CLIMATE CHANGE-RELATED IMPACTS IN THE SAN DIEGO REGION BY 2050

A Paper From:
California Climate Change Center

Prepared By:
Steven Messner, Sandra C. Miranda, Karen Green, Charles Phillips, Dr. Joseph Dudley – SAIC
Dr. Dan Cayan – Scripps Institution of Oceanography
Dr. Emily Young – The San Diego Foundation

FINAL PAPER

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Arnold Schwarzenegger, *Governor*

August 2009
CEC-500-2009-027-F

Acknowledgments

This paper relies heavily on the research conducted in the San Diego Foundation's Regional Focus 2050 Study (Focus 2050 Study), which was conceived of and commissioned by the Foundation's Environment Program. The Foundation contracted with the University of California, San Diego's Environment and Sustainability Initiative (ESI) to serve as the project manager for the Focus 2050 study and the Foundation was the project manager for this Public Interest Energy Research (PIER) Program study. Environment and Sustainability Initiative staff worked with a team of 40 experts from the region including universities, nonprofit organizations, local governments, public sector agencies and private sector entities to produce this document. It draws upon the most current scientific analyses from a broad array of experts in climate science, demography and urban/regional planning, water, energy, public health and ecology.

The Focus 2050 Study for the San Diego region is modeled, in part, on the Focus 2050 study undertaken by King County, Washington and is tailored for incorporation into the California Climate Change Center's Second Biannual Assessment of the implications of climate change for the State of California.

Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California's electricity and natural gas ratepayers. The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

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- Energy-Related Environmental Research
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- Renewable Energy Technologies
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In 2003, the California Energy Commission's PIER Program established the **California Climate Change Center** to document climate change research relevant to the states. This center is a virtual organization with core research activities at Scripps Institution of Oceanography and the University of California, Berkeley, complemented by efforts at other research institutions. Priority research areas defined in PIER's five-year Climate Change Research Plan are: monitoring, analysis, and modeling of climate; analysis of options to reduce greenhouse gas emissions; assessment of physical impacts and of adaptation strategies; and analysis of the economic consequences of both climate change impacts and the efforts designed to reduce emissions.

The California Climate Change Center Report Series details ongoing center-sponsored research. As interim project results, the information contained in these reports may change; authors should be contacted for the most recent project results. By providing ready access to this timely research, the center seeks to inform the public and expand dissemination of climate change information, thereby leveraging collaborative efforts and increasing the benefits of this research to California's citizens, environment, and economy.

For more information on the PIER Program, please visit the Energy Commission's website www.energy.ca.gov/pier/ or contract the Energy Commission at (916) 654-5164.

Table of Contents

Preface.. iii
Abstract ix
1.0 Introduction 1
2.0 Project Approach 2
2.1. Climate Change in the San Diego Area 2
2.2. Sea Level Scenarios and Coastal Impacts in 2050 3
2.2.1. Modeling Sea Level Rise in the San Diego Region 3
2.2.2. Combining Effects of Sea Level Rise and Wave Activity 4
2.3. Climate Impacts on Water in 2050 4
2.3.1. Demand Impacts 4
2.3.2. Supply Impacts 5
2.4. Wildfires in 2050 5
2.5. Ecosystems in 2050 6
2.5.1. Shrubland Models 6
2.6. Public Health in 2050 7
2.7. Electricity: Powering Growth in a Demanding Future 9
2.7.1. Peak Temperature and Cooling Degree Day Trends 9
2.7.2. Peak Demand Trends for Electricity 9
2.7.3. Annual Consumption Trends for Electricity 10
2.7.4. Extreme Temperature Events and Impact on System Reliability 10
3.0 Project Outcomes 10
3.1. Climate Change in the San Diego Area 10
3.1.1. Climate Change 10
3.1.2. Warming 12
3.1.3. Heat Waves 13
3.1.4. Precipitation 13
3.1.5. El Niño/Southern Oscillation 13
3.2. Sea Level Scenarios and Coastal Impacts in 2050 14
3.2.1. Modeling Sea Level Rise in San Diego Region 14
3.2.2. Combining Effects of Sea Level Rise and Wave Activity 14
3.3. Climate Impacts on Water in 2050 19
3.3.1. Demand Impacts 19
3.3.2. Supply Impacts 20
3.3.3. Effects of Climate Change and Regional Soil Moisture Content on Increased Water Use 21
3.4. Wildfires in 2050 22
3.4.1. Relationship between Climate Change and Wildfires 22

3.5. Ecosystems in 2050 23
3.5.1. Threats to Biodiversity and Ecological Processes 23
3.5.2. Specific Impacts of Climate Change 24
Forests 24
Southern California Shrublands 25
Coastal Ocean 25
3.6. Public Health in 2050 26
3.6.1. Climate Change Direct Effects on Public Health 26
Extreme Heat Events 26
3.6.2. Climate Change Indirect Effects on Air Pollution 27
Ozone Air Pollution 27
Particulate Matter Air Pollution Levels 28
Health Effects Modeling 29
3.6.3. Wildfire Impacts on Public Health 29
3.6.4. Climate Change Effects on Infectious Disease 30
Water-Borne Disease 30
3.7. Electricity: Powering Growth in a Demanding Future 31
3.7.1. Peak Temperature and Cooling Degree Day (CDD) Trends 31
Peak Demand Trends for Electricity 34
Annual Consumption Trends for Electricity 34
Extreme Temperature Events and Impact on System Reliability 35
3.7.2. Decreased Summertime Generation Capacity 35
Thermal Generator Efficiency 35
Wind Generation 35
Transmission Line Losses 35
3.7.3. Trends in Energy and Regional Water Use 36
4.0 Conclusions and Recommendations 36
4.1. Climate Change in the San Diego Area 37
4.2. Sea Level Scenarios and Coastal Impacts in 2050 38
4.2.1. Benefits to the San Diego Region 38
4.3. Climate Impacts on Water in 2050 38
4.3.1. Demand Management 39
4.3.2. Local Initiatives 39
4.3.3. Benefits to the San Diego Region 40
4.4. Wildfires in 2050 40
4.5. Ecosystems in 2050 41
4.6. Public Health in 2050 41
4.6.1. Benefits to the San Diego Region 42
4.7. Electricity: Powering Growth in a Demanding Future 42
5.0 References 43

6.0 Glossary 49

List of Figures

Figure 1. Change in annual mean temperature, San Diego region from the three GCMs, for the historical period (blue) and for the A2 (red) and B1 (brown) emission scenarios 12

Figure 2. Winter and summer temperature differences.....13

Figure 3. Sea level rise projections.....15

Figure 4. South Imperial Beach…….……..……17

Figure 5. Coronado Beach and Shores…….……..17

Figure 6. Mission Beach……..……..……...……18

Figure 7. La Jolla Shores……..……..……..……18

Figure 8. Del Mar Beach …….……..……19

Figure 9. Oceanside Beach……..……19

Figure 10. Projected water demand and supply in 2005, 2030, and 2050, under "normal year" and climate change conditions 19

Figure 11. Simulated Annual-Mean Soil Moisture, Western San Diego County 21

Figure 12. Acres burned in San Diego county per decade.....22

Figure 13. Days exceeding 97.3°F (36.3°C), Miramar A2 GFDL.....27

Figure 14. $PM_{2.5}$ projections 29

Figure 15. Peak temperature change (°F) by 2050 for the three climate models 32

Figure 16. Cooling degree day changes by 2050 (°F).....33

Figure 17. Peak electricity demand forecast.....34

Figure 18. Electricity consumption forecast.....34

List of Tables

Table 1. Expected mortality change in 2015, 2035, and 2050 from base year 2004.....29

Table 2. Increases in annual power consumption attributable to saltwater desalination throughout the San Diego region 36

Abstract

This report explores what the San Diego region will be like in the year 2050 if current trends continue. Focusing on interrelated issues of climate change, sea-level rise, population growth, land use, water, energy, public health, wildfires, biodiversity, and habitat, the report looks at the potential impacts of a changing climate by 2050, both quantitatively and qualitatively.

The simulated impacts discussed in this study are based on regional projections of climate change generated by scientists at Scripps Institution of Oceanography, using three climate models and two emissions scenarios drawn from those used by the Intergovernmental Panel on Climate Change. The impacts are discussed in the context of significant regional growth expected during the period as well as an aging population base.

Key issues explored in the report include potential inundation of six selected low-lying coastal areas due to sea level rise, potential shortfalls in water deliveries, peak energy demand increases due to higher temperatures, increasing risk of devastating wildfires, migrations of species in response to higher temperatures in an increasingly fragmented natural habitat, and public health issues associated with extreme temperature events.

Keywords: Climate change impacts, San Diego region, sea level rise; public health and climate, water and energy scarcity, biodiversity loss

1.0 Introduction

The San Diego region is renowned worldwide for its unique combination of mild climate, low rainfall, breathtaking shorelines, mountains, and deserts—all in close proximity. Not surprisingly then, the region has been one of the fastest-growing areas in the country. This unique set of climate and population characteristics also creates a unique fragility. The complex and fragile interrelationship of urban and natural systems here has been dramatically highlighted by devastating wildfires, as well as by more gradual changes in the region's natural ecosystems.

These complex and fragile relationships which characterize San Diego County (the term San Diego County is used interchangeably with San Diego region herein) are explored further here in the context of climate change. Higher temperatures, changing precipitation patterns, and a rising sea level will create new issues that will require considerable planning and coordination activities, as well as exacerbate existing stresses due to regional growth.

This study considers the regional impacts due to climate change that can be expected by 2050 if current trends continue. 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 were 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.

The population of San Diego County in January 2007 was 3,098,269 people living in 1,131,749 housing units.[1] The San Diego Association of Governments (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 is projected to fall below 1% and be slightly above that expected for the United States overall until 2030. The region's population is projected to reach 4.5 million in 2050

[1] 21 SANDAG, Current Estimates 2007.

(California DOF 2007), an increase of 524,000 persons beyond the 2030 projections.[2] On average the region's population increases by 0.7% per year after 2030, which matches the projected increase in the U.S. population between 2030 and 2050. This growing population will not only affect the way in which San Diego adapts to climate change, but exacerbate the effects of climate change as well.

As the region's population grows, it will also become older. Approximately one quarter of the region's current population is 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%. 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%, compared to an increase of 14% for the overall population. Age groups under 18, and between 18 and 64, will grow more slowly–at around 10% 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.

The goal of the Focus 2050 Study is to provide a scientific basis for local governments and public agencies to develop climate-preparedness plans, which include strategies for mitigating the damage from, and adapting to, climate change. A key message of this study is that there is not any single "silver bullet" to solve these projected impacts, rather that there is a serious need for coordinated actions among local, regional and state authorities to begin or advance planning activities in all of these areas. Additionally, the project's contributors expect the report will help to identify opportunities to capture economic benefits (public and private) from early action. The study is also intended to create a greater awareness of the likely local impacts of climate change compounded by population growth on sea-level rise, land use, water, energy, public health, wildfires, biodiversity, and habitat; and to provide information that can form the basis of informed decision-making by key policymakers in government, business, and community organizations.

2.0 Project Approach

2.1. Climate Change in the San Diego Area

The studies presented in this report are based on analysis using three climate models,[3] and two scenarios of energy use and greenhouse-gas (GHG) emissions.[4] The models and

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[2] 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.

[3] The three models are: the National Center for Atmospheric Research's Parallel Climate Model (PCM), the National Oceanic and Atmospheric Administration's Geophysical Fluids Dynamics Laboratory (GFDL) version 2.1, and the French Centre National de Recherches Météorologiques

scenarios were among those used in the most recent international climate assessment (by the IPCC), and they are included in the set of models Scripps Institution of Oceanography prepared for PIER for the 2008 California Climate Change Scenarios Assessment. 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 B1 emissions scenario presents a future with a high level of environmental and social consciousness combined with a globally coherent approach to more sustainable development. Because there is considerable uncertainty about future greenhouse-gas emissions scenarios, specific probabilities to any of these simulations were not assigned. 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.

2.2. Sea Level Scenarios and Coastal Impacts in 2050

To better understand the combined effects and possible impacts of sea level rise and wave activity on San Diego's coastline by 2050, models have been employed that take into account both of these key issues. Local sea level rise is projected using a semi-empirical approach based on global mean temperatures with additional consideration of the moderating influence of dams and reservoirs, which are common within San Diego County. The influence of future wave activity is estimated by applying the sea level rise projections to existing wave models for the region that account for physical variations in local coastline conditions (e.g., island sheltering, wave refraction and shoaling). Predicted impacts are mapped for six low-lying coastal areas to highlight the severity and frequency of shoreline inundation in areas of San Diego County prone to flooding. Coastal features vary among the selected (South Imperial Beach, Coronado Beach and Shores, Mission Beach, South La Jolla Shores, North Del Mar, and Oceanside Harbor); therefore, the predictions also illustrate how impacts may vary along the San Diego coastline in areas with cliffs, estuaries, sea walls, rock jetties, and other man-made structures. The analytical approach used to predict climate change impacts associated with sea level rise and wave activity is further described below.

2.2.1. Modeling Sea Level Rise in the San Diego Region

A well-known approach for forecasting sea level rise is the Rahmstorf 2007 semi-empirical method. This method links sea level rise to observed global mean temperatures. The method also assumes that sea level rise along the Southern California coast will be the same as global estimates. The sea level projections developed here also include a lower range of estimates which account for the worldwide growth of dams and reservoirs, which have changed, and will continue to change surface runoff into the oceans (Chao et al. 2008). The effect of these future dams and reservoirs will be a

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(CNRM).

[4] The IPCC's Special Report on Emissions Scenarios (SRES) A2 and B1 scenarios.

slowing in predicted sea level rise and therefore is a useful lower boundary case when looking at sea level forecasts.

2.2.2. Combining Effects of Sea Level Rise and Wave Activity

The results from the sea level rise projections were then applied to existing wave models used in the San Diego region to develop a better understanding of future wave activity on lower-lying areas. The wave model forecasts, derived from a global climate model simulation, were transformed to 10 meters depth using the Coastal Data Information Program[5] (CDIP) spectral refraction model developed by the Scripps Institution of Oceanography (SIO). The CDIP model was revised to look at offshore wave conditions for a coastline that is slowly progressing landward along with sea level rise. The CDIP model accounts for coastline variations that affect wave height and energy including island sheltering, wave refraction, and shoaling of waves in the southern California Bight. The increased elevation of the shoreline water level owing to wave run-up (called super-elevation) is estimated from the wave conditions using an empirical engineering formula.[6] Wave-induced super-elevation is then combined with tides, weather effects (e.g., storms), El Niño effects, and longer-term sea level changes (Cayan et al. 2007) to develop a time series profile of shoreline water levels at each site. To run the model, a run-up coefficient of 0.4 was determined by CDIP to represent the relatively mild-sloped cross-shore beach profiles that are seen in the low-lying areas being studied in the San Diego area. Finally, digital elevation data from October 21, 2006, LIDAR (Light Detection and Ranging remote sensing system) coastline surveys were combined with an analysis of the shoreline water level time series to create the maps of potential inundation.

