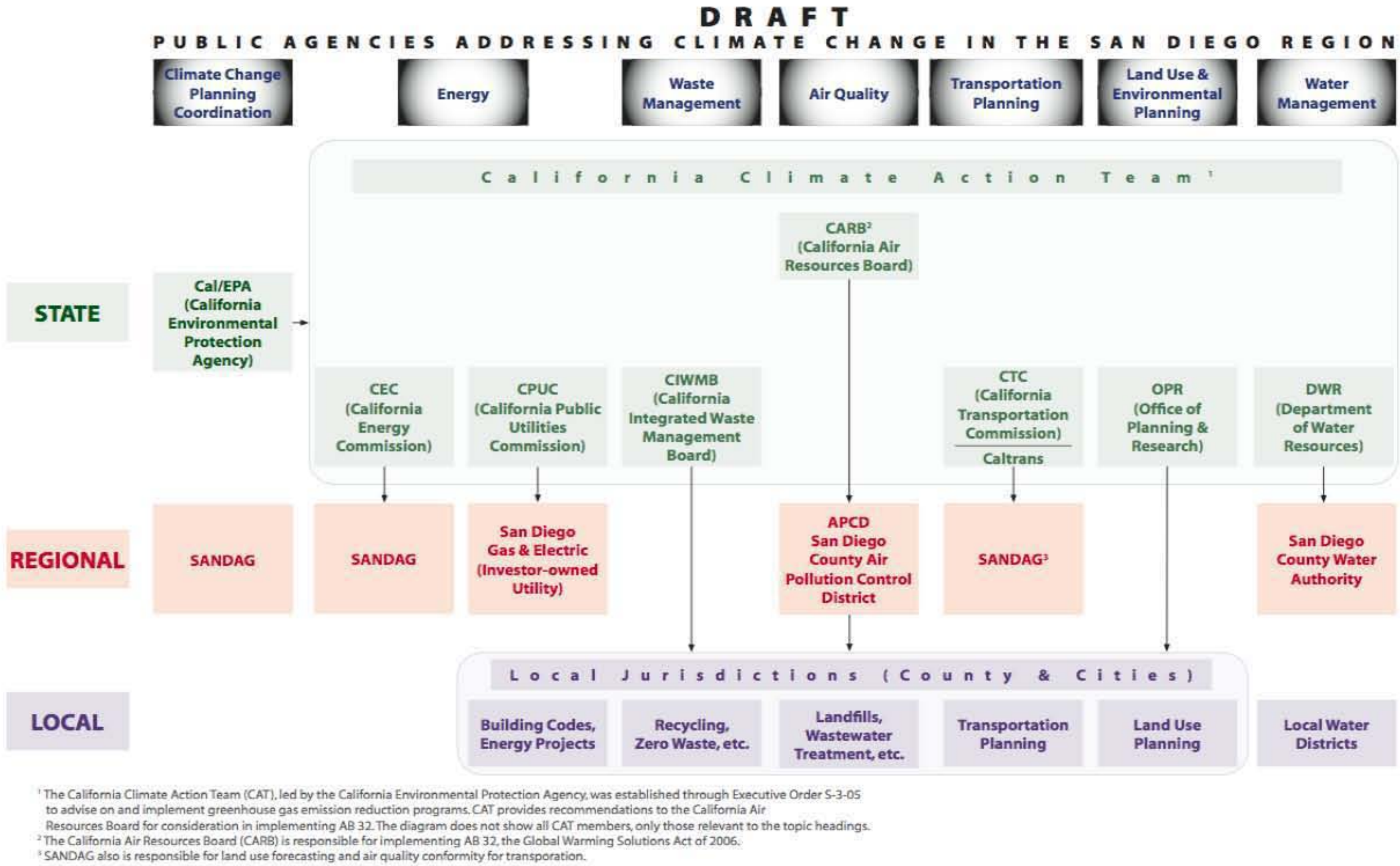

Figure 2 - 7. Public agencies addressing climate change in the San Diego region. Source: SANDAG

Appendix E gives an overview of the state and federal regulatory framework affecting greenhouse-gas emissions, and Appendix F compares federal regulations pertaining to GHG emissions.

Summary

This chapter describes the region's current condition and the outlook for the future beyond the issues of climate change, as a foundation for the subsequent analysis. The growing and increasingly elderly population, the geographic distribution of people and housing, and the projected increase in transportation all have the potential to contribute to increased greenhouse-gas emissions, and will increase the vulnerability of the region to the impacts of climate change. At the same time, state mandates and increased public awareness are beginning to draw attention from municipal authorities, and some effort is apparent in regional and local planning and programs to address climate mitigation and adaptation. This study is intended to contribute to that process and provide a basis for further action.

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CHAPTER 3: CLIMATE CHANGE SCENARIOS

Introduction

San Diego County's climate is changing. Over the next half century, it is very likely that the warming in the San Diego region will equal or exceed the warming that we have seen over the last 100 years. Summers will include more extreme hot days and heat waves will gradually begin to happen earlier, and also occur later during the warm season. Models suggest that the warming impacts will be greater in summer months than in winter, and will be more pronounced inland than along the coast. Sea level is projected to increase by 12-18 inches by 2050. These rates of rise are considerably higher than the region has seen over the last century; therefore, significant impacts on coastal regions can be expected. Precipitation in the region will retain its Mediterranean pattern, with winters receiving the bulk of the year's rainfall and summers being dry. Models lack consensus on whether it will be drier or wetter overall, but because of warming and effectively earlier summer conditions, there is some evidence that the area's landscape will fall into hydrological deficit (drought) more often than it has historically. There is no indication of significant change in the historical patterns of El Niño/Southern Oscillation or in severe storminess.

These projections are based on analysis using three climate models[1] and two scenarios of energy use and greenhouse-gas (GHG) emissions.[2] The models and scenarios were among those used by the Intergovernmental Panel on Climate Change (IPCC) and they are included in the set of models used for the 2008 California Climate Change Scenarios Assessment.[3] Because there is uncertainty about future greenhouse-gas emissions and climate models are still imprecise, we cannot assign specific probabilities to any of these simulations. However, the analysis provides strong and clear indications that the climate that we must plan for will not be the climate to which we have been accustomed.

Climate Scenarios

Climate change attributable to human-caused GHG emissions is happening and its impacts are only beginning to be seen around the world.[4] Scientists have developed predictive models that not only show global trends, but can be "downscaled" to provide more detailed projections of changes over time on the scale of cities and regions (Figure 3-1, San Diego area). Because society may respond to the challenges of climate change

[1] NCAR Parallel Climate Model (PCM), the NOAA Geophysical Fluids Dynamics Laboratory (GFDL) version 2.1, and the French Centre National de Recherches Météorologiques (CNRM).
[2] SRESA2 (A2) and SRESB1 (B1)
[3] These models were selected because they produced a reasonable representation of seasonal precipitation, the variability of annual precipitation and El Niño/Southern Oscillation, when run for historic periods and compared to known conditions. The A2 emissions scenario represents a differentiated world in which economic growth is uneven and the income gap remains large between now-industrialized and developing parts of the world. People, ideas and capital are less mobile so that technology diffuses more slowly. The B1emissions scenario presents a future with a high level of environmental and social consciousness combined with a globally coherent approach to more sustainable development.
[4] IPCC. 2007.

in different ways, analyses depend upon scenarios—different combinations of economic and other activity with different patterns of future GHG emissions. The magnitude, and sometimes the pattern, of climate impacts for the 21st century vary according to model and to the amount of greenhouse gas emissions. However, the simulations do converge in many aspects of the climate on a global scale and for the San Diego region. All six of the simulations warm over the next five decades. There is considerable uncertainty regarding future GHG emissions, so it is not possible to assign odds to either of the two emissions scenarios.[5] In short, the results of these models provide a set of possible climate outcomes with which to view the future, but they are not accurate predictions.

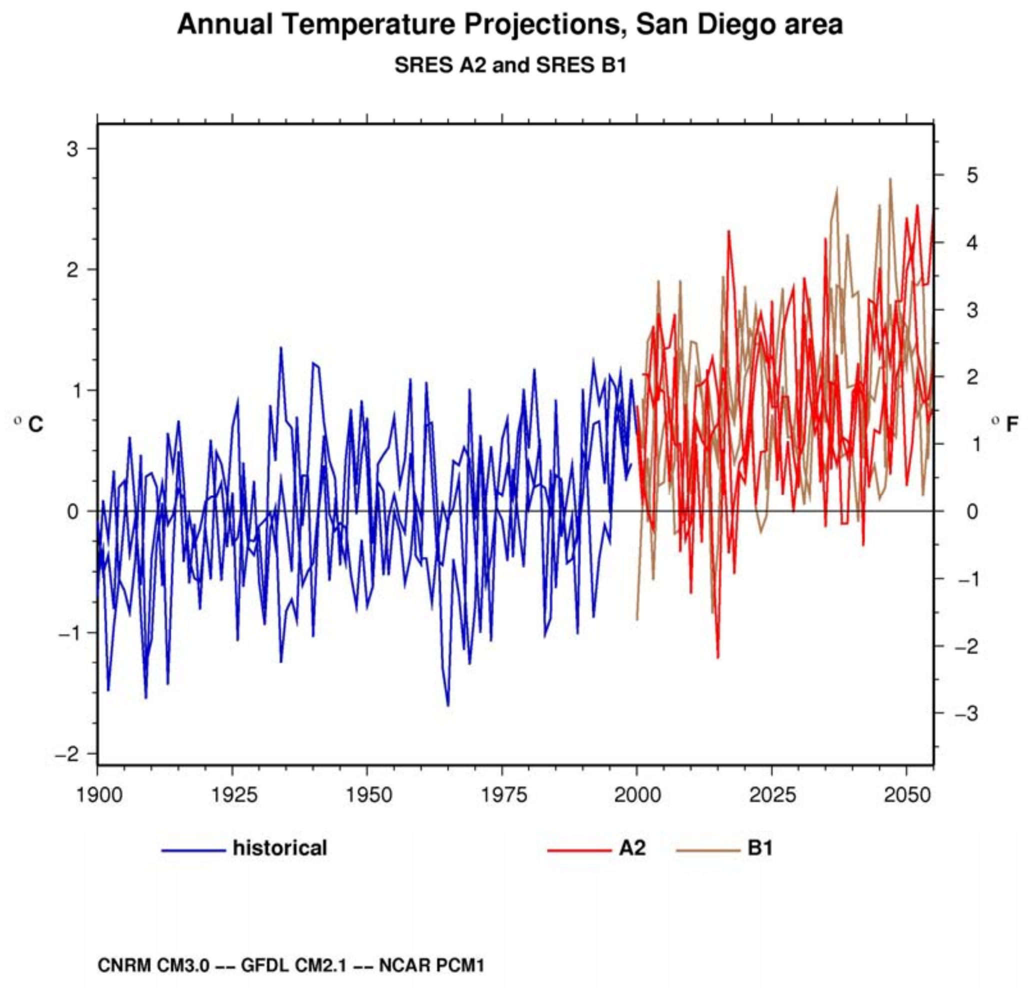

Figure 3-1. Change in annual mean temperature, San Diego region from the three GCMs, for historical period (blue) and for A2 (red) and B1 (brown) emission scenarios.

There is an important aspect of the San Diego 2050 time horizon that should be kept in mind. This study is confined to the period between now and the year 2050, but the

[5] Each model differs, to some extent, in its representation of various physical processes. The result is a set of model simulations having different characteristics, even when driven by the same GHG emissions scenario. The climate projections should be viewed as a set of possible outcomes, with each having an unspecified degree of uncertainty.

effects of GHG accumulations on climate, while somewhat slow to develop, are very long lasting in impact.[6] Also, most GHG emission scenarios, including the scenarios employed here, indicate that substantial man-made GHG emissions will continue beyond 2050. Because of this, ***the levels of warming, the amount of sea level rise, and other impacts will probably not reach their peaks by 2050***. Results of different mitigation strategies, as expressed by the two GHG emission scenarios,[7] do not become very clear by 2050—they are much more distinctly evident in the following decades.[8]

Warming

Historically, air temperatures over San Diego County appear to have risen significantly over the 20th century.[9] From observations and from model historical simulations, it seems that the temperatures began to warm more substantially in the 1970s; this is likely a response to effects of GHG accumulation, which began to increase significantly during this time period.[10]

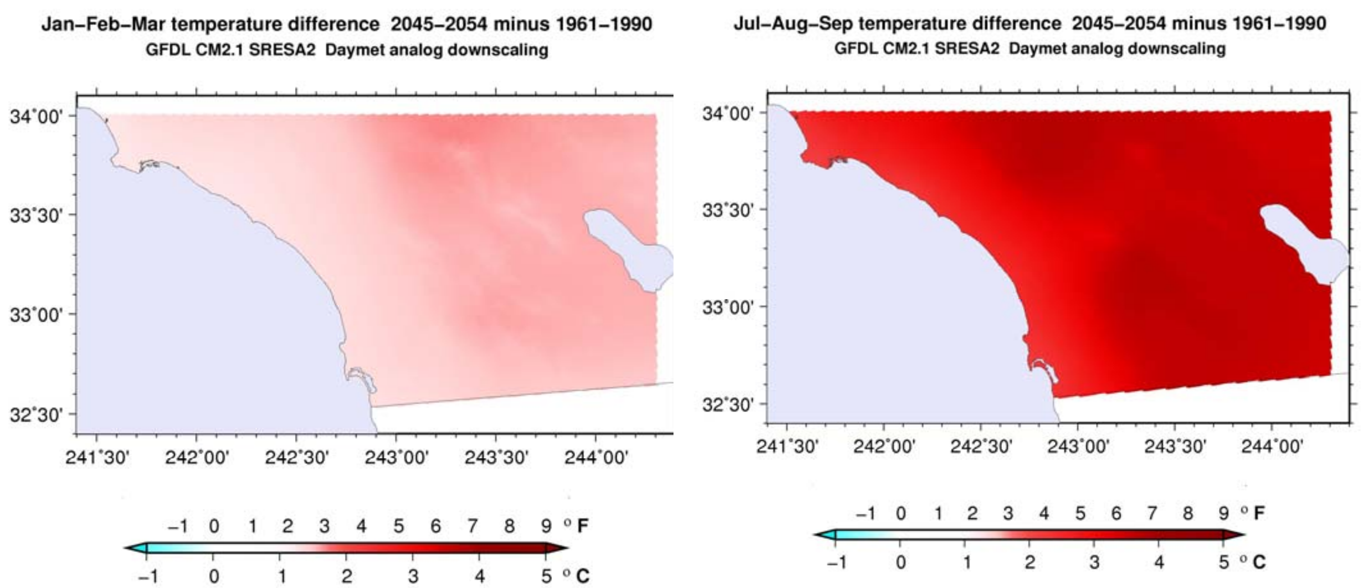

Figure 3-2. Winter and summer temperature differences.

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[6] IPCC 2007; Hansen 2005; Meehl et al. 2005.
[7] A2 –medium high emissions and B1 moderately low emissions
[8] IPCC 2007; Hayhoe et al 2006; Cayan et al. 2008.
[9] Quantifying how much warming has occurred is problematic because of the subset of weather stations in San Diego County that have existed for many decades, there are few (if any) that have not been contaminated by station moves and/or changes in the immediate surroundings at the station. Several stations contain increases of more than 2 degrees F since the early decades of the 1900s (see Table 1 in Appendix G). Almost all of the stations have stronger increases in minimum (nighttime) temperatures than daytime temperatures, in agreement with several previous studies of recent warming over the region and other areas of the globe. The annual temperature record at Chula Vista is representative of this increase and also contains fairly marked shorter period variability from time scales of a few years to a few decades.
[10] Bonfils et al. 2007; Barnett et al. 2008.

All of the climate model simulations exhibit warming across San Diego County - from about 1.5 to 4.5 degrees Fahrenheit (.83 to 2.5 degrees Celsius), with some differences in timing and geographic distribution of the changes (see Figure 3-2). The warming becomes progressively greater through the decades of the 21st century. There is greater warming in summer than in winter, with surface air temperatures in summers warming from 0.7 to more than 2 degrees F (.4 to 1.1 degrees C) over that found in winter***.*** There is a distinct Pacific Ocean influence wherein warming is more moderate in the zone within approximately 50km from the coast, but rises considerably, ***as much as 2 degrees F (1.1 degrees C) higher, in the interior landward areas*** of San Diego County as compared to the warming that occurs right along the coast. As indicated in Chapter 2, because the greatest population growth in San Diego is projected to occur in the interior areas, there are important implications for meeting the energy, water, publich health, and ecosystem needs in the region.

Heat Waves

Historically, extreme warm temperatures in the San Diego region have mostly occurred in July and August, but as climate warming takes hold, the occurrences of these events will likely begin in June and could continue to take place into September. All simulations indicate that ***hot daytime and nighttime temperatures (heat waves) increase in frequency, magnitude and duration***. For example, the GFDL A2 simulation for a location in the interior portion of San Diego County contains an increase in hot days of more than threefold in frequency (Figure 3-3) and a decided increase in intensity. ***Within a given heat wave, there is an increasing tendency for multiple hot days in succession—heat waves last longer***.

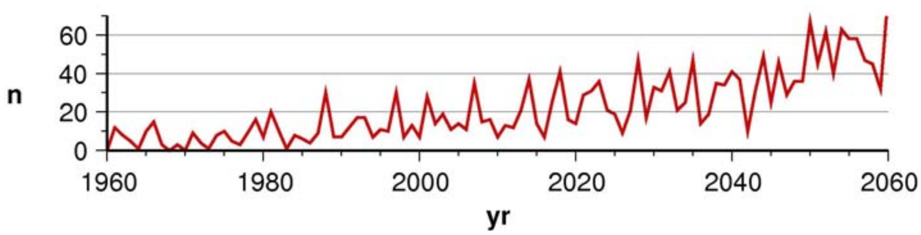

Figure 3-3. Overall number of hot days (exceeding 76 °F) for each year 1960 through 2060 in Chula Vista, CA.   GFDL CM2.1 SRESA2.

Precipitation

The climate change simulations indicate that San Diego will retain its strong Mediterranean climate with relatively wetter winters and dry summers. Projections of future precipitation have mixed results; three of the simulations become drier (12-35% drier than historical annual average) and three are wetter (12-17% wetter than historical annual average) overall. This reflects the reality that precipitation cannot yet be modeled with the same degree of consistency as other climate change parameters. The models vary in their projections of storminess[11] but none shows a significant change from past patterns.[12]

One important aspect of the climate model projected simulations is that the high degree of variability of annual precipitation that the region has historically experienced will prevail during the next five decades**.** This suggests that the region will remain vulnerable to drought**.** The occurrence of high daily precipitation events, as indicated by daily precipitation of 25mm (approximately 1 inch) or more, varies from year to year, but generally remains at about the same level during the 2000-2050 period as it was historically. The continued occurrence of significant storms within the model simulations suggests that future decades will continue to be threatened, occasionally, by floods in the San Diego region.[13]

El Nino/Southern Oscillation

Historically, El Niño/Southern Oscillation (ENSO) has been an important influence on weather conditions in southern California. Each of the climate models contains ENSO within its historical simulations. Although there is no evidence for an increase in the frequency or the intensity of ENSO, each of the simulations exhibits continued ENSO activity within the 21st century. There is a modest tendency for the San Diego region to experience higher than normal precipitation during El Niño winters and lower than normal precipitation during La Niña winters. This pattern is expected to continue under climate change conditions in the future.

Sea Level Rise

Low-lying coastal areas of San Diego are at risk due to the combination of waves, tides, regional wind and barometric effects, El Niño effects and sea level rise. ***Sandy beach areas, wetlands, commercial, municipal and residential properties will be lost or harmed, with implications for ecosystems, the economy, recreation and possibly public health.*** Over the past several decades, sea level measured at La Jolla has risen at a rate of almost 7 inches per century, which closely mirrors sea level rise averaged over the global ocean (estimated from an array of tide gages). In order to estimate future sea level rise, a method has been employed that relates the change in sea level to the increase in global air temperature.[14] The resulting scenarios (Figure 3-4) indicate that,

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[11] Indicated by the number of days per year when sea level pressure equals or falls below 1005mb.

[12] A remarkable aspect of the precipitation climatology is the large amount of variability, not only from month to month but from year to year and decade to decade. This variability stands out when mapped across the North Pacific and western North America complex, and is quite well represented by models in comparison to the observed level of variability from global atmospheric data, via the NOAA NCEP Reanalysis**.**

[13] Neiman et al. 2008 describe Pacific storms that set up many of the significant floods in southern California.

[14] Rahmstorf 2007 introduced a semi-empirical method linking sea level rise to observed global mean temperatures. The present estimates include those of Rahmstorf's method, assuming that sea level rise along the southern California coast will be the same as the global estimates. Also, the projections here include a second set of estimates which are a modification of Rahmstorf's method that attempts to account for the growth -- globally -- of dams and reservoirs, which have artificially changed surface runoff into the oceans (Chao et al. Science, 2008), in addition to the effects of climate change.

over the next five decades, sea level rise will increase substantially--by more than three fold to almost six fold--over its historical rate. ***By 2050, sea level increases, relative to the 2000 level, by 12-18 inches***. As sea level rises, ***there will be an increased incidence of extreme high sea level events (Table 2 in Appendix G), which occur during high tides***, often when accompanied by winter storms and sometimes exacerbated by El Nino occurrences.[15] Importantly, as decades proceed, these simulations also contain an ***increasing tendency for heightened sea level events to persist for more hours, which would likely impose a greater threat of coastal erosion and other damage***.

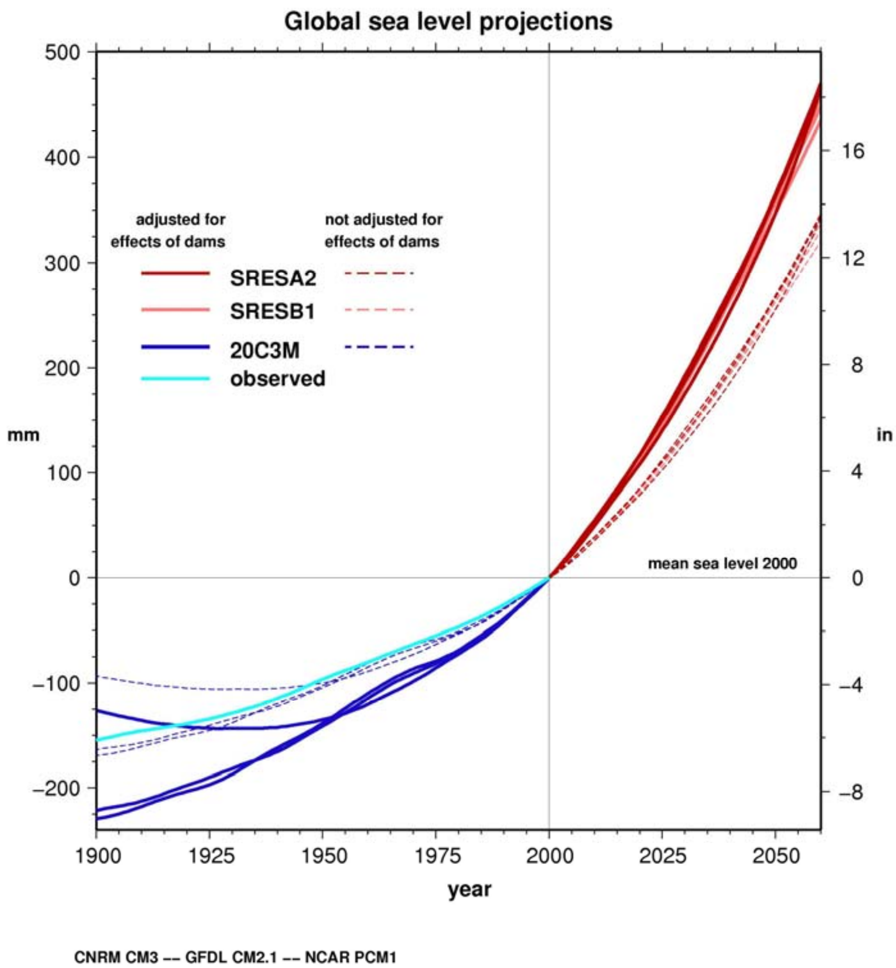

Figure 3-4. Global sea level projections.

Maps for 2050 projecting the impact of these changes were developed for six low-lying locations in San Diego County that are presently prone to flooding to estimate the severity and frequency of shoreline inundation at these sites (South Imperial Beach, Coronado Shores, Mission Beach, South La Jolla Shores, North Del Mar, and Oceanside Harbor). These sites include cliffs, beaches, estuary mouths, jetties, sea-wall, houses, and most other characteristics of the broader region's coastline. Other areas sensitive to sea level rise not surveyed, due to unavailability of background high-

[15] Cayan et al. 2007

resolution imagery, include low-lying locations along bay coastlines. Future research will be needed to understand the specific impact of changes in sea level in other areas of strategic (Naval Air Station North Island) and economic (San Diego Airport) importance. For more discussion of the methodology, see Appendix G.

Larger wave events were highly correlated with El Niño time periods in the simulation. During a particularly severe El Niño winter (e.g., similar to 1982-83), a chain of multiple "Moderately Rare" to "Somewhat Rare" events is possible.

These maps are conservative, in the sense that they only include the impact of waves on the portions of the shoreline exposed to the open ocean. Therefore, the back-bay areas only show inundation owing to sea level plus tides. In addition, the maps do not account for changes in shoreline elevation and potential increased inundation, owing to wave erosion. For example, in the south Imperial Beach map (Figure 3-6), the dune line between the border and the Tijuana River mouth remains intact because its highest elevations exceed projected inundation levels. In reality, the dune is likely to be eroded and overtopped. Beach loss and bluff failures, owing to increased exposure to waves at high tides with higher sea levels, could in turn significantly change an area's wave run-up characteristics and the extent of future flooding. Impacts to coastal bluffs, infrastructure, wetlands and bays may be severe and are not covered in this analysis. An example of coastal cliff erosion in the past, however, is shown below.

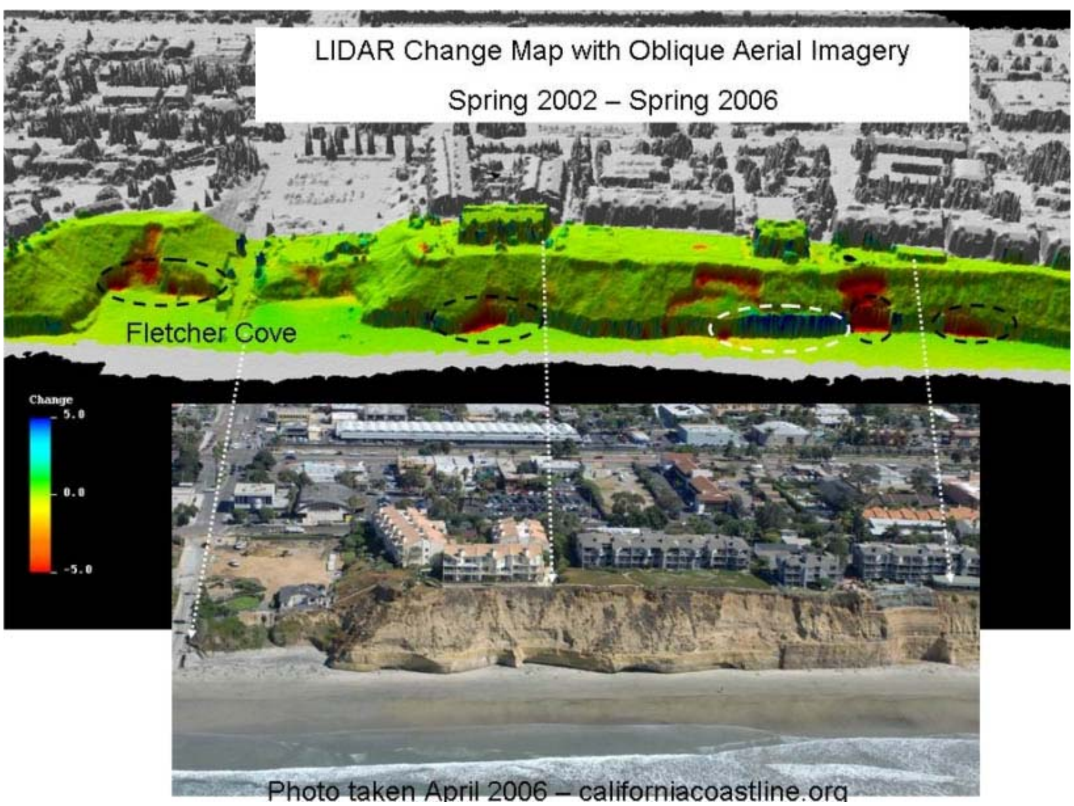

Figure 3-5. Coastal cliff erosion in Solana Beach from 2002 – 2006.

Erosion is displayed as red. Accretion is displayed as blue. Little or no change is displayed as green. Erosion from the effects of under-cutting during winter storms is highlighted by dashed black lines. The white dashed line displays an area of accretion where a sea-wall was built.

Climate change can have significant impacts on wetland structure and function, primarily through alterations in hydrology, especially water- table level. Wetland flora and fauna respond very dramatically to small changes in water-table levels. This is discussed in more detail in the Ecosystem chapter.

