Climate Action Team

Biennial Report March 2009

DRAFT

Table of Contents

1 Impacts of Climate Change on California's Public Health, Infrastructure and Natural Resources 1.1

1.1 Introduction and Background 1.1

1.2 Brief History of Climate Change Research Efforts in California 1.2

1.3 Impact Studies by Sector 1.3

1.3.1 Approach to Socio-Economic Scenarios 1.3

1.3.2 Approach to Climate Scenarios 1.5

1.3.3 Warming Trends 1.5

1.3.4 Precipitation 1.7

1.3.5 Sea-Level Rise 1.9

1.3.6 Agriculture 1.11

1.3.7 Forestry 1.12

1.3.8 Water Resources 1.17

1.3.9 Coastal Areas 1.20

1.3.10 Energy 1.23

1.3.11 Air Quality 1.26

1.3.12 Public Health 1.28

1.3.13 Crosscutting Issues 1.30

1.4 Summary of Major Findings 1.34

1.5 References 1.35

2 Economic Impacts of Climate Change on California 2.1

2.1 Introduction 2.1

2.2 Economic Valuations 2.1

2.3 Sectoral Economic Impacts 2.3
2.3.1 Economic Impacts on Agriculture 2.4
2.3.2 Economic Impacts on Forestry 2.9
2.3.3 Economic Impacts on Water 2.13
2.3.4 Economic Impacts on Coastal Regions 2.16
2.3.5 Economic Impacts on Energy 2.21
2.3.6 Economic Impacts on Air Quality 2.24
2.3.7 Ecological Services 2.25
2.3.8 Other Impacts Not Considered 2.27
2.4 Summary and Caveats 2.27
2.5 References 2.28
3 Climate Change Research in California 3.1
3.1 Introduction 3.1
3.2 Overview of Research Programs 3.3
3.2.1 National climate change research 3.3
3.3 California state-sponsored and directed climate change research 3.6
3.3.1 Regional climate modeling 3.12
3.3.2 Impact and adaptation studies 3.13
3.3.3 Greenhouse gas inventory methods 3.16
3.3.4 Greenhouse gas emissions reduction: Emerging technologies and strategies 3.17
3.3.5 Transportation 3.17
3.3.6 Electricity and natural gas 3.19
3.3.7 Low greenhouse gas technologies for other sectors 3.21
3.3.8 Carbon Sequestration 3.21
3.3.9 Economic impacts and considerations 3.23

DRAFT

3.3.10 Social science to support implementation, education, and outreach 3.24

3.3.11 Environmental justice impacts and considerations 3.24

3.4 Conclusion: Research and the 2050 challenge 3.25

3.5 References 3.27

3.6 White Papers from CAT Research Sub-Group 3.29

4 State Efforts to Adapt to Current and Future Effects of Climate Change 4.1

4.1 Introduction 4.1

4.1.1 Executive Order S-13-08: the Climate Adaptation and Sea Level Rise Planning Directive 4.1

4.1.2 California's Dual Climate Strategy: Mitigation and Adaptation 4.3

4.2 Development of a Climate Adaptation Strategy 4.4

4.2.1 CAS Components: Science, Policy and Action 4.5

4.3 Sector Working Groups 4.6

4.3.1 Water 4.7

4.3.2 Transportation 4.8

4.3.3 Oceans and Coastal Resources 4.9

4.3.4 Forestry 4.10

4.3.5 Agriculture 4.12

4.3.6 Habitat and Biodiversity 4.13

4.3.7 Public Health 4.14

4.4 Cross-Sector Interactions 4.15

4.5 Early Actions - Climate Adaptation Efforts 4.16

4.6 Climate Adaptation Tools for Stakeholders 4.17

Chapter I

1 Impacts of Climate Change on California's Public Health, Infrastructure and Natural Resources

1.1 Introduction and Background

In June 2005, Executive Order S-05-05 was signed by Governor Arnold Schwarzenegger which mandates the preparation of biennial science assessment reports on climate change impacts and adaptation options for California. The first Climate Action Team (CAT) Assessment Report was produced in March 2006, followed by the release of the 2008 Assessment Report. The 2008 assessment expands on the policy oriented 2006 assessment and provides new information and scientific findings. New information and details in the 2008 CAT Assessment Report includes: 1) Development of new climate and sea-level projections using new information and tools that have become available in the last two years; and 2) Evaluation of climate change within the context of broader social changes, such as land-use changes and demographic shifts. The 2006 assessment examined the impacts of climate change with the assumption that, in general, all other factors remained constant. However, to evaluate the economic impacts of climate change and develop strategies for adaptation, these impacts must be considered as part of a set of multiple stressors associated with the economic development and population growth patterns in the state. This latest assessment involved an attempt to consider the joint effect of increased urbanization on climate impacts.

A CAT steering committee comprised of the Scenarios Sub-group provided general guidance to the 2008 assessment effort. This committee includes technical representatives from California's Environmental Protection Agency, Natural Resources Agency, Air Resources Board, Department of Public Health, Office of Environmental Health Hazard Assessment, Department of Fish and Game, Department of Water Resources, Ocean Protection Council, Department of Forestry and Fire Protection, Department of Food and Agriculture, Department of Transportation, California Energy Commission, in addition to San Francisco Bay Conservation and Development Commission.

Brief History of Climate Change Research Efforts in California

California started inquiring about potential impacts of climate change in 1988. A report prepared by the California Energy Commission in response to a legislative mandate identified potential impacts (CEC 1989; CEC 1991). Research conducted since that early report has confirmed and greatly refined our understanding of California's vulnerability to climate change in critical sectors such as water, agriculture, coastal areas, and its precious ecological resources.

In the late 1990s, the National Oceanic Atmospheric Administration (NOAA), a federal agency whose mission includes predicting and understanding weather and climate, created the Regional Integrated Sciences and Assessments (RISA) research program to better understand information needs and provide research support on both short- and long-term operation and planning to regional and local resource managers. In California, under the NOAA RISA program, the California Applications Program (CAP) was established at the Scripps Institution of Oceanography, University of California San Diego with an emphasis on climate variability and climate change impacts on water resources, wildfire, and human health. CAP has been involved in climate impact studies and assessments produced in the state.

The U.S. Global Change Research Program in 2001 published the first national assessment of the potential consequences of climate variability and change (USGCRP 2001). As part of this work, several regional assessment reports were produced including one dealing exclusively with California (USGCRP 2002).

At the same time the National Assessment was under preparation, California initiated its own state-supported integrated climate research program. The California Energy Commission's Public Interest Energy Research (PIER) program started climate change research in 2001 with an exploratory project designed to investigate the potential impacts of climate change on water resources, forestry, agriculture, coastal properties, and ecosystems. PIER subsequently released its long-term climate change research plan in 2003 and has been implementing this plan with the creation and research activities of the California Climate Change Center. The Center has produced more than 100 peer-reviewed reports and some of them have resulted in papers published in top scientific journals. This research program has been closely coordinated with other state and federal agencies (Franco et al. 2008).

The passage of Assembly Bill 32, the California Global Warming Solutions Act of 2006, has invigorated new research initiatives such as the newly funded climate change research subprogram at the California Air Resources Board. Moreover, the Climate Action Team has begun to further coordinate climate change research in California (see Chapter VI).

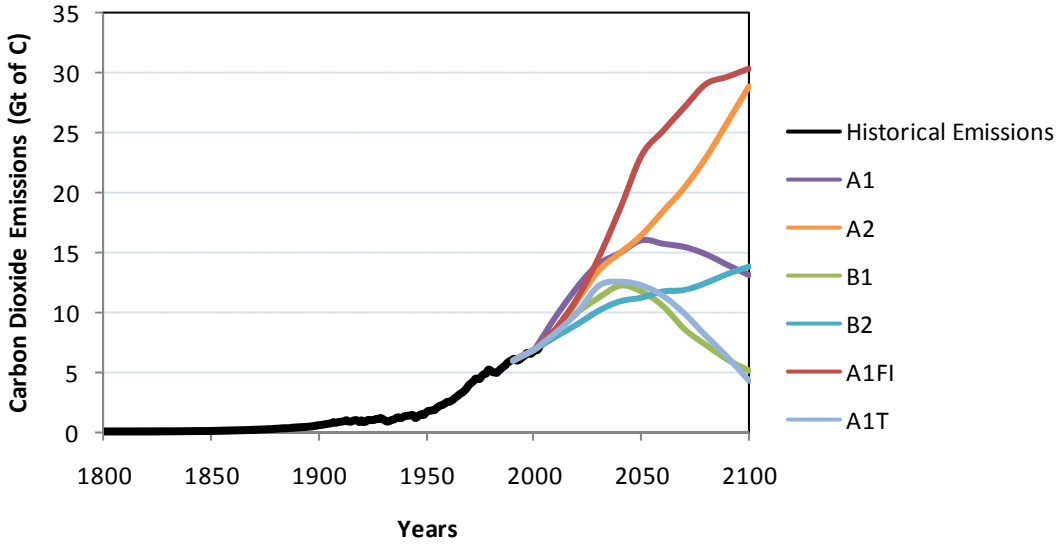
1.2 Impact Studies by Sector

This section summarizes the approaches used to study the impact of climate change in different sectors and their main findings.