2.3. Climate Impacts on Water in 2050

An overall objective of this part of the study was to extrapolate existing water demand and supply forecasts for 2030 out to 2050 to highlight the pressures of population growth and climate change on the regional water situation. The data used to project water demand and supply from 2005 to 2030 were primarily from the San Diego County Water Authority (Water Authority) 2005 Urban Water Management Plan, along with additional information provided by the San Diego County Water Resources Department Staff. Official San Diego County projections of water demand and supply between 2030 and 2050 are not available due to the lack of demographic and economic projections from local jurisdictions after 2030.

2.3.1. Demand Impacts

The demand was projected based on assessments of agency-by-agency trends around 2030. Due to the lack of official water demand projections for San Diego County after 2030, projections from 2030 to 2050 are straight-line extensions of per capita trends leading up to 2030 scaled down to reflect the expectation that the population growth rate in San Diego will decline by 25% (from the pre-2030 rate) after 2030.

It is important to note that the Water Authority projections assume a 12% per capita demand reduction by 2030 to reflect planned conservation and efficiency measures.

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[5] http://cdip.ucsd.edu/?sub=faq&nav=documents&xitem=future

[6] Run-up elevation = 0.4 * Wave Height @ 10 m depth.

These conservation efforts are assumed to continue from 2030 to 2050. The Water Authority's past conservation efforts have focused on indoor water savings. Their future conservation efforts will focus more on landscape irrigation and commercial, institutional, and industrial savings as well as new residential construction standards. Residential surveys conducted in the region by the Water Authority indicate that, depending upon the season, between 40% to 60% or residential water is used for landscaping. Most of the future growth in water demand is expected to be for municipal and industrial (M&I) uses, whereas agricultural water uses are projected to decline due to increase in conservation and efficiency. By 2030, 94% of the demand is expected to be for M&I, with agricultural demand shrinking from 13% of total demand in 2005 to 6% in 2030.

The relationship between droughts, soil moisture content, and water use in the San Diego region is also very important to understand how potentially more frequent and intense droughts might affect overall water demand. Based on evaluations of historical records, the Water Authority concluded for planning purposes that 1989 was a representative drought year. For this study, future soil moisture conditions for western San Diego County were simulated using the Variable Infiltration Capacity (VIC) water-balance model, with temperature and precipitation data supplied by the Geophysical Fluid Dynamics Laboratory's CM2.1 climate-model simulations of climate under A2 and B1 greenhouse-gas emissions scenarios. The future soil moisture conditions were then compared to the 1989 drought conditions as an index of climate effects on water supplies. The VIC simulation used the GFDL climate model data assuming future A2 and B1 scenarios. In order to calibrate the model the VIC simulation was run and compared against the recent historical period (1950–1999).

2.3.2. Supply Impacts

The supply projections for water imported from the Metropolitan Water District (MWD) and other new sources from 2030 to 2050 were obtained by estimating how much the projected demand exceeded projected supply from other sources.

There are two supply scenarios for 2050; the first was projected assuming "normal climate" conditions (climate change effects were not taken into account), and the second scenario makes the severe assumption that climate change could result in 20% reductions in the availability of imported water and local surface and ground water. The 20% reduction in water availability is based on the results of studies that predict Colorado River flows will decrease in response to climate changes by 18% to 20%. It should be noted that estimates of the reductions in Colorado River flows by the year 2050 have ranged from 6% to as much as a 45% (Christiansen et al. 2004; Milly et al. 2005; Christiansen and Lettenmaier 2007; Hoerling and Eischeid 2007).[7]

2.4. Wildfires in 2050

The frequency of fire incidents and their devastating impacts on the residents of San Diego has increased in direct proportion to human population growth since the vast

[7] Christiansen et al. 2004, -18%; Milly et al. 2005, -20%; Christiansen and Lettenmaier 2007, -6%; Hoerling and Eischeid 2007, -45%.

majority of ignitions are caused by human activities. It is likely that the changes in climate that San Diego is experiencing due to the warming of the region will increase the frequency and intensity of fires even more, making the region more vulnerable to devastating fires like the ones seen in 2003 and 2007. New research has been performed that models the magnitude of wildfire burns in the decade around 2050 as compared to present burn trends (Spracklen et. al. 2008). This research looked at the six ecosystems of the western United States that are most prone to wildfires: Pacific North West, California Coastal Shrub, Desert South West, Nevada Mountains/Semi-desert, Rocky Mountains Forest, and Eastern Rocky Mountains/Great Plains. The California Coastal Shrub ecosystem results are considered further in this study, as this is an important vegetation type relating to wildfires in the San Diego region.[8]

In addition, this study considers the possibility that fire suppression activities have contributed to the recent burn trends in the San Diego region by disrupting natural fuel structures.

2.5. Ecosystems in 2050

Future trends of San Diego ecosystems in response to climate change are evaluated based on relevant literature associated with the growing body of research in paleoclimatology, related studies of paleorecords and assessments of ecosystem changes in correspondence to major climate regimes, and use of new tools such as models to refine local predictions. Several different models were applied and/or modified for this evaluation. Shrubland models and distribution models were used to predict how climate change can affect terrestrial ecosystems and what changes in distribution of species are likely to occur with climate change.

2.5.1. Shrubland Models

The Center for Conservation Biology (CCB) at the University of California, Riverside has developed models predicting potential habitat for a variety of plant and animal species in different ecosystems in Southern California (Preston 2007) with a particular focus on shrubland communities that support a diversity of sensitive plant and animal species in the region (Preston, in press). To understand how changing climate conditions might affect these natural communities in the San Diego region, the CCB conducted climate sensitivity analyses for coastal sage scrub and chaparral vegetation as well as for plant and animal species found in these shrublands (Preston, in press). To assess the sensitivity of the species and the vegetation types to climate change, the models used different temperature and precipitation values[9] and compared them with current climate conditions. The CCB also developed models predicting suitable habitat for the federally

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[8] 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.

[9] The temperature and precipitation values come from the range of forecasts from the three climate models and two growth scenarios (SRES A2 and B1) considered in this study. Temperature values: [+ 0.6°C (1°F), +1.7°C (3°F), and +2.8°C (5°F)]. Precipitation values: 50%, 90%, 100%, 110%, and 150%.

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 models developed included associations between animal and plant species under the 2050 climate scenarios.

2.6. Public Health in 2050

Future trends for public health challenges in San Diego caused by climate change are based on the project team's reviews of studies from a growing body of research on the potential public impacts of climate change. Given the importance of air pollution issues in the region today, and projected increased importance of air quality issues in the future due to the aging population, the study team conducted a literature review and summary of public health issues associated with climate change including heat stress illness, respiratory illness due to higher ground level ozone concentrations resulting from higher temperatures, respiratory effects from wildfires, as well as infectious disease implications. The study team also performed quantitative modeling analysis of aerosol fine particulate matter emissions and ambient concentrations trends in the San Diego air basins to evaluate the possible impacts of changes in this key air quality parameter on public health.

Past research has identified links between fine particulate matter ($PM_{2.5}$) and numerous health problems including asthma, bronchitis, acute and chronic respiratory symptoms such as shortness of breath and painful breathing, and premature death. Public health risks from $PM_{2.5}$ are highest among young children and the elderly. Concentrations of air 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 (Bernard et al. 2001; CARB 2005). In general, San Diego County meets the EPA's Annual National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$ but exceeds the 24-hr NAAQS for $PM_{2.5}$ a few times during the cooler months of the year.

The mathematical model developed here is a first attempt to evaluate the influence of climate change on air pollutant levels in San Diego County. The model projects changes in emissions through population expansion, the application of emission control programs, and interaction between future temperature and future emissions through 2020, and extrapolates these trends through 2050. The analysis considered the three climate models[10] and two emissions scenarios[11] used for the overall study climate projections. An air quality box model approach was used to project fine particle ($PM_{2.5}$) concentrations for San Diego County. Due to time constraints, a box model was used to provide a reasonable approximation of the air quality impacts. Key parameters were incorporated into the model, including current and projected air pollution emissions

[10] Meteorological scenarios from the GFDL CM2.1, CNRM CM3, and NCAR CCSM3 were applied downscaling for San Diego County by 12 km x 12 km.

[11] SRESA2: Climate change simulation carbon dioxide (CO_2) 850 parts per million (ppm) max; self-reliance; population increases; economic growth slow. SRESB1: climate change simulation CO_2 550 ppm max; global solutions; population peaks and steadies; service and information economy.

patterns within the county, current and projected local meteorology, and atmospheric chemical transformation and removal processes (wet and dry deposition) for air pollutants. The model was refined beyond a simple box model so that the results would provide a better estimate. San Diego County was simulated as a 3-D box, with the area divided into five sub-regions and the vertical layer was divided into five levels. This allowed the use of more representative meteorology in each sub-region. Concentrations of chemical species were then assumed to be well-mixed within each sub-region and vertical layer, essentially using 25 separate "boxes" to simulate the county. The concentrations could change based on several processes: (1) chemical reactions were allowed to occur within each box, and were based on reaction rates in the literature., (2) dry deposition rates were calculated using applicable equations based particle size and the respective settling velocities and (3) wet deposition rates were calculated separately for gases and aerosols; for gases, Henry's law coefficient was used to determine the fraction of a trace gas that is in the liquid rain water, for aerosols, removal was calculated using a first-order loss process described in the literature. The PM contribution from outside San Diego was considered in the projections by using the California Air Resources Board (CARB) emissions data for 2006 and San Diego Air Pollution Control District (APCD)'s Del Mar, Camp Pendleton, and Otay Mesa monitoring stations data for 2006 since these monitors lie towards the boundary of the model. The model's performance was tested using the 2006 base year by comparing the modeled results with the ambient concentrations for the same year (2006) for all $PM_{2.5}$ monitoring sites in San Diego County (Kearny Mesa, Escondido, El Cajon, Chula Vista, and downtown San Diego). Overall, the model can predict the seasonal increasing and decreasing trends reasonably well.

One major challenge to this work was the development of realistic projections for emission inventories to year 2050. For the A2 scenario, it was assumed no change in emissions from the base year 2006. For the B1 scenario, CARB emissions projection for years 2010, 2015, and 2020 were used and emissions were assumed to be constant at the 2020 level for subsequent years until 2050. Similar emissions projections for reactive organic carbon (ROG), nitrogen oxides (NOx), and sulfur oxides (SOx), were used in the model to drive the chemical reactions. To model the effects from particulate matter ($PM_{2.5}$) on human mortality in the region, data for mortality rates of diseases associated with fine particulate aerosols were collected from the California Department of Health Statistics Website.[12] These data were then analyzed using the projected $PM_{2.5}$ concentrations from our model to obtain projected mortality rates, using parameters of Pope et al. (1995). According to Pope et al. (1995) each 10 microgram per cubic meter ($\mu g/m^3$)(over 16 year span) elevation in long-term average $PM_{2.5}$ ambient concentrations was associated with approximately a 4%, 6%, and 8% increased risk of all-cause, cardiopulmonary, and lung cancer mortality, respectively. This data were used to generate the mortality values in Table 1 (Section 3.6). In this mortality model, it was assumed that the population size, demographic characteristics, and long-term ecological effects were constant throughout the period under study. This model's predictions should be viewed as conservative estimates, given predicted future increase in both the absolute size of the population in the San Diego region and the relative proportion of

[12] http://www.dhcs.ca.gov/dataandstats/Pages/default.aspx.

this population that is at high risk from life-threatening respiratory illness from air pollution and heat stress.

Consequently, it is felt that the results provide a reasonable analytical approach for this project, given the constraints. Future climate analyses could benefit from the use of the latest photochemical dispersion models that provide for an integrated assessment of gaseous and particulate air pollution. Recommended models include the Community Multiscale Air Quality (CMAQ) model or the Comprehensive Air quality Model with extensions (CAMx).

2.7. Electricity: Powering Growth in a Demanding Future

Electricity consumption in San Diego County has increased steadily over the past 17 years with the exception of 2000-2001 due to the energy crisis. Voluntary efforts to reduce consumption have helped San Diego avoid extensive outages since 2001, but more recently consumption trends have resumed and even exceeded pre-crisis levels. The peak demand in 2006 was the highest on record in the San Diego Gas and Electric (SDG&E) territory, driven largely by cooling loads as a result of high summertime temperatures. The main thrust of this section is a quantitative analysis of future peak temperature data and electricity demand as well as a quantitative analysis of future Cooling Degree Day (CDD) trends versus annual electricity consumption. The section also summarizes an analysis of future high temperature days against two high temperature thresholds that SDG&E uses for critical peak pricing determinations to curtail demand. Lastly, this section qualitatively covers other issues relating to higher temperatures and the ability to generate and transmit electricity efficiently.

2.7.1. Peak Temperature and Cooling Degree Day Trends

Temperature data from the three climate models were analyzed to generate maps for peak temperature and cooling degree day (CDD) trends (see figures 15 and 16). The maps 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 (Energy Commission) uses temperature data from Lindbergh Field, Miramar, and El Cajon to simulate future demand. Cooling degree days are the amount of time during the year above a reference temperature of 65°F (18°C)—and so are much more indicative of annual temperature trends rather than daily peak trends. The Energy Commission has used another approach for annual consumption adjusted for temperature that correlates hourly temperature and hourly demand data over an entire year. This approach could not be used for this project as the necessary data were not readily available from SDG&E.

2.7.2. Peak Demand Trends for Electricity

Peak summertime temperatures have a well-established relationship to peak electrical demand that utilities use for the purpose of load planning. 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 and the four climate

zone[13] temperature trends and compared with an Energy Commission's 10-year peak demand forecast through 2018; these Energy Commission data are actually an average of readings from Miramar, El Cajon, and Lindbergh Field. This comparison showed very good agreement and gives confidence in using the same technique to project demand through 2050.

2.7.3. Annual Consumption Trends for Electricity

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). In order to simplify the analysis, the only variables taken into account were annual temperature and population. The authors converted the annual temperature data into CDDs by averaging the daily data for maximum and minimum temperature included in the climate models to determine the daily average temperature. The daily CDD values were calculated on a Base 65 basis. The daily CDDs were then summed for each year to get the annual values that were used for the analysis. These values were verified through a regression analysis that this correlation of population, CDDs, and energy consumption tracks closely to the Energy Commission's current 10-year forecast. This gives confidence in the projections to 2050.

2.7.4. Extreme Temperature Events and Impact on System Reliability

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 SDG&E's Critical Peak Pricing (CPP) tariff. Two thresholds were evaluated for Miramar: 84°F (29°C), which is currently used by SDG&E to trigger a Critical Peak Pricing event (when the cost of electricity to commercial customers increases significantly to incentivize reduced consumption); and 93.8°F (34.3°C), which represents the one-in-10 event for maximum temperatures over the last ten years.

3.0 Project Outcomes

3.1. Climate Change in the San Diego Area

3.1.1. Climate Change

Scientists have not only developed predictive models that show global trends, but also downscaled these global predictions to provide more detailed projections of changes over time on scale of cities and regions as has been done here for San Diego (see Figure 1). The magnitude, and sometimes the pattern, of climate impacts for the twenty-first century vary according to the 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.