The definition of terms used in the maps:

- **Very Likely** - predicted high tide range in 2050.
- **Moderately Common** – estimated sea level + tide + wave run-up elevation[16] recurrence, on average, every 5 years in the 50-year simulation. Expected to occur every few years when El Niño conditions are not present.
- **Moderately Rare**, estimated sea level + tide + wave run-up elevation recurrence, on average, every 10 years in the 50-year simulation; but expected in most years when El Niño conditions are present.
- **Somewhat Rare** - estimated sea level + tide + wave run-up elevation recurrence on average every 25 years, based on the 50-year simulation.
- **Very Rare** - highest combination of sea level + tides + wave run-up elevation in the 50-year simulation.

The following illustrations (Figures 3-6 through 3-11) show the projected impacts in 2050 in the six areas analyzed in depth, with a brief explanation of specific features. Although similar detailed analysis has not been done for other coastal areas in the region, we can expect similar risks. It is clear that in many areas along the San Diego coast, there will be a range of associated costs and consequences. Such an evaluation is beyond the scope of the present report, but would be an important contribution to future planning and risk management efforts.

[16] Wave run-up is the maximum vertical extent of wave uprush on a beach or structure above the still water level (SWL).

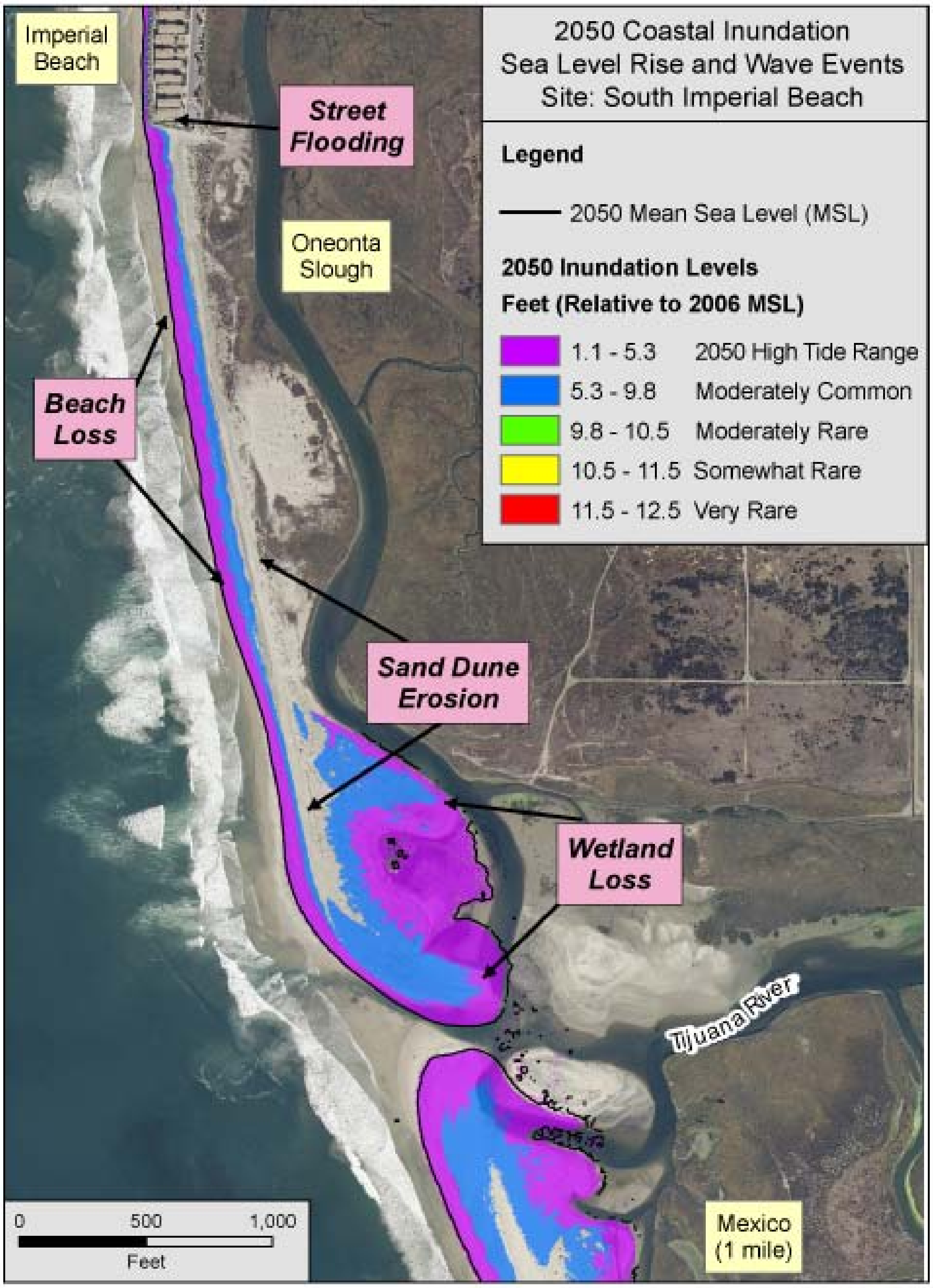

Figure 3-6. 2050 Coastal Inundation: South Imperial Beach. Tidal fluctuations alone (purple) appear to inundate sandy beach and the Tijuana River mouth. Adding run-up from moderately common wave events (blue) floods majority of sandy beach. Very rare wave events (red) flood sandy beach, areas of sensitive sand dune habitat and surface streets in south Imperial Beach. The dune line shown north of the river mouth would likely be eroded by even a moderately rare inundation event.

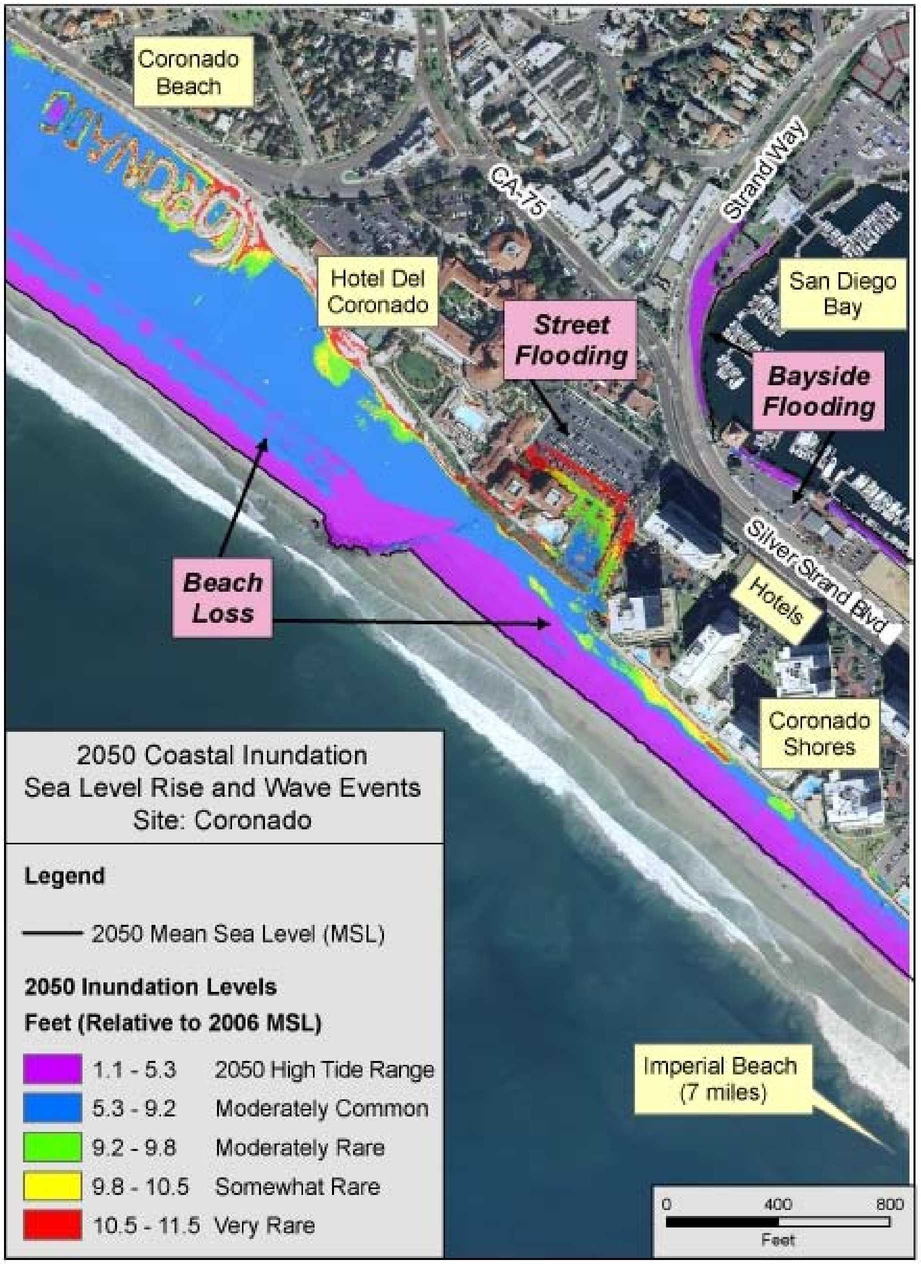

Figure 3-7. 2050 Coastal Inundation: Coronado Beach and Shores. Tidal fluctuations alone (purple) appear to inundate sandy beach and jetty. Adding run-up from moderately common wave events (blue) floods the majority of sandy beach and portion of parking lot at the Hotel Del Coronado. Very rare wave events (red) flood sandy beach, some surface streets and heavily-used boardwalk in front of hotels. "Coronado" is spelled out in the artificial dunes by the beach (maintained by a local resident) and demonstrates the fidelity of the LIDAR measurements.

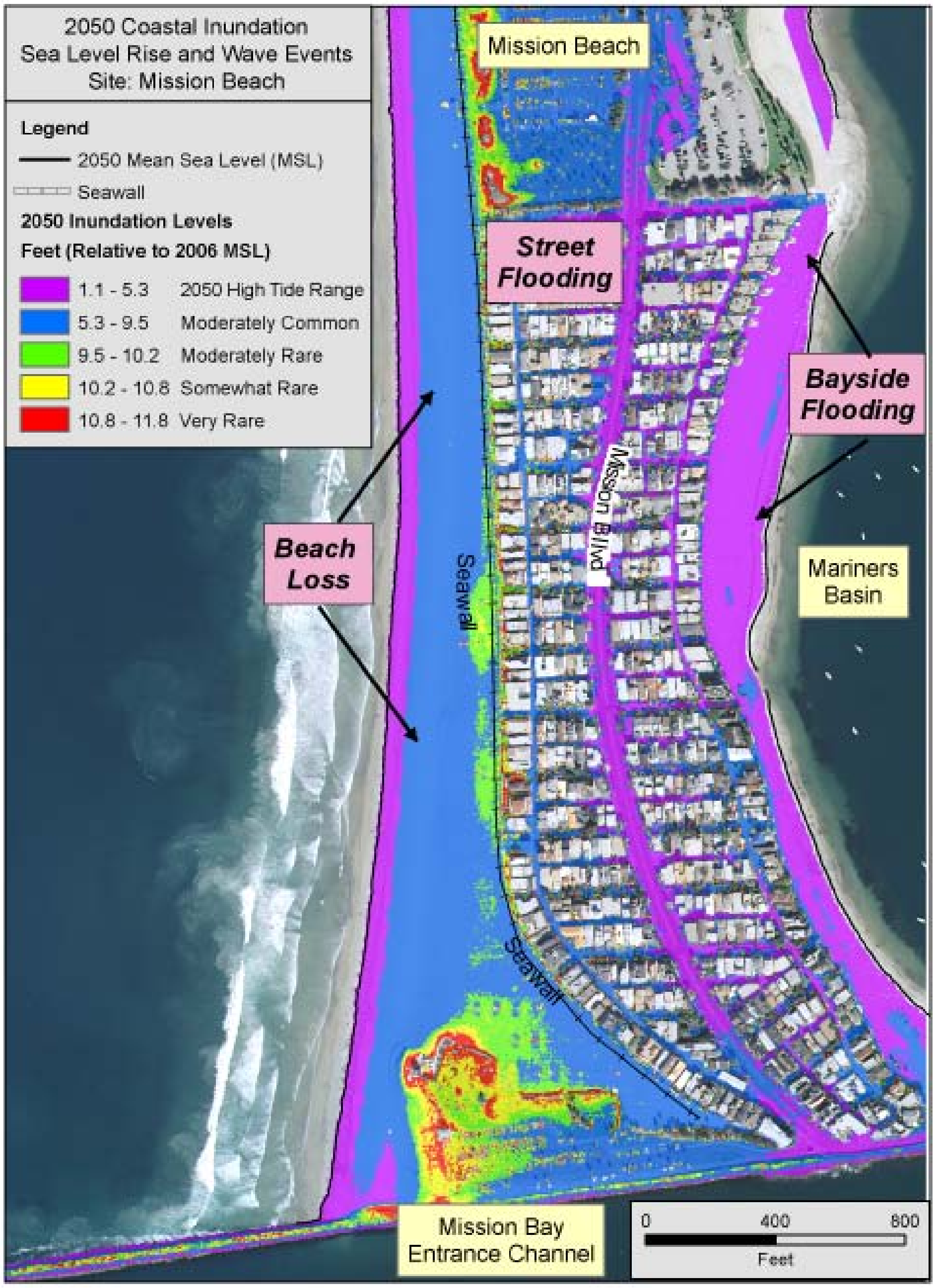

Figure 3-8. 2050 Coastal Inundation: Mission Beach. Tidal fluctuations alone (purple) appear to inundate portions of sandy beach and streets from bayside flooding. Adding run-up from moderately common wave events (blue) floods majority of sandy beach, streets and parts of Mission Beach Park. Moderately rare wave events (green) appear to breach seawall and inundate streets and sidewalks. Very rare wave events (red) flood sandy beach, surface streets and heavily-used boardwalk in Mission Beach.

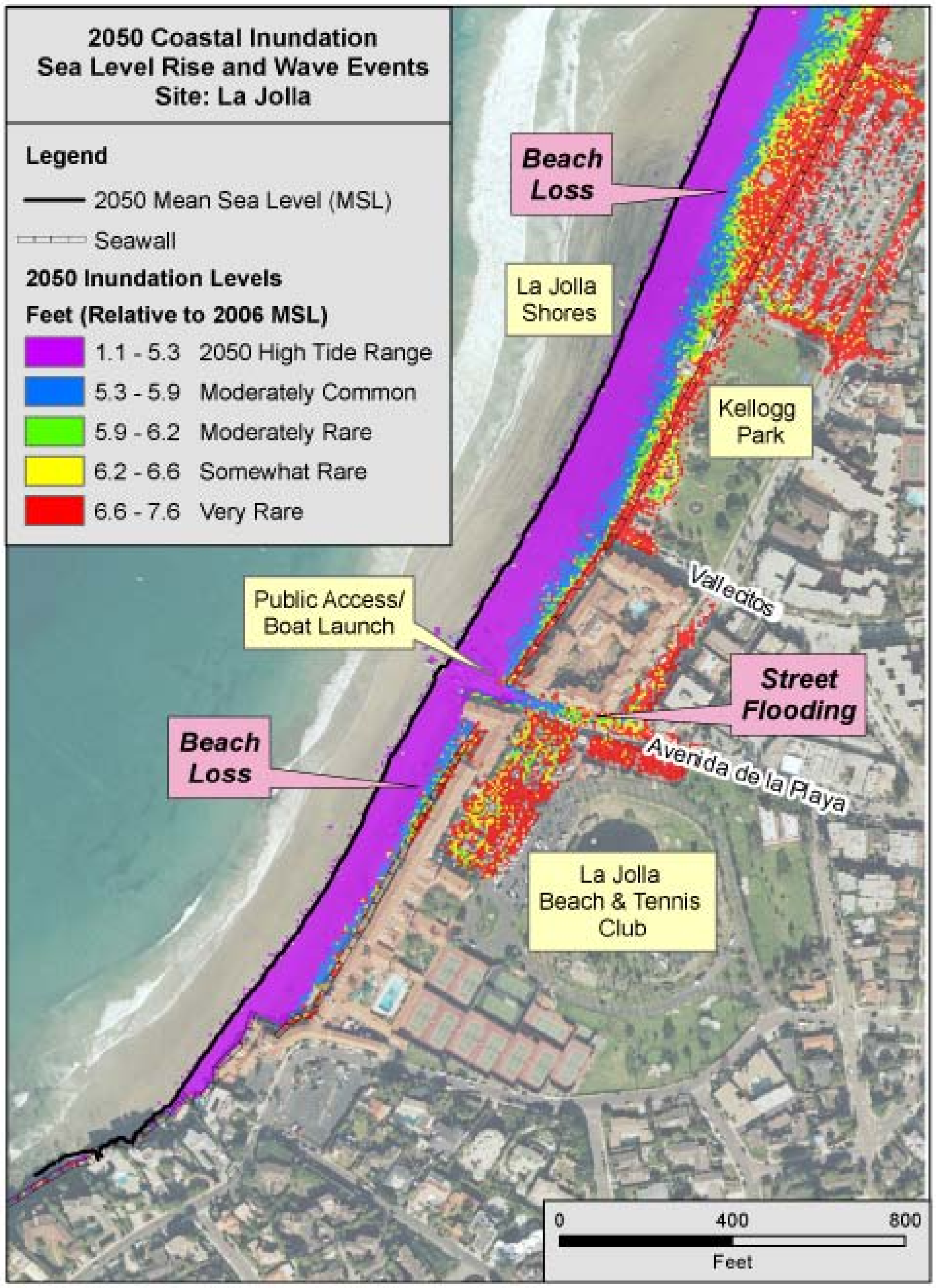

Figure 3-9. 2050 Coastal Inundation: La Jolla Shores. Tidal fluctuations alone (purple) appear to inundate majority of sandy beach and Boat Launch. Adding run-up from moderately common wave events (blue) floods majority of sandy beach and end of street at Avenida de La Playa. Very rare wave events (red) flood sandy beach, breaches seawall, floods some surface streets, parts of the heavily-used Kellogg Park and La Jolla Beach and Tennis Club.

Figure 3-10. 2050 Coastal Inundation: Del Mar Beach. Tidal fluctuations alone (purple) appear to inundate much of sandy beach and entrance to San Dieguito Lagoon. Adding run-up from moderately common wave events (blue) floods majority of sandy beach (Dog Beach) and causes bluff-side flooding. Very rare wave events (red) flood sandy beach, cause bluff-side flooding and may impact coastal homes. The more frequent exposure of the base of the bluffs to waves on high tides increases the likelihood of bluff failures.

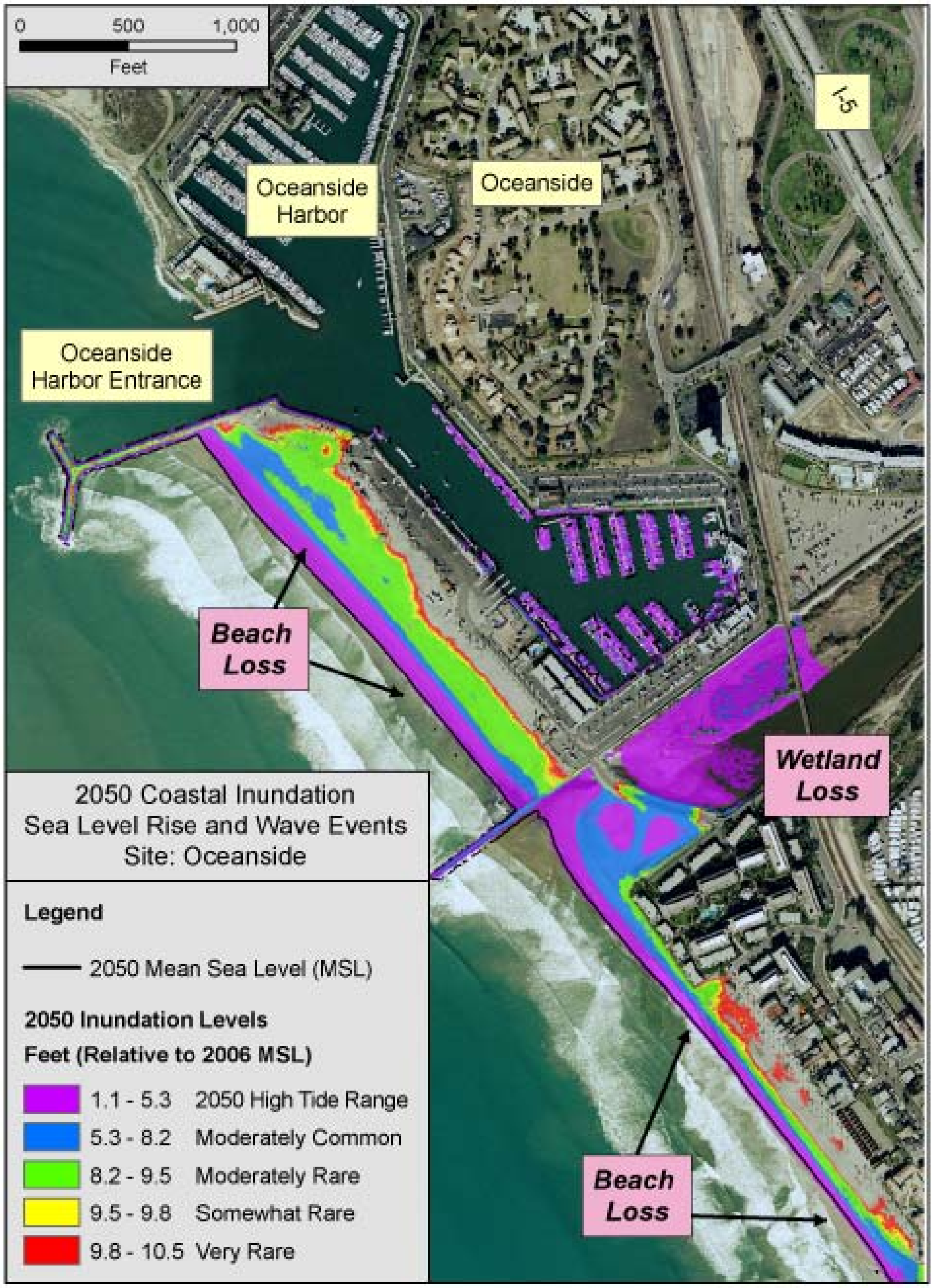

Figure 3-11. 2050 Coastal Inundation: Oceanside Beach. Tidal fluctuations alone (purple) appear to inundate portions of sandy beach and wetland. Adding run-up from moderately common wave events (blue) floods south jetty and portions of beach. Moderately rare wave events (green) flood majority of north beach.

Economic Implications

San Diego County has roughly 70 miles of coastline with a range of current uses, current value, level of susceptibility to damage from sea level rise, ease of protection and potential future uses. To date, the most detailed recent analysis[17] of the cost of mitigating sea level rise in San Diego County estimates that under the best possible investment strategy, the protection of 1.5 miles of developed coastline in Imperial Beach will cost $500,000 - $ 1 million.[18]

This analysis implies a one-time cost of protecting San Diego's coastline of $24 to 47.5 million for 'hard engineering' (e.g., armoring/sea wall construction), soft engineering (beach nourishment) and halting new building in heavily disturbed areas. Additional annual costs are estimated to be between $2 and $8 million (with the caveat that some years will be much more and others much less) by 2050. Clearly much more detailed analysis will be needed to develop detailed response strategies and cost projections. This brief summary is intended to provide a sense of the magnitude of the costs and is probably an underestimate. For example, Mission Beach, which is very susceptible to sea surge, has very high value property. Wetlands impacts are not included here as their value is not fully captured in economic markets. Erosion rates are not estimated and therefore the impact of coastal erosion on sea bluff property is not reflected in this figure either.

Summary

It is clear that climate change is happening and will alter the San Diego region in many ways. The combination of higher sea level, waves, tides, El Niño effects and weather conditions poses a serious threat to the coastal margins of the San Diego region. These areas are home to critical habitat, valuable real estate, recreational facilities and public infrastructure. This analysis should provide the basis for further analysis of vulnerabilities and the development of risk management strategies involving the public and private sectors.

The following chapters provide an initial assessment of what climate change will mean to the region in terms of water supply and demand, ecosystems, public health and electricity. As Isaac Asimov notes, "If knowledge can create problems, it is not through ignorance that we can solve them." The knowledge that climate change presents challenges to our region motivates us to educate ourselves to understand the potential impacts, so we can find solutions to reduce the rate of change and develop adaptation and risk management strategies for the future.

[17] Smith and Mendelsohn, 2006.

[18] This estimate does not ensure no yearly damage occurs, but rather is an optimal adaptation cost: there will still be damages due to sea surge, but this is the point beyond which the cost of more investment does not return an equivalent value in more protection. Additionally, this does not speak to the timing of sea surge protection: the longer San Diegans wait, the lower the cost measured in today's dollars, but the higher the potential cost of the materials due to rising prices of building materials.

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CHAPTER 4: WATER

Introduction

San Diego is a major urban area built by importing water from hundreds of miles away into what is essentially a desert environment. Continuing population and economic growth in San Diego will result in increasing demands for water, and climate change is expected only to exacerbate those demands. ***Climate change could yield more instances of drought and reduce the chances that existing water sources will be able to meet projected demands.*** Water supply and demand are driven by many factors, some controlled at the local and regional level, others outside the control of decision-makers and citizens of San Diego.

This chapter summarizes recent local and regional syntheses of water planning information to 2030,[1] makes informed projections to 2050, and provides some possible outcomes for consideration. Figure 4-1 summarizes recent projections of future demands for, and supplies of, water for the San Diego region under several 2050 scenarios (with and without severe climate-induced supply reductions). Challenges illustrated in the figure are discussed, with background, in the remainder of this chapter. ***There is much reason for concern that even with creative and innovative arrangements among competing water interests, with concerted conservation measures, and with enhancement of identified supply sources, the combined effects of regional growth, water-use practices, and climate change will expose the region to greater risk of water shortfalls even before 2050***.

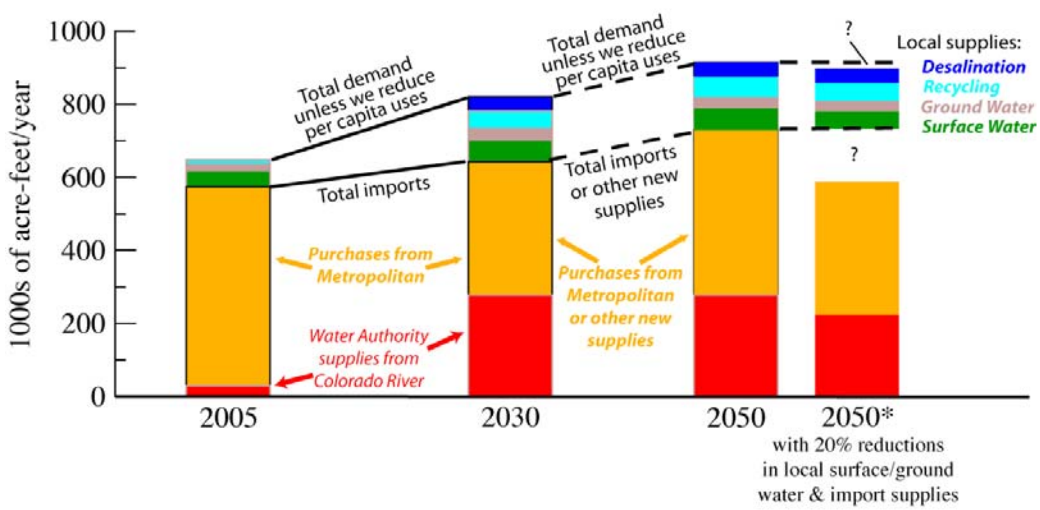

Figure 4-1. Projected water demands and supplies in 2005, 2030 and 2050, under "normal year" climate change conditions.

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[1] San Diego County Water Authority (SDCWA) 2005 Urban Water Management Plan and Water Resources Department staff.

In Figure 4-1, projected demands (assuming approximately 12% reductions in per capita demand), local water supplies, supplies of Colorado River water from recent Imperial County water county agricultural water transfers (red), and remaining projected demands for imported water from the Metropolitan Water District or other new sources of water are shown. For the future periods, these latter (orange) supplies were estimated solely by determining how much projected demands exceed projected supplies from other sources. The simple 2050 scenario shown assumes "normal climate" (neither climate change nor drought conditions) and is a direct extension of current 2030 predictions; the other 2050 scenario makes the severe assumption that climate limitations could reduce the availability of imported water and local surface and ground water by about 20%. Blank areas with question marks in the final bar indicate the shortfalls that would need to be accommodated under such a scenario.

Water Demands

Water demands in San Diego County are dominated by residential, commercial and industrial uses, with a diminishing share devoted to agriculture. As these demands grow in the future, San Diego's water supplies are likely to be challenged, especially in the context of (probable) adverse climate changes. By far, most of San Diego's demands are—and will continue to be—supplied by water imported from hundreds of miles away in the Colorado River and the rivers of northern California. Demands for this imported water by some jurisdictions are expected to decline as a result of new supply sources (e.g., Carlsbad with its seawater-desalination plant) and expanded uses of local water supplies including recycled water. Demands by other agencies--most notably the City of San Diego and Otay Water District--are projected to continue growing rapidly, until at least 2030. Official predictions of water demands between 2030 and 2050 have not yet been made due to the lack of post-2030 demographic and economic projections from local jurisdictions.