1.2.1 Approach to Socio-Economic Scenarios

For this 2008 Assessment, socio-economic storylines and key scenario elements for California were developed that are broadly consistent with two quantitative projections of global climate change conducted under the auspices of the Intergovernmental Panel on Climate Change (IPCC). These projections were driven in part by two economic model-generated scenarios of anthropogenic greenhouse gas (GHG) emissions, representing plausible 21st century trends in social and economic development around the world. These are the so-called A2 and B1 storylines in the IPCC's *Special Report on Emissions Scenarios* (SRES) (Nakicenovic and Swart 2000). The A2 and B1 storylines and their quantitative representations illustrate two quite different plausible trajectories for the evolution of the world economy, society, and energy system, and imply divergent paths of future anthropogenic GHG emissions, with projected emissions in the A2 being substantially higher than for B1 (Figure 1).

Figure 1
Historical and Projected Global Carbon Dioxide Emissions



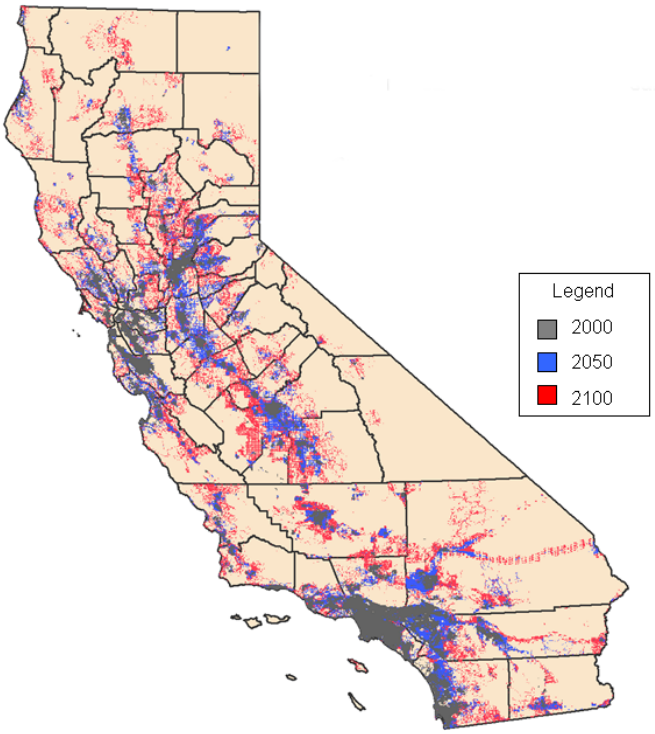
Data source: IPCC (2001) and Carbon Dioxide Information Analysis Center

The A2 SRES global emissions scenario represents a heterogeneous world with respect to demographics, economic growth, resource use and energy systems, and

cultural factors. There is a de-emphasis on globalization, reflected in heterogeneity of economic growth rates and rates and directions of technological change. These and other factors imply continued growth throughout the 21st century of global GHG emissions. By contrast, B1 is a "global sustainability" scenario. Worldwide, environmental protection and quality and human development emerge as key priorities, and there is an increase in international cooperation to address them as well as to convergence in other dimensions. Neither scenario entails explicit climate mitigation policies. The A2 and B1 global emission scenarios were selected to bracket the potential range of emissions and the availability of outputs from global climate models.

In contrast to the A2 and B1-driven regional climate projections, development of California socio-economic scenarios did not entail formal "downscaling" of the global scenarios or economic simulation modeling of 21st century California. Instead, to support the impact analyses in this study, this project focused on the general, qualitative socio-economic context as well as quantitative projections of key variables, including population, urbanization patterns, and economic growth that reflect the main elements of the global scenarios. These were developed using model output from the SRES and historical information on California and the United States, as well as through new projections of population and urbanization developed specifically for this assessment. As an example, Figure 2 shows the urbanization patterns analyzed in this assessment.

Figure 2
Historical and Projected Urbanization Patterns for California



Source: Sanstad et al. 2008

1.4

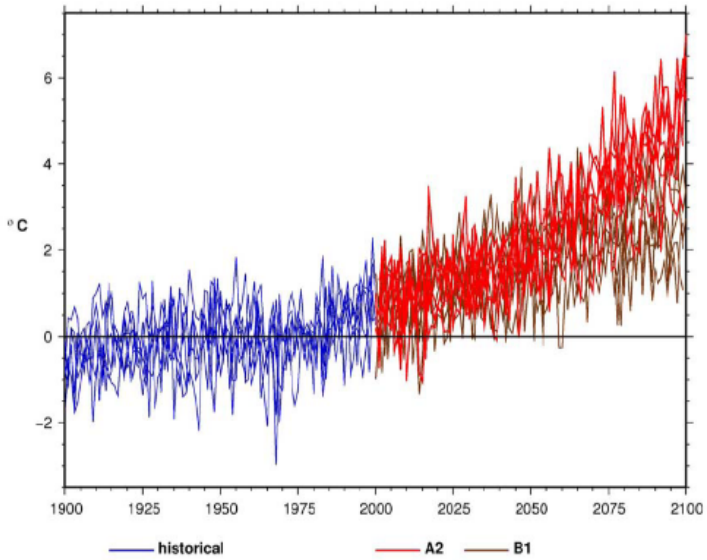
1.2.2 Approach to Climate Scenarios

There were six global climate models (GCMs,) run for the recent IPCC Fourth Assessment (IPCC 2007) using the A2 and B1 emission scenarios, were employed to assess climate changes and their impacts for the 2008 California Climate Change Assessment. For the assessment, the NCAR Parallel Climate Model (PCM), the NOAA Geophysical Fluids Dynamics Laboratory (GFDL) version 2.1, the NCAR Community Climate Model (CCSM), the Max Plank Institute's ECHAM3, the Japanese Model for Interdisciplinary Research on Climate (MIROC), and the French Centre National de Recherches Météorologiques (CNRM) models were selected. The set of GCM's expand the ones used in the 2006 California Scenarios Assessment.

1.2.3 Warming Trends

All of the climate model simulations exhibit warming globally and regionally over California. Through the first five decades of the 21st century, the amount of warming produced by the A2 simulations is not much greater than that of the B1 simulations (Figure 3), largely because warming over the next few decades is governed largely by past emissions. Thereafter, however, there is considerably greater warming under the A2 scenario compared to B1 as the effects of present-day and future increased GHG loading accumulates (Figure 3). Overall, the six models' summer warming projections in the first 30 years of the 21st century range from about 0.5 to 2 °C (0.9 to 3.6 °F) and by the last 30 years of the 21st century, from about 1.5 to 5.8 °C (2.7 to 10.5 °F). The upper part of this range is a considerably greater warming rate than the historical rates estimated from observed temperature records in California (Bonfils et al. 2008). There is greater warming in summer than in winter, under both the A2 and B1 emissions scenario simulations.

Figure 3
Annual Temperature Projections for the Sacramento Area: A2 and B1 Scenarios



Source: Cayan et al. (2008a)

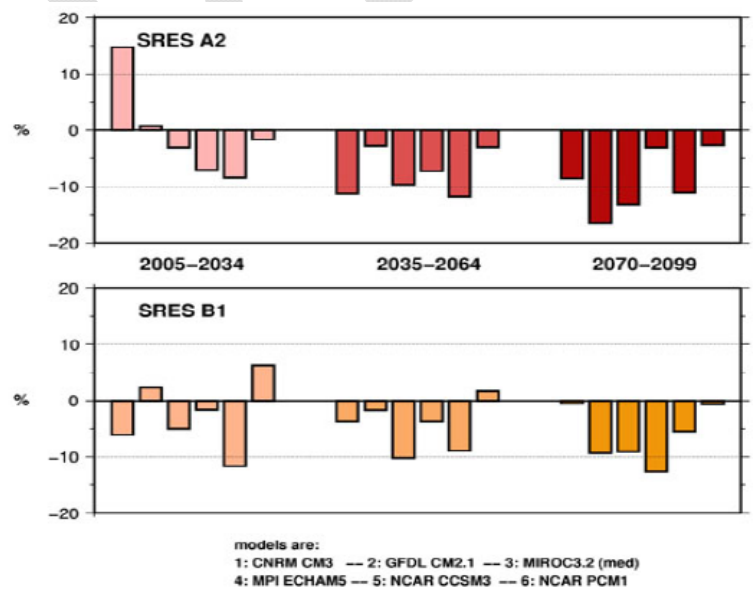
Historically, extreme warm temperatures in California have mostly occurred in July and August, but as climate warming takes hold, the occurrences of these events will likely extend to the entire period from June to September. All simulations indicate that extremely hot daytime and nighttime temperatures (heat waves) increase in frequency, magnitude, and duration from the historical period. Within a given heat wave, there is an increasing tendency for multiple hot days in succession—i.e., heat waves last longer. Furthermore, the number of days with simultaneously hot daytime temperatures in multiple regions in the state increases markedly; this has important implications for emergency response and satisfying electricity demand in the state.

In producing the climate scenarios for California, Scripps Institution of Oceanography has developed a new downscaling method to translate coarser global models to the finer scale detail required to understand how these changes will affect the state. Another new method, in development for the last two years, makes use of daily outputs from global climate models, which is expected to better capture extreme events. The 2008 Assessment used the new downscaling method along with an established method based on monthly statistics to produce climate projections for California at grid sizes of about 7.5 by 7.5 miles. These smaller scale projections are needed to provide information about specific problems relating to agriculture, energy, ecosystems and many other sectors of California's economy and its natural resources.