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[13] 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 in Appendix M. http://www.energy.ca.gov/maps/building_climate_zones.html

There is considerable uncertainty regarding future GHG emissions, so it is not possible to assign odds to either of the two emissions scenarios.[14]

[14] Each model differs, to some extent, in its representation of various physical processes. The climate projections should be viewed as a set of possible outcomes, with each having an unspecified degree of uncertainty.

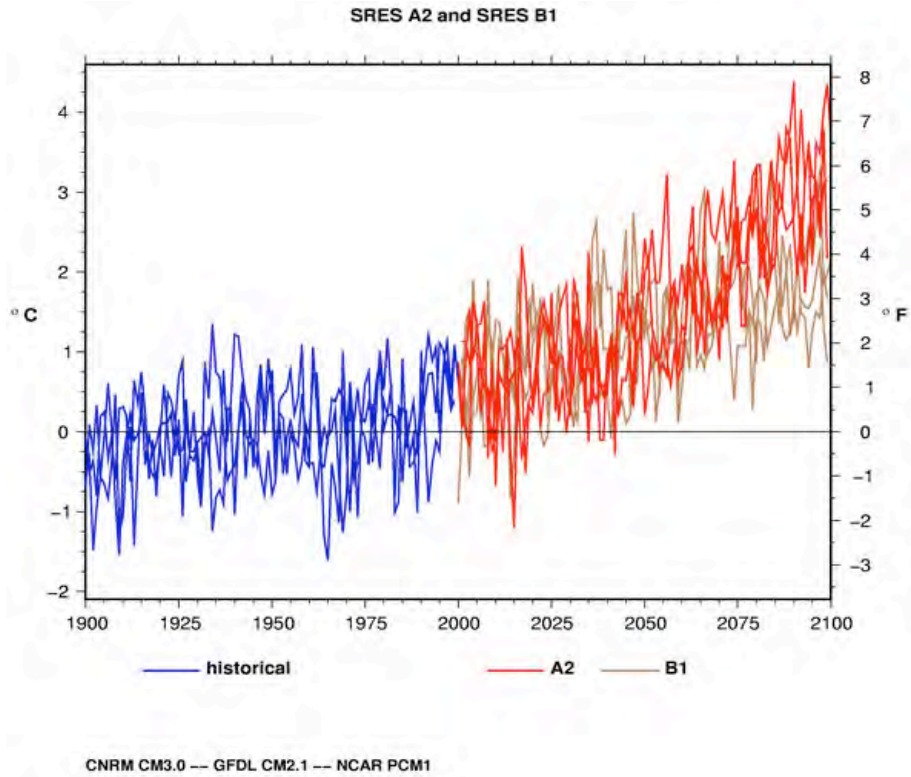


Figure 1. Change in annual mean temperature, San Diego region from the three GCMs, for the historical period (blue) and for the A2 (red) and B1 (brown) emission scenarios

3.1.2. Warming

From observations it appears 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(Bonfils et al. 2007; Barnett and Pierce, in press). All of the climate model simulations exhibit warming across San Diego County—ranging from about 1.5°F to 4.5°F (0.8°C to 2.5°C, see Figure 2), with some differences in the timing and geographic distribution of the changes. The warming becomes progressively greater through the decades of the twenty-first century. There is greater warming in summer than in winter, with surface air temperatures in summers warming from 0.7°F to more than 2°F (0.4°F to 1.1°C) over that found in winter. There is a distinct Pacific Ocean influence wherein warming is more moderate in the zone within approximately 50 km from the coast, but rises considerably, as much as 2°F (1.1°C) higher, in the interior landward areas of San Diego County as compared to the warming that occurs right along the coast. 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, health, and ecosystem needs in the region.

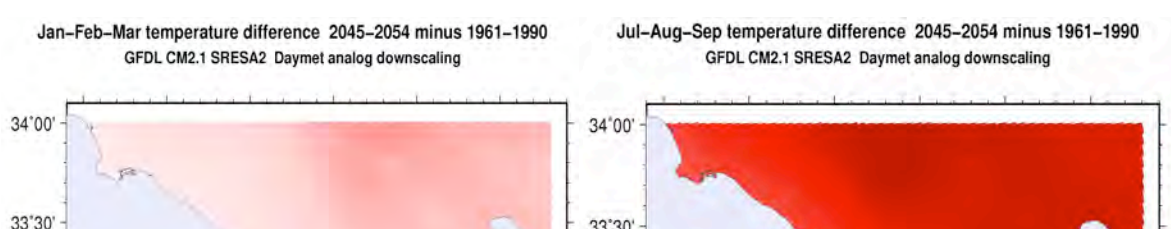


Figure 2. Winter and summer temperature differences

3.1.3. Heat Waves

Extreme warm temperatures in the San Diego region mostly occur 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 instance, in one inland portion of San Diego County there will be more than a threefold increase in hot days.

3.1.4. Precipitation

The 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[15] but none show a significant change from past patterns.

One important aspect of all 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 highly vulnerable to drought.

3.1.5. El Niño/Southern Oscillation

Historically, the 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 of ENSO, each of the simulations exhibits continued ENSO activity within the

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

twenty-first century. There is already 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. Regarding ENSO intensity, the IPCC scenarios show little change over the century, but this conclusion has come under recent criticism from leading scientists in the field who conclude that there is a "significant probability of a future increase in ENSO amplitude" in this century (Lenton et al. 2008). Changes in ENSO intensity will result in stormier years and drier years, which have implications for public health planning that is considered later in this study, as well as coastal impacts.

3.2. Sea Level Scenarios and Coastal Impacts in 2050

3.2.1. Modeling Sea Level Rise in San Diego Region

Results of three simulation scenarios indicate sea level increases of 12–18 inches by 2050. Projected sea level rises based on application of the Rahmstorf 2007 method with and without adjustment for the effects of dams are compared with observed values between 1900 and 2000 in Figure 3. Dams have retained significant amounts of water in the past and have skewed past trends. The model assumes that dams will not be able to continue this trend and a new equilibrium is being established. As sea level rises, there will be an increased incidence of extreme high sea level events, which occur during high tides, often when accompanied by winter storms and sometimes exacerbated by El Niño occurrences (Cayan et al. 2007). As the decades proceed, the simulations show an increasing tendency for heightened sea level events to persist for more hours, which will likely cause greater coastal erosion and related damage.

3.2.2. Combining Effects of Sea Level Rise and Wave Activity

Figures 4 through 9 show the projected impacts in 2050 in the six already flood-prone areas analyzed with the revised CDIP wave model, with a brief explanation of the specific impacts at each site. The colored zones represent new flooding areas. The Figures depict predicted wave event frequencies using the following definitions:

- **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.

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

These maps are considered conservative since 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 due to sea level plus tides and do not show any wave activity. In addition, the maps do not account for potential changes in shoreline elevation that could occur with future wave erosion. This could have a cumulative effect and cause increased inundation as wave erosion removes portions of the current shoreline. Additionally, there are many other sensitive areas along San Diego's almost 70 miles of coastline that have not yet been surveyed. Their inclusion, especially of those economically and strategically significant sites, is needed in future research.

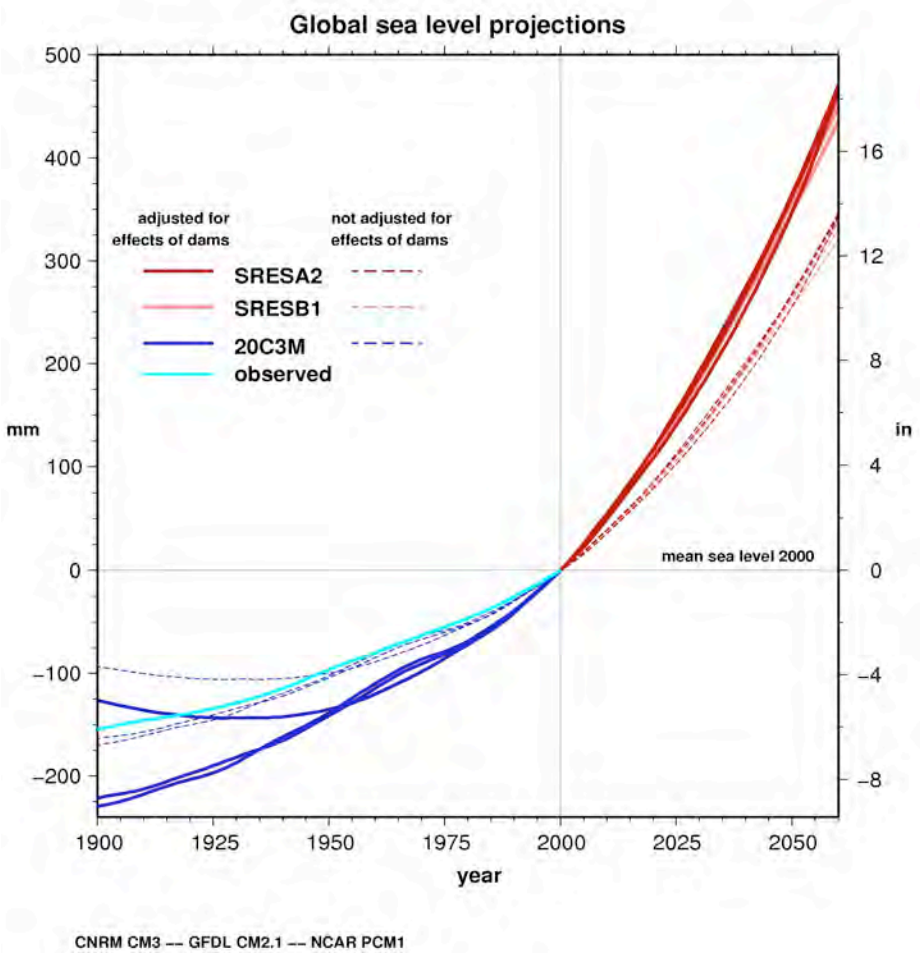
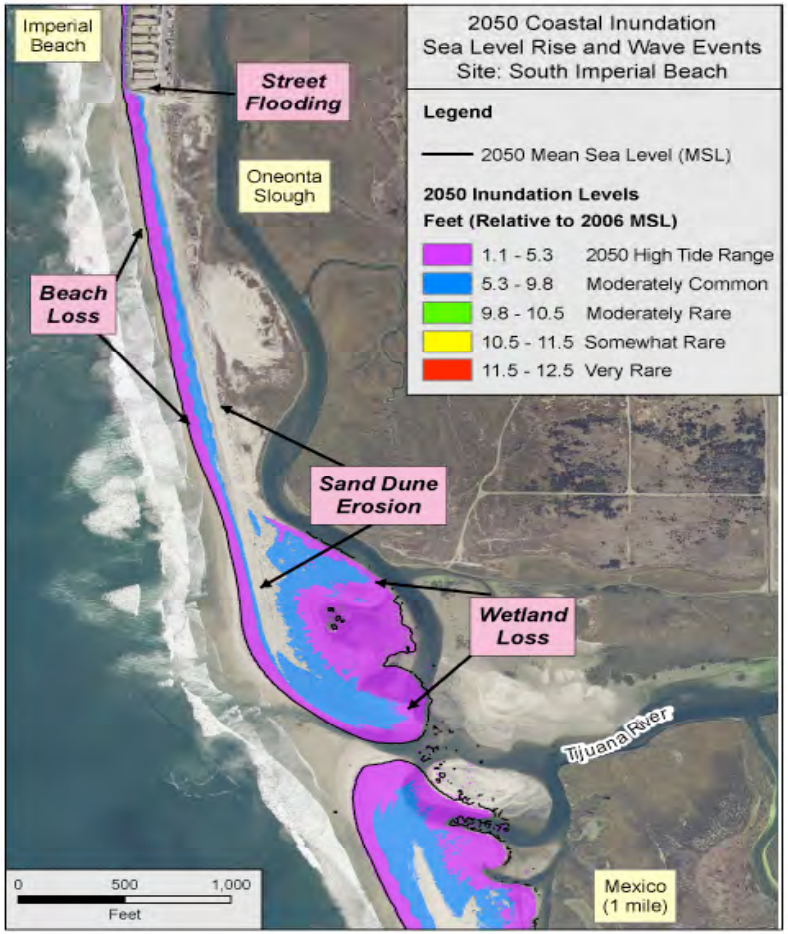


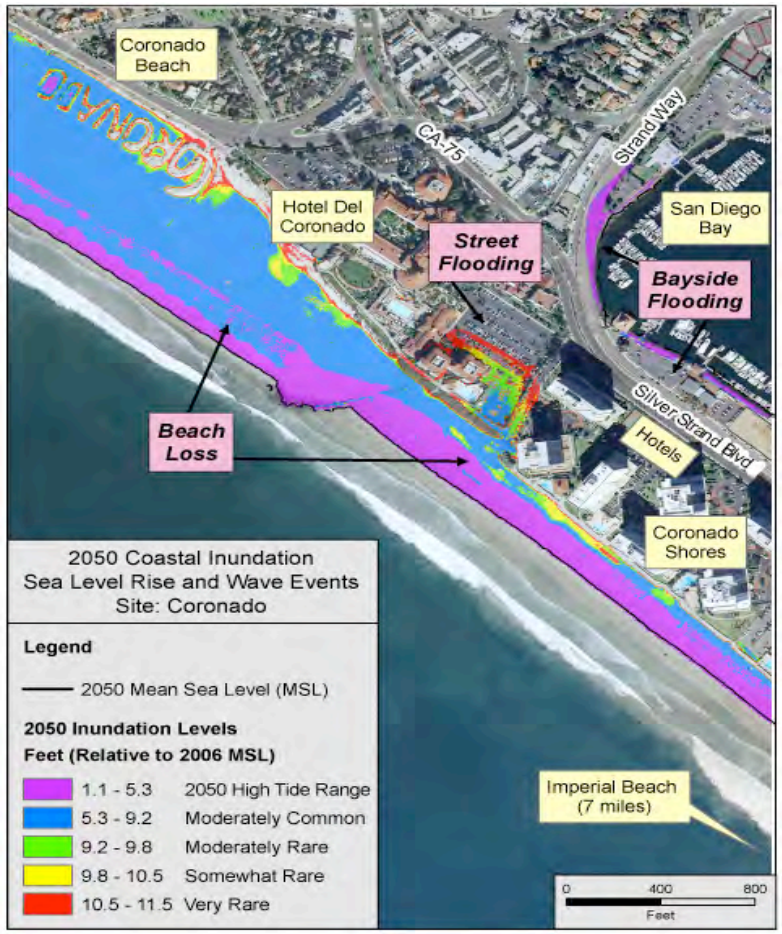
Figure 3. Sea level rise projections

Figure 4. 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 5. Coronado Beach and Shores