For the purposes of this report, rough estimates of the growth of demands were made based on assessments and continuations of agency-by-agency trends around 2030. [2] The Water Authority officially predicts that overall water demands (for imports plus local water supplies) will rise by about 24%, from a five-year average demand of 668,000 acre-feet/yr between 2001 and 2005 to about 830,000 acre-feet/yr in 2030 (Figure 4-1). Our estimate of demands in 2050 is about 915,000 acre-feet/yr, of which about 730,000 acre-feet/yr would need to come from imports (under current demand projections and planned local supplies). ***If this 2050 water demand and use is realized, it will amount to about a 37% increase over five-year average demands from between 2001 and 2005.***

Taken together, the predictions of water use by sector are shown in Figure 4-2. Most of the future growth in water demands is expected to be for municipal and industrial uses (M&I), with declines in agricultural water uses. By 2030, 94% of demands are expected to be for M&I, with agricultural demands shrinking from 13% of total demands in 2005 to 6% in 2030. Agriculture water use not only fails to grow as quickly as the M&I demands, but it is predicted to decline in absolute terms (a decline of about 40% by 2030).

[2] These straight-line extensions were then scaled down to reflect the expectation that population growth in San Diego will slow by about 25% after 2030.

The Water Authority is working to offset predictions of 30% growth in water demands for M&I (which is a faster growth rate than the 26% population increase) through increased conservation measures, including residential surveys and retrofits, landscaping changes, efficiency standards, and expanded uses of efficiency measures by commercial/industrial operations. However, in its current predictions and plans (summarized here), the Water Authority only includes about 12% reductions in demand (as in Figure 4-1) from such increased conservation and efficiency measures. This target falls well below the State's current calls for 20% cuts in water use by 2020.

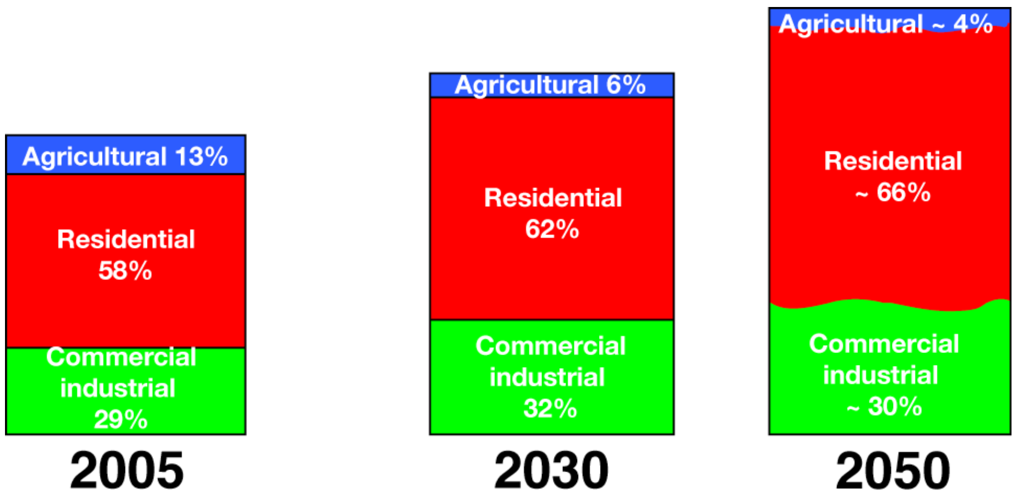

Figure 4-2. Proportions of San Diego normal-year water demands for several sectors in 2005, 2030 and 2050. Height of bars indicates total expected (or observed) water demands under "normal climate" assumptions; colors indicate the proportions of each water use. Water use total in 2050 is a rough estimate based on slowing rates of growth, with distribution of demand quite uncertain (indicated by wavy edges of sectoral divisions).

One use of water that is not discussed in plans for San Diego's future demands is the long-term need for environmental water. In other areas of the State and the Western US, water agencies have had to rethink many of their plans because "new" demands have been identified for keeping, or putting, water in rivers, wetlands, flood plains, and other areas for the protection or restoration of estuaries, beaches, ecosystems and landscapes. Often these new demands were identified long after best-laid plans for meeting all human needs were underway. In San Diego, every major river now has protection or restoration efforts under way. ***Under climate change conditions, just preserving the status quo on San Diego's rivers, wetlands, and riparian zones may require providing water to meet environmental goals, flows that have not figured into the very close fitting balances of supplies and demands that appear in the water agencies' projections.***

Climate Change & Water Demands

Weather and climate variations affect water demands in San Diego. The difference in total demand between a dry year (2004) and the subsequent wet years recently (2005) was 74,000 acre-feet, more than an 11% difference. The Water Authority analyzed past dry year conditions and estimates a 7% increase, on average, in forecasting water demands during dry periods. As noted earlier, elevated greenhouse gas levels are expected to produce temperature increases of 1.5 to 4.5 degrees F (.83 to 2.5 degrees C) over San Diego by the mid-21st century.[3] The effects of climate change on San Diego's water demands are likely to reflect both warming and (likely) drying trends. However, the Water Authority's analyses of San Diego dry-year demands have looked only at "drought" as lack of precipitation, rather than as the combined effect of warming and drying. More frequent and much drier (20% drier) drought years are projected for San Diego in the early 21st century in some climate projections (e.g., Figure 4-3). To the extent that climate changes combine to increase San Diego's water demands in the same way as a prolonged and increasingly severe drought regime, even the "normal year" demand projections presented thus far will be underestimates. Perhaps this underestimation will be by as much as the 7% dry year adjustment used by the Water Authority, or perhaps by something closer to the 11% difference between wet and dry years witnessed in recent years, perhaps by much more. Including climate change in the projections will require recognition that ***San Diego is facing a new and more demanding "normal" between now and 2050.***

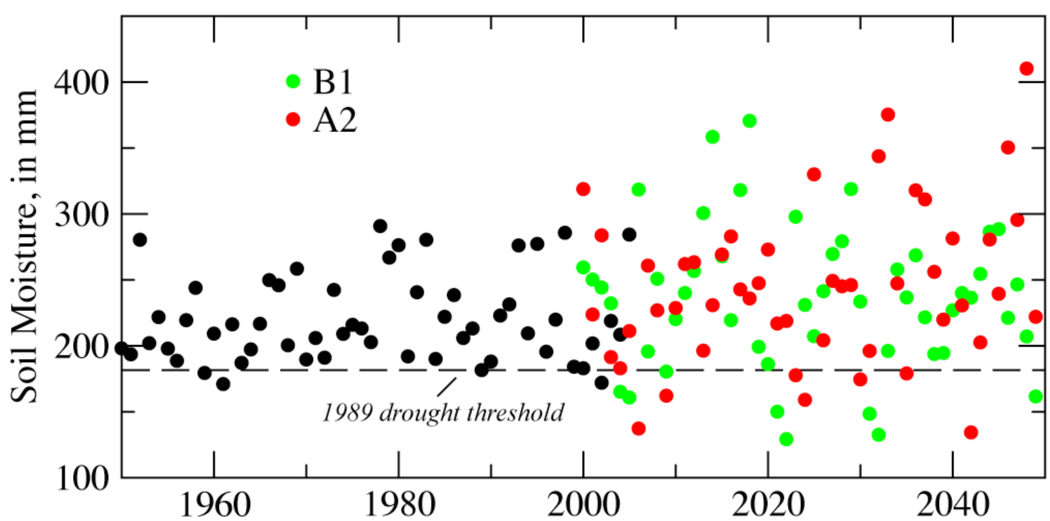

Figure 4-3. Simulated annual-mean soil moisture, western San Diego County[4]. Note increased numbers of years (dots) below the 1989 drought threshold in the future 50 years compared to the historical 50 years, indicating increased numbers of significant droughts under climate change. Black dots are simulated soil moisture contents using historical observed meteorology; historical climate-model meteorology results in a somewhat broader range of highs and lows (not shown), with about 50% less lows than among the green (B1) and red (A2) projected soil moistures.

[3] Cayan et al. 2008b.

[4] Simulated soil-moisture beneath western San Diego County under historical meteorology (black) and projected 2000-2050 climates from the Variable Infiltration Capacity water-balance model driven by the Geophysical Fluid Dynamics Laboratory's CM2.1 climate-model simulations of climate under B1 and A2 greenhouse-gas emissions scenarios.

By 2030, the Water Authority projects that a drought comparable to 1989 would increase overall demands by 6.5%. By 2050, overall demand (local plus imported) would increase from about 915,000 acre-feet/yr in a normal year to about 980,000 acre-feet/yr in 1989-style drought years, and ***drought years might happen as much as 50% more often (Figure 4-3). The drought years in the future might also yield larger demands than the 7% increase associated with 1989, because they are projected to be considerably drier than 1989.***

Water Supplies

To meet these various demands, water agencies in San Diego County currently depend on imported water from Metropolitan Water District of Southern California, local streamflow, ground water, and some recycled water. In the future, if growing demand is to be met, these supply types will have to be augmented by additional imported water, desalinated brackish or seawater, and increased supplies from other local sources. Climate change will affect all the possible sources of water supply. Some supplies may be reduced as a result of increased heat and changing precipitation patterns in our region and in other regions from which we import water; other supplies may be limited by costs and energy required to draw upon them. Because climate models do not yet reliably predict changes in precipitation, possible impacts on supply present a wide range of outcomes.

<u>Imported Water</u>

Prior to 2003, Metropolitan was the sole source of imported water for meeting San Diego's growing demands. In the future, Metropolitan will continue to play an important role, supplying over half of San Diego's imports from its supply sources in the Colorado River and Northern California. However in response to Metropolitan's delivery shortfalls during the droughts of the early 1990s, the Water Authority has developed additional, more secure sources of imported water. In 1998, the Water Authority negotiated an agreement with the Imperial Irrigation District for San Diego to acquire Colorado River water conserved by Imperial Valley farmers. Starting in 2003, San Diego also began receiving conserved Colorado River water from projects that reduce leakage from the All American and Coachella Canals. These new sources of imported water draw upon allocations of Colorado River water that are legally "senior" or ahead of Metropolitan in the order of water availability. Thus they should provide more secure, less expensive supply in drought periods, and do not count against San Diego's existing purchase agreements with Metropolitan. Together these new sources actually reduce the demands that San Diego will make on Metropolitan until about 2020, by which time the new sources will total about 268,000 acre-feet/yr, or about 45% of San Diego's projected demands for imported water. After about 2020, continued growth in demands and full ramp-up of current Water Authority transfer agreements will mean that San Diego's demands on Metropolitan or some other, as-yet-unidentified source of imports will begin to grow again. Purchases from Metropolitan (or other new imports) would need to increase to about 450,000 acre-feet/yr by 2050. Under the current Metropolitan tiered rate structure, rapid increases in deliveries can become quite costly.

<u>Local Water Supplies</u>

Although San Diego is a semi-arid to arid setting with limited precipitation, runoff and recharge, in addition to imported water, San Diego water agencies develop supplies from local sources like surface- and ground water, as well as some reuse of water. Surface water is expected to be the largest local source of water through 2030, but is also the most variable from year to year. Under normal rainfall conditions, Water Authority member agencies can draw about 60,000 acre-feet/yr from local surface water, and no major increases in the region's local surface water supplies are anticipated in published water management plans. In 2005, local groundwater wells supplies totaled about 14,000 acre-feet. Production from ground-water supplies is anticipated to increase by 75% to about 31,000 acre-feet/yr by 2015. Thus by then, local surface and groundwater supplies will have reached their foreseeable limits, and additional less-traditional sources will be needed to meet most new demands beyond those that will be supplied by imported water.

By 2030, the Water Authority projects that the County's uses of recycled water will have quadrupled from about 13,000 in 2005 to about 48,000 acre-feet/yr. Planned growth in recycled water use is expected to reached its projected capacity by about 2020. However, the Water Authority anticipates that additional (as yet unidentified) opportunities for using recycled water may be available well beyond 2030.

Taken together, by 2030, the official projections show that San Diego's projected normal-year imported-water demands through 2030 can be met, if climate or other unanticipated changes do not restrict the water availabilities indicated (see Appendix H for details). Even so, San Diego will need to develop additional local supplies, additional exclusive-use import supplies, or else compete with other Metropolitan member agencies for additional deliveries as its demands continue to grow through 2050. New local supplies beyond about 2015 will likely be restricted to additional increments of recycled water or additional desalination of seawater (which has implications for energy use and greenhouse gas emissions). These options are expensive, as are imports of water, especially in competition with the other growing member agencies of the Metropolitan customer base. Additional local conservation efforts could slow the projected growth in water demand, thereby avoiding a portion of the need and costs of these additional supplies.

Climate Change & Water Supplies

<u>Impact of Climate Change on Surface and Ground Water</u>

Even as the region attempts to develop these local supplies to meet its burgeoning demands, climate change may reduce the amount of local surface and ground water available. The drying trends associated with warming may significantly decrease the availability of surface water, the largest current and projected local water supply. Studies of climate-change projections over the Southwestern United States conclude that ***runoff and ground water are expected to decline by an average of about 7 inches/yr over the entire Southwest by 2050***. [5] [6] With San Diego's already dry conditions, such trends suggest that drying in the San Diego area could be quite extreme. Given the relatively limited extent and thickness of most of the County's aquifers, reductions in recharge would likely impact ground-water sources quickly. In addition to these projected impacts of warming, if future climate change includes significant declines in precipitation (which remains uncertain at present), ***surface and ground water resources in San Diego***

[5] Seager et al. 2007.
[6] Milly et al. 2005.

(comprising fully half of the projected local supply sources) would be even more directly and severely challenged.

Impact of Climate Change on Imported Water

The sources of most of San Diego's imported water are also likely to be challenged under climate change. By 2050, San Diego will need commitments for imported water equivalent to about 17% of California's current 4.4 million acre-feet/yr allocation of Colorado River water. However, climate change is expected to result in significant declines in Colorado River flows and thus in availability of these waters for import to San Diego. Recent projections have ranged from about a 6% decline to as much as a 45% decline in Colorado River flows.[7] In absolute terms, a 6% cut to California's allocation would amount to 264,000 acre-feet/yr less water availability; a 45% cut would amount to almost 2 million acre-feet/yr less water. In recent years, the states that draw water from the Colorado River have negotiated a shortage-sharing agreement that specifies how supply shortfalls from the River of as much as 8% might be shared. A new study[8] has estimated that, without this agreement, the major reservoirs of the Colorado River could be emptied within a few decades by the combination of large demands and climate change. However, additional calculations[9] indicate that overall demand for Colorado River water would have to be reduced by 20% to achieve a 90% chance of maintaining water in its reservoirs by 2050. These results suggest that (with or without climate change) ***even more extreme reductions from the Colorado River may need to be accommodated in the next few decades than envisioned in the shortage-sharing agreements***. The possibility for water shortages is very real, given the relatively close fit between San Diego's projected demands and its currently projected sources of imported water (mostly from the Colorado River) in the face of currently projected climate-change effects on the Colorado River.

In this context, San Diegans also want to consider the fact that Tijuana, with a population approaching that of the City of San Diego, and just a few miles away, gets about 90% of its water supply from the Colorado River as well.[10] San Diego will feel water-demand pressures placed upon its nearest neighbor directly or indirectly,[11] because water shortfalls in Tijuana could result in greater pressures for emigration and economic stresses there. Options for addressing serious shortages across the border may be almost as important for San Diego as for Tijuana.

Metropolitan also receives and distributes large amounts of water from Northern California by way of the State Water Project.[12] Currently Metropolitan has a contracted entitlement to about 2 million acre-feet/yr of this water, or almost half of the total volume carried through the Project as a whole. However, this amount has not, in fact, been

[7] Christiansen et al. 2004 -18%; Milly et al. 2005 -20%; Christiansen and Lettenmaier., 2007 -6%; Hoerling and Eischeid. 2007 - 45%.
[8] Barnett and Pierce. (In Press).
[9] D. Pierce, unpublished calculations, 2008.
[10] Ganster, 1999.
[11] Malinowski, 2004.
[12] This project stretches from the Feather River near the north end of the Central Valley to Perris Lake, southeast of Riverside, more than 600 miles. Water flows down the Feather River into the Sacramento River, into the Sacramento-San Joaquin Delta, and then is pumped into the California Aqueduct where it is conveyed to southern California.

delivered because of a variety of restrictions on the overall deliveries of water in the system.[13] In coming decades, the State Water Project also is expected to be impacted by climate change and other environmental challenges. Deliveries from Northern to Southern California are already being constrained by judicial restrictions to protect threatened fish species in the Delta, and nonetheless Delta ecosystems continue their decline.[14] Invasive species, aging and failing levees, and a poorly understood decline in the populations of key species all threaten the Delta, which is widely recognized as the weak link in the State's North-South water delivery systems. Efforts are underway by the CALFED Bay-Delta Program and by various other State commissions and agencies to develop policies and structures that aim to improve long-term State Water Project water-supply reliability for southern California while also restoring the Delta's ecosystems. The success of these efforts may well determine the extent to which the State Water Project continues to meet southern California's water needs in the future.

The State Water Project deliveries to southern California are also likely to be challenged by climate changes between now and 2050. Trends towards increasing amounts of rain vs. snow, less springtime snowpacks, and earlier snow-fed runoff from the Sierra Nevada have already been detected in California in response to modest warming over the past 30 years.[15] These changes are just the beginning if warming trends continue unabated. As warming grows more extreme, rain-fed and rain-on-snow flood risks may increase, summertime flows will dwindle, and ground-water recharge from California's mountain catchments may decline, making management of the State's water resources more difficult and potentially less productive.

Meanwhile, along with global warming comes sea-level rise, which poses unique threats to the Delta (which is mostly near or even below current sea level).[16] So far, engineering studies of the impacts of these changes on the ability of the State Water Project to continue to deliver water to southern California have yielded surprisingly optimistic results.[17] ***Nonetheless, estimates of reductions in water supplies from Northern California due to warming have ranged as high as 25%***,[18] ***but at present the most detailed studies have indicated that the ability of the State Water Project to continue to supply water hinges more on the extent to which precipitation rates in Northern California change***[19] ***than on projected degrees of warming.*** That is, recent studies indicate that the water infrastructure of Northern California is adequate to accommodate many of the challenges of warming alone (in the absence of changes in precipitation). However, those studies have not yet addressed the increased tension between using our reservoirs to manage floods (in a time of growing flood risks) and using reservoir as warm-season water supplies (when summertime flows have declined). Because current projections of precipitation change over Northern California are highly uncertain, the capacity of the State Water Project to maintain its deliveries of water in the face of climate change remains likewise uncertain, but could easily increase or decrease by 10 to 15% depending on how precipitation eventually changes.

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[13] At times, the deliveries have been much smaller, e.g., during 1991 in the protracted drought of the early 1990s, Metropolitan received only 381,000 acre-feet or 20% of its "entitlement".
[14] Healey et al. 2008.
[15] Luers et al. 2006.
[16] Cayan et al. 2008a.
[17] Medellin-Azuara et al. 2008; Anderson et al. 2008.
[18] Luers et al. 2006.
[19] Anderson et al. 2008.

Thus the amounts by which San Diego's crucial imported water supplies might decline due to climate change impacts on the Colorado River (which is generally predicted to decline, but by an uncertain amount) and on the rivers of Northern California (which may also decline) remain highly uncertain. Nonetheless, the risks of overall declines in the availability of imported water are high and merit detailed evaluations and inclusion in San Diego's long-term water supply plans. Figure 4-1 shows a 2050 "climate change" scenario that is quite severe, assuming that import-water supplies from the Colorado River and northern California might follow streamflow declines in those regions to result in 20% reductions in the anticipated import supplies. Meanwhile local surface-water and ground-water supplies are assumed to similarly decline whereas supplies of recycled and desalinated water are not so impacted. The blank areas in the final bar of Figure 4-1 represent the supply deficits that would need to be made up under such a scenario unless demands could be reduced substantially. This severe climate-impacts scenario does not include the potential for increased demands, which also could follow from warming, drying local conditions. ***The 2050 shortfalls that would need to be made up under this severe climate-impacts scenario total 164,000 acre-feet per year or about 18% of the total demands by then.***

Unfortunately, because of these uncertainties about the effects of climate change, precise estimates of the levels of depletion or shortfall that the region may face (like those in Figure 4-1) remain very uncertain. Even if a specific climate-change scenario was agreed upon, because of San Diego's strong dependence upon water imported from several distant sources through arrangements that are dictated by economic and institutional competition among many major political entities, the extent to which future supplies will be able to meet future demands in times of prolonged drought and adverse climate changes is almost impossible to quantify at present. ***San Diego's success in obtaining sufficient water by 2050 will depend more on our success in competition with other agencies that draw upon the Colorado River and Northern California than upon the net declines of those resources***, at least until those resources decline to a much greater extent than is projected here for 2050.

San Diego's projected demands for "normal year" imports of water (to round out its supply portfolio and just meet demands extrapolated here) is about 730,000 acre-feet/yr by 2050. This represents an astonishing 228 billion gallons of water per year. However, even if all of this water were derived from the Colorado River, it would only represent about 5% of total allocations from the river. Meeting San Diego's projected demands in the face of a 20% reduction in the river's flows would only raise its purchases of this supply source to about 6%, assuming it is still-available. When a resource is such a modest part of the whole, even small concessions for the sake of regional economic and political stability would make a large difference locally, and could remain regionally feasible. Thus as priorities for the use and deliveries of water (say, between urban and agricultural users) are sorted out in the face of declining river flows, San Diego's future ability to meet its water demands is far from being strictly a function of the overall supply. Rather San Diego's fate in the coming competitions for imported water will depend much more on its ability to make the case for its continued survival in times of shortages and less on the precise amount of resource depletion from the climate changes themselves. In this context, ***the more San Diego is perceived to be using its water supplies wisely and, especially, efficiently, the more likely the region may be to fare well in the regional redistributions of water that climate changes may require.***

Economic Implications

The cost of water in San Diego County will be adversely impacted both by increases in the costs of water imports and increases in demand, anticipated as a result of climate change. Currently, the cost of supplying additional water to San Diego—which can be inferred from the cost of new desalination and reclamation projects--is between $600-1800 acre-feet, depending on the water source. This cost may rise significantly by 2050 as less expensive ways to increase water supply are exhausted. Continued growth of the Los Angeles, Arizona, Las Vegas, and Central Valley is likely to increase competition for the same imported water supplies as San Diego, with the potential to drive up prices as purchase agreements are renegotiated in the future.

Additionally, San Diego County residents' water use responds less to price increases than do residents in other parts of the US and California. A 10% increase in price has been shown to reduce residential and commercial water demand by between roughly 2-4%.[20] This unresponsiveness could mean that San Diego residents and business already use water in an efficient and inelastic manner. However, some suggest that it reflects a low level of awareness of the importance of conservation. The Water Authority has done recent polling and conducted focus groups that indicate an increasing concern over water supply issues, but a current low level of behavioral change in response to this concern. Consequently the Water Authority has begun an aggressive public awareness campaign to address this public-response problem.[21]

A very conservative lower bound for expected yearly increased direct costs of water, with population growth effects removed, is $100 million/year[22]. A more reasonable estimate, accounting for increased demand due to climate change in regions that compete with San Diego, is on the order of $220 million/year, mostly due to lower expected supply. This represents yearly additional costs due to climate change. Under future climate changes, actual costs of water imports would be substantially more as more people in the Southwest compete for fewer water resources in more severe drought conditions. Methods to mitigate future increases in water costs due to climate change include; long-term water agreements (which guarantee set prices on imported water in drought years), more desalinization and wastewater research funded on the local and regional levels (to lower the costs of these water production sources), and statewide water pricing efficiency improvements on both urban and agricultural water users.

Mitigation and Adaptation Options

In recent years, the San Diego County Water Authority and its member agencies have developed and initiated far-reaching plans and projects to increase the amounts and reliability of water supplies that they can provide for San Diego's growing population and

[20] Hanemann et. al. 2007; Nauges. 2005.
[21] Correspondence with Marty Eberhardt, Water Conservation Garden. 2008.
[22] Tanaka et. al. 2006.

economy. Projections of climate change add significant additional burdens to the problems of meeting San Diego's future needs for water. Not yet included in agency plans and outlooks for coming decades are very likely reductions in surface-water runoff and ground-water recharge to local water supplies in San Diego under increasingly warm and dry climates. Probable reductions in Colorado River flows and supplies have been addressed by major agencies with new shortage-sharing agreements, but probably not to the extent required by current projections of climate-change-driven declines on order of 20% by mid-century. ***Uncertainties and risks facing deliveries of Northern California to Southern California are large and potentially dire.***

Additional conservation may be possible and would serve to reduce overall water use and demands, but presumably would require more vigorous measures than pursued to date. Since over half of the residential water uses in San Diego are for outdoor uses,[23] reductions in outdoor demands are likely to bring the look of many San Diego neighborhoods more into alignment with the native dry-land setting in which we live. In 2006, the Water Authority began a retooling effort to expand its outdoor water savings measures. Effective measures have focused on "hardwired" conservation (i.e., changes that make conservation automatic) like xeriscaping and replacement of natural grass with artificial turf rather than requiring repeated actions by residents.

The prospects for acquiring additional sources of imported water, or more local surface and ground water, seem particularly challenging in the face of climate change, given the large regional footprint of water-supply reductions that are likely to be imposed on the whole of the southwestern US. ***Indeed, holding on to currently available rates of supply from these sources is likely to become increasingly difficult.***

Increased reservoir capacity is one adaptive measure to enhance water supply stability to San Diego County in the face of climate change. This measure would lessen the region's annual imported demand requirements and help offset some of the future yearly import costs ($220 million/year as stated above) due to population growth *and* climate change. The Water Authority is currently pursuing a capital project to expand the City of San Diego's existing San Vicente Dam, motivated in part by just such benefits.

An important strategy for facing the potential effects of climate change on San Diego's water supplies is to remain adaptable and vigilant for developing impacts. Work by the RAND Corporation working with the Inland Empire Utilities Agency (IEUA), just north of San Diego, evaluated IEUA's plans in the face of 200 climate-change scenarios describing possible future climates of the next 35 years. The simple expedient of ***building more regular updates and chances for adapting the plan to unfolding future conditions reduced the chances of incurring large costs due to climate change by almost half*** compared to strict adherence to any of the augmentation options considered.

The lesson that San Diego can draw from this investigation is that, given the continuing large risks and uncertainties regarding climate change and how it will impact San Diego's water-supply sources, San Diego's water planning needs to incorporate climate change into its design and decision making, to provide for regular evaluations of whether the plan remains well adapted to developing conditions, and to focus even more on

[23] Estimates range from 60-75% with the higher percentage in inland areas.

improving water-use efficiencies if it is going to avoid the worst risks from climate change by 2030 or 2050.

Summary

San Diego's water supply plans through 2030 (the current planning horizon) are likely to be severely challenged by climate change, even as they balance supplies to address growing demands. The path to reliable water supplies in 2050 remains unclear. Options for meeting these challenges are likely to depend on much increased conservation and demand reduction (including water reuse), together with increased reliance on desalination where feasible. Moving forward on these options is a matter of political will and public commitment. Technological improvements in water efficiency and greenhouse emission reduction from energy use associated with desalination will help. Regular assessments of evolving climate knowledge incorporated into periodic evaluations of infrastructure and planning, will be important tools in moving government policy and public awareness. The critical factor will be forward-thinking public policy and leadership to change individual and collective behavior.

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CHAPTER 5: WILDFIRES

Introduction

San Diego County already has some of the worst wildfire conditions in the country, and ***the situation is likely to worsen with climate change — portending dangerous consequences for both humans and our native ecosystems*.**

A region's fire regime is defined by the number, timing, size, frequency and intensity of wildfires, which, in turn, are largely determined by weather and vegetation. San Diego's unique combination of fire-prone, shrubby vegetation and extreme fire weather means that fires here are not only very frequent, but sometimes very large and extremely intense. Vegetation on San Diego's coastal plains and foothills—where humans are most concentrated—is dominated by shrub species that burn hot and fast, and that renew themselves in the aftermath of fire (so long as they have sufficient time to mature and reproduce before the next fire). In our Mediterranean climate, this coastal sage and chaparral vegetation rapidly grows fine new twigs and leaves during the moist winters. This new growth then dries to a highly flammable state during the arid summer-fall season. Consequently, most fires burn during summer when fine, dry fuels become abundant, whereas the greatest total acreage burns in fall, when the largest fires are driven by hot, dry Santa Ana winds.

Fire frequency has steadily increased in San Diego County, in direct proportion to human population growth. This threatens biological diversity by not allowing sufficient time for native species to recover before they burn again. Coupling this increase in the number of fires with the effects of climate change suggests that more fires are likely to occur during the most dangerous, Santa Ana weather conditions. Consequently, we are likely to experience more devastating firestorms similar to those that destroyed so many homes and lives in 2003 and 2007.

Figure 5-1. Firefighter in the 2007 wildfires. Photo Source: Fred Greaves

Interaction between Climate Change and Wildfires

Different climate change models yield somewhat different predictions about the frequency, timing and severity of future Santa Ana wind conditions, leading to uncertainty about just how fire regimes may change in the future. According to some researchers, there is a 5 percent to 20 percent predicted increase in the number of days with ideal conditions for large-scale fires in the county due to climate change.[1] Preliminary analyses by the California Climate Change Center[2] for the period 2005-34 suggest that Santa Ana conditions (dry hot winds blowing down the mountains from the deserts in the east) may significantly increase earlier in the fire season (especially September), while they may decrease somewhat later in the season (in particular, December). ***This predicted shift to earlier Santa Ana occurrences would likely increase the frequency of huge Santa Ana fires as severe fire weather would coincide more closely with the period of most frequent fire ignitions (Figure 5-2)***.