1.2.4 Precipitation

Precipitation in most of California is characterized by a strong Mediterranean pattern wherein most of the annual precipitation falls in the cooler part of the year between November and March. The climate change simulations from these GCMs indicate that California will retain its Mediterranean climate with relatively cool and wet winters and hot dry summers. The model-driven climate simulations indicate that a high degree of variability from year to year of annual precipitation, similar to our historical experience in California, will prevail over this century, including a continued vulnerability to drought. While it will retain its overall character, models of the California climate also project important possible changes. For the Sacramento region, drying is evident as the simulation reach mid-21st Century. By the end of the 21st century, four of the six GCMs used in the 2008 Assessment produce drier (by 5 percent or more) than historical average conditions. In the northern part of California, the tendency for drying fades and even reverses but in Southern California the amount of drying becomes greater, with decreases in some simulations exceeding 15% drier. None of these model simulations became significantly wetter by the end of the century (Figure 4). Even if precipitation levels were to remain unchanged over the 21st century, however, the higher temperatures would increase evaporative water loss and thus produce overall drier conditions. Additional reductions in precipitation would exacerbate the issues associated with increased evaporative water loss.

Figure 4
Changes in Precipitation in Relation to the Average 1961 to 1990 Water Years: Northern California



Source: Cayan et al., 2008a

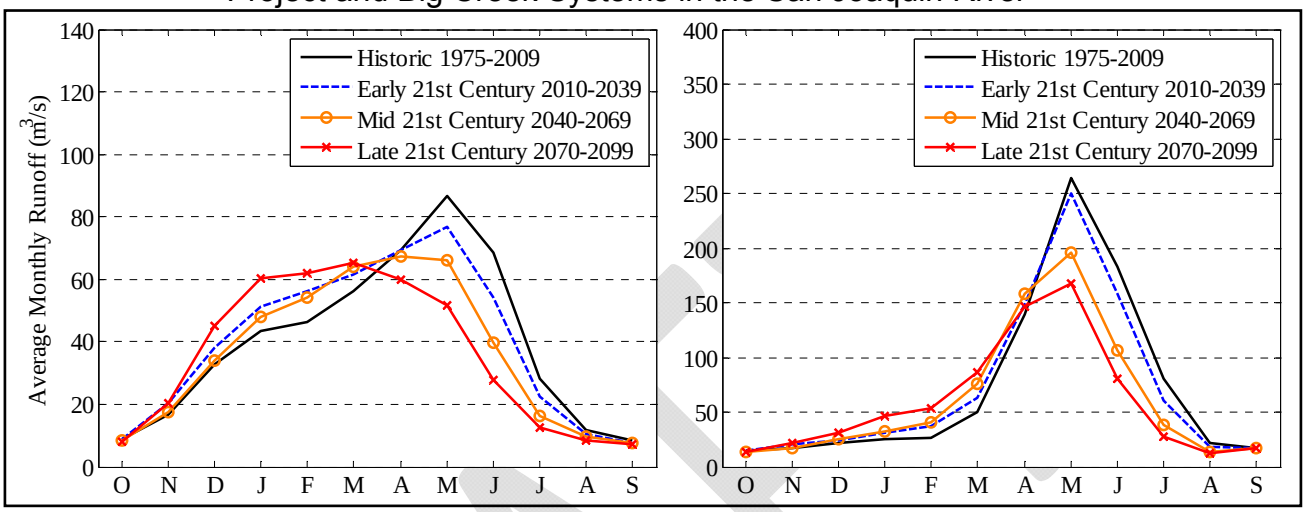
Cayan et al. (2008a) used the detailed temperature and precipitation projections with the Variable Infiltration Model (VIC), a hydrological model, to produce estimated

changes in runoff (water river flows), snow, soil moisture and other hydrologic measures in a statewide simulation of the California land surface and its key watersheds. Kapnick and Hall (2008) have obtained independent new results describing observed shifts brought on by warmer winters and springs and on potential effects of climate change on the mass and timing of the California Sierra snowpack, which, along with natural and engineered reservoirs, is a critical determinant of the state's water supply. Previous studies have examined possible climate change-induced changes in the peak snow water equivalent (SWE, a metric for the water content of snow) in April, yielding estimates of the gross effects of precipitation changes on water supply. The water system is designed to achieve joint water storage and flood control objectives based on the historical annual temporal patterns of snowpack accumulation, melting, and runoff. Changes in timing of melting and runoff can affect water supply even in the absence of significant shifts in precipitation levels. Kapnick and Hall constructed a new data set on historical SWE during the February to May phase, in order to study timing. They found that since 1930 there has been a trend toward earlier SWE peaking, and assessed the implications for this trend of the regional temperature increases projected by Cayan et al. (2008a): A shift of the peak from 4 to 14 days earlier in the season by 2100. This shift could adversely affect the capacity and reliability of the California water system with respect to water storage and flood management, and requires changes in water reservoir management rules.

The early melting of snow and precipitation trends will have an effect on river flows (runoff) in California. Figure 5 presents average monthly runoff for a region located in the Upper American and Rubicon basins (headwaters at 9,900 ft [≈ 3,000 m]); and a region in the upper San Joaquin basin (headwaters at 14,000 ft [≈ 4,200 m]).

As shown in Figure 5, there is a clear reduction of the snowmelt season runoff, consistent with the notion that increasing temperatures modify the timing of streamflow toward earlier in the water year. Under historical hydrologic conditions almost 70 percent of runoff flows during the typical snowmelt season in Upper American River area. This number is reduced by more than 20 percent in average for all projections. The conditions at the Big Creek system in the southern part of the Sierra Nevada in contrast show that the snowmelt season runoff represents almost 90 percent of annual runoff under historic conditions, and that number is reduced to slightly above 75 percent under future (end of century) projections. Finally, on average all scenarios show an increasing trend in extreme flows during the winter months. This is an expected response of snow dominated watersheds associated with temperature increases, but this could be compensated (or amplified) in some cases with reductions (or increases) in precipitation and runoff.

Figure 5
Average Changes in Monthly Hydrologic Conditions in the Upper American River Project and Big Creek Systems in the San Joaquin River



Source: Vicuna et al. 2008

1.2.5 Sea-Level Rise

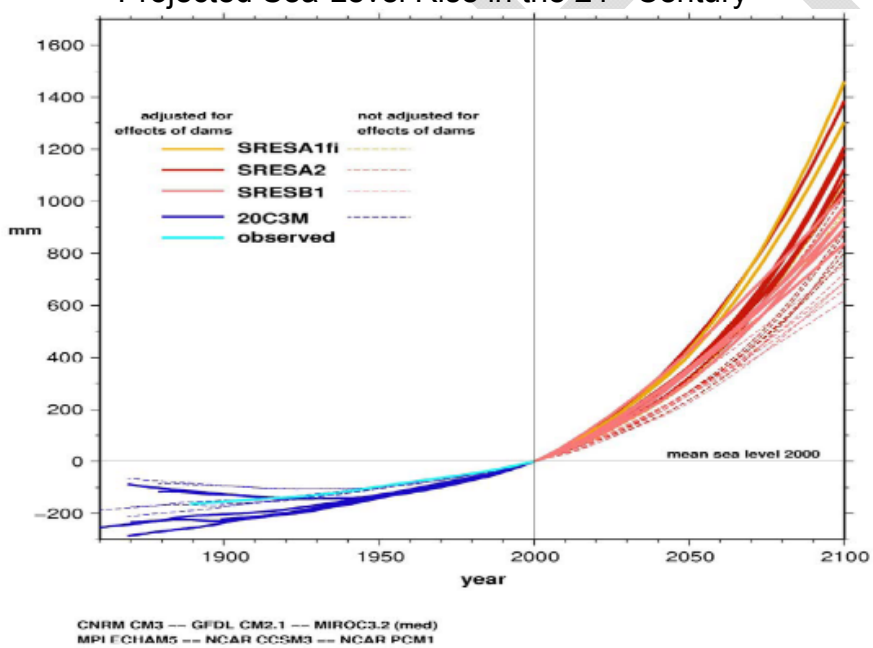
Sea level measured over several decades at California tide gage stations has risen at a rate of about 17 cm (7 inches) per century. The sea-level rise projections in the 2008 Impacts Assessment indicate that the rate and total sea-level rise in future decades may increase substantially above the recent historical rates. The 2008 estimates represent a significant departure from those in the 2006 CAT report. The 2008 sea level rise projections are based on new scientific findings of the last two years suggesting that prior estimates likely have been too low. A paper authored by Rahmstorf (2007) demonstrated in a semi-empirical manner that over the last century observed global sea-level rise can be linked to global mean surface air temperature. Thus, the new projections produced for California uses Rahmstorf's method, assuming that sea level rise along the California coast is roughly the same as the global average (as shown in the historical record).

A second set of sea level rise projections improves on the Rahmstorf method, by accounting for the global growth of dams and reservoirs, which have artificially reduced surface water runoff into the oceans (Chao et al. 2008). Global sea level rise would have been larger in response to climate change without the impoundment of water behind dams.

Under either the Rahmstorf method or Chao et al.'s augmented approach, the resulting estimates indicate that the rate of sea-level rise over the 21st century could considerably increase. By 2050, sea-level rise could range from 30 to 45 cm (11 to 18 inches) higher than in 2000, and by 2100, sea-level rise could be 60 to 140 cm (23 to 55 inches) higher than in 2000. As sea level rises, there will be an increased rate of extreme high sea-level events, which can occur when high tides coincide with winter storms and their associated high wind wave and beach run-up conditions. These high sea-level events can be exacerbated by El Niño occurrences. Sea levels at the California coast often rise substantially during El Niño winters, when the Eastern Pacific Ocean is warmer than usual and westerly wind patterns are strengthened.

Figure 6 indicates that even for the lower emissions B1 scenario sea-level rise would be on the order of 60 centimeters (23 inches), which was close to the level estimated for the high emissions scenario (A1Fi)[1] and the (slightly lower) A2 emissions scenario in the 2006 Assessment Report.