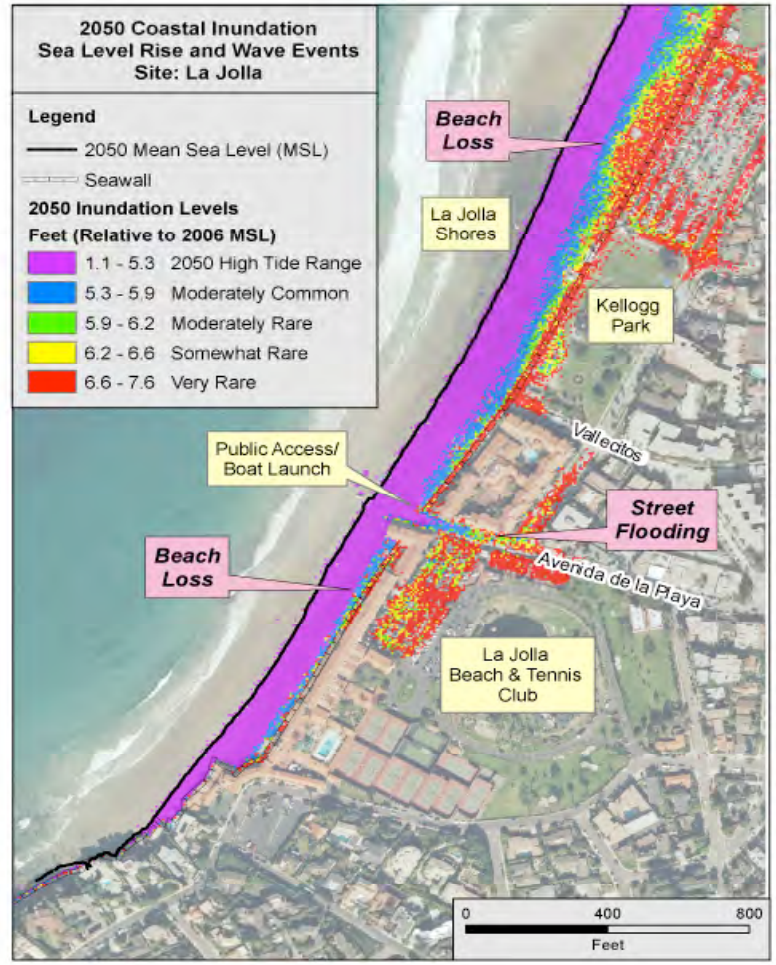


Tidal fluctuations alone (purple) appear to inundate sandy beach and jetty. Adding run-up from moderately common wave events (blue) floods the majority of sandy beach and portion of parking lot at the Hotel Del Coronado. Very rare wave events (red) flood sandy beach, some surface streets and heavily 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 6. Mission Beach

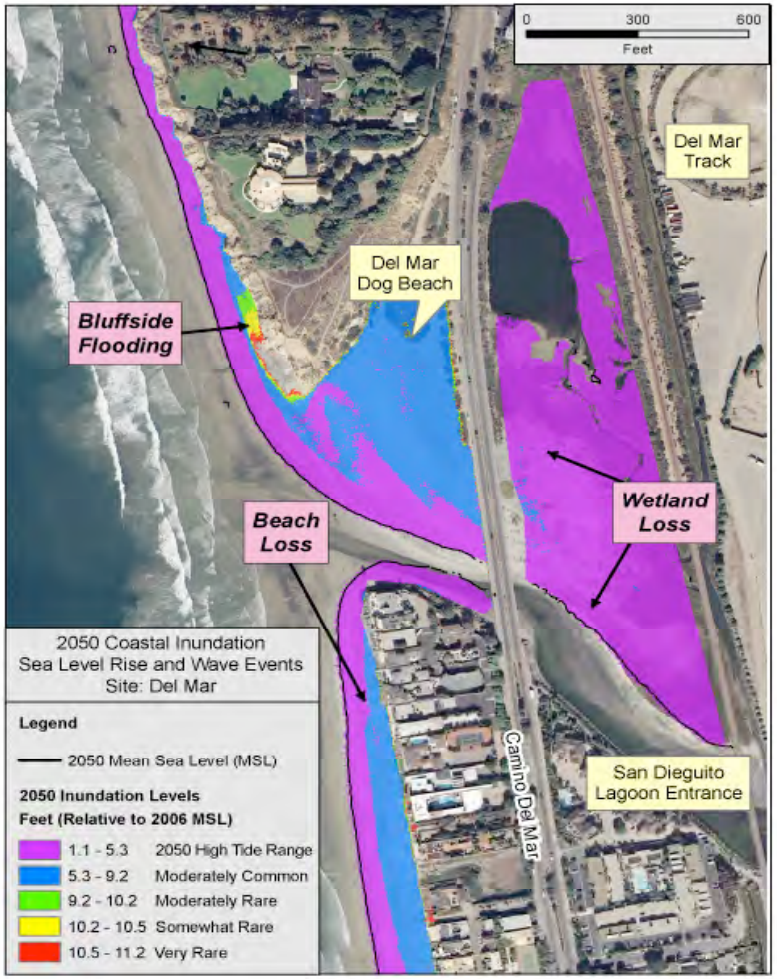
Tidal fluctuations alone (purple) appear to inundate portions of sandy beach and streets from bayside flooding. Adding run-up from moderately common wave events (blue) floods majority of sandy beach, streets and parts of Mission Beach Park. Moderately rare wave events (green) appear to breach seawall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

Figure 7. La Jolla Shore



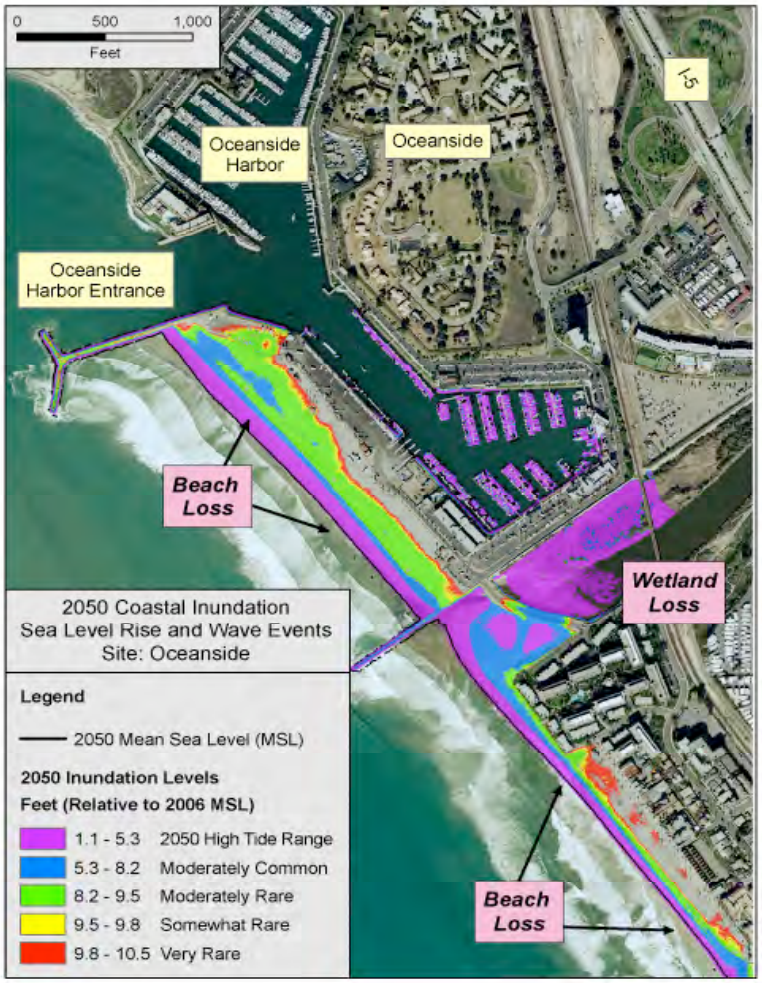
Tidal fluctuations alone (purple) appear to inundate majority of sandy beach and Boat Launch. Adding run-up from moderately common wave events (blue) floods majority of sandy beach and end of street at Avenida de La Playa. Very rare wave events (red) flood sandy beach, breaches seawall, floods some surface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

Figure 8. 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 9. 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.

3.3. Climate Impacts on Water in 2050

The results of the projected future water demands and supplies and modeled effects of drought and water use on soil moisture conditions are discussed below.

The projected water demands and supplies in 2005, 2030, and 2050 are illustrated in Figure 10. The height of the bars represents the water demand, and the expected sources of water are illustrated by the different colors of the bar segments. The two bars labeled "2050" show the expected water sources for San Diego in the year 2050 under the normal climate and climate change scenarios.

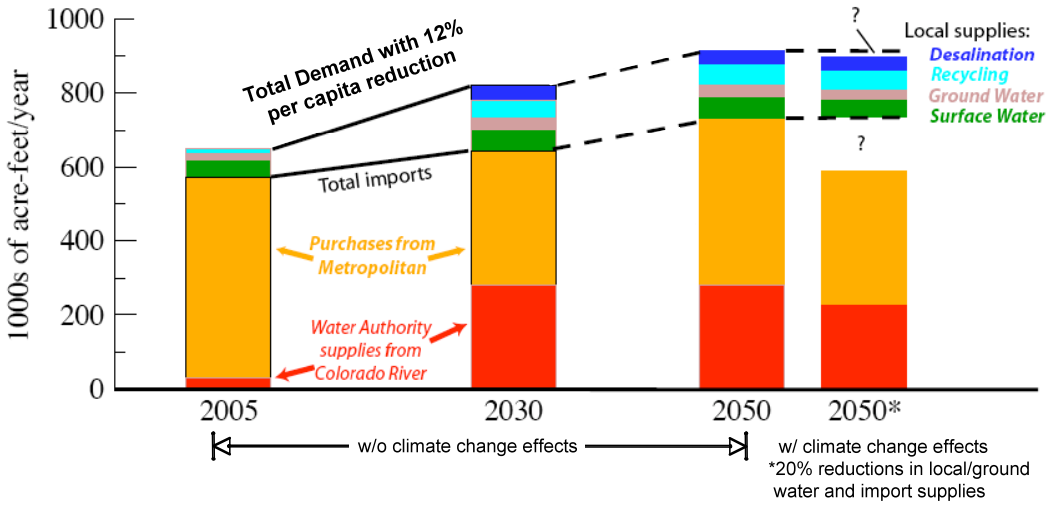


Figure 10. Projected water demand and supply in 2005, 2030, and 2050, under "normal year" and climate change conditions

3.3.1. Demand Impacts

The Water Authority predicts an increase in water demand of around 24%, from 668,000 acre-feet/yr (the 2001–2005 average) to about 830,000 acre-feet/yr in 2030: 70% of this demand is expected to come from imported sources. The estimated demand in 2050 is 915,000 acre-feet/yr. If this 2050 water demand and use is realized, it will represent an increase of 37% over the 2001 to 2005 period. Under current demand and planned local supply projections, about 80% or 730,000 acre-feet/yr of the water supply would be imported. Production from groundwater supplies is anticipated to increase by 75% to about 31,000 acre-feet/yr by 2015. After that, local surface and groundwater supplies will have reached their foreseeable limit and additional less-traditional sources will be needed to meet most new demands beyond those that will be supplied by imported water.

Figure 10 illustrates that increased demand from 2005 to 2030 is expected to be accommodated by increased supplies from the Colorado River, as well as from desalination and recycling. The increase in water supply from the Colorado River can be explained due to recent negotiations by the San Diego County Water Authority (SDCWA) to access new resources of water from the

Imperial Irrigation District (IID)/Colorado River. From 2030 to 2050, increased demand will have to be accommodated by increased purchases from MWD.

3.3.2. Supply Impacts

By 2050, San Diego will need commitments for imported water equivalent to 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 by 2050 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 by 2050 (Christiansen et al. 2004; Milly et al. 2005; Christiansen and Lettenmaier 2007; Hoerling and Eischeid 2007).[17] 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 around 2 million acre-feet/yr less water. Overall, the sources of most of San Diego's imported water are likely to be challenged due to climate change effects. Blank areas with question marks in the far right bar in Figure 10 (climate change scenario) indicate shortfalls in water supplies by 2050 due to the 20% reductions in the volumes of available imported water and local surface and ground water. These shortfalls in water supplies represent a significant concern to the San Diego region.

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 by water users. A new study (Barnett and Pierce, in press) estimated that, without this agreement, the major reservoirs of the Colorado River could be emptied within a few decades by a combination of increasing demand and climate change. In addition, recent calculations (D. Pierce, unpublished calculations, 2008) indicate that overall demand for Colorado River water will have to be reduced by 20% to achieve a 90% chance of maintaining water in its reservoirs by 2050.

Future water supplies to Southern California also are expected to be affected by the CALFED program, which is trying to balance water supplies with environmental goals for the Sacramento-San Joaquin River Delta, as well as the amounts and availability of freshwater associated with the Sierra snowpack. In particular, the goals of the CALFED program are to: (1) improve the reliability of the water supplies in California; (2) improve water quality in the Bay-Delta system; (3) restore ecosystems in the Bay-Delta estuary; and (4) stabilize the Sacramento-San Joaquin Delta levee system (Dettinger et al. 2003).

The Delta's deteriorating levee system may be subject to more frequent and severe winter rain storms as a result of climate change. A failure of the levee systems and/or greater salt water intrusion into the Delta, due to rising sea level, could result in significant reductions in water supplies or water quality. The watershed that drains to the Delta includes the western Sierra Nevada mountain range. In response to future climate change, the Sierra snowpack (and spring snowmelt) is projected to decline by at least 25% by the year 2050 (California Department of Water Resources 2007), thereby reducing freshwater flows to the Delta and the volume of water available for export. Consequently, adapting California's water management systems to future climate change represents will be a significant challenge in the twenty-first century.

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[17] Christiansen et al. 2004, -18%; Milly et al. 2005, -20%; Christiansen and Lettenmaier 2007, -6%; Hoerling and Eischeid 2007, -45%.

3.3.3. Effects of Climate Change and Regional Soil Moisture Content on Increased Water Use

The effects of climate change on San Diego's water demand are likely to reflect both warming and drying trends. Climate-change projections for the Southwestern United States indicate that by 2050, runoff and ground water could decline by an average of about 7 inches/yr over the entire Southwest (Seager et al. 2007; Milly et al. 2005). As noted earlier, elevated greenhouse gas levels are expected to produce temperature increases of 1.5°F to 4.5°F (0.8°C to 2.5°C) over Southern California by the mid-twenty-first century. More frequent and drier (20% drier) drought years are also projected for San Diego by the early twenty-first century, assuming increased ENSO intensity.

As illustrated in Figure 11, future soil moisture conditions are expected to drop below the 1989 drought threshold with an increasing frequency and greater severity. The model results shows droughts becoming 50% more common during the 2000–2049 period than during the 1950–1999 period. Figure 11 shows historical observations from 1950 to 1999 as well as future projections from the climate model. Three of the historical observations were dry or drier than the 1989 threshold. However, the model calibration over the historical period shows five years being dry or drier than 1989. The VIC model projects that in 2030, a drought comparable to 1989 would increase water demand by 6.5%, in large part due to decreased soil moisture content.[18] In 2050, the demand would increase from 915,000 acre-feet/yr in a normal year to 980,000 acre-feet/yr in drought years, and drought years might occur as much as twice as often (Figure 11). Drought years in the future might also yield larger demand than the 7% increase associated with 1989 because they are projected to be considerably drier than 1989.