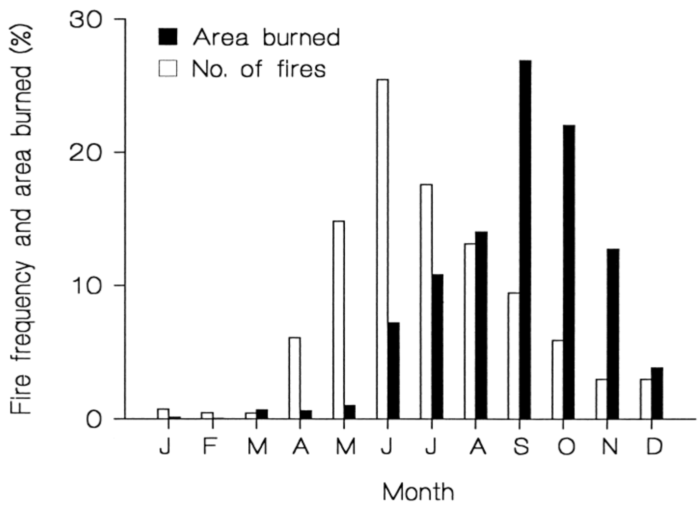

Figure 5-2. Monthly distribution of fire frequency and area burned from 1910 to 1999 in southern California[3]

Of course, fires also require an ignition source. Fires started naturally, by lightning strikes, are actually quite rare during our most dangerous autumn fire weather—when the hot, dry Santa Ana winds blow. Today, however, the vast majority of ignitions are caused by humans or our inventions. Even without climate change, the number of fires in southern California has steadily increased in direct proportion to human population growth (Figure 5-3). ***This increase in ignitions, especially if coupled with a longer fire-weather season, creates more opportunities for fires to start when conditions are most extreme.***

[1] Brown et al. 2004.
[2] Miller and Schlegel. 2006.
[3] Keeley and Fotheringham. 2000.

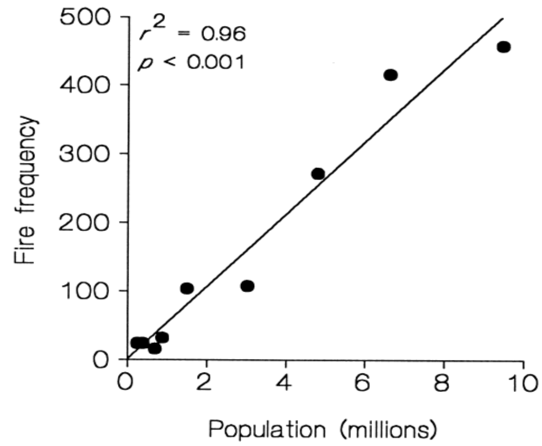

Figure 5-3. Fire frequency each decade since 1910 versus population density at the beginning of each decade in southern California[4]

Extended drought can increase the severity of wildfires when they are ignited. Projections made from various climate models and scenarios nationally include increased drought and thus extended fire seasons, more extreme weather and more frequent, large wildfire events.[5] Westerling et al.[6] showed that large wildfire frequency and longer wildfire durations increased in the mid-1980s, when there was a marked increase in spring temperatures, a decrease in summer precipitation, drier vegetation and longer fire seasons. The 2003 and 2007 wildfire events in San Diego were shaped by extended drought that reduced fuel moisture of chaparral and trees, the Santa Ana winds and high temperatures, and the ignition in chaparral that burned “uphill” into the forests.

Nevertheless, huge firestorms such as those during 2003 and 2007 are not new phenomena in this region. Studies of charcoal layers deposited on the ocean floor off the California coast indicate that such major fire events have recurred on average every 20 to 60 years, or roughly two to five times per century over the past 12 to 13 centuries.[7] These huge firestorms inevitably occur following wet years, at the beginning of drought periods.[8] How these inter-annual wet-dry cycles may change with our changing climate is as yet unclear.

Researchers are currently developing wildfire impact assessments for San Diego for 2050, which were being developed as this report was being finalized.[9]

Impact of Wildfire on Biodiversity

Fire is a key ecological process in the San Diego region and our native species are well adapted to the long-term *natural* fire regime. However, the current fire regime may be

[4] Ibid.
[5] McKenzie et al. 2004.
[6] Westerling et al. 2006.
[7] Byrne et al. 1977; Mensing et al. 1999.
[8] Mensing et al. 1999.
[9] Personal communication, Dr. Anthony Westerling, 5/14/08

changing faster than many species can adapt and human changes to the landscape exacerbate the problem.

In recent decades, fires have actually occurred less frequently than is natural in some higher elevation forests, where fire suppression has been fairly effective in excluding fire for long periods. In forests, these longer-than-natural inter-fire intervals allow fuels (e.g., dense thickets, dead and dying trees) to build up and can result in more severe fires than natural when they do occur. Mature trees that would survive typical fires can be killed under these unnatural conditions, potentially eliminating forest vegetation. For example, the huge, old sugar pines of the Cuyamaca Mountains were nearly eliminated by the 2003 Cedar Fire; and populations of birds that require mature coniferous forest, such as the pygmy nuthatch, western tanager and brown creeper, have been greatly reduced as a result.

Figure 5-4. The Cactus Wren. This native bird is dependent on a network of “old growth” cactus patches, which are becoming increasing sparse due to fire and invasive species. Photo Source: DonGettyPhoto.com

In contrast to high-elevation forests, chaparral and coastal sage vegetation closer to the coast, where humans are more concentrated, appear to be burning *more* frequently than is natural, despite efforts to control fires. This increase in fire frequency is due to the increase in human-caused ignitions (Figure 5-3) coupled with the inability of fire fighters to contain brush fires during severe fire weather, when the most acres burn. Consequently, unlike in pine forests, studies show that fire suppression has not successfully excluded fire from our shrub-dominated communities or contributed to unnaturally severe fires.[10] Moreover, these studies show that Santa Ana fires burn through vegetation of all type and ages, and that vegetation management has therefore not been effective at reducing the total amount of fire on the landscape or the size of the most destructive fires. However, vegetation management in shrub communities can be locally successful at reducing fire intensity and providing defensible space in strategic locations, such as near homes, to give fire fighters a chance to save them during a wildland fire.

[10] Keeley and Fotheringham. 2000; Keeley and Fotheringham. 2006; Moritz. 2003; Moritz et al. 2004

Under presettlement conditions, the largely unbroken habitats that existed allowed plant and animal communities to shift around on the landscape in response to fires and post-fire regrowth. However, today our human development patterns have reduced and fragmented the natural landscape such that there is sometimes nowhere for wildlife to shift to when large fires burn across habitat areas and into the urban interface. For some highly restricted species, a single fire could conceivably lead to extinction.[11] [12]

Plants and animals are adapted to the particular fire regimes under which they evolved. Many plant species display adaptations that are finely tuned to a particular frequency and intensity of fire. Some plants re-sprout from roots following fire, whereas the seeds of others require heat or chemicals from smoke to germinate. Some animals thrive in recently burned areas, whereas others require old-growth habitats that have not burned for many decades. What is perhaps counter-intuitive is that even those species adapted to—or even reliant on—fire can be put at risk by fire. For example, the rare Tecate Cypress requires fire to reproduce, but if fires recur too frequently they can kill the young trees before they mature and set seed to produce the next generation. This disruption of a finely-tuned life cycle threatens to eliminate this unique tree species from the county.

One final factor influencing biodiversity under these altered fire regimes is the proliferation of weedy, non-native species. These weedy invaders thrive in post-fire conditions. They also set seed and dry out earlier in the year than native plants, thereby starting the fire season even earlier and increasing chances of yet another fire. Referred to as "flash fuels" by firefighters, annual weeds also ignite more readily and burn more rapidly than native perennial plants, thus creating a more favorable environment for themselves—at the expense of the natives, which evolved under longer fire-return intervals. ***Due to the combined forces of changing climate, increasing fire ignitions and invasive weedy species, fires are likely to burn ever more frequently in a positive feedback loop.***

Future land use and climate changes will only exacerbate the altered fire regimes in the county. ***Concern about changing fire behavior transcends biodiversity conservation considerations alone; there are also important implications for public safety, the quality of our air and water and the economy.***

[11] Betzler et al. 2003.
[12] Although there is disagreement concerning whether there were native trout in Sweetwater River in recent years, some trout experts in the County (e.g., Alan Greenwood of San Diego Trout) maintain that native rainbow trout survived in the upper Sweetwater drainage until the 2003 Cedar Fire eliminated them and native stickleback populations; and the last native trout population in the County is currently threatened in Pauma Creek by sediments filling pools (after the 2007 wildfires and rainstorms).

Figure 5-5. The Thorne's Hairstreak Butterfly. This butterfly is a highly restricted species that had all known occupied patches burn in a single fire in 2003. Photo Source: Michael Klein

Impact of Wildfires on Public Health

Wildfires can be a significant contributor to air pollution in both urban and rural areas, and have the potential to significantly impact public health primarily through their smoke and increased particulates.[13] Climate changes are expected to affect the frequency, severity and distribution of wildfires in San Diego County, which in turn are predicted to have affects on mortality and morbidity through fire-related injuries. Fires also create secondary effects on morbidity as the result of increased air particulates causing worsened respiratory conditions. People most at risk of experiencing adverse effects related to wildfires are those with existing cardiopulmonary disease, and that risk seems to increase with advancing age. As the population of San Diego ages, with over one million people 65 and older in 2050, so too will the health impacts of wildfires (see Chapter Seven).

Economic Implications

The societal costs associated with wildfires include the direct costs of prevention, management and response by government agencies, the economic cost of homes and businesses lost or damaged, the public health impacts and the disruption of business-as-usual even in areas not directly threatened by flame. State and local governments face increasing direct costs of fighting the increasingly frequent and severe fires. These large-scale wildfires have large direct costs of management as observed in the wildfires over the past six years in San Diego County. In addition, the rest of the southwestern U.S. is predicted to see an increase in the occurrences of large-scale fires. If the status quo firefighting techniques are expanded, it is reasonable to think that the direct costs of fighting wildfires would increase roughly in proportion to the increase in fire-causing

[13] Luers et al. 2006.

conditions.[14] Econometric estimates of the direct and indirect productivity losses are difficult to measure. The cost of the 2007 wildfires in San Diego was estimated at nearly $2 billion for losses in residential and commercial properties.[15] In addition to the direct costs, during and immediately after severe wildfires, many private firms and public agencies are forced to shut down due to air quality. ***A complete three-day shutdown costs roughly 0 .75 to 1 percent of county output, or $1.5 billion***.[16] As a result, even one extra large-scale wildfire due to climate change can have very large indirect economic costs due to productivity losses.

One adaptation strategy to the increased costs of fighting large-scale wildfires is to coordinate a centrally-based regional firefighting unit based upon regional fire risk rather than state borders. Given that climate change could increase the number of large-scale wildfires, the large fixed cost of setting up such a regional wildfire fighting agency could be spread over events and be more cost effective than the status quo. Estimates for cost savings of this type of endeavor have yet to be determined econometrically.

Summary

The potential for interactions between climate change, weedy invasions, and changing fire regimes paints a grim picture for San Diego's biological diversity and watershed quality, as vast stands of diverse and soil-holding shrub communities are replaced by biologically sparse, shallow-rooted, fire-perpetuating weeds. While vegetation management programs may offer some help at the urban-wildlife interface, effective strategies to reduce fire risk in scrub and chaparral ecosystems, where the fire risk is increasing most rapidly, are not yet in place. Public discussion of issues such as building codes, prohibiting development in fire-prone areas, changes in landscaping and irrigation, and community fire planning will be needed to develop effective response strategies as the risk of wildfires continues to threaten the San Diego region. The consequences go beyond biodiversity and ecosystems and represent risks to public safety, human health and the quality of our air and water.

[14] The authors only examine climatic conditions in the 21st century. If there are more fires, then there would be less fuel for future fires, possibly making the direct cost of fighting fires rise slightly less than the increase in ideal fire conditions.
[15] Nash. (In Press).
[16] There was increased revenue in the hotel and restaurant industries during the 2007 wildfires, which is not accounted for in this figure.

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CHAPTER 6: ECOSYSTEMS

Introduction

The biological richness of San Diego County is difficult to overstate. Located at the heart of a global biodiversity hotspot[1] and ranked among our country's national hotspots,[2] the County is home to perhaps more species - and more imperiled species - than any other county in the continental United States.[3] Ensuring the persistence of that diversity through the changes to come in climate will be a formidable challenge for science, government, and our community at large. The persistence of the native plants and animals that characterize San Diego County will depend on sustaining the health of our ecosystems, which will, in turn, also help protect the quality of life for which the County is renowned. To understand potential effects of climate change on San Diego ecosystems and biodiversity, it is important to recognize the trajectories of change these natural resources are already on.

San Diego County ecosystems are highly varied, and are perhaps best imagined as a vast mosaic of different habitat types: coastal scrublands transitioning to chaparral covered foothills; coniferous forests and oak woodlands of the mountains then transitioning down to desert scrub. The habitat variation is the result of a complex set of soil and geologic conditions combined with a diversity of climatic conditions. For example, precipitation ranges from more than 40 inches per season on Palomar Mountain to 10 inches in coastal San Diego and 2 inches in Ocotillo Wells in the eastern desert. The biodiversity patterns we see on the landscape today are a result of millions of years of climatic and geologic flux. Over millennia, populations of our native biota expanded and contracted in range - some at local scales, others at hemispheric scales, some up and others down slopes - to find and adapt to the local conditions that allowed them to persist to this day. During drier periods, for example, the range of some species may have contracted to the refuge of mountaintops that provided the conditions necessary for survival; during wetter periods, those species may have expanded from those refuges to re-sort across the landscape that is now our County.

What this dynamic context reminds us is that change occurs at various temporal and spatial scales, and that while today's climate may be our baseline, our climate has not been and will not be static. It also underscores how critical connectivity is in our landscape: our extraordinary biological richness is to a great degree a product of species being able to shift in their range and adapt to changing climatic conditions. If that connectivity is lost, or if the climate changes outpace the ability of species to respond, or if populations are already reduced or stressed by other factors, species may be unable to persist through the climate changes to come.

The San Diego landscape today is highly altered by human land uses. Already home to three million residents, the County has experienced a great loss of natural habitat to urban, suburban, and agricultural development. Much of the habitat that remains is fragmented and to varying degrees altered. Such changes to the landscape can have

[1] Myers, et al. 2000.
[2] Stein, et al. 2000.
[3] Dobson et al. 1997.

substantial direct and indirect impacts on native species and natural communities, and many of these effects take a long time to unfold. Entirely new species may appear, while populations of familiar native species may increase, others may decrease, and others still may disappear. Thus, even if climate and land use patterns were somehow held constant, this County would still undergo dramatic change just by settling into the new "equilibrium" set by existing impacts. Said more starkly, some of our native species may already be challenged to avoid extinction.

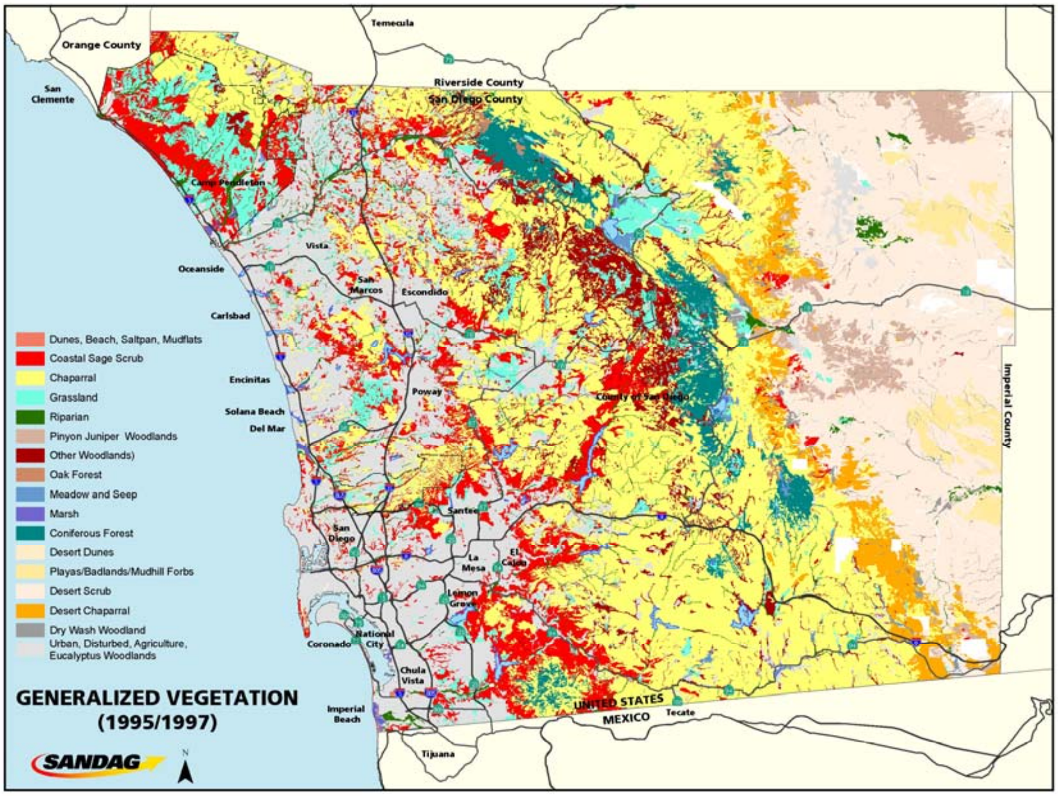

Figure 6-1. Map of San Diego County, showing vegetation in 1995, with vegetation in the eastern portion of the County mapped in 1997. Source: SANDAG

Table 6.1. Total species diversity in San Diego County

	Vascular Plants	*Birds*	*Mammals*	*Reptiles*
Total	2143	492	99	75
Threatened and Endangered	30	13	3	2

Thus, San Diego ecosystems are already fated to a long-term change trajectory - before we even consider the effects of future climate and future land use change. For many species and ecological processes, the direct and indirect effects of past and future land use change may create significant stresses, that left unmanaged could fate species to extinction. Some of these land use impacts may have a more significant impact than a changing climate. The challenge for the San Diego community is to parse out the anticipated effects of past and future land use change from those of climate change - so that we can better plan our strategies to protect ecosystem health and conserve our native biodiversity for future generations.

Characteristics of the San Diego Region

San Diego County is characterized by a Mediterranean climate with cool, wet winters and warm, dry summers. In this and other semi-arid regions, precipitation is a key driver of ecological productivity and therefore population dynamics. While some plants and animals may be less dependent on rainfall than on the moisture provided by coastal fog, other species in this region may be highly adapted to the within- and between-year variation in precipitation. Some species, for example, have evolved traits that allow them to persist through long drought periods; when high rainfall years occur, these species may be able to respond quickly to reproduce before the next drought cycle sets in. Episodic good years may be especially important for the survival of some species, so the frequency, duration and intensity of the dry-wet cycle can be critical. Vernal pools4 are an interesting case study of this finely-tuned adaptation: many plants and animals that are restricted to seasonal pools only appear from the soils when there is enough water to actually create a pool, and these species must complete their life cycle in the weeks before the pool again dries.

Figure 6–2. San Diego's Fairy Shrimp. Its lifecycle tends to be finely tuned to the inundation period of seasonal vernal pools. Photo Source: US Fish & Wildlife Service.

Within- and between-year patterns in rainfall also drive the hydrological regimes of our streams and rivers, and many aquatic and riparian communities rely on periodic flooding to maintain their native diversity. For many species, what will determine their ability to adapt to changes in climate will be not just how much less or more rainfall *on average* occurs, but rather, *how much -- and when,* it falls.

[4] Vernal pools are seasonal bodies of standing water that typically form in the spring, dry out completely in the hotter months of summer, and often refill in the autumn and provide important breeding habitat for many terrestrial or semiaquatic species such as frogs, salamanders, and turtles.

The objective of this chapter is to provide a qualitative baseline evaluation of the likely future trends in natural vegetation and wildlife diversity in light of future trends in regional climate change, population growth and regional development. Projections are based on expert assessments and quantitative analyses of how the increase in regional temperatures, growing frequency and intensity of drought conditions and heat waves, longer dry seasons, and sea level rise may affect San Diego's natural environments. We acknowledge that there will be a multitude of different future impacts of climate change and demographic changes on specific species, ecosystems, ecological processes and ecosystem services, many of which are little understood at this point or possibly not even appreciated in their importance. In this chapter we provide an expert-based selection that focuses on those effects that are particularly pertinent to San Diego and have been specifically studied in the region. Two key areas of impact are examined in this chapter: 1) existing threats to biodiversity and ecological processes and 2) impacts of climate change on San Diego's forests, shrublands and coastal ocean. Gaps in knowledge and research needs are addressed in Appendix B.

DEFINITIONS

Biodiversity – sum of the species, ecosystems and genetic diversity of Earth
Species – plant or animal that is biologically distinct
Natural communities – groupings of plants and animals that generally coexist in an undisturbed condition
Ecosystem – system formed by the interaction of plants and animals and their environment
Ecological process – natural interaction of animals, plants and the physical environment
Ecosystem services – fundamental life-support services upon which human civilization depends (e.g., water provisioning, soil/slope stabilization, recreation, quality of life)
Habitat fragmentation – breaking up the natural landscape into small patches separated by urban and agricultural development
Mitigation – act of reducing impacts of land development through setting aside land and/or enhancing habitats

Threats to Biodiversity and Ecological Processes

<u>Land Use</u>

Looking across San Diego County we see how existing land use changes have brought significant, often cascading impacts to biodiversity and ecosystems - and we have seen how these have threatened the quality of life for the human residents as well. Ecological impacts of land use have been well documented in San Diego; indeed, pioneering research in the field of conservation biology has come from studies conducted locally on habitat fragmentation. The starkness of the fragmentation pattern in San Diego sets up an experimental array for investigating how the size, shape and isolation of habitat fragments affect their ability to support native species.

We know that when habitat is fragmented by human land uses, it can trigger ecological cascades that result in the loss of species. Top predators like coyotes may be lost if habitat patches become too small or isolated, and that can lead to an increase in smaller predators that prey on native songbirds.[5] Fragmentation can also affect communities from the bottom up. When coastal scrub habitat is fragmented, non-native Argentine ants invade and native ant species disappear;[6] horned lizards soon also disappear because they have lost the native ant species that are their main food resource. Such "ecosystem decay" leading to loss of biodiversity may take decades to play out following the fragmentation. ***In human-dominated regions of the world such as San Diego County, the combination of climate change and habitat fragmentation is a central challenge facing conservation.***

Climate Change

A changing climate will add to the stress on ecological systems in ways that may create feedback cycles with significant consequences. For example, if the amount of rainfall occurring within (and between) years changes, the effects of fragmentation on native species may be even more intense. More frequent fires may facilitate invasion by non-native weeds (especially in areas where nitrogen deposition resulting from anthropogenic emissions is high) and that, in turn, increases fire risk (see Chapter Five). Human demand for limited water supplies may have negative effects on native plants and animals, particularly species associated with rivers. Meanwhile, increased irrigation run-off from hard surfaces in an urbanized watershed can fundamentally alter hydrological regimes.[7] These threats may create population problems for native species and possibly lead to extinction.

Most of the direct impacts from the extreme urbanization pressure on southern California have occurred recently, and this means that the indirect effects have yet to unfold. Some areas of San Diego County will likely witness an acceleration of those effects. Compounding the ecological impacts of land use change is a rapid shift in climate that is perhaps unprecedented. The "climatic envelopes" that species need - the locations where the temperature, moisture and other environmental conditions are suitable for persistence - will move. For many species, a changing climate is not the problem per se. The problem is the rate of the change: the envelope may shift faster than species are able to follow. For other species, the envelope may shift to areas already converted to human land use. Human impacts may have undermined the resilience of some populations to adapt to the change (e.g., by lowering their overall population). Human land uses also may have severed the ecological connectivity in the landscape that would provide the movement corridor from the current to the future range.

When ecological processes and native species are altered to this degree, the transformation of the county to a management dependent ecosystem will be complete. This new reality demands that a desired future condition for San Diego be defined. Only when we are informed with a sober assessment of the current and future challenges confronting our native species, and a clear articulation of ecological and socio-economic goals, will we be able to manage our native species and systems through the transformation ahead.

[5] Crooks and Soulé. 1999.
[6] Suarez et al. 1998.
[7] White and Greer. 2002.

Figure 6-3. The Coast Horned Lizard. This lizard is a California and federally protected species. One subspecies is believed to be extinct in 45 percent of its original range in southern California due to habitat destruction along the coast. Photo Source: San Diego Natural History Museum

Specific Challenges of Climate Change in San Diego

San Diego County harbors an outstanding diversity of plants and animals, so the impact of climate change promises to be especially daunting. All species have somewhat unique climatic and biological requirements for persistence and are expected to respond differently to the same climatic change. The response of species is determined by external conditions, including temperature, but also by conditions such as interactions with other species and their ability to adapt to experienced changes.

Under the forecast for rapid climate change, native San Diego species will face novel environmental conditions with very little time available to adjust. Even if the changes in climate are gradual, we know that the changes will be steep. Species unable to shift their geographic range within a limited time period, and those with limited ability to adapt are under particular threat. Some species may even require assistance moving to new regions.

Even with a gradual change there may be tipping points in the system, whereby ecological complexities interact and there is a dramatic step change in the system. These may include die-back of forests over broad scales due to aberrant drought conditions; conversion of shrub habitat to non-native grassland with too-frequent fires; and the scouring of a watershed, excessive erosion and alteration of geomorphology of our streams and rivers, with rain after catastrophic fire. Such fundamental conversion of our ecosystems could be abrupt and irreversible and we do not know where such points of no return (thresholds) might be.

Widespread ecological and evolutionary responses to climate change were recently summarized by Parmesan.[8] Some of these responses have been observed locally, and were described by 46 scientists, managers, and educators who met on November 7, 2007 to learn about projected climate changes, to review local observations of direct and indirect effects, and to discuss ways to document future ecosystem responses to climate change.[9] Although there are few scientific studies and correlations of climate change to San Diego's plant and animal distributions, observations over the past two decades include the following:

- **Elegant terns, black skimmers**, and other marine and coastal birds are nesting in more northward locations in southern California. San Diego birders report that some **migrating birds** are arriving earlier in the spring, compared with a few decades ago.

Figure 6-4. A Black Skimmer. Photo Source: Earl Cryer

- Insects such as the **Quino Checkerspot Butterfly** depend on availability of host plants during their larval stage. The larvae are adapted to periodic droughts of short duration. If host plants do not grow for a long series of seasons due to prolonged drought conditions, the butterfly populations may be eliminated. This is compounded by loss of host plants due to habitat destruction, fragmentation and degradation by invasive non-native plants.

- Exotic grasses and weeds have replaced **coastal sage scrub species** where wildfires burned repeatedly in the same place, when shrubs are not mature enough to flower and produce seed, or do not resprout vigorously. About 800,000 acres burned in 2002 to 2007 of which about 50,000 acres burned twice and are not likely to regrow to coastal sage scrub and chaparral.

- The 2003 wildfires burned 20,000 acres of **Jeffrey, Coulter and Sugar Pine** trees in Cuyamaca Rancho State Park, at temperatures so hot that conifer trees and seedlings were completely combusted. The oaks are resprouting and stands

[8] Parmesan. 2006.
[9] Hawke et al. 2007.

of chaparral have spread into former forest areas. Only a few areas of conifers remain. Much of the forest will be permanently altered unless conifers are extensively replanted.

- Many **Coast Live Oaks** in the Descanso area are dying, and tree experts cannot isolate a disease or insect in these trees. It may be caused by lowered water tables, as excessive groundwater pumping is drying out local streams, habitats, and wells in the backcountry-and future droughts will reduce groundwater recharge and supplies even more.

- **Vernal pools** and the unique and endangered **Fairy Shrimp** and plant populations have been nearly eliminated from the San Diego region. They were abundant on mesas near the coast and now remain in a few locations and the Miramar Marine base. They are small pools that naturally fill with winter rainfall and as such are highly dependent on regular precipitation. Drier conditions may reduce them further.

- Two relic colonies of **Harvester Ants** have disappeared from Quail Botanical Gardens since 1995. There are no longer any sightings of western toads, California quail, acorn woodpeckers, grey fox, bobcat, roadrunner, and spadefoot toad.

- The **Southern Sagebrush Lizard** is found only at elevations above 5,000 feet, enjoying open ground, clear sunlight and low vegetation. Their populations are now reduced and they may disappear from local mountains that "top out" at 6,000 feet if temperatures continue to rise.

Figure 6-5. A Southern Sagebrush Lizard. Photo Source: Bradford D. Hollingsworth (San Diego Natural History Museum)

Here we focus on three specific example systems of particular relevance to illustrate the array of impacts on San Diego's unique ecosystems expected under climate change: forests, shrublands and the coastal ocean.

Climate Change in San Diego’s Forests

Extended drought can stress individual trees, increase their susceptibility to insect attack and result in widespread forest decline. Plant species respond differently and entire species may die off when drought occurs in an area that already has predictable seasonal droughts, such as San Diego's summers.[10] Stressed trees have less resistance to insects, such as bark beetles that girdle and kill the trees. More indirectly, warmer winter temperatures projected for San Diego's future can increase insect survival and populations. Drought and abnormally warm years that began in the 1980s have resulted in unprecedented pest outbreaks and tree dieback in western North America.[11] Also, as noted in the previous chapter, drier and warmer conditions may also compound the intensity of wildfires.