Figure 6
Projected Sea-Level Rise in the 21st Century



Source: Cayan et al. (2008b)

The group at Scripps enhanced the work done for the 2006 Assessment Report by not only estimating hourly sea level rise conditions for one location (San Francisco) but generating the same information for additional locations (Crescent City and San Diego). A compounding element as the sea level rises is the continued occurrence of winter

[1] Figure 1 shows the carbon dioxide emission levels associated with the A1Fi global emission scenario

North Pacific storms, which elevate sea level due to wind and barometric effects, especially during high tides. However, by the end of the 21st Century, the models yield a somewhat subtle tendency for fewer larger coastal storms, a feature that is consistent with the drying tendency in the central and southern part of California that was noted above.

1.2.6 Agriculture

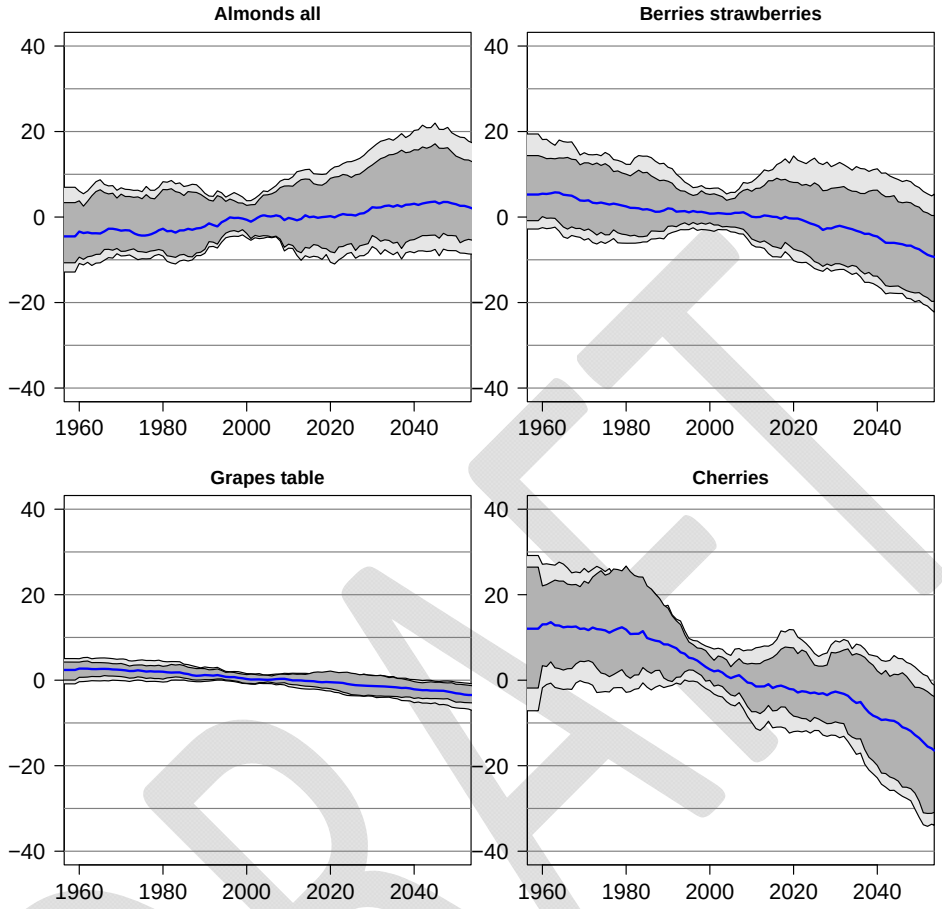
The diversity and size of California's agricultural sector creates unique opportunities and challenges in its responses to climate change. Global warming is likely to change precipitation, temperature averages, maximums and minimums, pest and weed ranges, the length of the growing season, and other factors. These will all affect crop productivity. Extreme events may be among the greatest challenges, as they can lead to large losses.

Lobell and Field (2008) investigated the impacts of climate change on perennial crops, which represent an important contribution to agricultural value in California. They used historical county crop yields and weather data to establish models that relate weather changes to yield changes, and used these weather-yield models to project the impacts of climate changes through 2050. Results vary for the various crops with slight positive impacts on crop yields for almonds and significant decreases in cherry yields (Figure 7).

In another study, Lee and Six (2008) looked at productivity changes from 1950–2099 for seven annual field crops: alfalfa (hay), cotton, maize, winter wheat, tomatoes, rice, and sunflower. They used a model to simulate processes that affect plant productivity, including interactions with soil organic matter, nutrient cycling, and soil temperature and moisture. Compared to 2000, in 2050 cotton, maize, sunflower, and wheat yields decrease from 3 percent to 8 percent, while rice and tomato yields were essentially the same. Alfalfa yields increased, but the results were not consistent across counties. The differences in yields between a high-emissions scenario and a low-emissions scenario were small. However by the end of the century yields of all crops except alfalfa decreased, and the differences between high- and low-emissions scenarios were pronounced.

The results suggest that climate change will decrease annual crop yields in the long-term, particularly for cotton, unless future climate change is minimized and/or adaptation of management practices and improved cultivars becomes widespread.

Figure 7
Simulated Change in Crop Yields for Four Crops



The thick blue line shows the average of all projections, the dark shaded area shows 5 percent to 95 percent range of projections when using multiple climate models, and the light shaded area shows 5 percent to 95 percent range when using multiple climate models and multiple crop models. The results are presented as percent changes from the 1995–2005 average yields, and as 21-year moving averages in order to emphasize the trend rather than year-to-year variability.
Source: Lobell and Field (2008)

1.2.7 Forestry

California timber production has been declining over the past few decades due to several factors, including moderate warming, increased wildfires, land use change and growing emphasis on recreation. Climate change has the potential to further affect the extent of forests, the amount of timber production in the state and the value of timber on the market. The direction, magnitude, and exact nature of future change will depend on individual site characteristics, climate changes, and impacts on other timber-producing areas. The ecological responses to climate change are dynamic and, therefore, dynamic modeling is required to capture impacts in the sector.

Costello et al. (2008) performed a statewide analysis using a process model known as 3-PG (Physiological Principles for Predicting Growth). The 3-PG model uses species physiological characteristics to model growth in single species, even aged stands. Monthly climate data—consisting of maximum temperature, minimum temperature, precipitation, and solar radiation—drive the simulation. The model uses these to calculate rates of carbon fixation from photosynthesis (i.e., net primary production) and partitions the resulting biomass into foliage, stems, and roots according to species specific ratios.

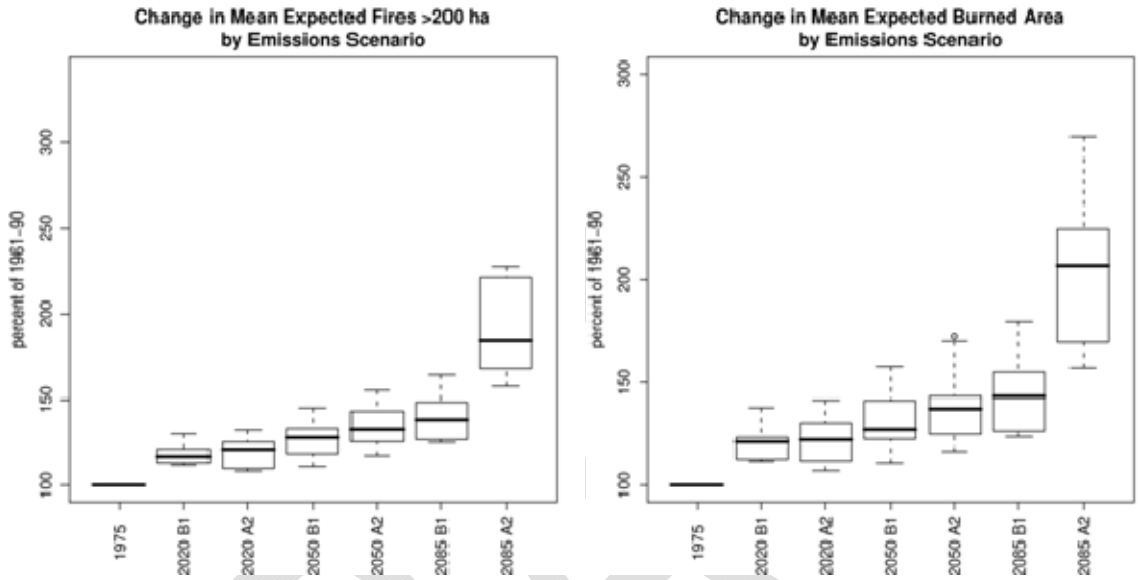
Douglas fir, ponderosa pine, redwood and western hem-fir collectively account for over 92 percent of harvest value on private lands in California, according the California Board of Equalization Timber Tax Database (Spero 2006). The researchers simulated timber production under future climate conditions with the 3-PG model using these four species as representative for the entire industry.

Battles et al. reported in the 2006 Assessment that climate change in California would reduce the productivity of timberlands in the Sierra Nevada. In particular, the growth of ponderosa pine (*Pinus ponderosa*) was projected to decline under a drier and warmer climate. They obtained these results by adapting an industry standard planning tool to forecast 30--year tree growth and timber yields for forest stands under a changing climate. However, they recognized the inherent risk of applying a model, even an adapted one, to situations for which it was not specifically designed. For the 2008 Assessment, Battles et al. built from scratch a climate-sensitive forest growth model using the best available data and applied the model to a 20 year-old pine plantation near Whitmore in Shasta County, a major timber producing county. Preliminary results simulating growth of a commercial pine plantation over a 50-year management cycle (20 to 70 years old) for 18 climate simulation runs projected increases in yield as measured in total tree volume. The increased growth was most directly tied to the consistent projections of warmer temperatures during the twenty-first century. Under the different climate scenarios, pine yield increased from 9 percent to 28 percent above baseline by 2100. This result contradicts their previous work, which reported decreases in pine yield by 2100 under similar climate projections. Further evaluations are under way to better estimate the reliability of the new model.