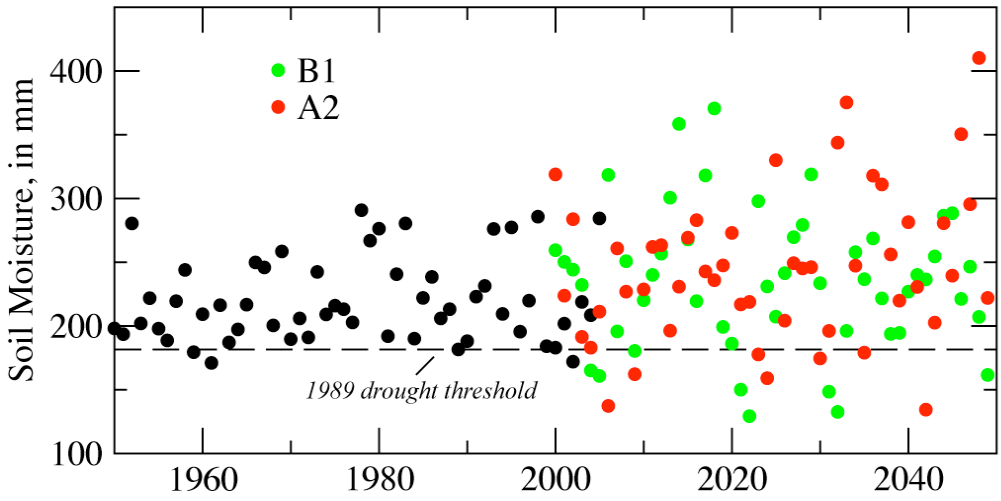

Figure 11. Simulated Annual-Mean Soil Moisture, Western San Diego County

[18] A lower soil moisture content increases agricultural and landscaping water demands.

Consequently, there is much reason for concern that even with creative and innovative arrangements among competing water interests, along with concerted conservation measures and 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.

3.4. Wildfires in 2050

3.4.1. Relationship between Climate Change and Wildfires

Extended drought conditions forecasted by climate models in the coming decades are expected to increase the likelihood of large wildfires. A past study of the western United States has shown (Westerling et al. 2006) 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. A more recent study (Spracklen et al. 2008) explores these relationships to 2050 using temperature and precipitation data from a global climate model (GISS). This study suggests that 42% more California Coastal Shrub acreage will burn in the decade around 2050 as compared to present trends and that overall, 54% more acreage in the western United States will burn compared to present.

Wildfires in the San Diego region occur throughout the year, but most strongly during late summer and early fall. Over the twentieth century, the area burned by wildfires has undergone substantial fluctuations, but in the last 10 years the extent of these wildfires was unprecedented, greatly exceeding that during any past decade (Figure 12). In 2003 and 2007, wildfires burned nearly 740,000 acres. The question of whether we are now in a higher state of vulnerability to such fires due to climate change merits further research to better inform disaster preparedness efforts.

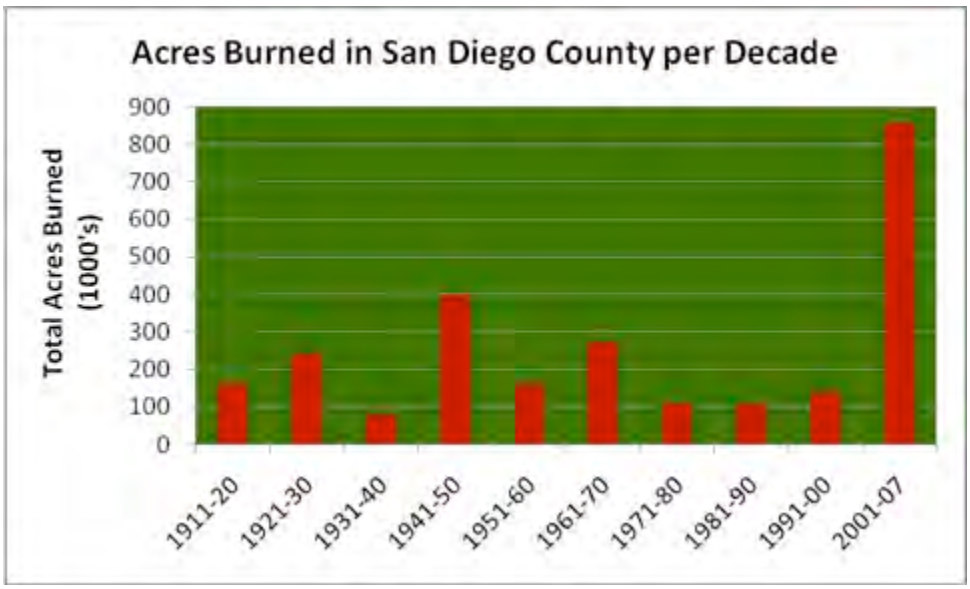

Figure 12. Acres burned in San Diego county per decade

Climate change models yield somewhat different predictions about the frequency, timing and severity of future Santa Ana wind conditions, leading to uncertainty regarding how Santa Ana winds will affect San Diego regional fire regimes in the future. A recent study on anthropogenic reduction of Santa Ana winds (Hughes et al. 2008) indicates that these events are expected to decrease by the mid-twenty-first century in both frequency and intensity due to higher temperatures in the desert during wintertime creating less pressure gradient between the mountains and the ocean.

An earlier analysis (Miller and Schlegel 2006) for the period 2005–2034 suggested 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 increase the frequency of Santa Ana fires, as severe fire weather would coincide more closely with the period of most frequent fire ignitions.

Some recent research indicates that fire suppression activities have had a negative effect on fires in California. A study by Minnich and Franco-Vizcaíno compared chaparral and forest fire regimes in Southern California (SCA) undergoing suppression activities with that of Baja California (BCA) where fires run free (Minnich et al. 2009). This study concluded that while suppression activities in SCA have reduced the number of fires, it has increased the size of old-growth patch elements and therefore increased the spatial extent of fires that do occur. Another study by Goforth and Minnich (in press) concludes that historical records of pre-suppression wildfires in Southern California chaparral are not reliable to evaluate the effects of fire suppression activities.

There are different opinions among scientists regarding the effects of fire suppression activities in the recent regional fires. A recent study specific to the San Diego area showed that over the last 130 years there has been no significant change in the incidence of large fires greater than 10,000 hectares. This is consistent with the conclusion that local fire suppression activities are not the cause of these fire events (Keeley and Zedler, In press). The research also showed that eight megafires (≥50,000 hectares) are recorded for the region and half have occurred in the last five years. These burned through a variety of age classes of vegetation, which raises doubts that accumulation of old age classes explains these events. The research concludes that drought is a plausible explanation for the recent fires as it increases dead fuels that promote the incidence of firebrands and spot fires.

3.5. Ecosystems in 2050

3.5.1. Threats to Biodiversity and Ecological Processes

Located at the heart of a global biodiversity hotspot, the biological richness of San Diego is difficult to overstate. A 1997 study presented in *Science* magazine listed it as one of two counties in the nation as having the greatest convergence of endangered and threatened species (along with Santa Cruz) with fish, mammals, and plant hot spots all coinciding. Past and present land use changes have brought significant, often cascading impacts to biodiversity across San Diego County. The starkness of the fragmentation[19] pattern in San Diego reveals how the size, shape,

[19] *Fragmentation* is the emergence of discontinuities in an organism's preferred environment (habitat).

and isolation of habitat fragments affect their ability to support native species. When habitat is fragmented by human land uses, it can trigger ecological cascades that result in the loss of species. Such "ecosystem decay" leading to loss of biodiversity can take decades to play out following the fragmentation.

A changing climate will add to the stress on ecological systems in ways that may create feedback cycles with significant consequences. For example, as the amount of rainfall occurring within (and between) years changes, the effects of fragmentation on native species may be even more intense. Also, the current fire regime is changing rapidly and many species will not be able to adapt fast enough, which can lead to the extinction of native plants and animals. There is evidence pointing to nitrogen deposition as being one of the factors contributing to the recent changes of fire regimes in Southern California. Although more research is needed in this area, nitrogen deposition may contribute to greater fuel loads by facilitating the proliferation of invasive grasses and thus altering the fire cycle in the region (Allen et al. 2003).

With climate change, the "climatic envelopes"[20] that species need will move due to increasing temperatures and more frequent fires. For many species, a changing climate is not the problem per se. The problem is the rapid rate of climate change: the envelope will shift faster than species are able to follow. For other species, the envelope may shift to areas already converted to human land use. To put the rate of temperature change for species survival into context, a 1°F–5°F (0.56°C–2.8°C) increase by 2050 predicted by the three climate change models is 10–50 times faster than the temperature changes (2°F, or 1.1°C per 1000 years) that occur when ice ages recede.

3.5.2. Specific Impacts of Climate Change

Forests

California climate projections indicate forest ecosystems will be substantially affected by temperature rise and indirect climate change effects (Cayan et al. 2008a). Extended drought can stress individual trees, increase their susceptibility to insect attack and result in widespread forest decline. For example, it is thought that lowered water tables from drought and excessive groundwater pumping is causing coast Live Oaks in the Descanso area to die out as experts cannot isolate a disease or insect causing their ruin.

The projected warmer winter temperatures may indirectly increase insect survival and populations, including pest species such as bark beetles that girdle and kill the trees. Forest-dependent fish and wildlife species may be lost as a result of reduced forest habitat and other indirect effect of climate change, such as drought, increased non-native grasslands, and wildfire. Latitudinal and/or elevation range shifts in the distribution of plant and animal populations in response to climate change could be severely constrained in the county as a

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Habitat fragmentation can be caused by geological processes that alter the layout of the physical environment or by human activity such as land conversion, which can alter the environment on a much faster time scale.

[20] Locations where the temperature, moisture and other environmental conditions are suitable for persistence of species.

result of population growth and development, habitat degradation by non-native grasses, unsuitable soils or other physical limitations (Parmesan 2006).

Southern California Shrublands

The results of the CCB modeling showed that in response to rising temperatures and reduced precipitation, each vegetation type moves to higher elevations where conditions are cooler and there is greater precipitation. The suitable environmental conditions for coastal sage scrub were predicted to decrease between 10% and 100% under altered climate conditions, with the greatest reductions at higher temperatures and extremes in precipitation. Chaparral 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. As noted above, elevation shifts in response to climate change are expected to be substantially constrained in San Diego County. Projected increases in non-native grasses and fire frequency also may substantially reduce the range and extent of future shrublands.

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. The CCB models predicting suitable habitat for the Quino Checkerspot butterfly and California Gnatcatcher, when in association with plant species, 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% relative to the climate-only models under altered climate conditions.

Coastal Ocean

The intertidal[21] and subtidal[22] habitats along the coast of San Diego contain a large diversity of marine algae, invertebrates and fish. Marine ecosystem productivity is strongly influenced by climate regime shifts (Chelton et al. 1982; MacCall et al. 2005). Human-induced impacts associated with discharges and harvesting also affect populations on local to regional scales. By the year 2050, the diversity of the marine species along the San Diego coast will almost certainly be different from today.

The predicted increase in global temperatures over the next century will cause an increase in the temperature of the sea and will also have other effects on coastal oceanography, such as

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[21] *Intertidal* refers to the area along an ocean coastline that is exposed to air during low tide and submerged at high tide; organisms in the intertidal zone are adapted to harsh conditions.

[22] *Subtidal* refers to the area along an ocean coastline below the intertidal zone; the subtidal zone is always covered by water.

changes in the intensity of winds along the coast that can lead to major changes in upwelling[23] patterns (Rykaczewski 2008), which, in turn, influence nutrient supply and coastal ecosystem dynamics. However, the relationship between climate change and wind-driven upwelling is complex (Harley et al. 2006) and specific predictions of how upwelling patterns in San Diego and in adjacent regions will change are not yet available. Predicted sea level rise also is likely to have an impact on the marine communities in San Diego County. Effects of sea level rise mainly apply to intertidal species (Harley et al. 2006). As sea level rises, the boundary between land and sea moves landwards and whether intertidal habitat is lost would depend on the coastal topography. When intertidal habitats are bordered by high cliffs or anthropogenic structures such as seawalls and breakwaters, existing intertidal habitats (beaches, rocky shores) are prevented from migrating landwards, which results in a net loss (drowning) of these habitats (Galbraith et al. 2002).

Loss of rocky beach habitat is of particular concern because the two main intertidal marine reserves in San Diego, 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.

Monitoring programs have been funded by a variety of entities with different study objectives; consequently, considerable knowledge gaps remain regarding the status of marine resources within the Southern California Bight. State agencies such as the California Ocean Protection Council and the State Coastal Conservancy are aware of the needs for additional information and have recently stated: "The relationship between ocean observation technologies and on-the-ground management needs is not well understood by state and federal environmental and resource agency managers, members of the California State Legislature or members of Congress" (California Ocean Protection Council 2008).

3.6. Public Health in 2050

3.6.1. Climate Change Direct Effects on Public Health

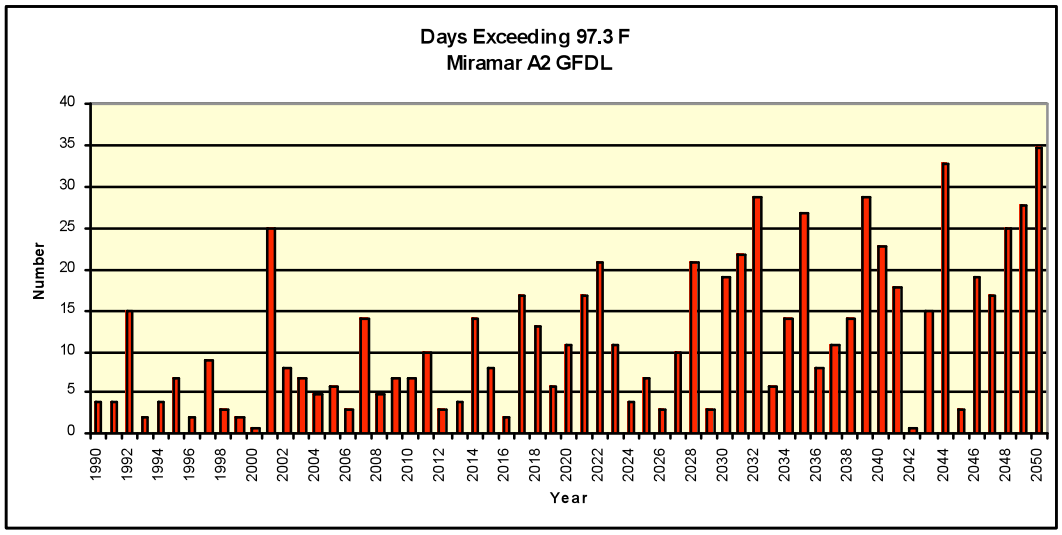
Extreme Heat Events

Heat waves have claimed more lives over the past 15 years than all other declared disaster events combined in California, and heat waves are expected to increase in frequency, magnitude and duration in San Diego over the next 50 years. As shown on Figure 12, the number of days over 97.3°F (36.3°C) in the Miramar area is projected to increase six-fold, accompanied by a projected four-fold increase in the number of days over 93.8°F (34.3°C) for the years 2041–2050. Days over 84°F (28.9°C) are projected to increase from the recorded current average of 78 days to 129 days during the period 2041–2050 and these hot days are expected to occur from April to December. Public health risks around extreme heat are not equal; certain individuals, populations and communities are at greater risk than others. A recent analysis of temperatures during summers with no heat waves (1999–2003) found a 3% increase in deaths in

[23] *Upwelling* is an oceanographic phenomenon that involves wind-driven motion of dense, cooler, and usually nutrient-rich water towards the ocean surface, replacing the warmer, usually nutrient-depleted surface water.

any given day for a 10°F (5.6°C) increase in temperature (including humidity) (Basu et al., unpublished.).