Forest-dependent fish and wildlife species may be lost in the indirect effects of climate change, drought and wildfire. Forest management such as thinning and the removal of drought-induced dead trees may enhance forest health and result in wildfire impacts more closely resembling historical low-intensity, higher-frequency intervals. Some of this was accomplished with federally-funded removal of dead trees in the past three years. However, a forest management plan and further forest cultivation investments are needed in the county.

<u>Plant and Animal Species in Southern California Shrublands</u>

The Center for Conservation Biology (CCB) at the University of California, Riverside developed and evaluated models predicting potential habitat for a variety of plant and animal species in different ecosystems in southern California.[12] A particular focus has been on shrubland communities that support a diversity of sensitive plant and animal species in the region. To begin to understand how changing climate conditions might affect these natural communities, the CCB has conducted climate sensitivity analyses for coastal sage scrub and chaparral vegetation as well as for plant and animal species found in these shrublands.[13]

To assess sensitivity of species and vegetation types to climate, the models used varied temperature[14] and precipitation[15] compared with current climate conditions. These values fall within the range of various climate forecasts for the region,[16] although the emerging consensus is that the region will become more arid.[17] In response to rising temperatures and reduced precipitation, ***each vegetation type moves to higher elevations, where conditions are cooler and there is greater precipitation compared with locations previously inhabited by these shrublands.***

Suitable environmental conditions for natural communities of coastal sage scrub were predicted to decrease by between 10 percent and 100 percent under altered climate conditions, with the greatest reductions at higher temperatures and extremes in precipitation. Chaparral communities responded in a similar manner as coastal sage scrub, although higher percentages of suitable habitat remain at the elevated temperatures with current or reduced levels of precipitation. Similar analyses were conducted for five different coastal sage scrub shrub species; California sagebrush

[10] Hanson and Weltzin. 2000.
[11] Logan et al. 2003.
[12] Preston and Rotenberry. 2007. See Appendix I for a discussion on the development of the models.
[13] Preston et al. (In Press).
[14] [+ 0.6 degree C (1 degree F), +1.7 degrees C (3 degrees F), and +2.8 degrees C (5 degrees F)]
[15] 50 percent, 90 percent, 100 percent, 110 percent and 150 percent
[16] Hayhoe et al. 2004.
[17] Seager et al. 2007.

(*Artemisia californica*), brittlebush (*Encelia farinosa*), flat-topped buckwheat (*Eriogonum fasciculatum*), laurel sumac (*Malosma laurina*), and white sage (*Salvia apiana*). The CCB also modeled two annual host plants, California plantain (*Plantago erecta*) and white snapdragon (*Antirrhinum coulterianum*) for the endangered butterfly Quino Checkerspot (*Euphydryas editha quino*). All plant species, except brittlebush, flat-topped buckwheat and white snapdragon showed similar sensitivities as coastal sage scrub and chaparral to altered climate conditions. These three exceptions showed higher levels of potential habitat remaining at elevated temperatures, particularly flat-topped buckwheat.

The CCB also developed models predicting suitable habitat for the federally-endangered Quino Checkerspot butterfly and threatened California Gnatcatcher (*Polioptila californica*). The intent was to investigate whether associations between species, such as an animal species' dependence on a particular type of vegetation or specific plant species for food or shelter, might affect their potential distribution in a changing climate. The premise is that species are likely to differ in their sensitivity to climate change. For example, an animal species might rely upon a particular vegetation type or plant species that is more sensitive to changing climate conditions than the animal species. If this plant or vegetation type becomes more restricted in distribution as a result of changing climate, this could further limit the animal species' distribution. Models were developed that included associations between animal and plant species under altered climate conditions,[15,16] and predictions of suitable habitat were compared with predictions from models that included only climate variables and did not consider species associations. It was found that when vegetation, shrub or host plant species were included in the animal models, ***potential habitat for the butterfly and songbird were reduced by 68-100 percent relative to the climate-only models under altered climate conditions. This suggests that suitable habitat for some species under climate change may be reduced by their dependence on certain vegetation types or particular plant species.***

Appendix J contains distribution models run for five species currently found in San Diego County by UC Santa Barbara researchers. The models were used to predict distribution changes with climate change.

Climate Change Impacts to the Biodiversity of San Diego's Coastal Ocean

The intertidal and subtidal habitats along the coast of San Diego harbor a large diversity of marine algae, invertebrates and fish. Changes in compositions of these communities are already evident in response to changing climate as well as other more direct human impacts such as recreational and commercial harvesting of invertebrates and fish. By the year 2050 the diversity and composition of marine communities along the San Diego coast will almost certainly be different from today. This section outlines current knowledge about general responses of marine species to climate change and other human-caused impacts in order to discuss the types of changes that we are likely to see along the coast of San Diego by the year 2050. Appendix B includes a discussion of research initiatives needed to ascertain the data needed to support more specific predictions of how marine biodiversity along the coast of San Diego will look by the middle of this century.

Effects of climate change on coastal marine biodiversity

The predicted increase in global temperatures over the next century will cause sea surface temperatures to increase and also lead to other changes in coastal oceanography. In particular, changes in the intensity of winds along the coast can lead to major changes in upwelling patterns,[18] which in turn influence nutrient supply and coastal ecosystem dynamics. Upwelling intensity along the California coast has been increasing over the last three decades and this trend is likely to continue.[19] However, the relationship between climate change and wind-driven upwelling is complex[20] and specific predictions of how upwelling patterns in San Diego and adjacent regions will change are currently not available. Sea-level rise is another consequence of climate change that is likely to impact coastal regions adversely (see Chapter Three). Expansion of seawater as it warms, combined with the melting of polar ice sheets, will cause global sea levels to rise substantially by the year 2050.[21] Furthermore, the growing concentration of CO_2 globally is likely to make ocean waters more acidic - a potential problem for many marine organisms that have calcium carbonate ($CaCO_3$) skeletons.[22]

Effects of urbanization on coastal marine biodiversity

Continuing population growth in the San Diego region is likely to affect the biodiversity of the coastal ocean in a number of different ways. Harvesting of coastal marine organisms for food, bait and other uses is negatively influencing the population biology of many species (see below) and these impacts are likely to intensify as more people use intertidal and subtidal resources. Likewise, trampling of intertidal has a negative impact on the biodiversity of many of the well-known tidepools of San Diego as more people visit these habitats.[23] On a larger spatial scale, changes in land-use patterns as well as continuing coastal development are likely to increase the input of land-derived nutrients into the coastal ocean and also change freshwater inputs. Nutrient loading of coastal waters due to sewage discharge and run-off can lead to eutrophication. It can also degrade water quality and negatively impact coastal marine biodiversity as well as biogeochemical cycles.[24] Armoring of coastal zones with seawalls, riprap and other structures is another common but underestimated impact of urbanization on intertidal biodiversity. Such constructions change the nature of the substrate available for intertidal species to colonize and thereby favor certain species over others.[25] As sea levels rise in response to climate change, such structures are certain to cover more of the San Diego coastline.

Changes in species distributions and compositions of ecological communities

Temperature and coastal oceanography are important determinants of species' geographic ranges and shifts in the distributions of those species are a common response to climate change.[26] Some of the marine invertebrate and fish species that are common today along the San Diego coast are likely to become rarer or even locally extinct as the climate warms. Conversely, some southern species are likely to extend

[18] Rykaczewski and Checkley. 2008.
[19] Snyder et al. 2003.
[20] Harley et al. 2006.
[21] IPCC. 2001.
[22] Feely et al. 2004.
[23] Addessi. 1994.
[24] Schlesinger. 1997.
[25] Pister. 2007.
[26] Roy et al. 2005.

their ranges into the San Diego region. As a result of such range shifts, compositions of coastal marine communities are likely to change - leading to changes in ecosystem functions and services.

Similar shifts in the northern range limits of southern species have also been documented more recently. For example, many southern species of invertebrates and fish extend their distributions into southern California during El Niño years,[27] but those populations do not persist once the waters become colder again. As coastal ocean temperatures rise, many of these species are likely to become permanently established in the San Diego region. Some of these changes are already apparent. In many rocky intertidal habitats along the San Diego coast, one of the most common intertidal mollusk species seen today is *Mexicanthina lugubris*. This species occurs in very high densities and is a predator of barnacles and other small invertebrates. As the name suggests, historically the distribution of this species has been along Baja California. Prior to 1970 it was only sporadically seen in San Diego and southern California.[28]

Coastal upwelling brings nutrient-rich colder waters to the surface and it is a major contributor to abundant supplies of many coastal fish[29] and invertebrate species. For example, a recent study has shown that the abundance of Pacific sardine in the California Current Ecosystem is closely tied to wind-driven upwelling.[30] As upwelling patterns change in response to climate change, it is likely to affect the distribution and abundance of a number of species.

The changes seen in the fossil record, as well as emerging evidence from other parts of the California coast[31] and elsewhere,[32] suggest that it is very likely that by 2050, climate change will lead to changes in the distributions and abundances of many marine species found along the San Diego coast. Like those on land, marine species have three options in the face of changing climates: they must "adapt, move, or die."[33] However, predicting which species in San Diego will adapt to warmer temperatures and which will relocate or go extinct remains a challenging problem.

As discussed below, we still lack an adequate inventory of marine species along the San Diego coast. Monitoring programs required to document the types of changes mentioned above are either non-existent or only focus on a handful of species. The knowledge gap is particularly large for small invertebrates (species less than 2mm in size, generally known as the meiofauna) and marine microbes. Both of these groups play critical roles in the functioning of coastal marine ecosystems, yet we know little about the distributions or abundances of these species or how they are being affected by climate change. Even for larger species, a well-designed monitoring program for intertidal and subtidal benthic communities is lacking (except locally in the kelp forests and a few of the estuaries).

[27] Zinsmeister. 1974.
[28] K. Roy and others unpublished; for past occurrences see http://www.biology.ucsd.edu/labs/roy/CBRISC/species-reports/T256Mlugubris.html
[29] Ryther. 1969.
[30] Rykaczewski and Checkley. 2008.
[31] Barry et al. 1995.
[32] Harley et al. 2006.
[33] Hewitt and Nichols. 2005.

Increases in coastal populations and urbanization by 2050 will undoubtedly also have a negative impact on coastal marine species. Size-selective harvesting has led to reductions in body sizes of many intertidal species in southern California[34] and large individuals of many species commonly seen in San Diego tidepools in the past are now extremely rare.[35] Such reductions in size are problematic since they affect many fundamental aspects of life history and ecology of species.[36] As human coastal populations continue to increase in the San Diego region, the pressure on marine species from exploitation is likely to grow, resulting in further negative impacts. Increasing urbanization and changing land-use patterns in the San Diego region will almost certainly lead to changes in nutrient and freshwater inputs into the coastal ocean. It is well documented that nutrient loading of coastal waters can lead to large changes in the compositions of both benthic and pelagic communities and also affect biogeochemical cycles.[37] In the case of San Diego, effects of nutrient and metal pollution are particularly problematic for San Diego and Mission Bay, yet with increasing coastal development, the tidepools and lagoons are also at risk. Specific predictions about the biological consequences are again difficult due to the lack of appropriate information about the rate and magnitude of these inputs.

Sea level rise, local extinctions and changes in intertidal biodiversity

Species living in subtidal environments are expected to adjust to future increases in sea level without many adverse effects.[38] However, the same is unlikely to be true for intertidal species along the San Diego coastline. As sea levels rise, the boundary between land and sea moves landwards. Whether intertidal habitat is lost or not depends on the coastal topography. When intertidal habitats are bordered by high cliffs or anthropogenic structures such as seawalls and breakwaters, existing intertidal habitats (beaches, mudflats, rocky shores) are prevented from migrating landwards. This results in a net loss (drowning) of these habitats.[39]

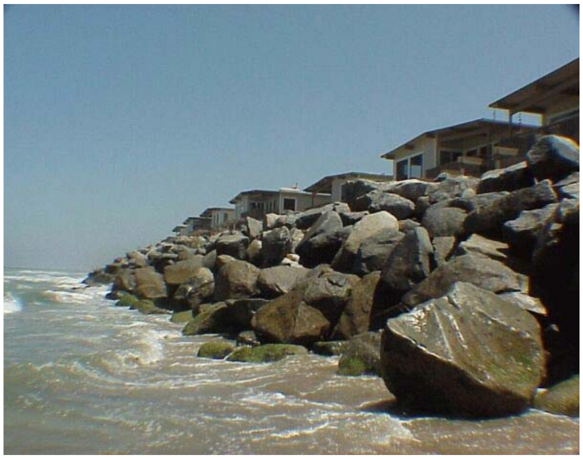

Figure 6-6. Seawall in San Diego. Such seawalls and other anthropogenic structures along the coastline could restrict intertidal habitats from migrating landwards as sea level rises.

[34] Pombo et al. 2007.
[35] Roy et al. 2003; Fenberg and Roy. 2008.
[36] Fenberg and Roy. 2008.
[37] Lane. 2007.
[38] Harley et al. 2006.
[39] Galbraith et al. 2002.

A net loss of marsh habitat can also result when the rate at which sea levels rise exceeds the accretion rate of a marsh.[40] Such loss of intertidal habitats translates into local extinctions of species living there. Many of the beaches and tidepools bordering the open coast in San Diego County are at the base of steep cliffs and therefore, many of these habitats will drown because of rising sea levels. Similarly, much of the shoreline in San Diego and Mission Bay is heavily armored to prevent erosion, which will also prevent landward migration of the intertidal zone. Of particular concern is the fact that the two main intertidal marine reserves in San Diego, Cabrillo National Monument and Scripps Coastal Reserve, both contain rocky, intertidal areas that are bordered by steep cliffs. As sea level rises over the next century, these reserves will almost certainly lose much of their rocky habitats.

Currently well over a third of the southern California coast is covered with some type of anthropogenic structure.[41] With accelerating coastal erosion as sea levels rise, we are likely to see an increase in armoring of the coast, which in turn is likely to exacerbate the loss of intertidal habitats and the rate of local extinctions of many intertidal species. On the other hand, because structures such as ripraps and seawalls can support a diverse community of intertidal invertebrates and algae,[42] many rocky intertidal species are likely to do well on these artificial habitats. The net result is likely to be a loss of sandy beach, mudflat and marsh communities in favor of those species that thrive on artificial, rocky habitats. The loss of sandy beach, mudflats and marshes can also have cascading effects on other species such as shorebirds that depend of these habitats for feeding.[43]

Synergies and Feedbacks

Climate change and the pressures associated with urbanization can lead to large changes in coastal biodiversity. The ecological effects of these changes are increasingly being documented, but the synergistic effects of climate change, harvesting pressure and urbanization on coastal marine ecosystems remain poorly understood - even though they are likely to be extremely important in regions such as San Diego. With species subjected to large-scale changes in the environment driven by climate change, rapid population growth is fueling an increase in the exploitation of intertidal and subtidal species as well as runoff and nutrient loading into coastal waters. It is not unreasonable to expect that direct impacts such as harvesting can undermine the resiliency of species to climate change. For example, historic data show that body size of marine mollusks plays an important role in determining which species are likely to shift their geographic distributions in response to climate change.[44] Yet body sizes of many intertidal species in southern California have decreased substantially over the last century as a result of human harvesting of these species.[45] Furthermore, such size declines can result in major changes in growth rates, reproductive outputs and life histories of species; they can even lead to changes in the compositions of ecological communities.[46] How such

40 Scavia et al. 2002.
41 Pister. 2007.
42 Ibid.
43 Galbraith et al. 2002.
44 Roy et al. 2001.
45 Roy et al. 2003; Fenberg and Roy. 2008.
46 Ibid.

changes in the biology of the species affect its resiliency to climate change is still poorly understood but the potential for feedback effects certainly exists.

Summary

The fragmented habitats of San Diego County represent an internationally-renowned case study (thanks to a substantial body of scientific literature) in how ecosystems can unravel with fragmentation. The cascading ecological changes we already know to be unfolding in San Diego likely foreshadow the complexity and gravity of the changes to come as the effects of future changes in climate and land use interact.

San Diego County must brace for change. Even without the climate changes, our native plants and animals, and the ecosystems on which we all rely, will be severely strained in the decades ahead.

Climate change will only exacerbate – perhaps dramatically – variations that are already underway in the composition and distribution of natural communities. Some species may disappear as their habitats are pushed beyond the confines of the county. Other species' range may expand to include San Diego County (requiring that we broaden and clarify our concepts of "native", "invasive" and "alien" species). Species with a limited ability to disperse will be especially challenged. Others will suffer an accumulation of myriad synergistic interactions. Some of our native species may be wholly reliant on the San Diego community mobilizing to ease them through the transitions to come.

Careful, science-based management strategies offer some hope. In San Diego County researchers have already helped improve understanding of the ecological mechanisms underlying the changes to our natural communities and how species may be lost with fragmentation. If we are able to focus our research attention and resources accordingly – and we are only at the beginning of a long process – we should be able to come to a useful understanding of (a) the potential impacts of climate change, and (b) possible avenues for adaptation. We must invest in research while developing practical strategies to manage our natural resources through the change ahead. Action will be imperative, so expert opinion may be needed in the absence of published scientific results. While some mistakes will be made, the bigger mistake would be to delay addressing the issue of safeguarding ecosystems from the effects of climate change. We must strive to anticipate the changes to come, and distinguish between the drivers of those changes and how they each contribute to the imperilment of species and ecosystems.

One major basis for hope is that we already know a great deal about how we can increase the resilience of our species and systems to climate change: we can reduce the non- climate stressors, e.g., fragmentation of habitat and further alteration of hydrological and fire regimes. Our most important strategy to lessen adverse impacts and increase the likelihood of our natural systems adapting to the new climate regime is to protect the ecological cohesion of the landscape. It is imperative that we protect a network of conservation reserves representing the diversity of communities in San Diego County, and that we maintain the connectivity between those reserves. In particular, we need to protect corridors along the elevational gradient that would allow upward migration of cold-adapted species. Conservation programs have been begun in this region supported by Federal, State and County agencies to conserve areas of natural habitat to insure that species have land on which they can reproduce, and also to provide connections so that they may be able to migrate as the climatic conditions cause changes to their habitat. The goal is not to exacerbate the effect on biota from humans in this area when combined with climatic change

San Diego's human communities face this same climate transition and the fate of biodiversity in the region is intertwined with our own safety and quality of life. Good land-use planning is good conservation planning. For example, keeping homes out of indefensible, fire-prone environments can keep people and property out of harm's way, while also preventing the fragmentation of landscapes and all of its subsequent cascading effects. Maintaining permeability in the landscape for species to move and adapt to climate change (by creating a connected network of conservation lands) also furnishes invaluable benefits to our communities in the form of services supported by these ecosystems.

Perhaps the greatest basis of hope we have is the San Diego community's deep appreciation of the county's natural heritage – and a desire to safeguard that heritage by addressing these difficult issues. We have leading research institutions, dedicated land managers as well as visionary community and business leaders. There are many options for proactive engagement on climate issues if we mobilize now, but we will need the full complement of that human capital to engage the issue.

Our ability to understand the climate and land-use issues will determine the fate of our natural communities and the ecosystem services that provide for the well-being of our human communities. Conservation problems may incorrectly but conveniently be attributed to climate change even when the real source of the problem may be conversion and fragmentation due to land use. Obscuring the real driving forces could result in missed opportunities to prevent and manage impacts. If so, that shortsightedness could lead to species extinctions that might otherwise be avoidable.

We can hope that biodiversity and ecosystems in San Diego County in the year 2050 will be characterized by the prevention of global species extinctions and the continued functionality of ecosystem processes. The former fulfills our global ethical obligation, especially as one of the wealthiest regions of the world, while the latter would "save the evolutionary stage" and enable one of the greatest complements of native species to persist. While the current configuration and composition of general vegetation communities will surely be different, we should aim for these communities to be characterized predominantly by species native to the region. The landscapes of 2050 should also require the *least* amount of management in order to sustain native species and functionality. Provisioning of ecosystem services for our human communities should continue, but in a manner that also supports biodiversity. San Diegans appreciate the extraordinary natural heritage of the county and its contribution to our quality of life – and they are committed to the protection of that heritage.

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CHAPTER 7: PUBLIC HEALTH

Introduction

As one of the nation's largest metropolitan areas, San Diego County will face numerous challenges over the next few decades, including public health. There is considerable complexity underlying the health of a population, and many contributing factors.[1] Public health drivers include changing demographics, travel (especially international), the pace of information dissemination as well as environmental changes that can alter the relationship between disease agent, host, and environment. The relationship between climate change and changes in public health is difficult to predict, and there will be challenges to public health regardless of the effects of global warming. Yet significant climate changes are expected to have a discernible and negative effect on public health.

By 2050, there may be 4.5 million people residing within San Diego County. Public health factors for San Diego in the next few decades are expected to include an aging population and increased life expectancies; chronic and disparate health conditions; food safety issues; emerging infectious diseases; funding levels for public health; complex healthcare systems; growing demographic changes resulting in higher proportions of the population being of different racial and ethnic groups; border-related issues; and environmental health. These factors could be exacerbated by changing climate conditions.

Many of the projected changes in climate could have ramifications for public health in San Diego.[2] The impacts identified as most significant to public health in California include mortality and morbidity related to temperature, air pollution, vector and water-borne diseases, and wildfires.[3]

The objective of this chapter is to project a range of future trends in public health in light of climate change, population growth and regional development. Projections are based on analyses of changing temperature and precipitation conditions as they relate to extreme weather events (e.g., heat waves), deteriorating air quality and climate-sensitive diseases. This chapter gives an overview of the existing knowledge of specific public health impacts due to climate change in San Diego. There are still many gaps that need to be addressed in order to better understand these complex issues. Such research needs are listed in Appendix B.

[1] California Climate Change Center. 2006.
[2] McMichael, A. J., and A. Githeko. 2001.
[3] California Climate Change Center. 2006.

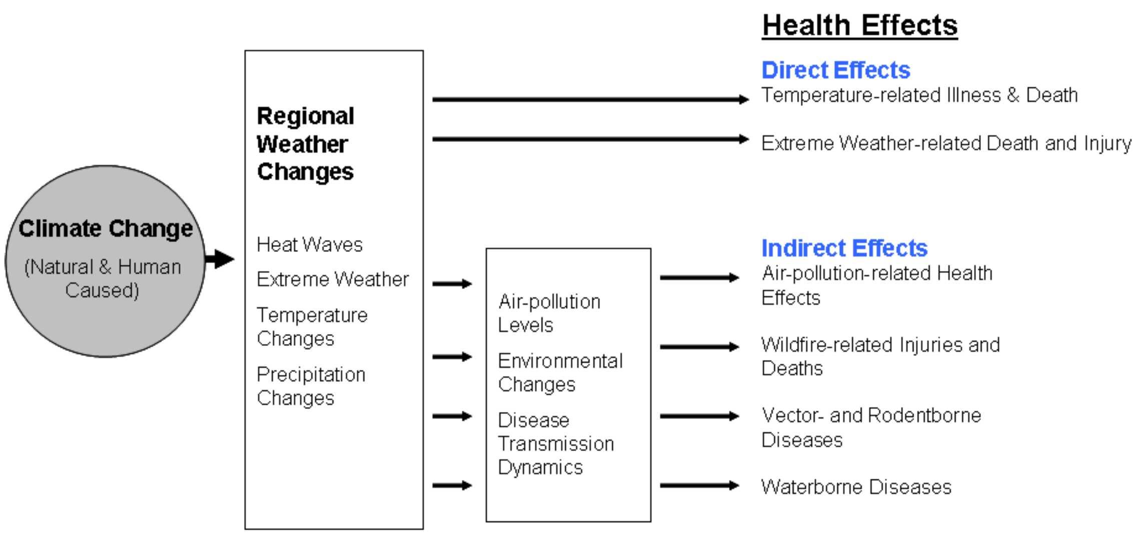

Figure 7-1. Climate change effects on the general public[4].

Direct Effects on Public Health

Temperatures in San Diego under some scenarios of future climate change are projected to increase by 2050, with temperature ranges varying depending on the emission scenario used and the sensitivity of the climate model (see Chapter Three). In one of the more threatening climate change scenarios,[5] southern California warms in summer by 9 degrees F (5 degrees C) over present-day levels. Under this scenario, San Diego's daytime temperature in 2050 would be comparable to inland La Mesa's today.[6] Increases in temperature will be accompanied by longer, more frequent and more severe extreme-heat conditions. These increases are expected to affect human health through direct effects on heat-related mortality, indirect effects on air pollution, potential effects on various infectious diseases, and wildfires.

Extreme Heat Events

Heat waves are expected to increase in frequency, magnitude and duration in San Diego over the next 50 years. For an increasingly urbanized population, extreme heat waves create a significant health risk.[7] Public health risks around extreme heat are not equal; certain individuals, populations and communities are at greater risk than others. Local identification of vulnerable individuals and populations is essential to mitigate the negative impact of heat waves more effectively. Factors that should be considered when identifying community-level risk include the incidence of relatively high percentages of: children under 5 years of age and elderly people 65 and over; households living at U.S. poverty levels; medically underserved populations; chronically ill persons (especially those suffering cardiovascular or respiratory conditions); and socially isolated

[4] Adapted from Patz et al. 2000.
[5] GFDL model, A2 GHG Emission Scenario.
[6] Cayan 2050 Workshop Presentation.
[7] California Climate Change Center. 2006.

individuals. Of the 140 heat death cases that occurred in the California July 2006 heat wave, fully 46 percent were individuals who lived alone.[8]

Heat waves have claimed more lives over the past 15 years than all other declared disaster events combined in California. The worst single heat wave event in California occurred in Southern California in 1955, when an eight-day heat wave resulted in 946 deaths. The July 2006 heat wave in California caused the death of at least 140 people over a 13-day period, including at least five deaths in San Diego. Since 2006 when there was a prolonged period of extreme heat across the state of California, San Diego County has developed an Excess Heat Preparedness and Response Plan.[9]

Analyses of deaths and their relationship to temperature have consistently reported that deaths from pre-existing cardiovascular and respiratory diseases increase with both low and high temperatures, mainly among the elderly and other vulnerable populations.[10] A recent analysis of temperatures during summers with no heat waves (1999-2003) found a three percent increase in deaths in any given day for a 10 degree F increase in temperature (including humidity).[11] The number of deaths that are heat-related may remain elevated even after a heat wave has subsided.[12] One identified risk factor for temperature-related death is age above 65 years. In 2050 there will be one million seniors 65 years and older in San Diego, roughly equal to nearly one-quarter of the region's total population. The aging population of San Diego will likely face more mortality events associated with an increase in temperature due to climate change. It is essential that the public health and emergency response infrastructure be robust enough to attenuate the risks of morbidity through appropriate planning.

Storms

An increase in frequency or severity of storms associated with climate change could have significant implications for public health in San Diego County. However, current climate models do not project any major changes in storm patterns for this region (see Chapter Four). Storm-related issues will therefore not be considered further, but if future climate models change this outlook, the potential impacts on public health should be carefully evaluated.

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[8] California Department of Public Health and the Public Health Institute. 2007.

[9] The State Department of Health Services adopted the following definitions of Excessive Heat; Heat Alert is triggered by one or more of the following: excessively hot weather accompanied by night temperatures of 75 degrees or more for 3 days or less; National Weather Service Advisories of excessive heat for 3 days or less; and/or high heat accompanied by electrical blackouts or rotating blackouts. A Heat Emergency is triggered by one or more of the following: weather conditions with a heat index of over 105 degrees with credible weather forecasts of excessively hot weather for more than three days. These weather conditions include high daytime temperatures accompanied by night temperatures of 75 degrees or more; National Weather Service Heat advisories or warnings for more than three days; abnormal human medical emergencies and mortality due to heat; and/or high heat accompanied by extended electrical blackouts.

[10] Kunst et al. 1993; Basu et al. 2005.

[11] Basu et al. unpublished.

[12] Basu et al. unpublished.

Indirect Effects on Air Pollution

Ambient air contains a large number of pollutants, although the public health impacts of only a few have been studied to any extent. Asthma prevalence has quadrupled in the U.S. since 1980. New drivers include rising CO2, which increases the allergenic plant pollens and some soil fungi, and dust clouds containing particles and microbes coming from expanding deserts, compounding the effects of air pollutants and smog from the burning of fossil fuels.[13] The majority of air pollution-related impacts are attributable to particulate matter (PM) and ozone, which are the air pollutants of greatest concern for public health. Concentrations of these pollutants are affected not only by the direct emissions from different air polluting sources, but also by ambient temperature, humidity, wind speed, mixing height and precipitation.[14]

Californians experience the worst air quality in the nation, resulting in an estimated 8,800 deaths annually (3,000–15,000 probable range) and a yearly economic cost of approximately $71 billion ($36–$136 billion).[15] Today, levels of PM and ozone in San Diego are declining, but this trend may reverse in the future as emissions of air pollutants increase due to population growth and increased economic activity in the region.