Westerling et al. (2008) constructed a statistical model of wildfire as a function of climate and land surface characteristics in California. Their model predicts the monthly probabilities of large fires occurring on a one-eighth degree latitude/longitude grid (approximately 7.5 by 7.5 miles) over California. This work expands on an analysis by Westerling and Bryant performed for the 2006 Assessment that considered the effects of climate change on California wildfire and wildfire-related damages that held development fixed at the 2000 census and assumed unchanged vegetation patterns. Their new study assesses the range of outcomes given numerous sources of uncertainty including three GCMs with different sensitivities to anthropogenic forcing, two emissions scenarios, population growth projections and changes in the spatial distribution of vegetation. Model results suggest increases in wildfire, although the

range of outcomes is large and expands with time (Figure 8). The long-term increase in fire occurrence associated with the higher emissions pathway (A2) is substantial, with increases statewide ranging from 58 percent to 128 percent by 2085. Likewise, estimated burned area increased 57 percent to 169 percent under the A2 pathway.

Figure 8
Change in Expected Fires and Burned Area by Emissions Scenario

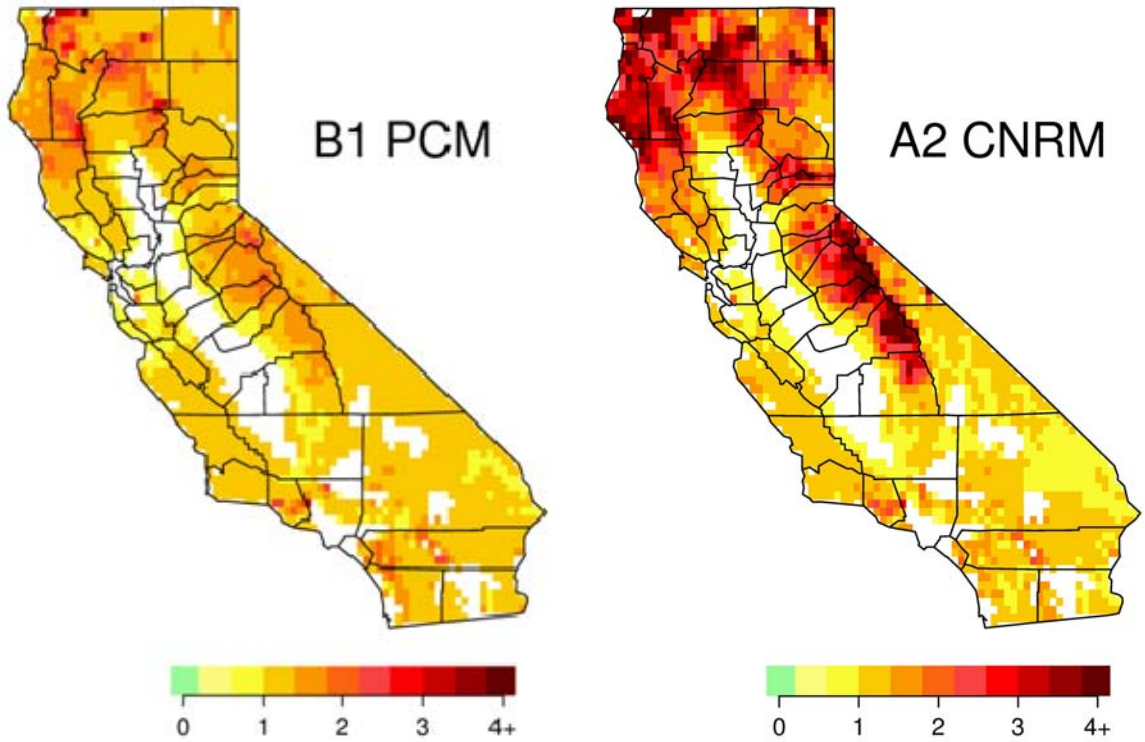


Source: Westerling et al. (2008)

Figure 9 illustrates the geographical distribution of estimated increases in fire risk for the B1 and A2 emission scenarios for a period centered in 2085.[2] The panel on the left shows results for the PCM model and the panel on the right for the CNRM model to illustrate results close to the lower and upper range shown in Figure 8. The results show that fire probability is likely to increase multiple times in the extreme North and Northwest of the State, as well as in the Central California Coastal Ranges, the high Sierra, and different regions in southern California.

[2] The fire risk in Figure 9 is the multiple of the risk in the historical period (e.g., an increased risk of 2 means that the fire risk would double by 2085 in comparison to what has been already experienced in California).

Figure 9
Fire Probabilities in 2085 as a Multiple of the Probability of Fire Occurrence during the Reference Period (1961-1990)



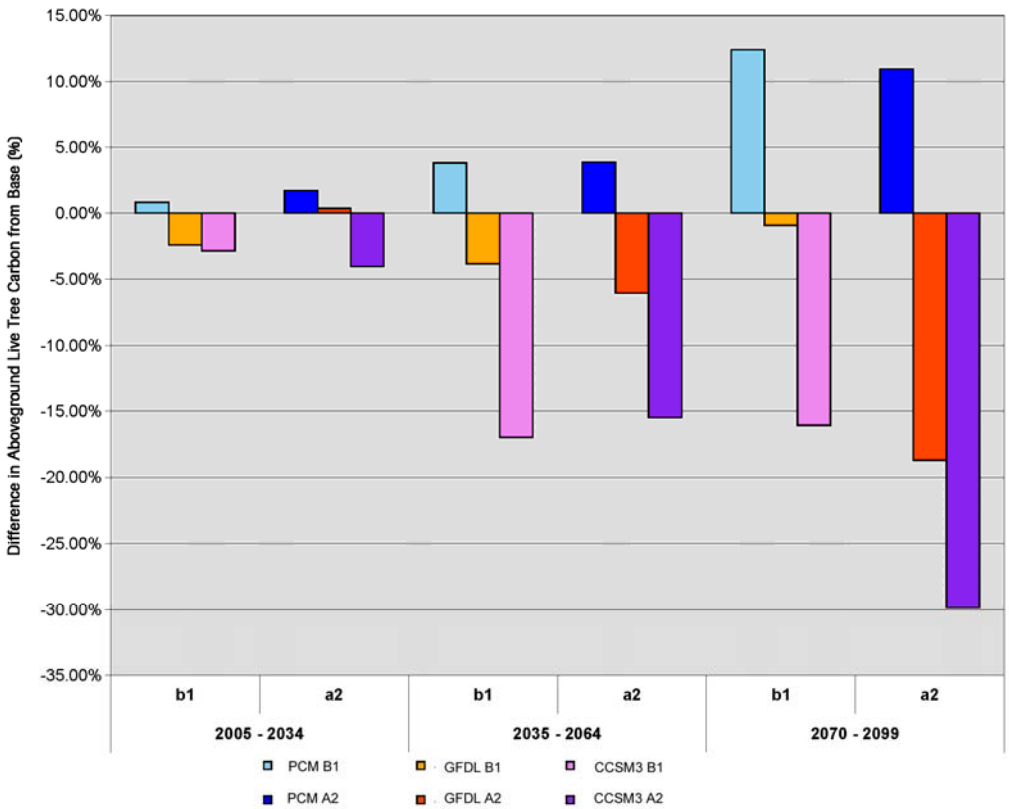
Source: Westerling et al. (2008)

Hughes et al. (2008) studied the potential effects of 21st century climate change on the Southern California Santa Ana winds, which are hot, dry, and strong winds blowing westward from the desert during fall and winter. The Santa Ana winds have significant ecological and socio-economic effects. Their timing – following common hot and dry summer conditions in Southern California – coupled with increased development, particularly residential housing, in critical areas, makes them a major risk factor for economically costly wildfires. At the same time, they contribute positively to biological activity in coastal ecosystems, as well as to improved air quality in the South Coast Basin. Using a high-resolution dynamic regional climate model to simulate conditions in Southern California, Hughes et al. found a decrease in both the frequency and intensity of Santa Ana winds over this period. Using a numerical weather model, they concluded that future global warming will lead to a further decrease.

Shaw et al. (2008) estimated potential changes in aboveground live trees for different climate scenarios as shown in Figure 10. The researchers used the MC1 Dynamic Global Vegetation Model (MC1-DGVM) developed by the US Forest Service at the Forestry Sciences Laboratory in Corvallis, Oregon. The impact of climate change on carbon sequestration depends in part on whether the future will be warmer and wetter, as projected by the PCM1 model, or hotter and drier, as projected by the GFDL and

CCSM3 models. Using the warmer, wetter model (PCM1), MC1 projects an increase in aboveground carbon for both the lower (B1) and higher (A2) emissions scenarios above the baseline scenario (Figure 10). In contrast, the hotter, drier model (GFDL) projects much lower carbon stocks than the baseline scenario, with a marked drop around 2080 in the A2 emissions scenario. The climate future generated by CCSM3 results in an even sharper decline in carbon stocks over the 21st century, with the largest loss expected under the A2 scenario. By 2070 to 2099, carbon stocks could increase by 9 percent in the warmer, wetter future, or drop by 26 percent in the hotter, drier scenario.