Figure 13. Days exceeding 97.3°F (36.3°C), Miramar A2 GFDL



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; chronically ill persons (especially those suffering cardiovascular or respiratory conditions); and socially isolated individuals. 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. Following the events of 2006 when there was a prolonged period of extreme heat across the state of California, San Diego County developed an Excess Heat Preparedness and Response Plan.[24]

3.6.2. Climate Change Indirect Effects on Air Pollution

Ozone Air Pollution

San Diego County is currently out of compliance with the federal ozone standard, and the U.S. Environmental Protection Agency (EPA) has projected that this will still be the case in the year 2020. 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% of the time for days with temperatures between 85°F–89°F

[24] 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°F (24°C) or more for three days or less; National Weather Service Advisories of excessive heat for three 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°F (41°C)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°F 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.

(29°C–32°C) (Environment California 2007). For days over 90 degrees, the state ozone standard was exceeded 16% of the time. An increase in hot, sunny days due to climate change causing increased population exposure to ground-level ozone has been projected for San Diego in the year 2050. In addition to potential increases in ozone levels, there will be increased stress from extreme heat days, coupled with an increase in the number of vulnerable people present within the San Diego region. These changes are likely to present a significant public health and economic impact.

Particulate Matter Air Pollution Levels

The modeled results show how under the two different IPCC scenarios, the $PM_{2.5}$ concentrations move in different directions (see Figure 14). In the B1 scenario, emissions are reduced as outlined by CARB due, in part, to technological improvements and stringent air quality regulations. The decreased projected emissions lead to a decrease in particulate pollutant levels, and thus, a slightly better air quality. Also, the IPCC SRES B1 scenario is defined as one where the world will become more integrated and more ecologically friendly; and global solutions to economic, social, and environmental stability are emphasized. The climatic effects of the B1 scenario can be observed slightly after 2030 as the $PM_{2.5}$ concentrations stabilize and shift slightly upward. 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 current federal standard for $PM_{2.5}$. This trend is observed using the data from all the climate models.

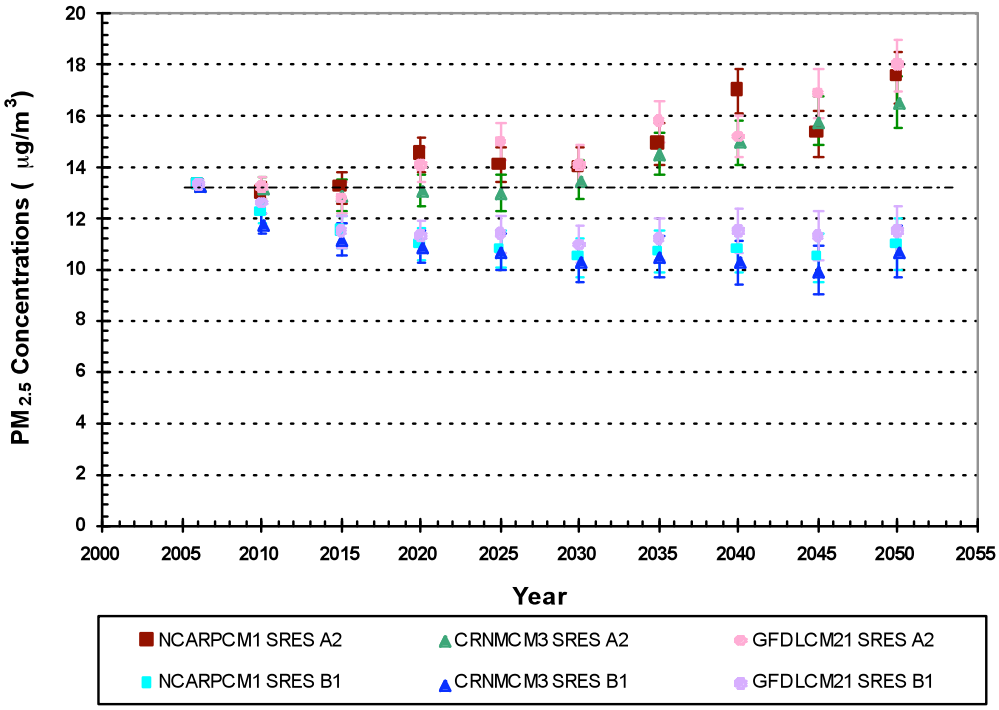


Figure 14. $PM_{2.5}$ projections

Health Effects Modeling

The projected impact on mortality rate under the different climate models and emissions scenarios (see Table 1) show that mortality decreases in the year 2015 for both scenarios. The $PM_{2.5}$ model is predicting an overall decrease in $PM_{2.5}$ concentrations until approximately 2015, which explains the decrease in mortality in 2015. This decrease of $PM_{2.5}$ is driven by the decrease in emissions in California for many of the chemical species (NOx, ROG) that lead to the formation of secondary particulate matter (nitrates and secondary organic compounds).

However, in 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 A2 scenario. For the B2 scenario, there appears to be a decrease in mortality.

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

IPCC SRES			2015			2035			2050		
	Cause of Mortality	Mortality in 2004	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%

3.6.3. 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 through particulates and volatile organic compounds in smoke plumes. Wildfire smoke contains numerous primary and secondary pollutants, including particulates, polycyclic aromatic hydrocarbons, carbon monoxide, aldehydes, organic compounds, gases, and inorganic materials with toxicological hazard potentials (Künzli et al. 2006). Future land use and climate change will exacerbate the risk of wildfires as a result of the alteration of fire regimes in the county. 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 children and individuals with existing cardiopulmonary disease, and that risk seems to increase with advancing age.

3.6.4. Climate Change Effects on Infectious Disease

Climate change in San Diego County could increase the risk of certain vector-borne diseases, while decreasing the risk of others. The occurrence of vector-borne disease is influenced by a variety of factors. 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 patterns affect both the composition and abundance of arthropod vectors (mosquitoes, fleas, ticks, etc), as well as animal hosts (Lang 2004). Behavior patterns of hosts, such as indoor living, and vector preferences for particular hosts and periods of peak activity, also influence transmission opportunities.

The San Diego region will experience increased public health risks from mosquito-transmitted West Nile Virus (Dudley et al., in press) assuming more intense El Niño cycles (Anyamba et al. 2006) and rodent-transmitted hantavirus (Yates et al. 2002), and higher temperatures predicted for the region could facilitate the local establishment of tropical vector-borne diseases such as malaria and dengue fever, while reducing public health risks from the endemic mosquito-transmitted diseases Western Equine Encephalitis and St. Louis Encephalitis (Gubler et. al. 2001). Climate warming effects on the geographic and altitudinal ranges and population densities of rodent hosts and flea vectors will alter the distribution of high-risk areas for plague *(Yersinia pestis)* in the San Diego region (Lang 1996, 2004). Predicted future increased residential development and recreational activities within the unincorporated areas of San Diego County due to population growth, which will increase the potential for contact between humans and wildlife disease hosts and vectors, may result in higher public health risks from diseases transmitted by rodents and rabbits such as tularemia, plague, and hantavirus (Smith 1992).

Water-Borne Disease

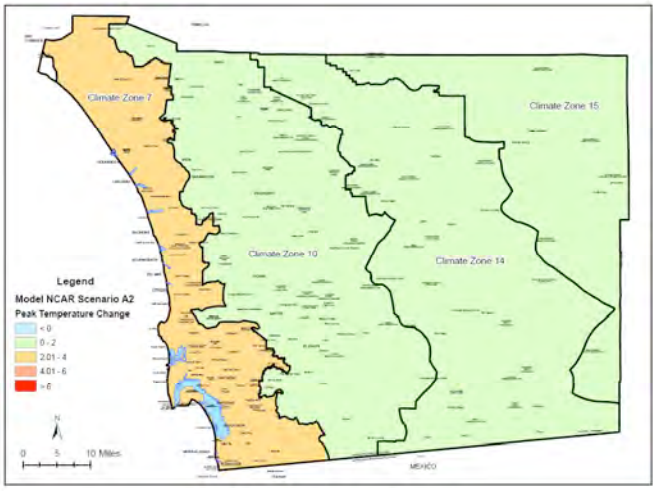
Climate change is predicted to have direct and indirect effects on the hydrology and ecology of freshwater and estuarine systems in San Diego. Predicted changes in temperature, precipitation, surface radiation, humidity, winds, and sea level may lead to significant impacts on regional-scale hydrologic processes. Contaminant levels in almost 60% of shoreline waters from Point Conception, California to Punta Banda, Mexico currently exceed water quality standards for the protection of human health during part of the year, and the rapid urbanization and land development occurring in San Diego and adjoining coastal areas of Southern California will continue to degrade coastal water quality given current trends unless aggressive measures to correct these problems are instituted. Coastal and inland wetland extent are sensitive to factors associated with climate change with possible impacts to human health, and projected surface temperature increases of 1.5°F to 4.5°F (0.8°C to 2.5°C) in 2050 in local lagoons and waterways as well as the near shore ocean could increase the risk of disease risks from exposure to harmful algal blooms (red tides), microbes (*Vibrio spp.*, *Listeria monocytogenes*, *Clostridium botulinum*, *Aeromonas hydrophila*), and other waterborne agents (Feldhusen 2000; Tamplin 2001). In addition, changes in the ethnic composition of the population could result in increased levels of exposure to these water-borne diseases and contaminants from changes in the rates and seasonality of fish and shellfish harvesting for personal consumption.

3.7. Electricity: Powering Growth in a Demanding Future

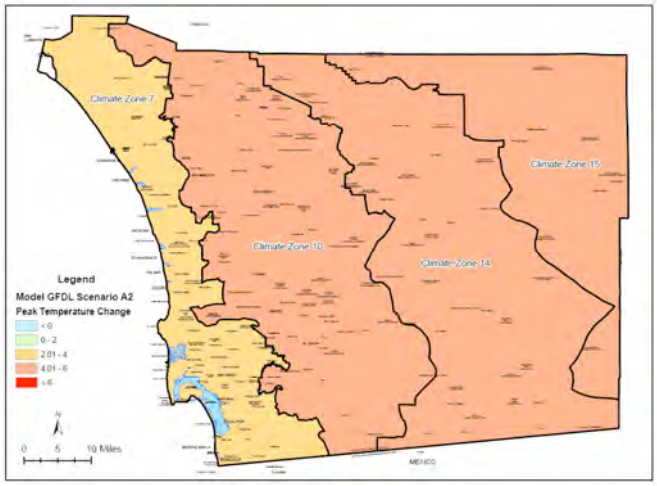
3.7.1. Peak Temperature and Cooling Degree Day (CDD) Trends

CDDs are the amount of time during the year above a reference temperature of 65°F (18°C). 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 (see Figures 15 and 16).