Particulate Matter Air Pollution Levels

The objective of this section is to project $PM_{2.5}$ (also known as Fine Particulate Matter and defined as particles with diameter of 2.5 micrometers or smaller) emissions and ambient concentrations trends in the San Diego air basins and to use a simplified modeling approach to quantify the possible impact on public health. The analysis shows that the two IPCC emissions scenarios used in the climate analysis have different results – the A2 (business-as-usual) scenario is projected to lead to increased $PM_{2.5}$ levels with associated negative health outcomes. The B1 (slower GHG emissions) scenario leads to a reduced level of $PM_{2.5}$ and an improvement in health results.

Methodology

The analysis of climate change on regional Fine Particulate Matter ($PM_{2.5}$) concentrations is less certain because the atmospheric processes which lead to the

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[13] Harvard Medical School. 2005.

[14] Bernard et al., 2001; CARB, 2005b

[15] Recent estimates for only a few of the most serious public health impacts associated with current concentrations of ozone and PM compared with attainment of the California ambient air quality standards for ozone and PM (CARB, 2002, 2005b,c) suggest that annually the following number of cases occur in California:

- 8,800 (3,000–15,000 probable range) premature deaths,
- 9,500 (4,600–14,000 probable range) hospitalizations and emergency room visits,
- 4.7 million (1.2–8.6 million 95% confidence interval) school absences,
- 2.8 million (2.4–3.2 million probable range) work loss days.

An annual value of $2.2 billion ($1.5–2.8 billion) is associated with hospitalizations and the treatment of major and minor illnesses related to air pollution exposure in California (CARB 2005c). In addition, the value of premature deaths resulting from exposure to air pollution in excess of the state's PM and ozone standards is $69 billion ($34–$133 billion) (CARB 2005c).

formation and loss of PM are quite complex and computationally challenging. It involves many variables, all of which are difficult to forecast with any degree of certainty. Meteorology plays a significant role in the determination of air pollution concentrations in California. Rising temperature will increase the rate at which atmospheric chemical reactions proceed, thereby increasing concentrations of PM. In urban areas, the formation of secondary air pollutants (defined as pollutants that are formed from chemical reactions of pollutants that are directly emitted from sources) is enhanced at higher temperatures. Also, less frequent rainfall may cause airborne PM concentrations to increase. The mathematical model used here is the first attempt to examine the influence of changes in meteorology on San Diego County's fine particulate matter. Changes to emissions inventory through population expansion, application of emissions control programs, and interaction between future temperature and future emissions have been considered to make this projection until 2020 and this trend was extrapolated until 2050. The analysis considered the three climate models and two emissions scenarios used for the overall study climate projections. Details of the methodology are found in Appendix K.

Ambient Concentration Projection

In general, San Diego County meets the Annual National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$ set by the US Environmental Protection Agency (EPA), but exceeds the 24-hr NAAQS for $PM_{2.5}$ a few times during the cooler months of the year. The standards have been set to protect public health and welfare; for $PM_{2.5}$ the annual standard is 15 $\mu g/m^3$ and the 24-hr limit is 35 $\mu g/m^3$. Figure 7-2 shows the seasonally averaged fine particle concentrations currently observed in San Diego. Fall and wintertime fine particle concentrations usually tend to be higher because of the increased atmospheric stagnations that are observed during this time. Stagnation events cause the pollutants to be trapped in the lower part of the atmosphere limiting pollutant dispersion. As temperatures increase, it is estimated that the frequency and duration of these stagnation events will increase leading to even higher concentrations of fine particulate matter during the fall and winter seasons.

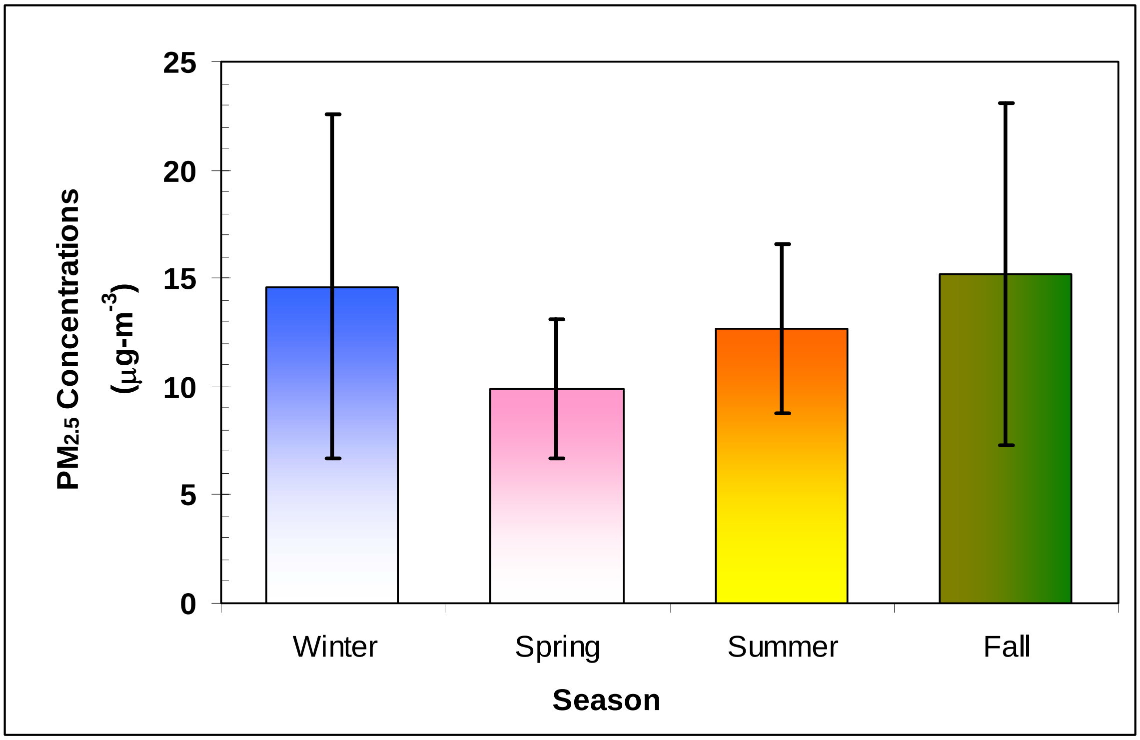

Figure 7-2. Seasonal averaged $PM_{2.5}$ concentrations in San Diego.

Ambient $PM_{2.5}$ concentrations were modeled for downtown San Diego in 5 year increments over the study period. The modeled results show how under the two different IPCC scenarios, the $PM_{2.5}$ concentrations move in different directions (see Figure 7-3). In the B1 scenario emissions are reduced as outlined by the California Air Resources Board (CARB) and, as a result, we see decreases of $PM_{2.5}$; whereas, in the A2 scenario, emissions are kept constant at their 2006 base year level and the $PM_{2.5}$ concentration increase is influenced only from climatic effect. It is interesting to note that, using all three models, starting from year 2015, we predict significantly higher $PM_{2.5}$ concentration for the A2 scenario and significantly lower $PM_{2.5}$ concentration for the B1 scenario. Under the A2 scenario, starting from 2035, it appears that San Diego may have problems meeting the Federal standard for $PM_{2.5}$ which is currently set to 15 $\mu g/m^3$. This trend is observed using the data from all three climate models.

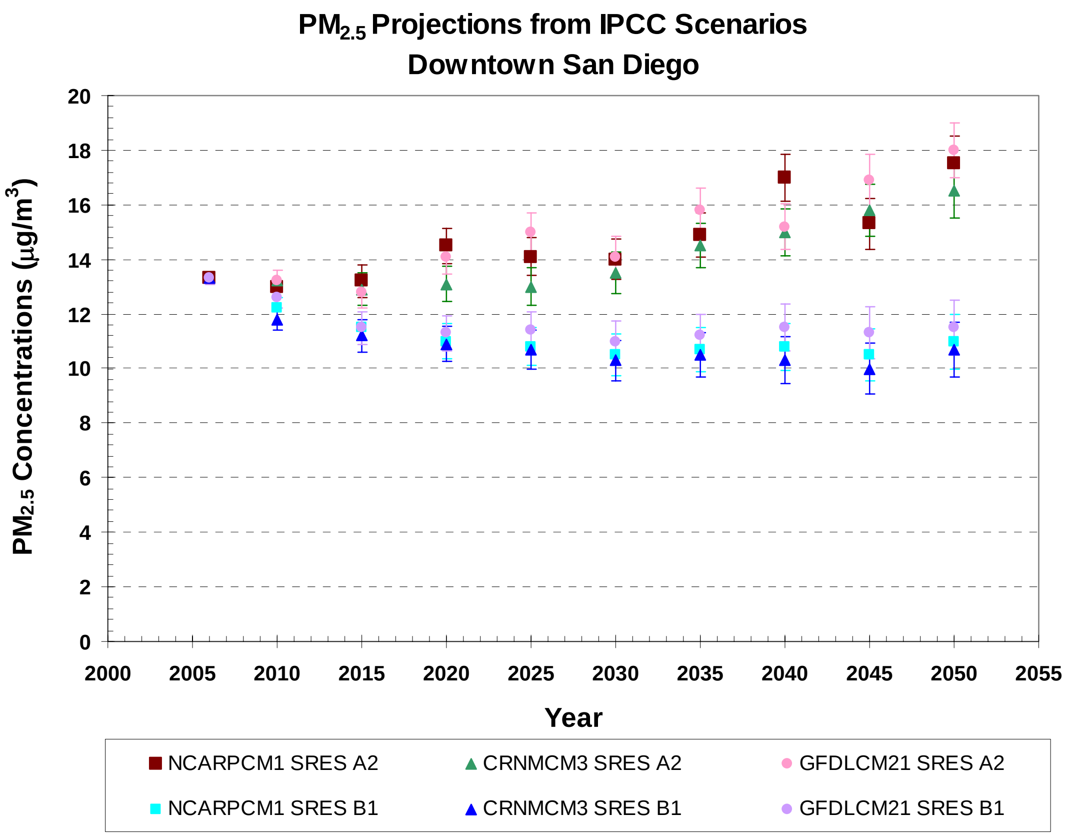

Figure 7-3. $PM_{2.5}$ projections from the three climate models and two emissions scenarios.

Health Effects of Fine Particulate Matter Projection

Most public health literature fairly consistently reports statistically significant associations between changes in $PM_{2.5}$ concentrations and a range of adverse health outcomes, both on a daily and a long-term basis, based on epidemiologic studies. Associations between daily and long-term average changes in $PM_{2.5}$ and mortality appear to be independent of the effect of weather factors, seasonality, time, and day of week.[16] Mortality occurs primarily in elderly populations, but an effect is also apparent for infants.[17] Data from the past quarter-century suggest that long-term PM exposures are associated with increased risk of mortality from cardiopulmonary causes.[18] Associations with $PM_{2.5}$ have also been reported for chronic respiratory symptoms or disease, and possibly with decreased lung function.[19] As our region's demographic composition shifts towards a larger population of elderly residents, the population at increased risk is expected to increase.

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[16] Dockery et al. 1993; Pope et al. 1995; Krewski et al. 2000; Burnett and Goldberg. 2003; Fairley. 2003; Ito. 2003.
[17] Romieu et al. 2004; Diaz et al. 2004; Kaiser et al. 2004; Ha et al. 2003; Bobak and Leon. 1999; Loomis et al. 1999; Woodruff et al. 1997.
[18] Dockery et al. 1993; Pope et al. 1995, 2002; Krewski et al. 2000.
[19] e.g., Ferris et al. 1973; Hodgkin et al. 1984; Mullahy and Portney. 1990.

Analyzing the projected impact in terms of mortality under the different climate models and emissions scenarios, we find that mortality decreases for year 2015 for both. However, for the A2 scenario, by 2035 there is a slight increase in mortality compared to 2006, and a significant increase by 2050 – as many as 45 additional deaths from lung cancer and 258 from cardiopulmonary causes. For the B2 scenario, there appears to be a decrease in mortality.

Table 7-1. Expected mortality change in 2015, 2035, and 2050 from base year 2004.

IPCC SRES	Cause of Mortality	Mortality in 2004	2015			2035			2050		
			NCARPCM1	CRNMCM3	GFDLCM21	NCARPCM1	CRNMCM3	GFDLCM21	NCARPCM1	CRNMCM3	GFDLCM21
SRES A2	Cardiopulmonary	9110	-0.06%	-0.24%	-0.30%	0.96%	0.72%	1.49%	2.53%	1.93%	2.83%
	Lung cancer	1,187	-0.08%	-0.32%	-0.40%	1.28%	0.96%	1.99%	3.39%	2.57%	3.79%
	All cause	19104	-0.04%	-0.16%	-0.20%	0.64%	0.48%	1.00%	1.69%	1.28%	1.89%
SRES B1	Cardiopulmonary	9110	-1.08%	-1.26%	-1.08%	-1.55%	-1.67%	-1.26%	-1.38%	-1.56%	-1.08%
	Lung cancer	1,187	-1.44%	-1.68%	-1.44%	-2.07%	-2.23%	-1.68%	-1.84%	-2.07%	-1.44%
	All cause	19104	-0.72%	-0.84%	-0.72%	-1.04%	-1.12%	-0.84%	-0.92%	-1.04%	-0.72%

San Diego has attained existing ambient air quality standards for fine particulate matter. In order to protect public health, these standards are being tightened. Thus it is becoming more and more technologically challenging and costly to meet these air quality standards. The magnitude of health impacts attributable to PM in the future will be a function of the region's ability to meet ambient air quality standards. It is clear that increasing temperatures will make attainment of these standards more difficult.

Ozone Air Pollution

San Diego County is currently out of compliance with the federal ozone standard, and the EPA has projected that this will still be the case in the year 2020.

High ozone levels have been definitively associated with adverse human health effects, including exacerbation of asthma and other respiratory diseases, cardiac effects and mortality.[20] Ozone is an air pollutant that is formed by the interaction of sunlight with other pollutants.[21] Hot, sunny days promote the formation of ground-level ozone, and climate change is expected to cause an increase in the number of hot, sunny days in San Diego County. (At Miramar the number of days over 97.3 degrees F is projected to increase six-fold and the number of days over 84 degrees F is projected to increase 1.6-fold (see Chapter 3).

[20] See Appendix K for more discussion of the health effects of ozone.
[21] e.g. oxides of nitrogen, NOx, from motor vehicles and volatile organic compounds, VOCs, from gasoline, paints, and other solvent sources.

Additional hot, sunny days will likely result in increased population exposure to ground-level ozone.[22]

The health effects of increased exposure to ground level ozone will be most severe for the most sensitive individuals: children, the elderly and those with pre-existing respiratory conditions. As is the case with $PM_{2.5}$, ***the changing San Diego demographic profile presents an increase in vulnerable residents, which, combined with the increase in ozone exposure, is likely to present a significant public health and economic impact.***

Over the last 30 years, ozone levels have been decreasing in San Diego County due to gains in controlling emissions of precursor pollutants (e.g., vapor-recovery nozzles at the gas station to prevent gasoline vapors from escaping into the air). In 1981 for example, the number of days when ozone levels exceeded the standard for more than one hour totaled 192, while only 24 days exceeded this standard in the year 2000.[23] Further reductions will be more difficult and costly to obtain, even though the new permissible ozone levels are lowered. An EPA projection for the year 2020 shows San Diego and other Southern California counties as exceeding the new 8-hour ozone standard (see Figure 7-4).

One problem in the past and projected for the future is that some of San Diego's ground-level ozone is transported here from the Orange County and Los Angeles areas.[24] Even if San Diego were successful in controlling the emission of precursor pollutants, the ozone problem would still depend on the ability of the Los Angeles area to control ozone.

[22] Tropospheric ozone, or ground-level ozone, is sometimes called "bad ozone" to distinguish it from "good ozone." Both types of ozone have the same chemical composition (O3). "Good ozone" occurs naturally in the upper portions of the Earth's atmosphere and forms a layer that protects life on Earth from the sun's harmful rays. "Bad ozone" at ground level is harmful to breathe. Ozone is not emitted directly into the air, but forms when emissions of nitrogen oxides (NOx) and volatile organic compounds (VOCs) are exposed to sunlight . Emissions from industrial facilities, electric utilities, motor vehicle exhaust, gasoline vapors and chemical solvents are the major man-made sources of NOx and VOCs.

[23] Note that the one-hour standard is less stringent than the new 8-hour standard. See http://www.sdapcd.org/air/reports/APCD10-24airqualityinsd.pdf

[24] www.sdapcd.org/info/reports/ANNUAL.pdf

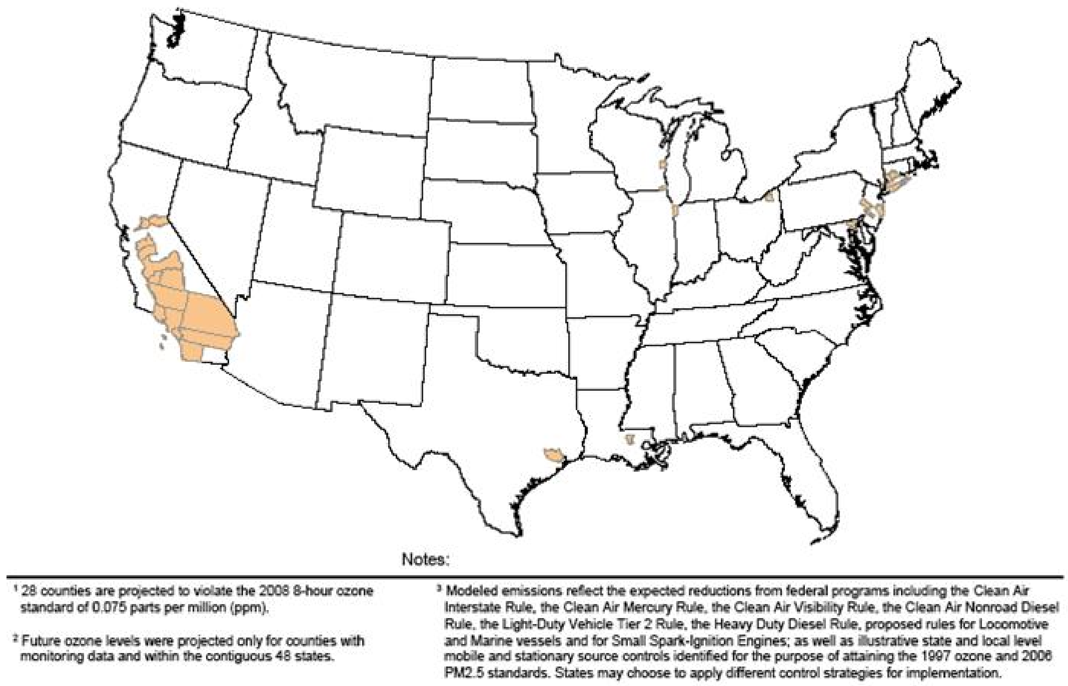

Figure 7-4. Counties with monitors projected to violate the 2008 8-hour ozone standard of 0.075 parts per million (ppm) in 2020. [25]

Ozone Air Pollution in San Diego County in 2050

The effect of hot, sunny days on the generation of ozone air pollution can be seen by comparing ozone pollution data in San Diego with temperature. Ozone levels exceeded the state 8-hour standard in San Diego 8 percent of the time for days with temperatures between 85-89 degrees Fahrenheit.[26] For days over 90 degrees, the state ozone standard was exceeded 16 percent of the time. As stated previously, an increase in hot, sunny days due to climate change has been projected for San Diego in the year 2050. One projection for that same year estimates a 5.9-fold increase in days over 97.3 degrees F, measured at Miramar. Days over 93.8 degrees would jump from an average of 10 days for the period 1950–1975 to 39.3 days on average for the years 2041 – 2050. For days over 84 degrees, the projected increase would be from 78.2 days to 128.8 days for 2041-2050.

Not only will ozone levels potentially increase, but at the same time, the stress from extreme heat days and the number of vulnerable people exposed in San Diego will also increase.

Indirect Effects on Infectious Disease

Meteorological changes can influence human disease through both direct and indirect effects on pathologic microorganisms, vectors, reservoirs and hosts.[27] Available

[25] U.S. Environmental Protection Agency. 2008.

[26] Environment California Research and Policy Center. 2007.

[27] Colwell and Patz, 1998.

evidence suggests that the incidence and spread of a number of infectious diseases can be affected by various weather-related factors and therefore would be affected by climate change.[28]

Vector-Borne Disease

The occurrence of vector-borne disease is influenced by a variety of factors. For example, the availability of suitable reservoirs and susceptible hosts can influence vector abundance and the frequency of disease transmission. Prevailing temperature influences the rate of development of larvae of some vectors, as well as the rate of development of the infectious agent in the vector. Humidity and rainfall affect both the composition and abundance of vectors, as well as animal hosts. Behavior patterns of hosts, such as indoor living, and vector preferences for particular hosts and periods of peak activity, also influence transmission opportunities.

Modeling the occurrence of vector-borne diseases is difficult because the above factors interact in complex and poorly understood ways. ***Climate change in San Diego County could increase the risk of certain vector-borne diseases, while decreasing the risk of others. Overall, climate is not the major driving force for most vector-borne disease in San Diego County.*** Indoor living and other activity patterns in human hosts and vector control practices will likely continue to be the dominant influences, so no significant changes in vector-borne disease incidence are projected. This study looked at the major vector-borne diseases and found no basis for anticipating any change in San Diego County's vulnerabilities in malaria, arboviruses [spread mainly by blood-sucking insects,[29] including Western Equine Encephalitis, St. Louis Encephalitis, and West Nile Virus] and lyme disease.

Rodent- or Small Mammal-Borne Disease

If climate models predict increased amplitude or periodicity in annual rainfall cycles (e.g., increased occurrence of very wet years followed by very dry years), then we would expect rodent and other small mammal populations to undergo correspondingly large swings in population size. Such population fluctuations could increase the risk of zoonotic disease transmission events. However, evaluation of increased risks from climate change projections show *no* expected impact on tularemia, plague or hantavirus (although there is a possible increased risk driven by population growth, particularly in unincorporated areas).

Public health experts considered other diseases and were not able to establish any basis for projecting changes due to climate impacts in the following: visceral larval migrans (caused by *Baylisascaris procyonis* from raccoons or several nematode species from domestic dogs and cats); flea-borne typhus (caused by *Rickettsia typhi*); or Rocky

[28] NRC. 2004; Colwell and Patz. 1998.

[29] In the United States, arboviruses are most commonly spread by mosquitoes. Birds are often the source of infection for mosquitoes, which can then spread the infection to horses, other animals and people. Most infected people have no symptoms. When symptoms occur, they usually start suddenly, with fever, chills, headache, muscle aches, and tiredness. In rare cases, infection can lead to encephalitis (inflammation of the brain). Prevention depends mainly on public health action to control mosquitoes and on individual action to avoid mosquito bites.

Mountain Spotted Fever (caused by Rickettsia *rickettsii*). Neither climate change nor population growth is expected to increase significantly the incidence of these diseases.

Water-Borne Disease

The occurrence of waterborne disease is influenced by a number of factors with complex interactions. This makes it difficult to make accurate forecasts of incidence trends. However, projected temperature increases of 1.5 to 4.5 degrees F (.83 to 2.5 degrees C) in 2050 are expected to result in surface temperature increases in local lagoons and waterways. This could increase the risk of harmful algal blooms and promote growth of a number of waterborne agents.

As a coastal city, San Diego will be affected by both climate change and demographic changes by the year 2050. The rapid urbanization and land development that is occurring throughout the coastal margin of Southern California, including San Diego, will continue to degrade coastal water quality unless the region takes aggressive measures to correct these problems. Urbanization is now recognized as the single most significant factor in the degradation of coastal water quality. This rapid urbanization, coupled with global change and climate alteration, may have significant synergistic affects on water quality in the region.

In urban areas, storm water and urban runoff, even during dry weather, are linked to major coastal problems. California's greatest urban runoff problems are in the southern part of the state where expanding urbanization, development and an increasing population generate pollution that is discharged to the watershed and flows into the Pacific Ocean.[30] Already, during wet weather, almost 60 percent of shoreline waters from Point Conception, California to Punta Banda, Mexico, have been found to exceed water quality standards for the protection of human health.

Climate change is predicted to affect temperature, precipitation, surface radiation, humidity, winds, and sea level in San Diego. These changes may lead to significant impacts on regional-scale hydrologic processes such as evapotranspiration, runoff, groundwater levels, and snowmelt. The occurrence, structure, and functioning of aquatic ecosystems could be directly or indirectly affected by climate-driven changes in hydrology. Coastal and inland wetland extent is also sensitive to factors associated with climate change with possible impacts to human health.

Harmful Algal Blooms

The Southern California Bight, and San Diego in particular, have experienced "red tides" since records have been kept (the earliest report is from 1902). A red tide is a dense proliferation of phytoplankton; these "blooms" can be benign or harmful, depending on the dominant species.

The causes of red tides in the Southern California Bight remain unclear, so it is difficult to predict the consequences of climate change on the dynamics of these blooms. There is some indication that over the last decade blooms have begun earlier in the year, though it is not clear whether red tides are more frequent or more intense than earlier decades. Dense blooms can lead to low oxygen levels in the water during the bloom's

[30] Dwight et al. 2002.

decline and decay; these low oxygen levels are responsible for everything from smelly lagoons to fish kills. The steep shelf along the Southern California Bight leads to strong exchanges of coastal water with offshore waters, making coastal anoxia an unlikely event except in isolated basins, bays and lagoons.

Many of the species that form local red tides require a relatively stable water column because they are very sensitive to turbulence. Such conditions *could* be a consequence of climate change: as surface waters warm, they enhance the temperature difference with deeper waters. This creates a strong barrier to vertical mixing, favoring the growth of flagellates over benign species. Phytoplankton grow faster in higher temperatures, thus increasing the likelihood of more frequent or intense phytoplankton blooms. It is also possible that wind stress may change: a decrease in wind stress will decrease the turbulence in the upper ocean – favoring the more harmful species.

Figure 7-5. Red tide in La Jolla. Photo source: Scripps Institute for Oceanography

There is evidence that toxic bacteria such as *Vibrio cholerae* thrive in the organic-rich environment created by these dense phytoplankton blooms. It is also possible that human pathogenic bacteria introduced through runoff and sewage outfalls may be affected by the presence of red tides. Thus conditions that promote the growth and maintenance of red tides may also lead to increased health risk through other mechanisms due to their effects on unrelated pathogens.

Wildfire Impacts on Public Health

Wildfires can be a significant contributor to air pollution in both urban and rural areas, and have the potential to significantly impact public health primarily through their smoke.[31] Future land use and climate changes will only exacerbate the risk of wildfires as a result of the alteration of fire regimes in the County. Climate changes are expected to affect the frequency, severity and distribution of wildfires in San Diego County, which

[31] Luers et al. 2006.

in turn are expected to influence mortality and morbidity through fire-related injuries. Fires also create secondary effects on morbidity as the result of increased air particulates that can worsen lung disease and other respiratory conditions. People most at risk of experiencing adverse effects related to wildfires are those with existing cardiopulmonary disease, and that risk seems to increase with advancing age. See Chapters Five and Six for more discussion of climate change and wildfires in the San Diego region.

Summary

There are many potential public health issues that are likely to impact San Diego in 2050, both directly and indirectly. They are driven by climate change and demographics. Projections of a growing and aging population suggest a larger number of people will be vulnerable to environmental health risks, and our projections for climate change indicate more stressful conditions facing vulnerable populations. Specific impacts include:

- Increased heat waves creating a significant risk of adverse health effects and heat-related mortality;
- Increased exposure to air pollution resulting in adverse health effects, including exacerbation of asthma and other respiratory diseases, cardiac effects, and mortality;
- Impacts to the range, incidence and spread of infectious diseases affected by weather-related factors; and
- Increasing incidence of wildfire, which will contribute to direct injuries and mortality as well as indirect health effects of air pollution.

The complexity of public health issues makes it difficult to quantitatively predict the effects that climate and demographic change will have on health issues going forward. One key to examining the impact on public health could come from downscaling models to a regional scale, e.g., the particulate matter model described above. A quantitative estimate of the impact of climate change on temperature-related deaths, air pollutant emissions and air-quality impacts, as well as on human health in San Diego in the future will require more data and further study. However, it is clear that with a population that skews increasingly older, and with its residents living in areas that are expected to experience more extreme-heat conditions and a decline in air quality, San Diego is likely to face intensified public health concerns.

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CHAPTER 8: ELECTRICITY

Introduction

This chapter summarizes the trends in electric-power requirements as the San Diego region copes with the dual challenge of population growth together with temperature increases resulting from climate change. The main climate impact on electricity demand and associated supply issues will be the increased need for summer cooling. Overall, peak demand for electricity and annual electricity consumption will rise dramatically in the San Diego region by 2050. ***Annual electric consumption is expected to increase more than 60 percent.*** That will push consumption from the current level of approximately 20,000 gigawatt hours (GWh) to more than 32,000 GWh in 2050. While population growth is an important contributor to increased demand, ***warmer temperatures are expected to push total energy consumption up to 2 percentage points above the population-driven change by 2050. Similarly, peak electric demand is expected to increase by over 70 percent***, from approximately 3,700 megawatts (MW) to as much as 6,400 MW in 2050. ***Increased average and peak temperatures (i.e., climate-driven changes) are projected to account for approximately 7 percent of the total increase in peak demand***.

Supplementing this chapter is Appendix L, which summarizes current electricity use in the region, and the regulatory issues affecting future electricity use as well as the greenhouse-gas (GHG) emissions associated with electricity. Other aspects of energy, including natural gas and transportation fuel, are not addressed. Natural-gas demand does not have a strong correlation to temperature increase, so it is not specifically addressed in this chapter. In fact, increasing temperatures could have the opposite effect on demand for natural gas as the need for winter heating diminishes. Transportation as a driver of climate change is being addressed in other venues, including regional climate action plans as well as in mitigation and adaptation strategies.