Figure 10
Percent Change from the Future Baseline Climate in Carbon Storage in Aboveground Live Trees for Lower and Higher Emissions Scenarios for Three Global Climate Models (PCM1, GFDL, and CCSM3)



Source: Shaw et al. (2008)

In summary, in the forestry sector several tools were used to assess the impacts of climate change. A more sophisticated analysis of forest fires confirms prior studies suggesting an alarming, increasing trend in the frequency of these fires. The productivity of forest for timber in general is estimated to decline on a statewide basis but some species and in some locations timber production may increase. Further studies are needed to confirm and refine these results. The amount of carbon

sequestered in aboveground live trees is expected to decline but results are not consistent across the different climate projections produced by the range of models used in this assessment.

1.2.8 Water Resources

Two groups conducted studies of water resources under changing climate conditions using two different models: CALVIN and CalSim-II. The CALVIN model is an engineering-economic optimization model that has been enhanced for climate change studies. Since the model assumes perfect water markets with water being delivered where it is needed to minimize economic losses or increase benefits to the overall water sector, results from CALVIN should be interpreted with caution and representative of minimum impacts given physical constraints only (i.e., as best case scenarios). By comparison, the CalSim-II model is a simulation model that accounts for the existing rules and regulations governing the water system in California. The model assumes that current rules, regulations, and practices remain unchanged in this century. Since climate change will undoubtedly result in changes in water management, results from CalSim should be considered conservative.

The CALVIN work conducted for this assessment (Medellin-Azuara et al. 2008) explored water supply adaptation strategies under two climate scenarios, assuming 2050 levels of socio-economic development. The first climate scenario used a warmer-drier climate with high GHG emission levels and low precipitation levels; the second climate scenario (warmer only) includes historic patterns of precipitation with high levels of emissions and increased temperature. The warmer-drier scenario comes from the downscaled outputs from the GFDL model for the A2 emissions scenario while the warmer-only scenario retains the warming from the GFDL model but assumes no changes in average precipitation levels from the historical record. The CALVIN model integrates economic costs in agricultural and urban locations, operating costs, and water storage and conveyance infrastructure within the network connecting and transporting water resources within and across the state. CALVIN suggests economically promising water management strategies, such that water is allocated to minimize total scarcity and operating costs in California considering a set of physical and operating constraints.

Table 1 below shows the amount of unmet water demand (scarcity) using historical climate conditions with future population and urban growth and the two climate projections described above. Overall, urban uses are supplied at their target demand. Small shortages close to 28 thousand acre-feet (TAF) per year are most likely in Southern California in historical and warmer-only scenarios. Affected urban centers include some parts of the Metropolitan Water District of Los Angeles and some cities east of Los Angeles within the Mojave and Imperial Valley regions. This finding

assumes that current infrastructure development projects will be in operation. The warmer-drier scenario doubles shortages for urban locations to 59 TAF/year. The CALVIN model estimates that urban areas are basically able to receive the water they need from water transfers from the agricultural sector.

It is important to point out that the warmer-drier climate scenario comes at a cost to some environmental flows. Reductions in environmental flow requirements for the Trinity River, Clear Creek, and the Sacramento River, the San Joaquin/Mendota refuges, and Pixley were required to achieve model feasibility under this drier scenario. A reduction of 8 TAF/year, roughly 11percent of the average annual minimum streamflow requirement, was applied to Mono Lake water releases from Grant Lake. Changes in end-of-period storage policies in selected reservoirs (such as Shasta) were also needed to accommodate reductions in required minimum streamflows. Such reductions in streamflow would need to be reviewed for potential environmental impacts, and the respective costs and benefits carefully weighed.

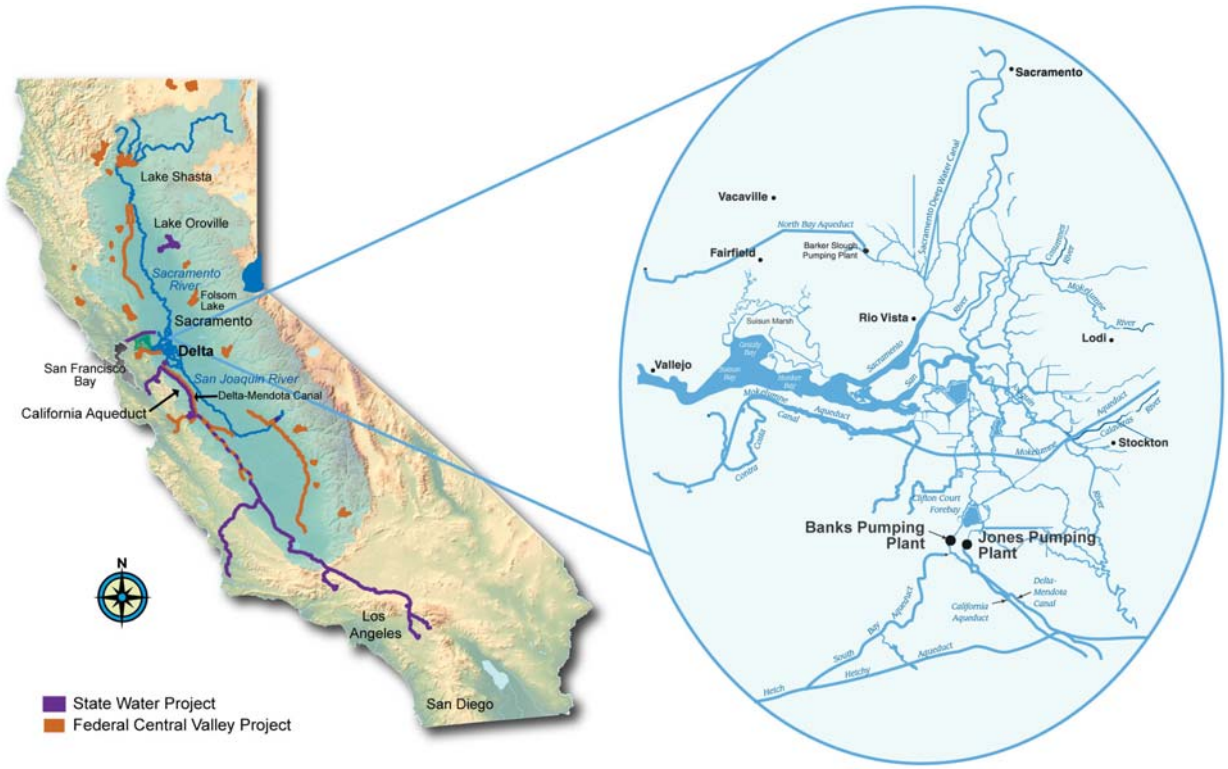
Table 1
Water Scarcity, in Percent of Water Deliveries by 2050

Scenario	Scarcity (Thousand Acre-Feet/year)	Delivery (Percent of Target)
Historical		
Agriculture	970	95.9
Urban	28	99.7
Total	998	
Warmer-Only		
Agriculture	1,229	94.8
Urban	29	99.7
Total	1,258	
Warmer-Drier		
Agriculture	5,153	78.2
Urban	59	99.4
Total	***5,212***	

Chung and Anderson (2008) used the CalSim-II model to estimate potential impacts of climate change on operation of the State Water Project (SWP) and the Central Valley Project (CVP) (Figure 11) using 12 climate projections for both the middle and the end of the century. The indicators of water supply reliability analyzed were annual Delta exports, reservoir carryover storage, Sacramento Valley groundwater pumping, power supply, position of a Delta salinity indicator known as X2, and the frequency and extent of system vulnerability to operational interruption. In analyzing the study results, it was

assumed that each climate projection was equally likely and that no changes were made to the existing SWP and CVP infrastructure.

Figure 11
State Water Project and Central Valley Project in California (left)
Sacramento-San Joaquin Delta (right)



Source: Chung and Anderson (2008)

The reliability of the SWP and CVP water supply systems is expected to be reduced for the range of future climate projections studies. Decreases in annual Delta exports would reduce water deliveries south of the Delta. Reductions in reservoir carryover storage would reduce the systems' flexibility during water shortages. In the Sacramento Valley, reduced surface water supplies are likely to be augmented by increased groundwater pumping. Both power generation and power use by the SWP and CVP are anticipated to decrease under climate change due to the expected reduction in water deliveries. The SWP and CVP are expected to continue meeting X2 Delta salinity standards. Under climate change, in some years water levels in the main supply reservoirs (Shasta, Oroville, Folsom, and Trinity) could fall below the lowest release outlets making

the system vulnerable to operational interruption. In those years, additional water would be needed to meet current regulatory requirements and to maintain minimum system operations. This water could be obtained through additional water supplies, reductions in water demands, or a combination of the two. For current conditions, the system is not considered vulnerable to operational interruption.

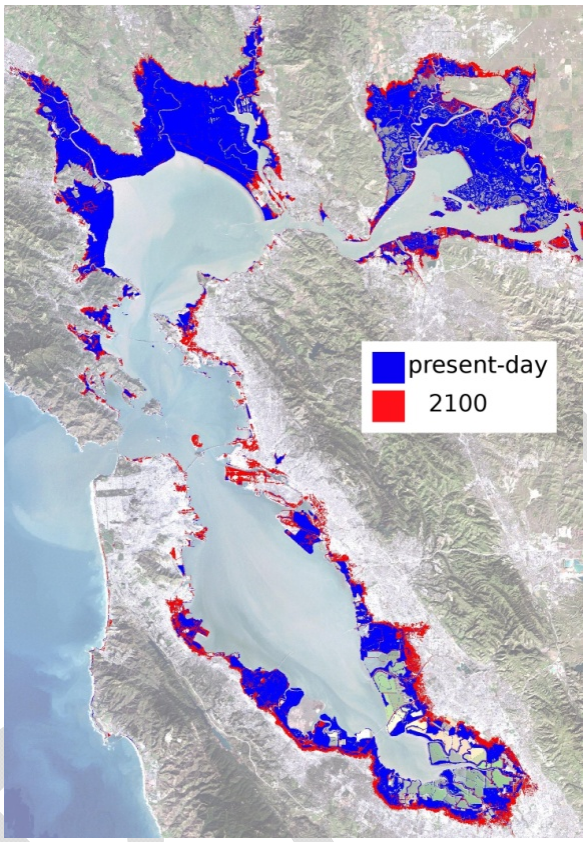
In summary, without changes in operating rules for the water system in California the reliability of water supply will be severely affected. On the other hand, it seems that California could afford the implementation of adaptation measures that could significantly reduce the system's vulnerability.