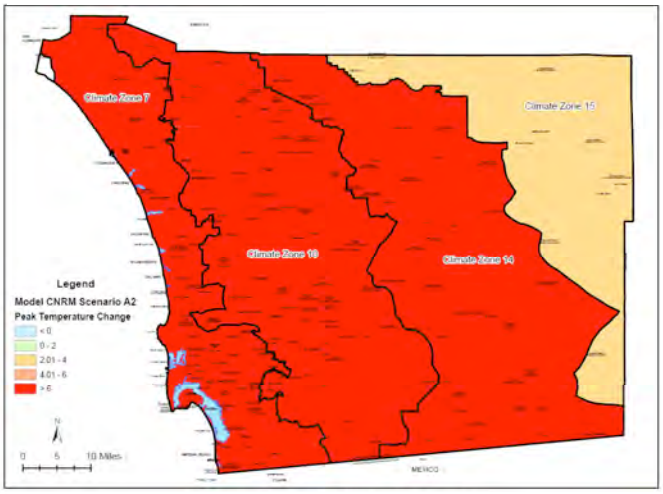
A2 Scenarios



Change in Peak Temperatures by 2050 Model NCAR

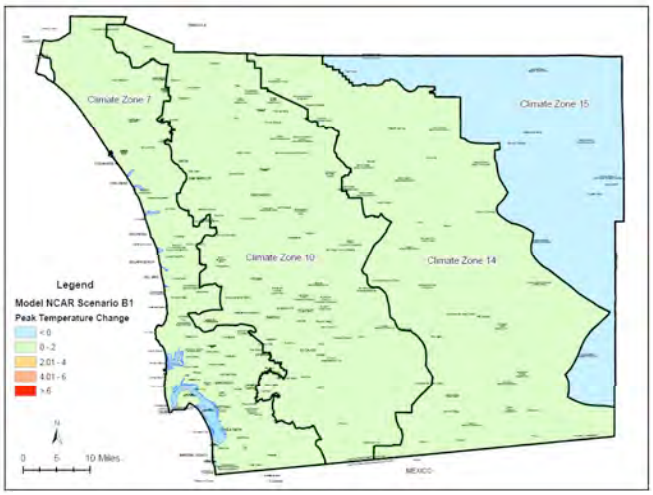


Change in Peak Temperatures by 2050 Model GFDL

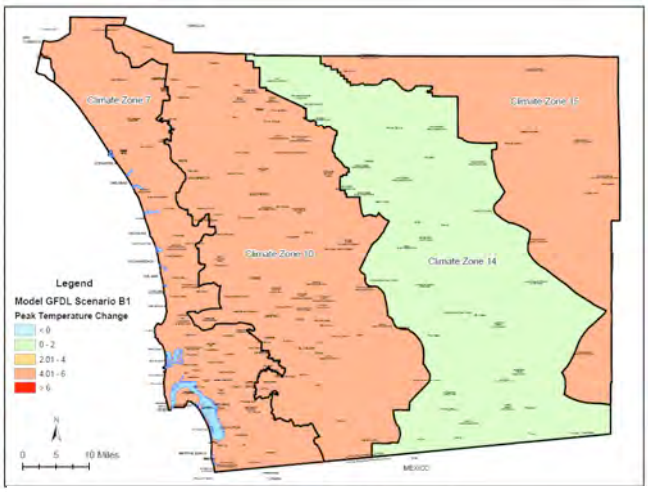


Change in Peak Temperatures by 2050 Model CNRM

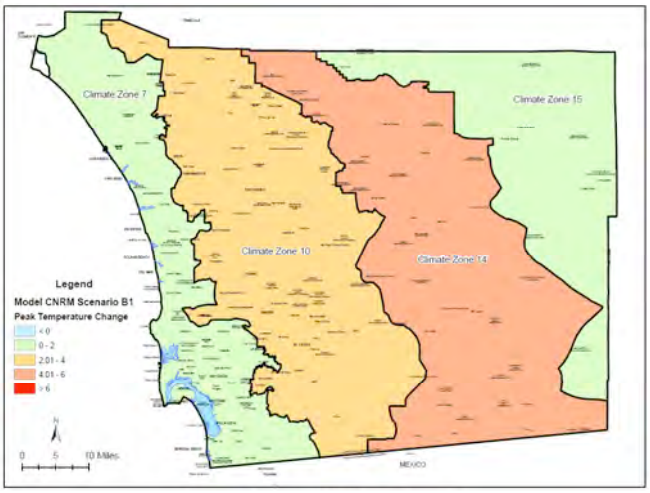
B1 Scenarios



Change in Peak Temperatures by 2050 Model NCAR

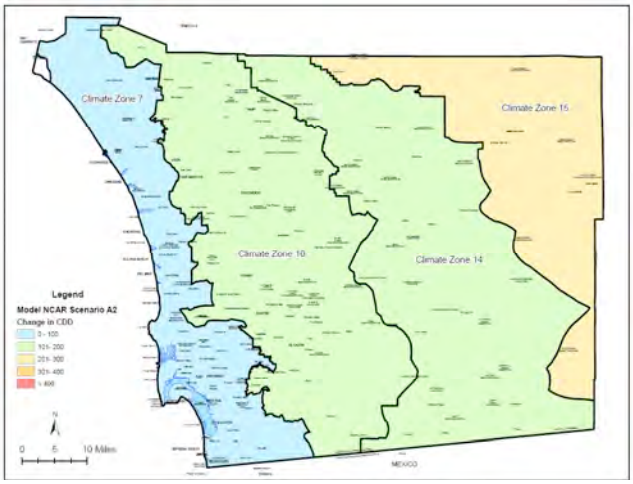


Change in Peak Temperatures by 2050 Model GFDL

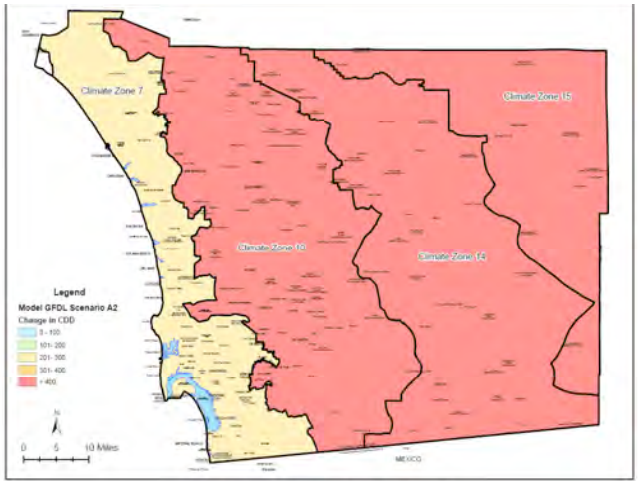


Change in Peak Temperatures by 2050 Model CNRM

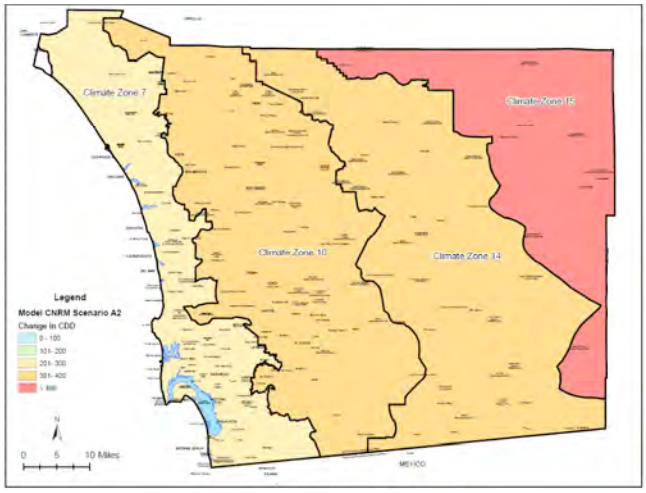
A2 Scenarios



Change in Cooling Degree Days by 2050 Model NCAR

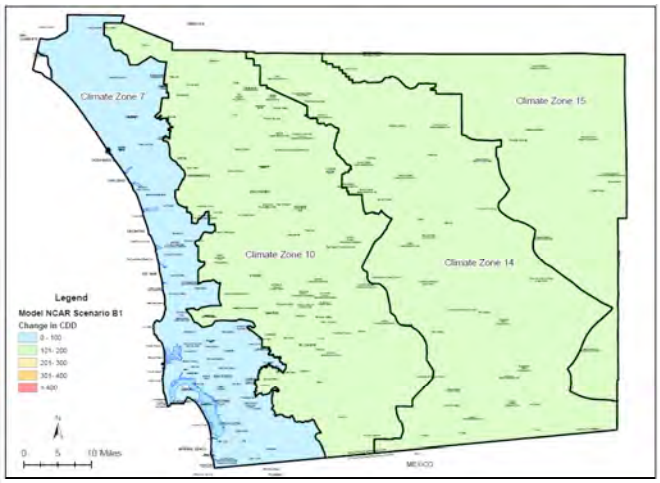


Change in Cooling Degree Days by 2050 Model GFDL

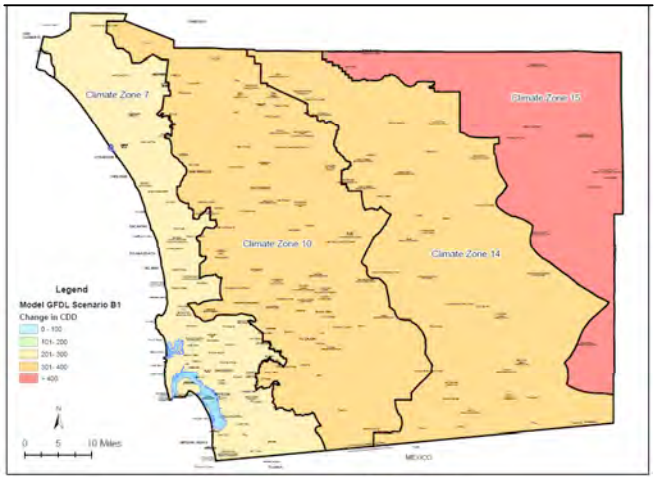


Change in Cooling Degree Days by 2050 Model CNRM

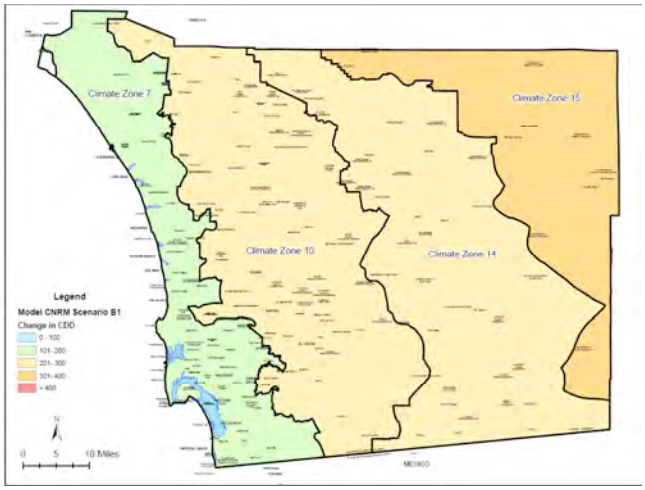
B1 Scenarios



Change in Cooling Degree Days by 2050 Model NCAR



Change in Cooling Degree Days by 2050 Model GFDL



Change in Cooling Degree Days by 2050 Model CNRM

Peak Demand Trends for Electricity

The forecast shows a dramatic increase of 60%–75% in peak electricity demand by 2050 (see Figure 17)—an increase of more than 2,500 megawatts (MW) from present levels. The differences between the models account for roughly 7% 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).

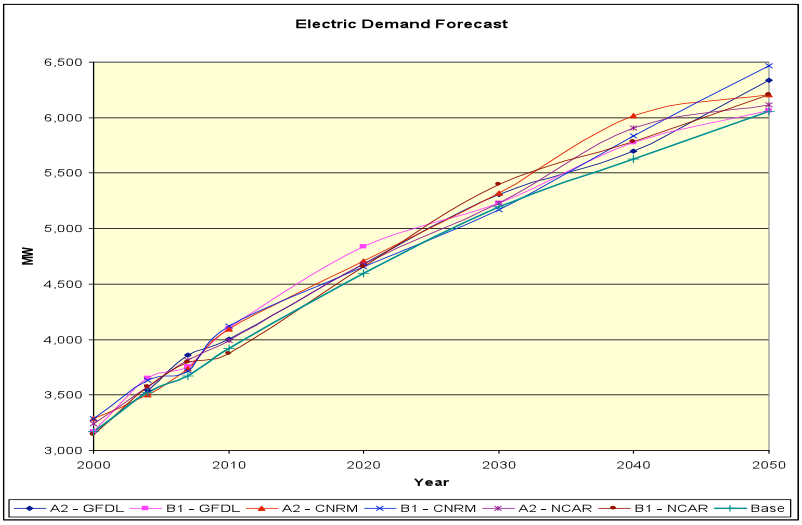


Figure 17. Peak electricity demand forecast

Annual Consumption Trends for Electricity

There is 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. Overall annual electricity consumption is expected to increase of 60%–62% by 2050 (see Figure 18) compared to current demand. Rising temperatures account for approximately 2% of the increase in consumption.

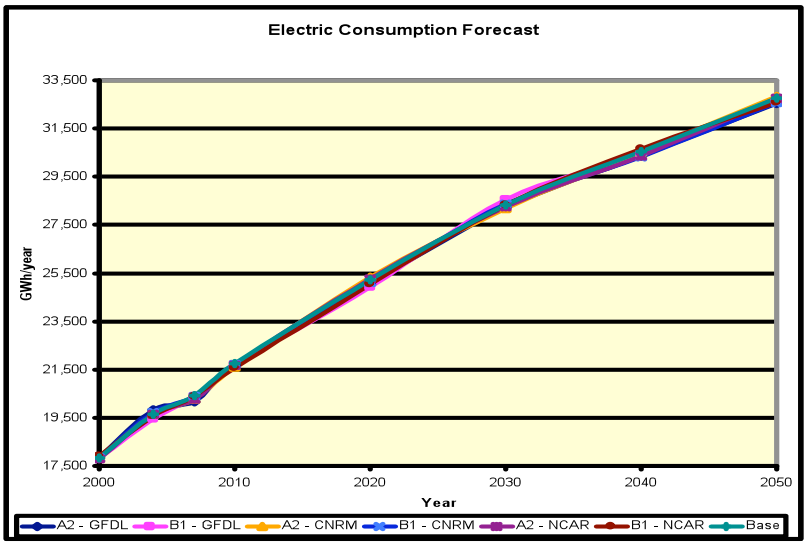


Figure 18. Electricity consumption forecast

Extreme Temperature Events and Impact on System Reliability

Peak demand will be even more challenging to deal with under future climate scenarios because of the increased frequency of extreme-heat events. To avoid reliability problems and increased outages, the electric utility will need to make additional investments and customers will need to modify consumption patterns in order to reduce peak summer electricity demand. In general terms, the analysis of the climate models and extreme temperature events conducted in this study shows that there will be a three-month expansion of higher-temperature events as well as an increased frequency of 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.

3.7.2. Decreased Summertime Generation Capacity

Summertime, when demand is highest, is also the time when operating efficiency is lower and line losses increase—both due to temperature effects. 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 delivery problems unless utility investments keep pace with these effects.

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.

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. 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 (San Diego Regional Renewable Energy Group 2005). 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 (U.S. Climate Change Science Program 2007). 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 (Feenstra et al. 1998.). 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. However, it is conductor temperature (a function of load) that is the main cause of sagging power lines. Currently, there are insufficient data to

conclude that ambient temperature increases of a few degrees would have a significant impact on line sag.

3.7.3. 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 will bring with it an increase in regional energy demand. Reverse osmosis (RO) systems do not require thermal energy to heat feedwater. Therefore, RO is generally more energy efficient than other desalination technologies. 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 kilowatt-hours per acre-foot (kWh/af) of water produced (California Department of Water Resources 2003), the rise in energy demand attributable to meeting the Water Authority's desalination goals are summarized in Table 2. Comparing this table to regional electricity consumption in Figure 16, 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%.

Table 2. 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

Desalination will increase regional power demand. Some other regional options such as recycling and local groundwater are less energy intensive, 400 kWh/af and 570 kWh/af respectively, according to a Pacific Institute study, *Energy Down the Drain* (Cohen et al. 2004). That study concluded that satisfying future growth in water demand in the San Diego region via conservation would reduce the overall energy intensity of the SDCWA water supply by 13%. In comparison, satisfying growth in water demand via recycling would reduce overall energy intensity by only 4%, while using seawater desalination to satisfy growth would increase overall energy intensity by 5%. This emphasizes the overall energy savings of conservation versus other regional alternatives. The energy savings will also result in less overall GHG emissions from the utility sources providing the power.

4.0 Conclusions and Recommendations

A key message of this study is that the San Diego region is uniquely threatened by climate change. 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 supplies from the Sacramento Delta and Colorado River imports, increased energy demands, and public health issues associated with heat waves and an increase in some infectious diseases like West Nile Virus. 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. Likewise, water agencies and fire prevention agencies should have a uniform understanding about the likelihood of droughts and precipitation patterns.

Land use planning agencies will have to deal with the combined challenges of sea level rise in coastal areas, increasing fragmentation of ecosystems, as well as mitigation measures to address local emissions that could require increasing future population centers around transportation corridors. Although this study has focused on adaptation needs, it is important to also recognize the importance of local mitigation measures as they can create positive health effects as well as provide a local economic stimulus.

4.1. Climate Change in the San Diego Area

There is an important aspect of the 2050 time horizon that should be kept in mind. This study is confined to the period between now and the year 2050, but the effects of greenhouse gas accumulations on climate, while somewhat slow to develop, are very long-lasting in impact (IPCC 2007; Hansen 2005; Meehl et al. 2005). 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 not reach their peaks by 2050. The results of different mitigation strategies, as expressed by the two GHG emission scenarios,[25] do not become very clear by 2050—they are much more distinctly evident in the following decades (IPCC 2007; Hayhoe et al 2004; Cayan et al. 2008b). California's 2008 Climate Change Impacts Assessment estimates up to 55 inches of sea level rise by 2100.

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 happen earlier, and also occur later during the warm season. All of the climate model simulations exhibit warming across San Diego County—ranging from about 1.5°F to 4.5°F (0.8°C to 2.5°C). Models suggest that the warming impacts will be greater in summer months than in winter, with surface air temperatures in summers warming from 0.7°F to more than 2°F (0.4°C to more than 1.1°C) over that found in winter, and this warming will be more pronounced inland than along the coast. 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 evidence that the area's landscape will fall into hydrological deficit (drought) more often than it has historically.