Rising demand for electricity will need to be addressed by adding electrical infrastructure, including power generation, transmission and distribution resources. This infrastructure could include a combination of power generation from fossil fuels as well as from renewable energy sources, notably wind and solar. With widely deployed renewable resources, resource planning will be complex due to the new demand characteristics and the attributes of renewable power: for example, peak power generation may *not* coincide with peak demand periods. ***Peak demand will coincide with extreme heat events in the future, which increases the risk of outages as system performance is less efficient and less reliable under peak heat conditions***. If the region develops additional water desalination plants to address water-supply needs, this could create additional demand for electricity, depending on the desalination technology. Current planned systems are projected to add 1-1.5 percent to total regional electricity consumption by 2030.

Climate and Population Impact on Energy Use

This section addresses the future relationship of regional development patterns in residential and commercial growth with temperature trends and electricity demand predicted under the different three global climate models and two emissions growth assumptions described in Chapter Three.

Population Growth and Location

The population maps below, based on SANDAG population-growth forecasts by zip code, and extrapolated for this study to 2050, show significant growth trends in the same inland areas that will be subject to higher temperatures in coming decades. The first map (Figure 8-1) shows the percentage changes from present. The second map (Figure 8-2) indicates growth in absolute figures. The maps divide the San Diego region into four climate zones corresponding to California Energy Commission-determined Building Climate Zones for the San Diego region. They were judged by the authors at the outset of this project to have the greatest potential correlation with energy demand projections.

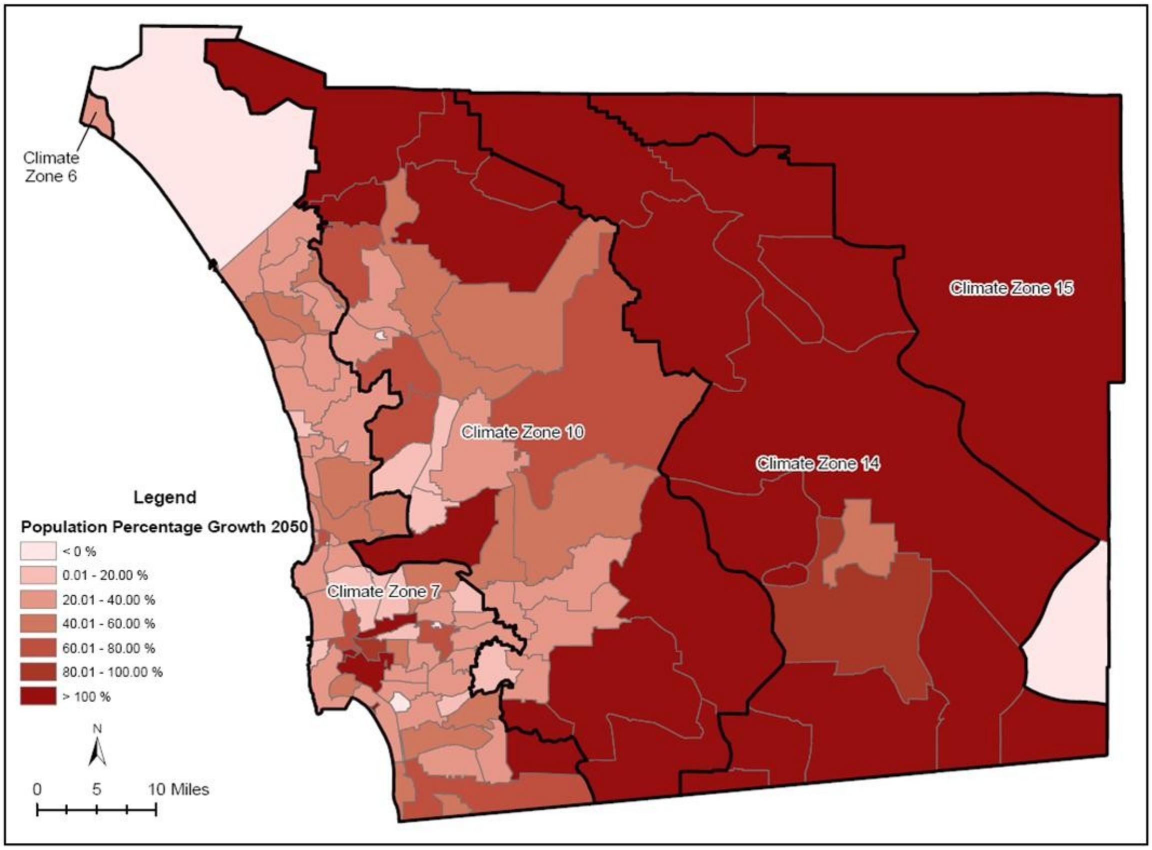


Figure 8-1. Percentage population growth in San Diego County, 2007-2050

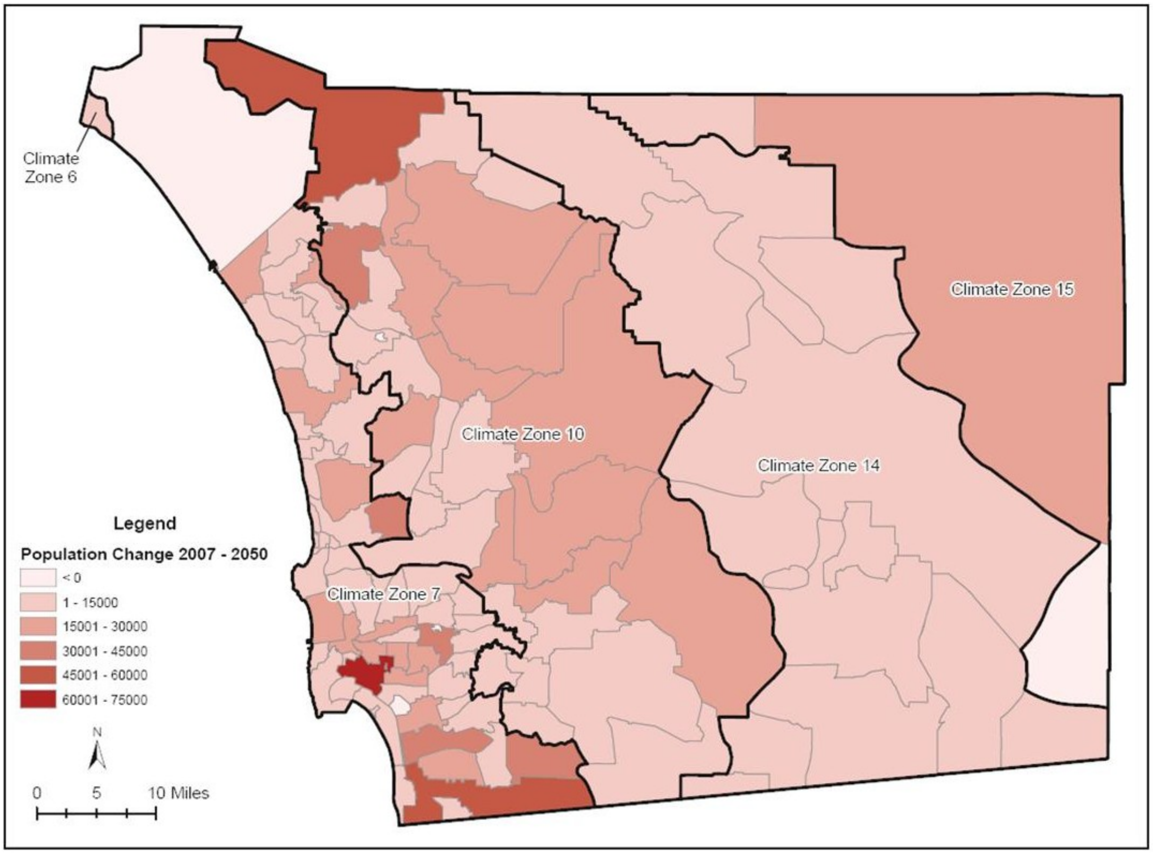
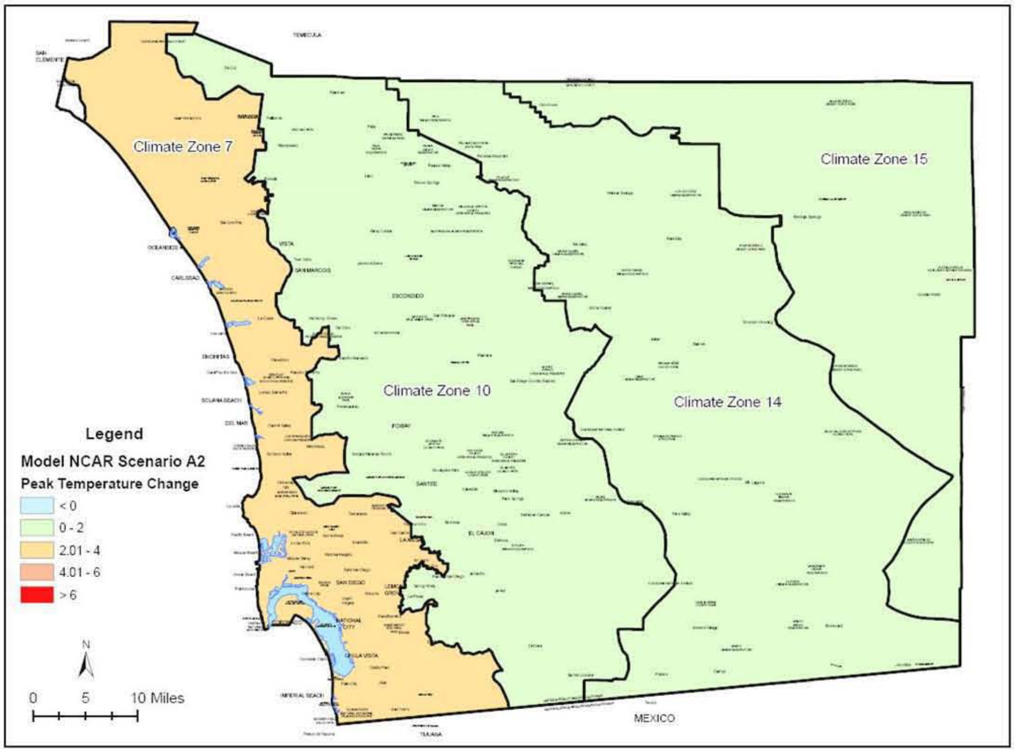


Figure 8-2. Population change in San Diego county, 2007–2050.

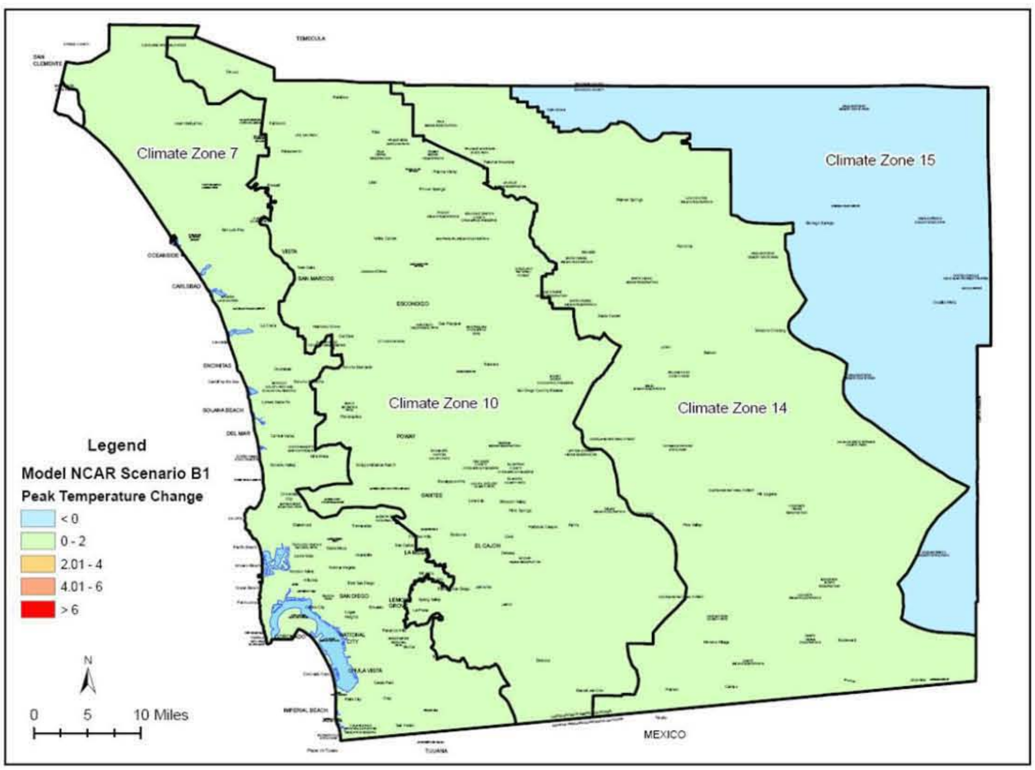
Peak Temperature and Cooling Degree Day Trends

Temperature data from the three climate models was analyzed for peak temperature and Cooling Degree Day (CDD) trends. CDDs are the amount of time during the year above a reference temperature of 65 degrees F. This measure is considered more indicative of annual temperature trends than daily peaks. CDD trends between the models do not show the same relationships as the peak temperature trends.

To some extent, these trends are all increasing, although there is notable variation among them. The maps above divide the San Diego region into four climate zones, using data from four commonly used temperature station locations (Lindbergh Field, Miramar, El Cajon and Borrego Springs). For San Diego energy forecasting, the California Energy Commission (CEC) commonly uses temperature data from Lindbergh Field, Miramar, and El Cajon to simulate future demand.

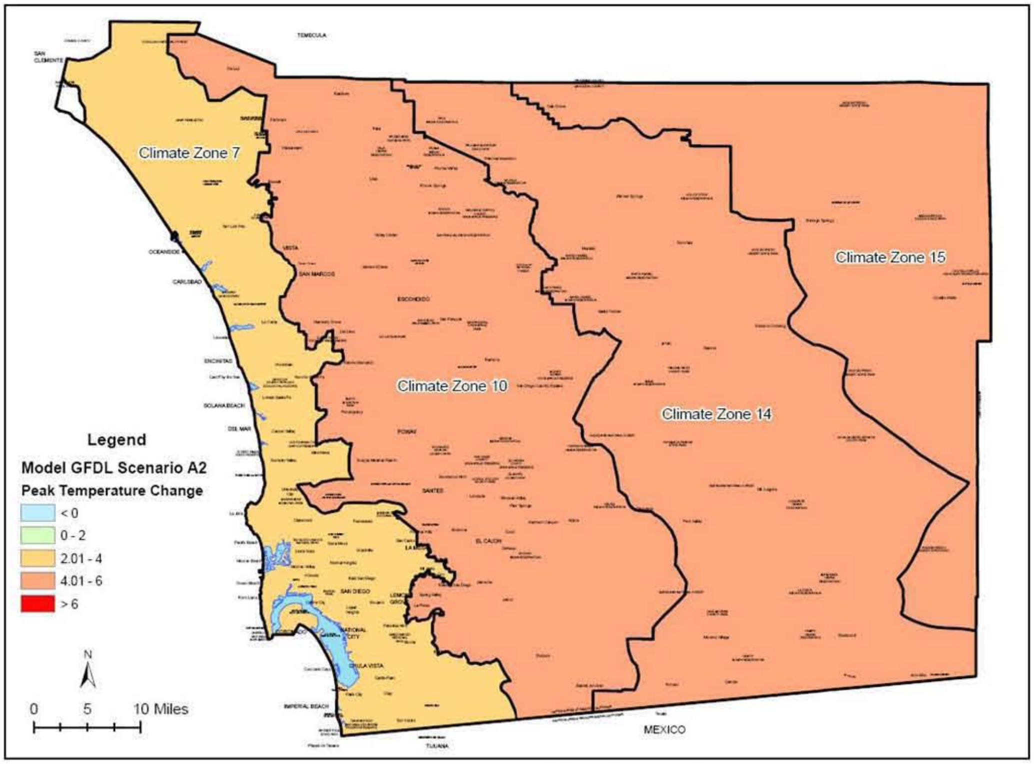


Change in Peak Temperatures by 2050 Model NCAR Scenario A2

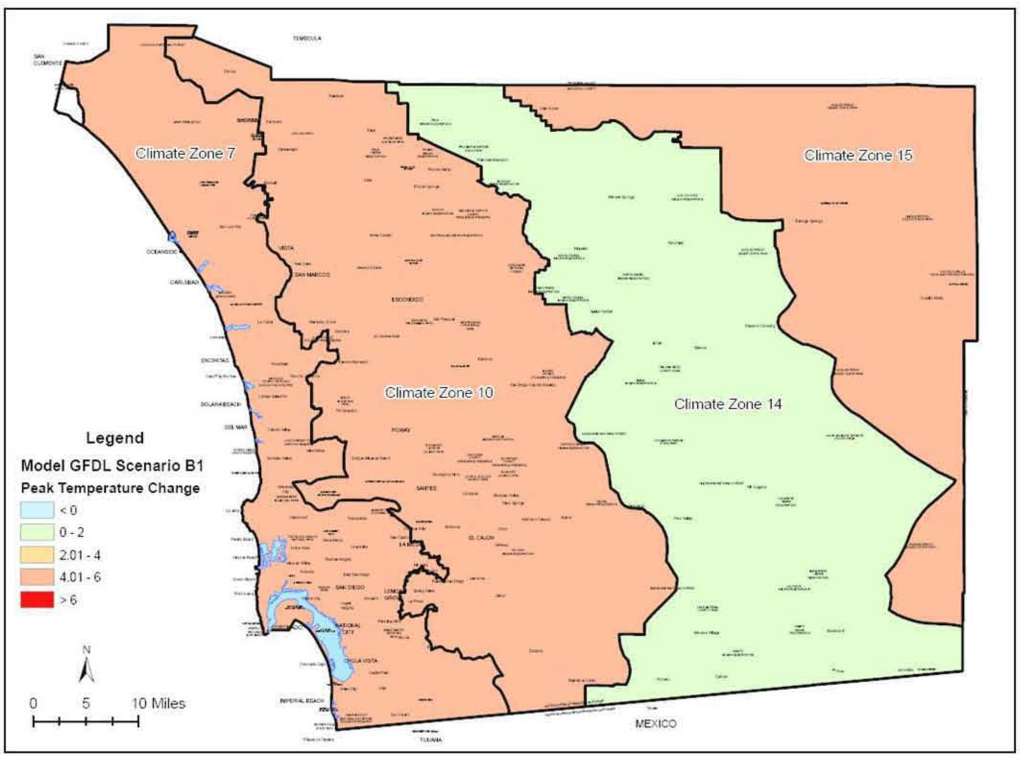


Change in Peak Temperatures by 2050 Model NCAR Scenario B1

Figure 8-3. Peak temperature change. NCAR climate model; A2 and B1 scenarios.

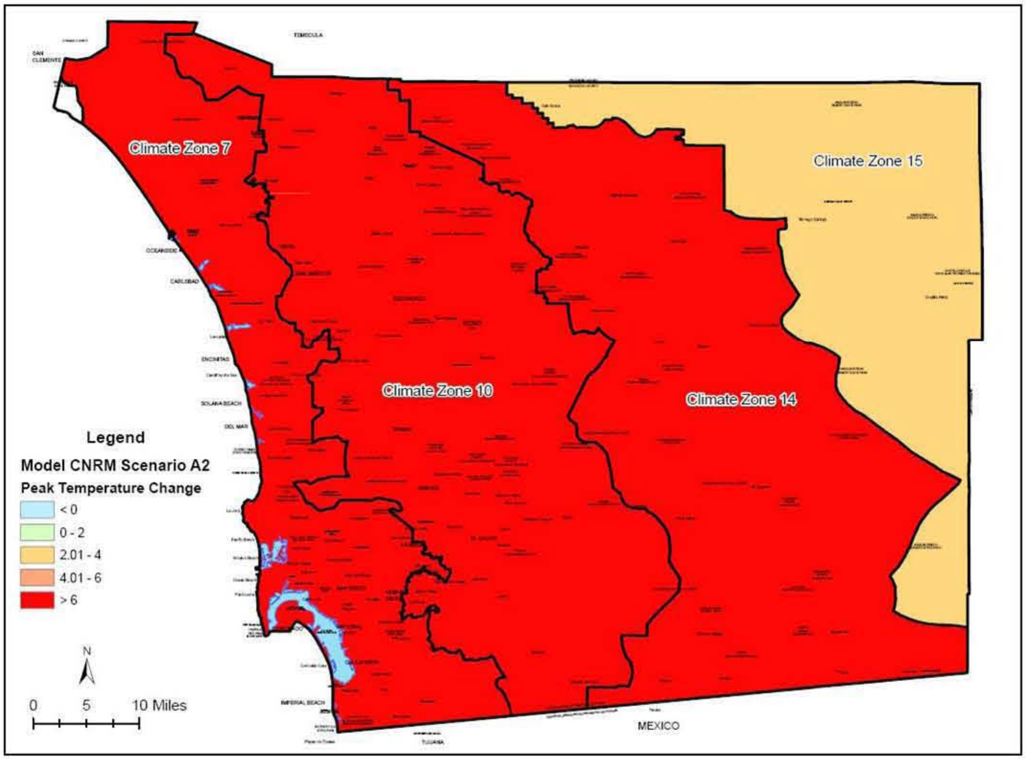


Change in Peak Temperatures by 2050 Model GFDL Scenario A2

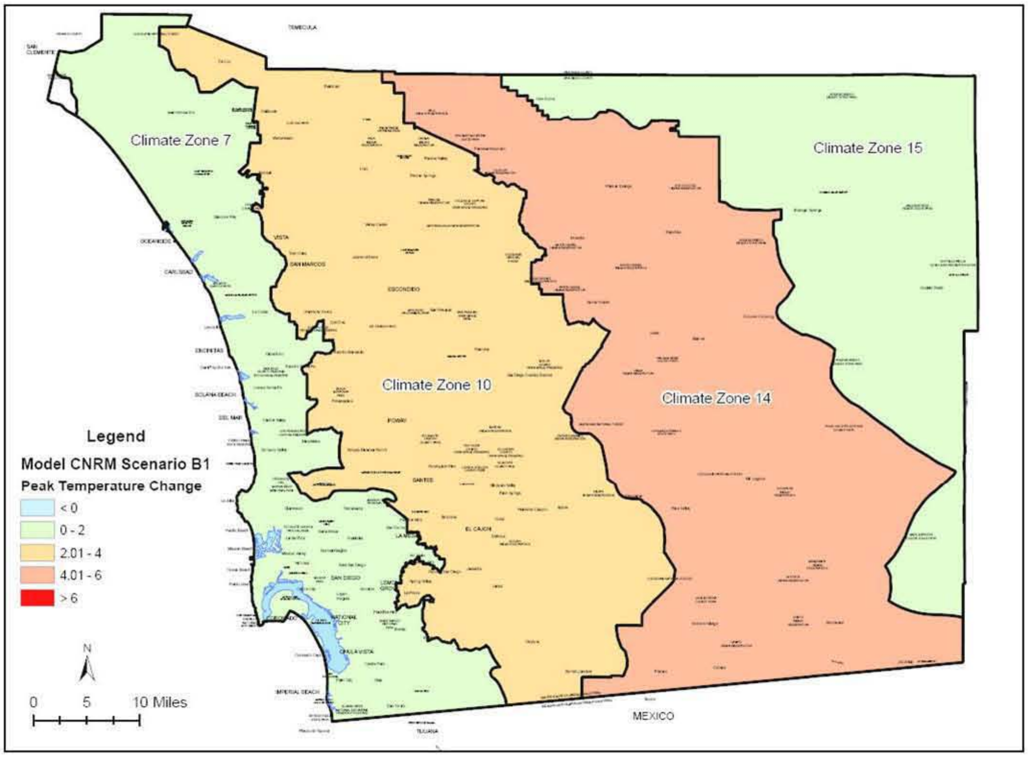


Change in Peak Temperatures by 2050 Model GFDL Scenario B1

Figure 8-4. Peak temperature change. GFDL climate model; A2 and B1 scenarios.

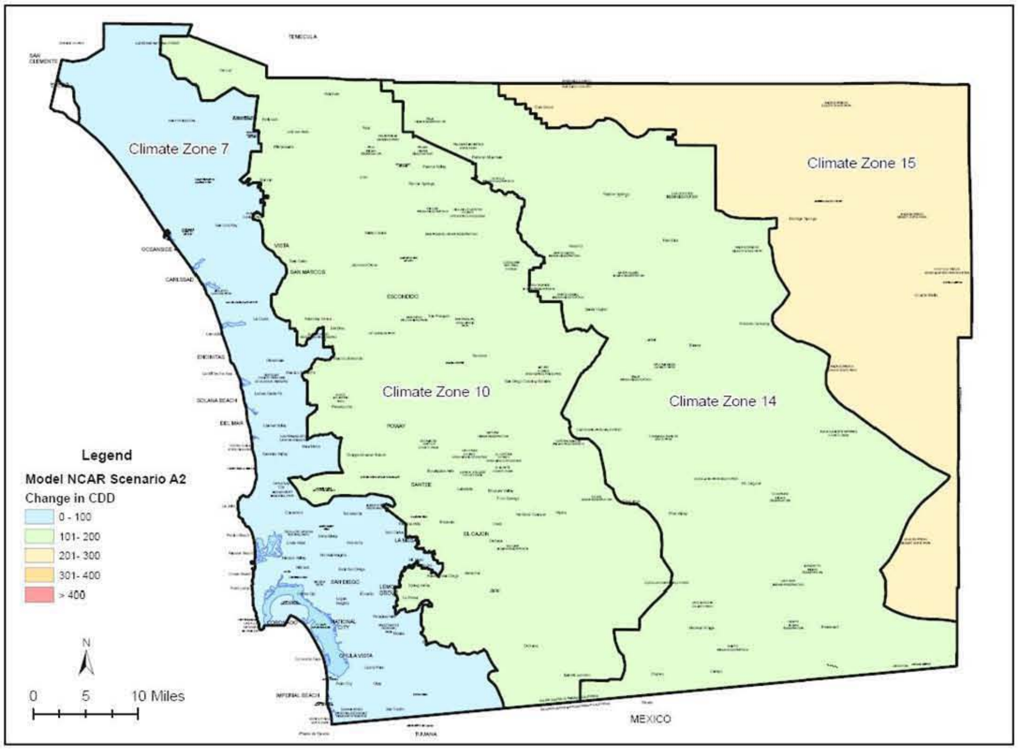


Change in Peak Temperatures by 2050 Model CNRM Scenario A2

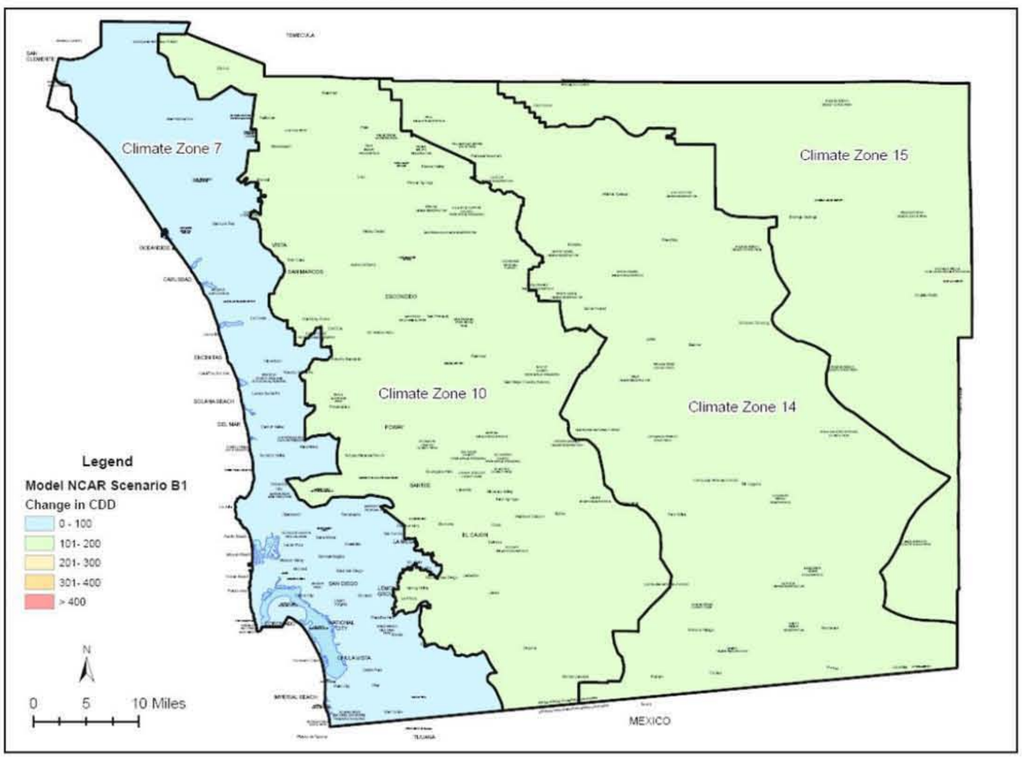


Change in Peak Temperatures by 2050 Model CNRM Scenario B1

Figure 8-5. Peak temperature change. CNRM climate model; A2 and B1 scenarios.