1.2.9 Coastal Areas

Several studies assessed the impacts of climate change on the coastal sector. Knowles (2008), assembled and mosaicked the highest resolution elevation data for the San Francisco Bay region currently available and used a hydrodynamic model to assess the extent of inundation with a 140 cm (55 inch) increase in mean sea level from the present day (measured at the Golden Gate Bridge) (Figure 12).

Many of the areas indicated as vulnerable to inundation are presently behind levees and would only be inundated if those levees breached or were overtopped, or they include wetland areas which are inundated by high tides only occasionally today. The most prominent features subject to inundation in the North Bay are the wetlands surrounding San Pablo and Suisun Bays; municipal and industrial areas along the Martinez-Pittsburg corridor; the Richmond-Pinole peninsula; and areas in eastern Marin. In the Central and South Bays, a ring of developed areas currently behind levees would be newly at risk as sea level rise is expected to greatly increase pressure on existing levees and increase the risk of breaching. Other areas, such as San Francisco airport, that are not currently protected behind levees would need levee protection.

Figure 12
Present and Future Inundation Scenarios at Mean High Tide in the San Francisco Bay



Inundation of San Francisco Bay areas that lie below average annual high water levels under conditions of present mean sea level (blue), and under conditions of a 140 cm increase in mean sea level (red).

Source: Knowles (2008)

Peter Gleick and colleagues (2008) used the inundation maps produced by Knowles for the San Francisco Bay region and produced similar maps for open coast regions to estimate the area, population, and assets potentially affected by higher sea levels. They also estimate the costs of protecting them from the encroaching sea (for results on the economic estimates, see Chapter III). They estimated that $50 billion of property, along with 260,000 people, are located in areas that are currently vulnerable to flooding. Existing levees protect some of these areas but will no longer be sufficient with projected sea-level rise. Their analysis reveals that $100 billion of property and 475,000 people are located in Bay and open coast areas vulnerable to inundation in 2099. However, risk is not evenly distributed among the counties in the San Francisco Bay, with San Mateo and Alameda counties having 40 percent of assets at risk, the greatest

amount in the Bay Area. Marin, Santa Clara, and San Francisco counties are also exposed to a high degree of risk; exposure to risk in these counties is higher than in all other counties along the Pacific coast, with the exception of Orange County. Exposure to risk in Sonoma and Napa counties is relatively modest.

While all sectors are vulnerable to the impacts from sea-level rise, 70 percent of all assets at risk are residential, followed by the commercial sector with 20 percent. In addition to buildings and their contents, a wide range of other critical infrastructure, such as roads, hospitals, schools, emergency facilities, water and wastewater treatment plants, and others will also be at increased risk of flooding. Continued development in vulnerable areas would put additional assets and people at risk.

Another study by Adams and Inman (2008) estimated changes in beach width and volume both historically and for different scenarios of climate change. The authors found that southern California beaches behaved very consistently over the period between 1949 and 1998. Some beaches had chronic erosion (e.g., Point Dume, Will Rogers, Dockweiler, and Torrance), while one was had continuous accretion (e.g., Dan Blocker), with the remaining beaches (Malibu, Las Tunas, Topanga, Santa Monica, Venice, El Segundo, Manhattan, Hermosa, and Redondo) being mixed in their trend of sedimentary health, exhibiting both erosion and accretion reaches. In all instances the beaches experienced the greatest amount of change during severe winter storms, especially during El Niño events.

Climate-driven sea level rise and changes in the characteristics of waves could cause some beaches to erode more while others may actually get wider. During El Niño events, wave direction is more westerly and of longer period than during non- El Niño conditions. Recent evidence suggests that El Niño frequency has already increased commensurate with the warming global climate. The authors used a model that relates deep-water wave conditions to beach response, to identify erosion hotspots under different climate scenarios. They found that a higher frequency of El Niño-like conditions will increase potential longshore divergence of sediment at exposed sites by as much as 300 percent, increasing erosion or turning previously accreting sections of the beach into erosion hotspots. They also found that when waves are large, of long period, and from westerly directions erosion can increase by nearly 20 percent for a 1 meter rise in sea level.

Together, the three studies suggest that climate change-driven sea-level rise is likely to be more severe and potential economic impacts considerably higher than previously projected. The long-term commitment to sea level rise (due to the thermal inertia of the oceans) and high development of much of California's coastline for residential, industrial, recreational, and infrastructure uses suggest that mitigation can reduce the magnitude of sea level rise over the very long term (hundreds of years), while adaptation is the only way to deal with the impacts from sea level rise over the coming decades and century.

1.2.10 Energy

Anticipated climate change will affect residential electricity demand patterns for California's households. Increases in mean temperature and the increased frequency of extreme heat events combined with the uneven distribution of new residential development across the state will drive up the demand for cooling in summertime, which is only partially offset by decreased heating needs in the wintertime. Auffhammer and Aroonruengsawat (2008) combined four years of residential billing data for California's three largest utilities with daily temperature and pricing information to estimate temperature consumption response functions by the climate zones defined for the California Energy Commission's building standards.

Figure 13 presents estimated per-household changes in residential electricity demand due to warming using the results from the PCM global climate model. The maps on top represent results for the B1 scenario and the maps on the bottom show results for the A2 scenario. The maps on the left are average increases for the 2020 to 2039 period and the ones on the right for the 2080 to 2099 period.[3] Increases in demand in the coastal regions are relatively modest due to the lower increase in coastal temperatures while increases inland, especially in the Central Valley, are substantial. Demand in the next 40 years generally is insensitive to the global emissions scenarios considered while demand at the end of this century is heavily dependent on global emissions pathways in this century. The increased electricity demand in the residential sector for the A2 scenario is higher by about a factor of two than in the B1 scenario by the end of the 21st century.

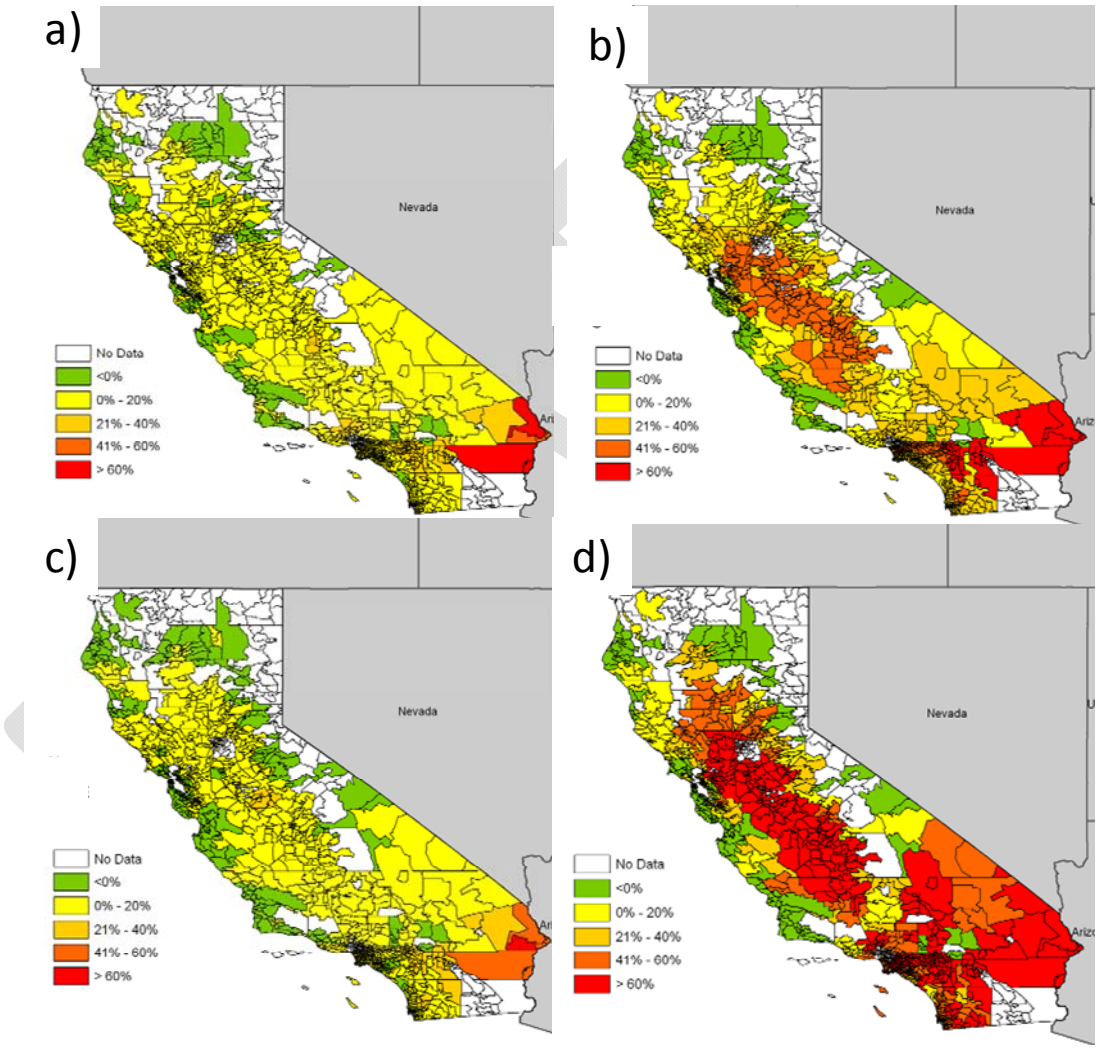
On average statewide electricity demand in the residential sector would increase by about 7 percent in the next few decades beyond that of anticipated population growth alone. By end of this century demand would increase by 20 percent in the B1 scenario and by 50 percent in the A2 scenario. These changes represent substantial impacts to California's residents and an added stress to the electricity generating sector.