[25] The SRES A2 (medium high emissions) and B1 (moderately low emissions) scenarios.

4.2. Sea Level Scenarios and Coastal Impacts in 2050

The combination of higher sea level, waves, tides, El Niño effects, and weather conditions poses a serious threat to several identified vulnerable areas of the San Diego region. These areas are home to critical habitat, valuable real estate, recreational facilities, and public infrastructure. Results of three simulation scenarios indicate sea level increases of 12–18 inches by 2050. Future research will be needed to better understand the impact of changes in sea level in other areas of strategic (San Diego Naval Air Station North Island) and economic (San Diego Airport and the Port of San Diego) importance. This analysis should provide the basis for further analysis of coastline vulnerabilities and the development of risk management strategies involving the public and private sectors. This analysis should also be conducted in the context that sea level rise is expected to accelerate in decades following 2050.

4.2.1. Benefits to the San Diego Region

San Diego County has roughly 70 miles of coastline with a wide range of current economic and residential uses that will be threatened by sea level rise. The potential impacts to these areas if mitigation measures are not adopted are not estimated here, but they would undoubtedly be extremely high. To develop a county-wide mitigation cost estimate, it is essential to know details on the degree of impact expected from the sea and the amount of development already in the area. At the lower end, building simple sea walls in moderately impacted residential areas will run approximately $250 to $350 per foot or $1.3 million to $1.8 million per mile. A mid range estimate of $935 per foot (Smith and Mendelsohn 2006) ($5 million per mile) would project out to $350 million for the 70 miles of coastal protection. At the upper end, for example, work to replace the 1.9 mile Elliott Bay seawall in the heavily developed port area of Seattle will be $400 million, according to the State of Washington.[26]

There is a need to fully consider the long term implications of sea level rise in San Diego Bay, Mission Bay, and other heavily developed coastal areas to determine the extent that the higher end cost estimates should be used. In addition to seawall costs, much higher costs could be involved to build new breakwaters, seawalls for port areas, wharf improvements, embankment improvements, and additional storm gates to control flows after current gates are inundated. A study that considered protecting Japan's coastal resources against sea level rise (Kojima 2000) found that only 11% of overall costs involved sea walls to protect residential and commercial areas, with the other 89% including the previously mentioned improvements. Considerable research will be needed to better understand the costs of preparation for the entire region, as well as the overall savings in future storm and flooding damage that will be realized. In some cases, local agencies may have to stop the development of low-lying coastal communities or abandon existing areas of low value.

4.3. Climate Impacts on Water in 2050

San Diego's water supply plans through 2030 are likely to be severely challenged by climate change, even as authorities balance supplies to address growing demand. The path to reliable water supply in 2050 is even more challenging. The estimated demand in 2050 is 915,000 acre-feet/yr, an increase of 37% over the 2001–2005 period, and around 80% of the water supply is

[26] www.wsdot.wa.gov/Projects/Viaduct/Questions.htm

expected to be imported. The remaining demand will have to be met by local sources through the increase in conservation efforts, water recycling and desalination plants.

4.3.1. Demand Management

The City of San Diego and the County Water Authority have already taken notable water conservation efforts. For example, citywide water usage currently is at the same level it was 16 years ago, despite a significant increase in population. Since 1990 the Water Authority and its member agencies have achieved savings of 430,000 acre-feet of water through the implementation of conservation programs. However, city and county authorities will need to exercise even more leadership on water conservation and supply issues as climate change and intensified drought implications will need to be considered in all managerial decisions.

It is imperative to make an evaluation of the best conservation techniques and to raise awareness among the public now. Due to critically dry conditions during 2007 and 2008, the government of California has declared a statewide drought. The San Diego Water Authority and its agencies have developed a drought management plan that targets 10% to 40% reductions in customer consumption, depending on the level of drought intensity. One of the adopted initiatives under this program is the "20 Gallon Challenge," which calls for a variety of end user voluntary conservation steps. This challenge targets 10% reductions in consumption (roughly 20 gallons per person) in the current drought. Current evidence suggests that a much smaller reduction is being achieved (3% as per San Diego City Council discussions on July 28, 2008) despite public advertising and awareness campaigns. Successfully achieving the higher reduction figures (40% or more) will rely on mandatory control measures, which will become increasingly necessary if voluntary measures have limited effectiveness.

4.3.2. Local Initiatives

Other important steps being taken by the Water Authority include the design of a model Drought Response Ordinance for the various (22) San Diego local water districts to consider for adoption that would help achieve the above reduction targets during droughts. The local districts are now in various stages of development of their conservation/drought response ordinances. Not yet included in agency plans and outlooks for coming decades are very likely reductions in surface-water runoff and groundwater recharge to local water supplies in San Diego under increasingly warm and dry climates. 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. Additional recommended adaptation tasks include updating landscaping ordinances and incentives, supporting infrastructure updates and updating development codes, promoting water reuse together with increased use of desalination where feasible, and ensuring that "Must Serve" Letters use water projections that are sensitive to climate changes that can help meet the challenge.

The Colorado River is forecasted to deliver an increasing share of the region's water by 2030, mainly due to the Water Authority's 1998 agreement with Imperial Irrigation District and due to the 2003 leakage reduction projects conducted at the All American and Coachella canals. Existing shortage-sharing agreements cover how water will be distributed in the event of reductions in flow of up to 8%, but these may need to be updated in the near future to account

for even greater reductions in flow. Water deliveries from the MWD and the Sacramento-Delta could also be limited by 2050, placing an even greater emphasis on local conservation measures. In short, regular assessments of evolving climate knowledge incorporated into periodic evaluations of infrastructure and planning will be an important tool in moving government policy and public awareness. The critical factor will be forward-thinking public policy and leadership to change individual and collective behavior.

4.3.3. Benefits to the San Diego Region

The cost of water in San Diego County will be adversely affected 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-foot, depending on the water source. This cost may rise significantly by 2050 as less expensive ways to increase water supply are exhausted. Continued growth in Los Angeles, Arizona, Las Vegas, and the 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. Aggressive actions to plan for future water supplies as they vary with climate change and to curb demand through conservation measures will have significant economic benefits as well as overall improvements in the reliability of water deliveries to the public.

4.4. Wildfires in 2050

San Diego County already has one of the worst wildfire conditions in the country. The potential for interactions between climate change and changing fire regimes will exacerbate these conditions, specially as drought periods increase in the coming decades. San Diego officials are engaging in several activities to build upon lessons learned after the 2003 fires such as a community protection planning, restoration planning, regional evacuation planning, increased training of county personnel, purchasing of additional fire fighting equipment, implementation of public education programs and campaigns, building codes changes and implementation of brush and vegetation management plans. While vegetation management programs may offer help at the urban-wildlife interface, an overall strategy to reduce fire risk in scrub and chaparral ecosystems is not in place. More public discussion of issues such as newer building codes, prohibiting development in fire-prone areas, changes in landscaping and irrigation, and community fire planning are needed to develop more effective response strategies, which will be a key part of an overall climate change adaptation process.

One potential strategy to address the fighting of large-scale wildfires is to coordinate a centrally based regional firefighting unit focused on regional fire risk. 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. The cost of the 2007 wildfires in San Diego was estimated at nearly $2 billion for losses in residential and commercial properties (Nash, in press). In addition to the direct costs, many private firms and public agencies are forced to shut down during a large-scale wildfire event. A complete three-day shutdown costs roughly $1.5 billion.[27] Therefore, one extra large-scale

[27] There was increased revenue in the hotel and restaurant industries during the 2007 wildfires, which are not accounted for in this figure.

wildfire due to climate change can have a major impact on the economy due to productivity losses.

4.5. Ecosystems in 2050

Climate change has the potential to substantially alter species composition and abundance within terrestrial and aquatic ecosystems within the San Diego. Some species will likely disappear as a result of migratory shifts in distribution while other species' ranges may expand to include the county. Even without climate change effects, native plants and animals may be increasingly constrained from projected population growth and development. County authorities have taken important steps to protect San Diego's ecosystem, one good example is the San Diego Multiple Species Conservation Program,[28] which was implemented 10 years ago. The plan is designed to preserve native vegetation and to meet the habitat needs of many species by acquiring conservation lands and identifying areas for future development. San Diego has over 200 animal and plant species that have been listed as endangered, rare or considered sensitive. Around half of these species occur within the MSCP study areas. The MSCP program works across political boundaries and it combines efforts from landowners, local governments, and other stakeholders.

Distinguishing ecosystem changes associated with climate change from those induced by human factors may be difficult if the separate forces produce similar effects. However, distinction of causes for observed changes in species and population conditions will be critical for appropriate assessment of status and developing effective strategies for resource management. Science-based ecosystem management based on a climate-informed approach offer potential solutions. Allocating enough sufficient resources to research and monitoring will be challenging but very important to better understand (a) existing resources and baseline conditions, (b) rates and local consequences of climate change, (c) possible avenues for mitigation, and (d) ongoing refinement of regional watershed, multiple species conservation program, and shoreline preservation plans and strategies.

There also is a need for further integration of climate change projections with land use planning. City and county agencies that consider land use planning decisions will need to consider the settlement of *Center for Biological Diversity v. County of San Bernardino*, which challenged an environmental impact report prepared for a general plan update for the county, and was settled with substantial commitments from the county to develop a target for reduction of greenhouse gas emissions attributable to the county's discretionary land use decisions. Maintaining permeability in the landscape for species to move and adapt to climate change (by creating a connected network of conservation lands) would help alleviate projected population growth development constraints on the ability of natural populations to adjust distributions in response to climate change effects.

4.6. Public Health in 2050

There are many potential public health issues that are likely to affect San Diego in 2050, both directly and indirectly. Projections of a growing and aging population with changing ethnic profiles suggest a larger number of people will be vulnerable to environmental health risks, and

[28] www.sandiego.gov/planning/mscp/index.shtml

the projections for climate change indicate more stressful conditions facing vulnerable populations. Specific impacts include: (1) increased heat waves, creating a significant risk of adverse health effects and heat-related mortality; (2) increased exposure to air pollution resulting in adverse health effects, including exacerbation of asthma and other respiratory diseases, cardiac effects, and mortality; (3) increasing incidence of wildfire, which will contribute to direct injuries and mortality as well as indirect health effects of air pollution; and (4) increases in the levels of exposure to vector-borne or infectious diseases—potential increases in West Nile Virus and hantavirus will require particular attention and increased medical resources to address. All of the above impacts have a magnified effect on an aging population base and will therefore require increased efforts and resources to effectively manage.

4.6.1. Benefits to the San Diego Region

Californians experience the worst air quality in the nation, resulting in yearly economic costs of approximately $71 billion ($36–$136 billion), with about $2.2 billion ($1.5–$2.8 billion) associated with hospitalizations and medical treatment of illnesses related to air pollution exposure.[29] Although the proportion of this cost for the San Diego region is not documented, it is undoubtedly significant. Deteriorating air quality from increases in ambient ozone levels as well as possible increases of PM levels in some scenarios will push these costs even higher. Local and regional emission mitigation activities will be essential in reducing these costs and improving regional public health.

It is essential that the public health and emergency response infrastructure be robust enough to mitigate risks due to extreme heat events and respond appropriately. The State of California Office of Emergency Services has recently (April 2008) updated their State Contingency Plan for Excessive Heat Emergencies. Local and regional entities should review the guidance and checklists for local governments in this plan and determine what measures should be adopted in the San Diego region.

4.7. Electricity: Powering Growth in a Demanding Future

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. 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 electricity consumption is expected to increase more than 60%. That will push consumption from the current level of approximately 20,000 gigawatt-hours (GWh) to more than 32,000 GWh in 2050.

[29] Recent estimates for several of the most serious public health impacts associated with current concentrations of ozone and PM (CARB, 2002, 2005b,c) suggest that annually the following number of cases occur in California due to non-attainment of air quality standards:

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.

While population growth is an important contributor to increased demand, warmer temperatures are expected to push total energy consumption up to two percentage points above the population-driven change by 2050. Similarly, peak electric demand is expected to increase by over 70%, from approximately 3,700 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% of the total increase in peak demand.

To meet San Diego's future power demand, SDG&E has developed a 10-year energy plan that includes the implementation of energy efficiency programs, conservation programs, solar PV roof programs, smart home and smart grid programs, the construction of new power plants including in-area renewables, and new transmission lines such as the Sunrise Powerlink. Over the longer term, we can expect that the electric utility will need to make additional investments, and customers will need to further modify consumption patterns to reduce peak summer electricity demand, avoid a reduction in reliability, and avoid system outages. The utility may include advanced approaches such as the implementation of more advanced smart grid technologies, additional in-area 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 Leadership in Energy and Environmental Design (LEED) or Energy Star certifications.

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6.0 Glossary

APCD	Air Pollution Control District
ARIMA	Auto-Regressive Integrated Moving Average model
CALFED	California Bay-Delta Authority
CARB	California Air Resources Board
CCB	Center for Conservation Biology
CCD	Cooling Degree Day
CCSM3	NCAR Community Climate System Model (CCSM), version 3
CNRM	Centre National de Recherches Météorologiques
CDIP	Coastal Data Information Program
CEC	California Energy Commission
CPP	Critical Peak Pricing
EIR	Environmental Impact Report
ENSO	El Niño/Southern Oscillation
EPA	Environmental Protection Agency
ESI	Environment and Sustainability Initiative
Focus 2050 Study	The San Diego Foundation's Regional Focus 2050 Study
Foundation	The San Diego Foundation
GCM	Global Climate Model
GFDL	Geophysical Fluid Dynamics Laboratory
GHG	Greenhouse Gas
GISS	Goddard Institute for Space Studies
GtC	Global carbon emissions
GWh	Gigawatt hours
IID	Imperial Irrigation District
IPCC	Intergovernmental Panel on Climate Change
LEED	Leadership in Energy and Environmental Design
LIDAR	Light Detection and Ranging remote sensing system
M&I	Municipal and Industrial
MW	Megawatt
MWD	Metropolitan Water District
MWh	Megawatt hour
NAAQS	National Ambient Air Quality Standards
NOAA	National Oceanic and Atmospheric Administration
NOx	Nitrogen oxides
PCM	Parallel Climate Model
PIER	Public Interest Energy Research
PM	Particulate matter
$PM_{2.5}$	Fine particulate matter
RD&D	Research, development, and demonstration

RGF	Regional Growth Forecast
RO	Reverse Osmosis
ROG	Reactive organic carbon
SANDAG	San Diego Association of Governments
SDG&E	San Diego Gas and Electric Company
SIO	Scripps Institution of Oceanography
SOx	Sulfur oxide
SRES A2	A2 scenario from Special Report on Emissions Scenarios (IPCC)
SRES B1	B1 scenario from Special Report on Emissions Scenarios (IPCC)
SWL	Still water level
VIC	Variable Infiltration Capacity
Water Authority	San Diego County Water Authority