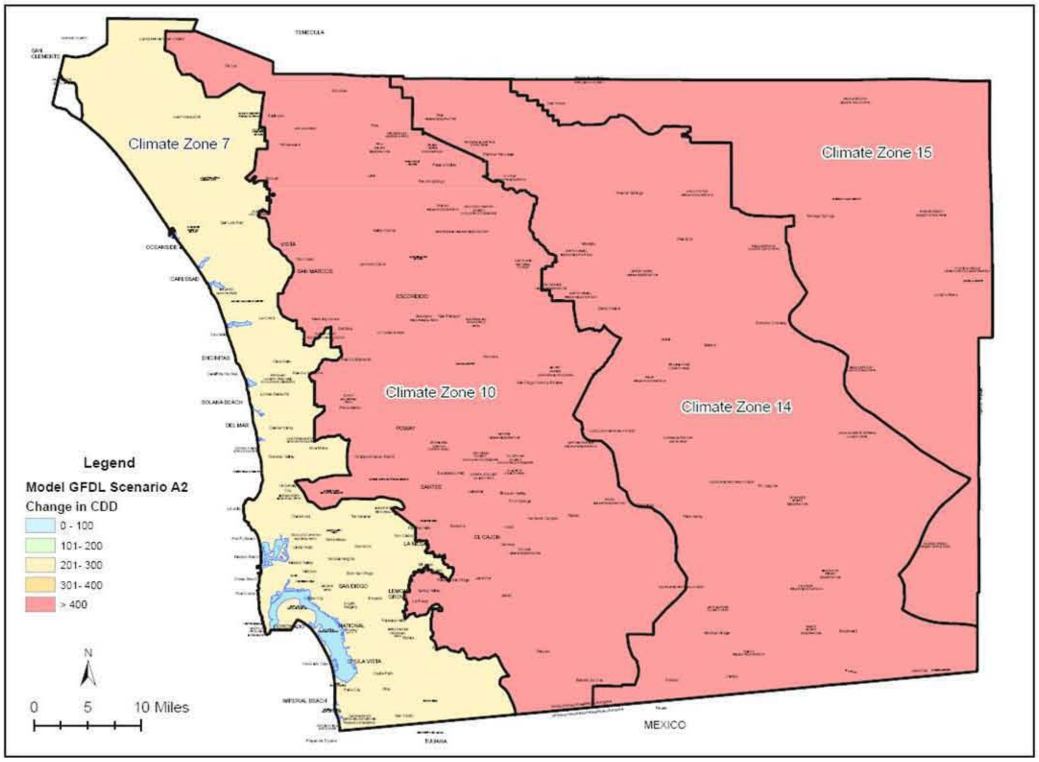


Change in Cooling Degree Days by 2050 Model NCAR Scenario A2

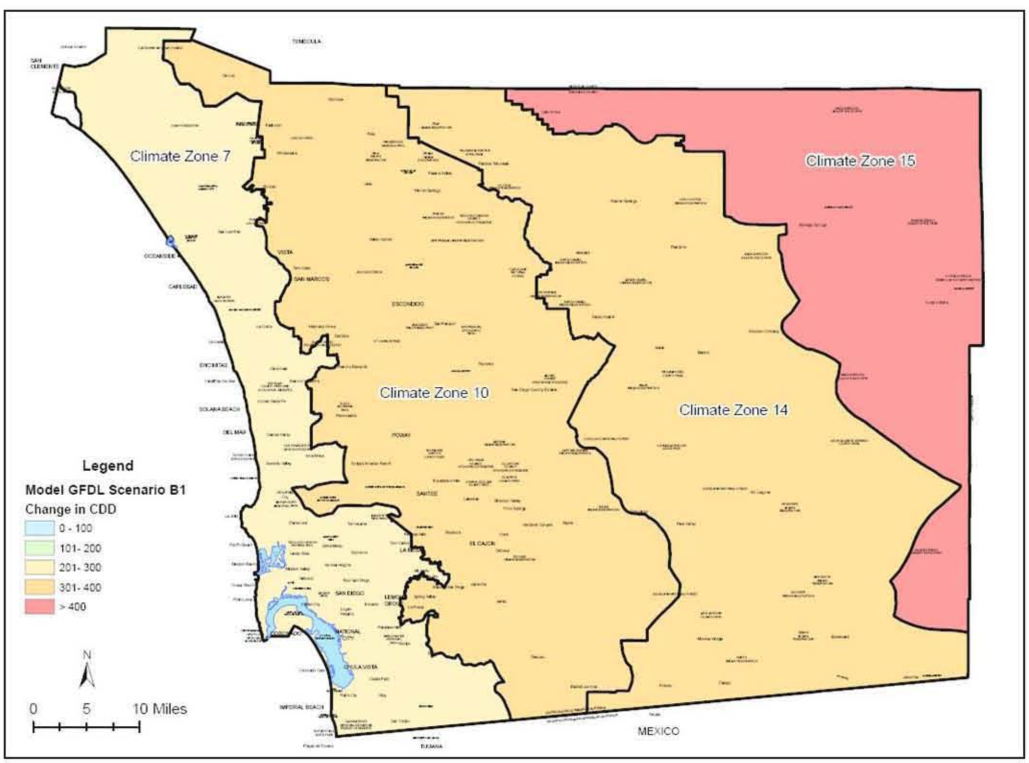


Change in Cooling Degree Days by 2050 Model NCAR Scenario B1

Figure 8-6. Change in cooling degree days. NCAR climate model; A2 and B1 scenarios.

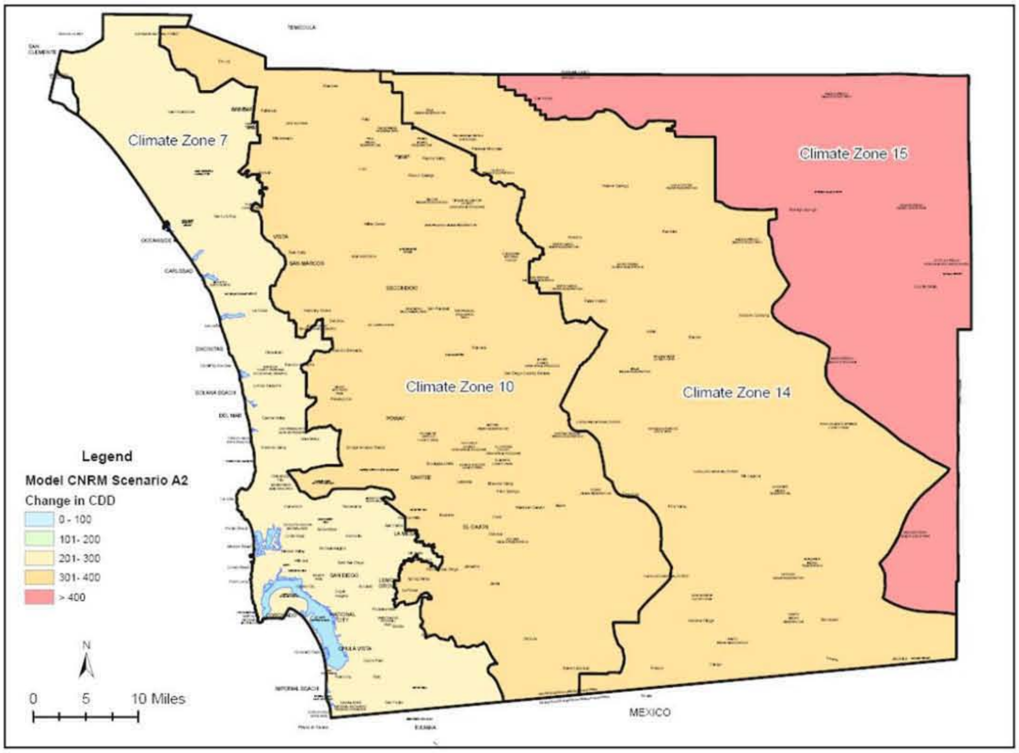


Change in Cooling Degree Days by 2050 Model GFDL Scenario A2

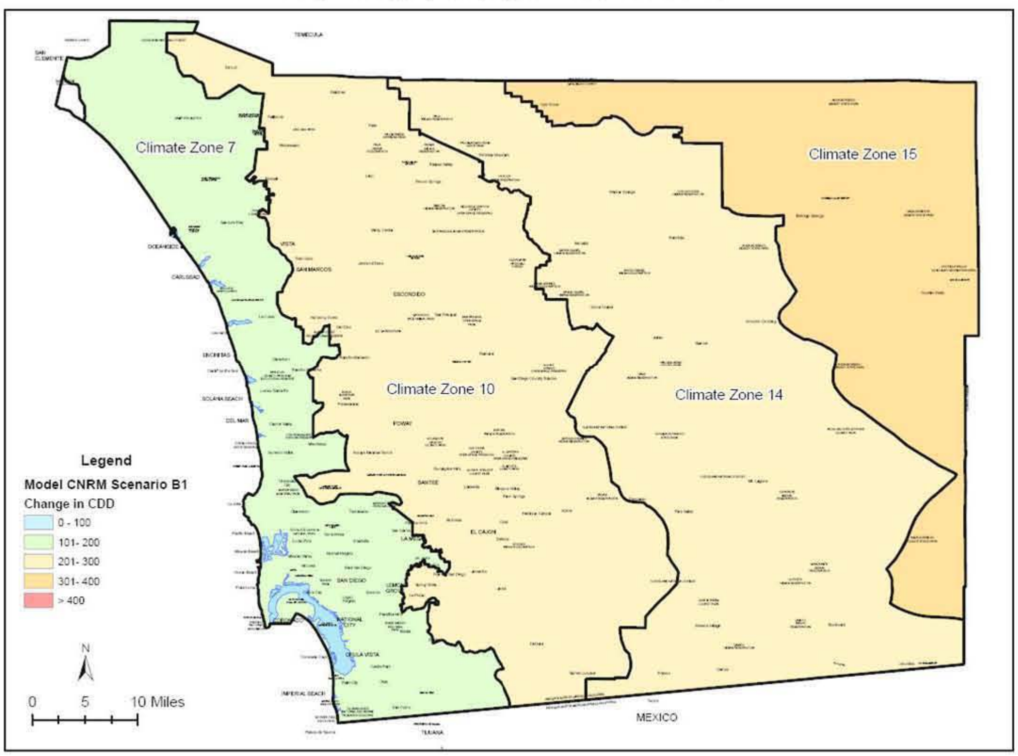


Change in Cooling Degree Days by 2050 Model GFDL Scenario B1

Figure 8-7. Change in cooling degree days. GFDL climate model; A2 and B1 scenarios.



Change in Cooling Degree Days by 2050 Model CNRM Scenario A2



Change in Cooling Degree Days by 2050 Model CNRM Scenario B1

Figure 8-8. Change in cooling degree days. CNRM climate model; A2 and B1 scenarios.

Peak Demand and Annual Consumption Trends for Electricity

Analysis of Peak Demand Trends

Peak electricity levels in 2050 are projected to be 60-75 percent higher than today's peak electricity usage. Of that increase, climate change accounts for approximately 7 percent, and the remainder is driven by population growth in San Diego County.

Peak summertime temperatures have a well-established relationship to peak electrical demand that utilities use for the purpose of load planning. Figure 8-9 depicts this relationship in the San Diego region and is taken from a CEC planning document for peak load.[1] The graph shows a roughly linear relationship between peak demand and peak weekday temperatures. It also shows that periodic heat-wave events can result in significant spikes in demand that are 5-10 percent higher than for typical summer days. These CEC data are actually an average of readings from Miramar, El Cajon, and Lindbergh Field.

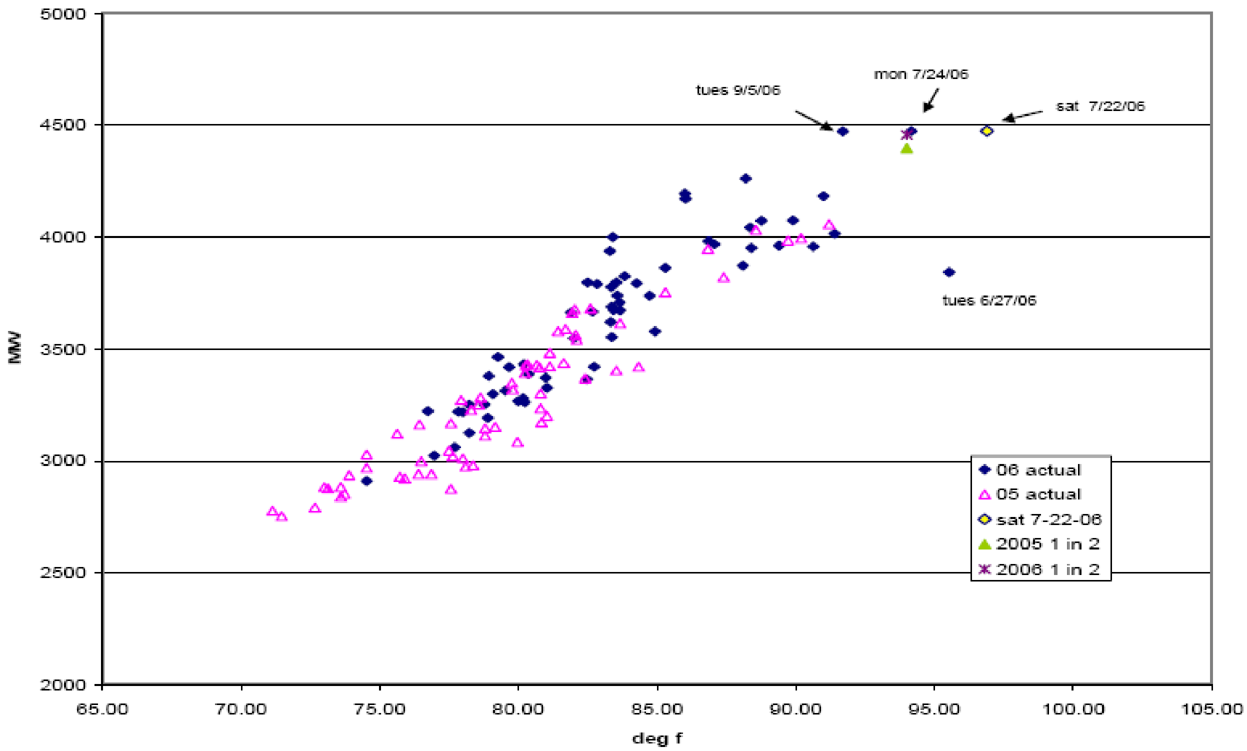


Figure 8-9. 2005-2006 Electricty demand and summer weekday peak temperatures.

The study team reviewed actual and predicted peak temperatures and electricity demand data from 1980 through 2050 for the three climate models and two growth scenarios. The analysis was performed using the moderate peak temperature model (GFDL – A2 scenario) to correlate historical electricity demand with regional population

[1] California Energy Commission. 2007.

and the four climate zone[2] temperature trends and compared with the CEC's 10-year peak demand forecast through 2018.[3] This comparison showed very good agreement and gives confidence in using the same technique to project demand through 2050.

The results of this forecasting effort are shown in Figure 8-10.

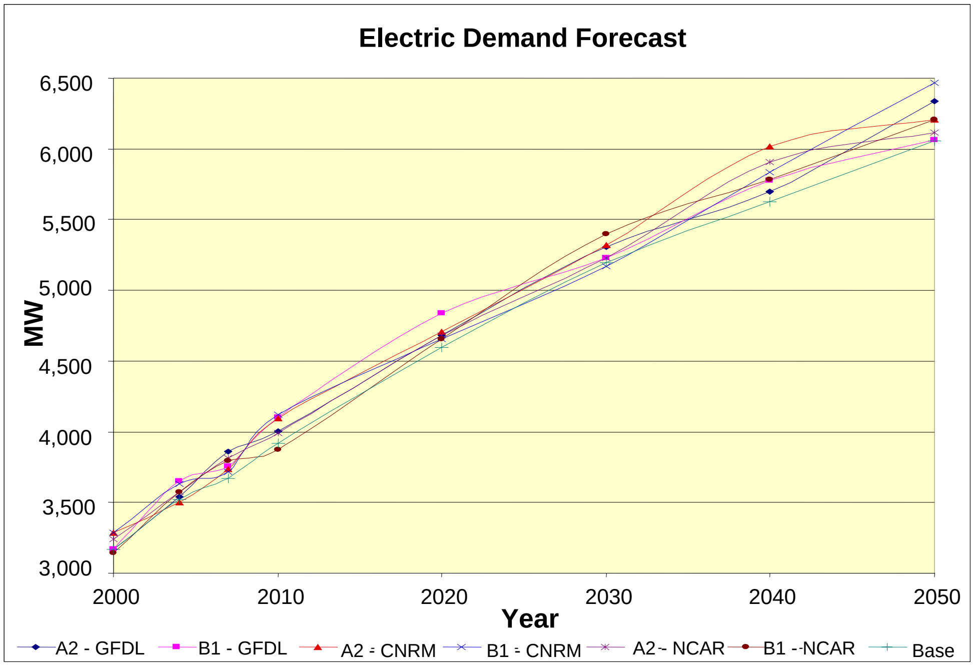


Figure 8-10. Peak electricity demand forecast

The forecast shows a dramatic increase of 60-75 percent in peak electricity demand by 2050 – an increase of more than 2,500 MW from present levels. The differences between the models account for roughly 7 percent of the total, or approximately 400 MW. The "base case" on the graph shows what peak demand would be if temperatures did not increase (i.e., demand based on population growth alone).

Analysis of Annual Consumption Trends

Overall we can expect an increase of 60-62 percent in annual electricity consumption by 2050 compared to current demand. ***Rising temperatures account for approximately two percent of the increase in consumption***. To look at annual energy consumption in 2050, a different technique was used than for peak demand. Annual electricity consumption forecasts can be quite complex, with many variables (among them economic growth, population, temperature and efficiency). For this analysis, the authors attempted to simplify the analysis into annual temperature and population variables only. We converted the annual temperature data into Cooling Degree Days (CDDs) and

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[2] California has 16 climate zones as defined by the California Energy Commission. These zones represent regions with similar weather characteristics and are used in Title 24 energy analysis and compliance. A map of the climate zones is presented at http://www.energy.ca.gov/maps/building_climate_zones.html.
[3] See Appendix L for regression analysis.

verified that this analysis of population, CDDs, and energy consumption tracked closely to the CEC's current 10-year forecast. This gives confidence in the projections to 2050.

Figure 8-11 shows the results of this forecast for the three models and two scenarios.

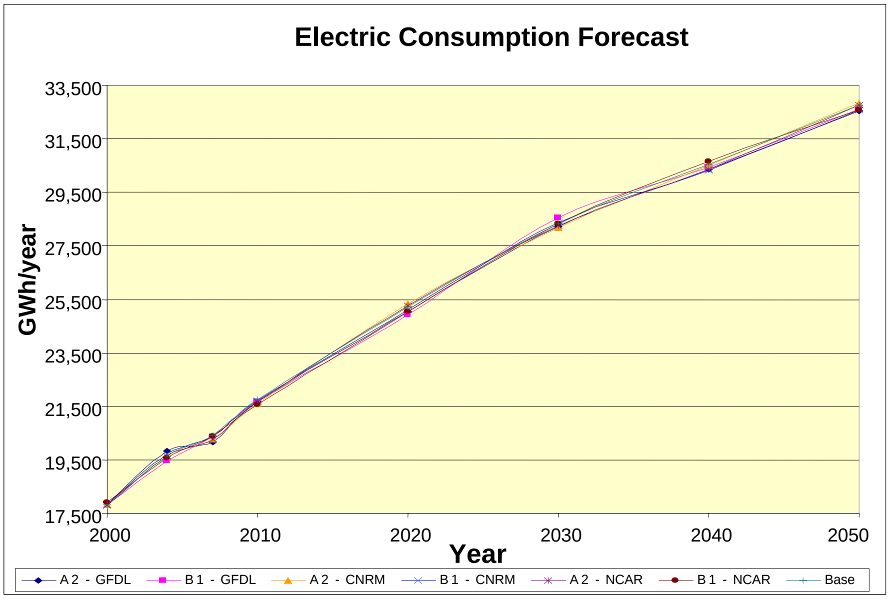

Figure 8-11. Electricity consumption forecast

There is only a nominal difference in the forecasts based on the model and scenario. This means that assumptions about electricity consumption in the forecasting model are primarily population-dependent and only marginally temperature-dependent for estimating annual electric consumption. The authors attempted to differentiate this forecast more efficiently by analyzing population in each climate zone along with the temperature trends in each zone, but found no significant additional insights.

Extreme Temperature Events and Impact on System Reliability

The previous section explored the relationship of future peak temperatures and peak electricity demand. Peak demand will be even more challenging to deal with under future climate scenarios because of the increased frequency of extreme-heat events. ***We can expect lower reliability and more widespread outages if utility planning assumes that current conditions will continue.*** This may result in the need for significant investment in utility resources, a change in consumer usage patterns or a combination of both in order to maintain reliable energy delivery to the region.

In order to look more closely at future extreme-heat events, the authors considered future peak temperatures at Miramar. Miramar was selected because the Marine Corps Air Station is currently used as the station that determines San Diego Gas & Electric Company's (SDG&E) Critical Peak Pricing (CPP) tariff. Although the tariff is too complex to fully discuss here, it is generally triggered on weekdays when forecasted temperatures are above 84 degrees F. Detailed graphs are presented in the appendix.

In general terms, ***there will be a three-month expansion of higher-temperature events. In other words, the period when high-temperature days are most frequent, currently between June and September, will expand to May through November. Early November will "feel" like September currently does.***

<u>Decreased Summertime Generation Capacity</u>

Summertime, when demand is highest, is also the time when operating efficiency is lower and line losses increase. The decrease in summertime generation is attributable to reduced generator and transmission line performance. This will result in further need for utilities to purchase or build additional power supplies. Further, transmission line congestion is worst during times of peak demand, which will exacerbate the problem.

Thermal Generator Efficiency

The efficiency of thermal power generators, including fossil fuel as well as nuclear-fired units, goes down when air temperature goes up. Higher outdoor air temperatures reduce the efficiency and capacity rating of natural gas and oil units by reducing the ratio of high and low temperatures in the power cycle. The efficiency of power plants that rely on cooling towers, including gas, oil and nuclear-fired units, is further reduced by the negative effect of increased outdoor air temperatures and humidity on the cooling-tower condensing process. The impact of temperature on the thermal efficiency, or heat rate, of a typical cogeneration power plant is illustrated below.[4] An increase in ambient temperature of just 10 degrees F from 100 degrees F to 110 degrees F would result in a 4.5 percent decrease in net output capacity from this power plant.[5]

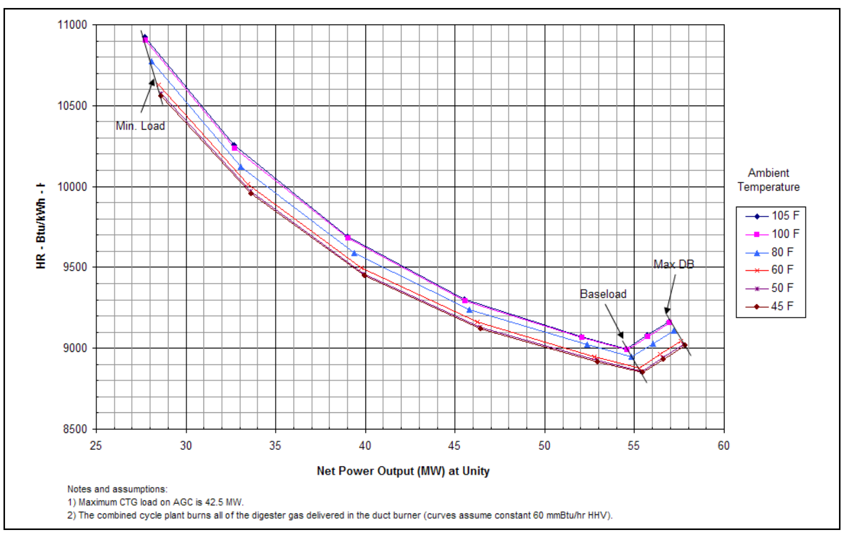

Figure 8-12. Cogeneration plant combined cycle performance under varying ambient temperatures.

[4] Assumes 50,000 lb/hr steam exported to thermal hosts.
[5] Assumes both combustion turbines operating at 100 percent load, evaporative cooler running and 80 percent ambient humidity.

Wind Generation

The availability of wind power may also be affected by climate change, although projected climate impacts on wind are highly uncertain at this time. While San Diego only has about 50 MW of large-scale wind generation currently installed, there is significant wind potential in the eastern portion of the county. A 2005 study estimated that there could potentially be as much as 1,500 MW of wind power generated in or near eastern San Diego County.[6] Wind is likely to comprise a significant portion of the energy resources used to meet California's renewable portfolio standard, which requires investor-owned utilities to generate or procure 20 percent of their energy needs from renewable sources by 2020. Further research in this area is needed because changes in wind resources are not currently modeled in the global climate scenarios. The U.S. Climate Science Program predicted that overall wind-power generation would decrease in the mountain areas of the West, but could *increase* in California.[7] New research could provide more specificity with regard to both the location of impacts on wind resources and the timing of those effects, so that utilities may consider wind's impact on generation in the context of both installed capacity and imported energy.

Transmission Line Losses

Transmission line losses may increase as a result of climate change, although there is a need for further research in this area. One study quantified temperature impacts on electricity transmission line losses, noting that "electric transmission lines have greater resistance in warmer temperatures, and thus climate change will result in increased line losses. For a country with 8 percent line losses, a 5.4^{o}F temperature increase will cause… an increased need for generation of about 1 percent." [8] A separate concern is line sag. As demand increases during hot weather, transmission line conductor temperatures increase, which causes the lines to stretch and sag. If a line sags into an object such as a tree, the current can be discharged to the ground, causing a short-circuit that could initiate a major power outage. It is precisely this sag phenomenon that triggered the two large U.S. blackouts in 1996 and 2003.[9] However, it is conductor temperature (a function of load) that is the main cause of sagging power lines. Currently, there is insufficient data to conclude that ambient temperature increases of a few degrees would have a significant impact on line sag, especially in light of the clearance practices on transmission rights of ways.

Trends in Energy and Regional Water Use

The San Diego County Water Authority (Water Authority) is exploring seawater desalination as a means of diversifying its supply of water resources. As an energy-intensive process, the development of desalination facilities in the San Diego region will bring with it a growth in energy demand.

As a part of its Seawater Desalination Action Plan, the Water Authority intends to acquire desalinized water from a proposed reverse osmosis (RO), privately-owned

[6] San Diego Regional Renewable Energy Group. 2005.
[7] U.S. Climate Change Science Program. 2007.
[8] Feenstra et al. 1998.
[9] U.S. Department of Energy. 2005.

desalination facility located adjacent to the Encina Power Station. Production is anticipated to start in 2011, and output is expected to increase over time up to the plant's maximum capacity of 56,000 acre-feet of water per year (af/yr) as demand for desalinized water increases. As part of the regulatory approval process for this desalination plant, plans call for carbon-neutral operations, to be achieved through a combination of strategies, including offsetting investments in carbon sequestration. This may mitigate climate impacts from the plant, but would not necessarily reduce direct demand for electricity.[10]

Energy requirements for desalination vary by the technology type, the salinity and temperature of the feedwater, and the purity requirements of the produced water. RO systems do not require thermal energy to heat feedwater. Therefore, RO is generally more energy efficient than other desalination technologies (including vapor compression and multi-stage flash systems). Since it does not require fuel-burning permits for a thermal conversion process, RO technology is the type most likely to be employed throughout the San Diego region. Assuming an energy intensity of 4,000 kWh/af of water produced,[11] the rise in energy demand attributable to meeting the Water Authority's desalination goals are summarized in Table 8-1. Comparing this table to regional electricity consumption in Figure 8-9, it can be seen that consumption of desalinated water in 2030 is likely to boost overall electricity use in the region by 1-1.5 percent.

Table 8-1. Increases in annual power consumption attributable to saltwater desalination throughout the San Diego region

Year	Scenario	Desalination capacity added to region (acre-feet/year)	Resulting increase in annual power consumption (MWh)
2020	*low case*	40,000	160,000
	high case	56,000	224,000
2030	*low case*	56,000	224,000
	high case	89,600	358,400

Summary

Demand for electricity in San Diego County is projected to increase significantly by 2050. That increase will be largely driven by population increases, augmented by increased average and peak temperatures, especially in inland areas where population growth rates are highest. Electric-power generation and transmission are less efficient and less reliable under peak temperatures and peak loads, increasing the risk of system outages at critical times. Additional energy needs for water desalination may further contribute to increased demands.

Overall, we can expect that the utility will need to make additional investments and customers will need to modify consumption patterns in order to reduce peak summer electricity demand, avoid a reduction in reliability and to avoid system outages. The utility may include advanced approaches such as the implementation of smart grid

[10] Poseidon Resources. 2007.
[11] California Department of Water Resources. 2003.

technologies, utility-scale renewable energy power plants, market-based pricing mechanisms, strategic deployment of distributed generation, and automated demand response technologies. With a combination of incentives, tax credits, and electricity price signals, consumers will be more proactive in the adoption of energy efficiency technologies, installing on-site generation equipment, installing load shifting technologies, and implementing improved building standards along the lines of LEED or Energy Star certifications.

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