California's water and hydropower energy resources are also vulnerable to climate change, motivating a series of studies in recent years. Hydropower constitutes around 15 percent of in-state energy generation in California, its greatest value being associated with peak use. More than half of this energy generation occurs at high elevation (over 1,000 feet) in systems that have less storage capacity but higher natural head than lower-elevation systems. In high elevation systems snowpack is used as a natural reservoir to deliver water for hydropower generation in the spring and summer seasons.

[3] The new estimates reported by Auffhammer and Aroonruengsawat (2008) seem to be substantially higher from what has been reported in prior studies. The potential reasons for the discrepancies are being investigated.

Figure 13
Projected Changes in Electricity Demand in the Residential Sector

Simulated increase in per-household electricity consumption by zip code for the periods 2020–2039 (a)(c) and 2080–2099 (b)(d) in percent over simulations using climate data for the 1980–1999 period. Model NCAR PCM forced by IPCC SRES B1 (a)(b) and A2 (c)(d).



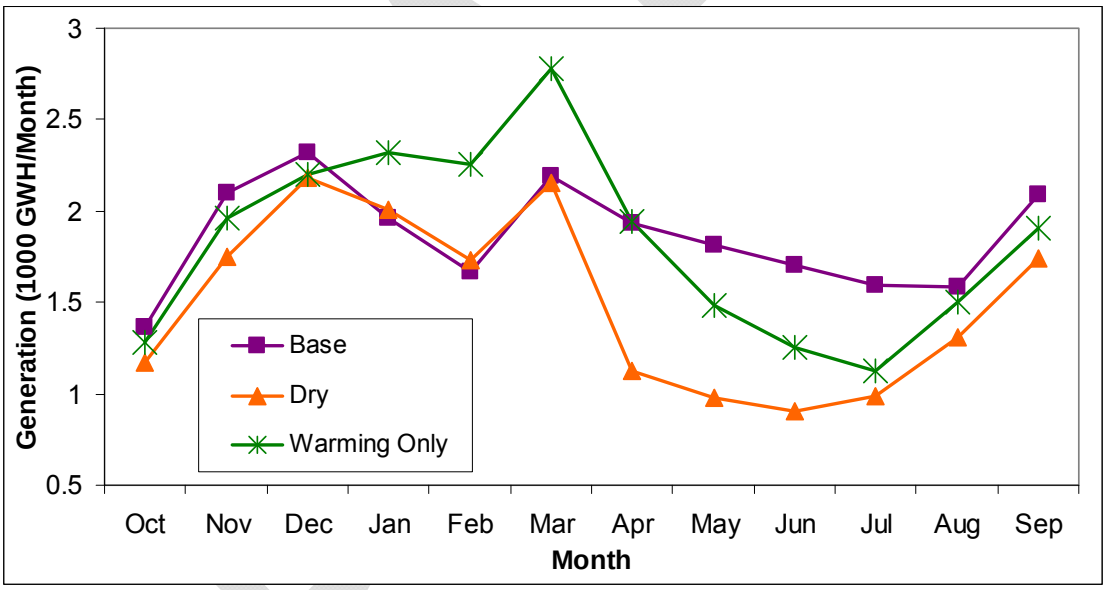
Source: Auffhammer and Aroonruengsawat (2008)

Chung et al. (2008) reported that power generation by the Central Valley Project (CVP) is expected to decrease by three percent at mid-century and by six percent by the end of the century, and the power used by the CVP is expected to decrease by one percent

by mid-century and three percent by the end of the century. The power generation by the State Water Project (SWP) is equally expected to decrease by three percent by mid-century and by six percent by the end of the century, and the power used by the SWP is expected to decrease by six percent by mid-century and 10 percent by the end of the century. Both CVP and SWP include low-elevation hydropower units associated with the major reservoirs belonging to these two systems.

For high-elevation hydropower units, Medellín et al. (2008) reported up to 20 percent decreases in annual electricity generation for the about 150 high-elevation hydropower units available in California. Total annual generation is a strong function of the amount of precipitation falling in California. If precipitation levels were to remain at historical levels for the rest of this century, annual hydropower generation in high-elevation units would not be severely affected. However, electricity generation decreases in the summer months when it is needed the most to meet peak electricity demand (Figure 14).

Figure 14
Average Monthly High-Elevation Hydropower Generation in California
Under Different Climate Scenarios



Source: Vicuña et al. 2008

Vicuña et al. (2008) performed a very detailed engineering study of two high-elevation hydropower systems in California: the Upper America River Project, operated by Sacramento Municipal Utility District in Northern California, and the Big Creek system, operated by Southern California Edison in Southern California. The operations of these two high-elevation systems were simulated using historic climate conditions and the future climate change scenarios. Hydrologic scenarios under climate change imply an average reduction in runoff for both systems (with a greater reduction for the Big Creek

systems) and a change in the hydrograph (distribution of runoff in different parts of the year) towards earlier timing of runoff. The changes are greater for the Upper America River Project system because of the lower elevation of the basins where the system is located. The simulation results indicate that the reduction in runoff results in a reduction in energy generation in both systems. However, due to the greater change in the hydrologic conditions for the Upper America River Project system, spills are greater in that system, and hence the reduction in energy generation (and associated revenues) is greater as well.

1.2.11 Air Quality

Californians experience, on a cumulative basis, the worst air quality in the nation. Ozone and particulate matter (PM) are the pollutants of greatest concern, especially in the problematic South Coast and San Joaquin air basins. The current control programs for motor vehicles and industrial sources cost about $10 billion per year. As the population of California increases, the climate warms, and forests, croplands, and native vegetation become altered, scientists expect that air pollution in coming decades may worsen. Climate change could slow progress toward attainment of health-based air quality standards and increase pollution control costs by increasing the potential for high ozone and high particulate days. Reductions needed to counter man-made and natural biogenic emissions will be particularly important during strengthened temperature inversion events and summertime stagnation episodes.

Potential air quality impacts of climate change are being assessed using both empirical and deterministic methods. The empirical methods use meteorological parameters to find if conditions conducive to high air pollution episodes will change with climate change. Deterministic methods rely on air quality photochemical models.

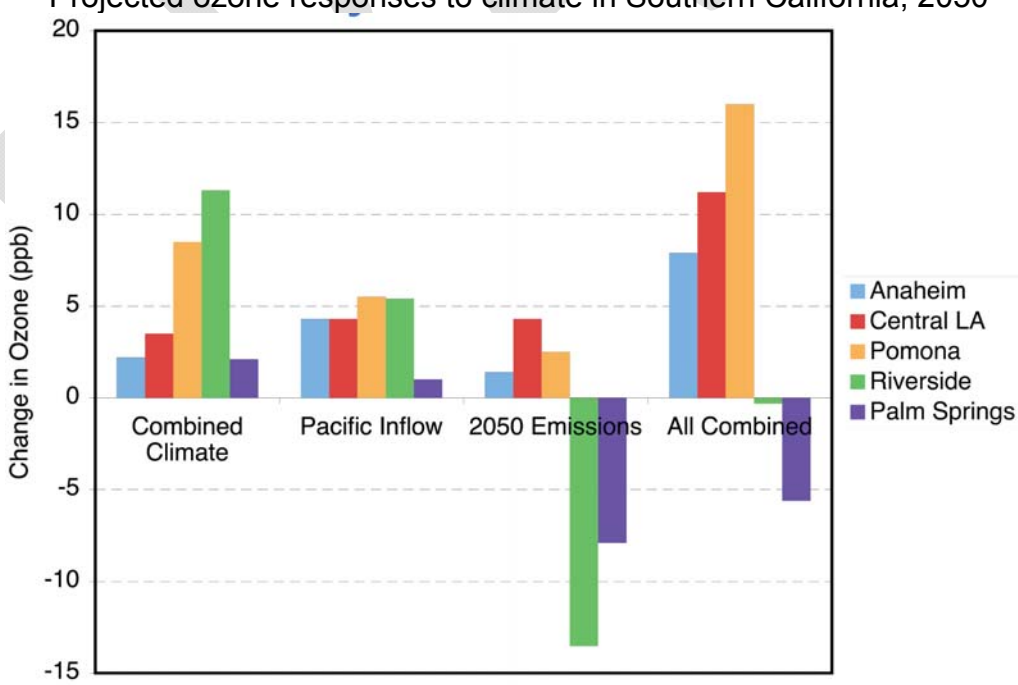
Concentrations of several of the key air pollutants, such as ozone and PM, depend strongly upon the vertical gradient of temperature in the lower atmosphere. The persistence of California's ozone problem is associated with inversions, warm sunny days with stagnant atmospheric conditions that trap emissions close to the surface where they have ample opportunity to accumulate and to form smog. Iacobellis et al. (2008) investigated how atmospheric circulation and other conditions have accentuated or diminished these inversions during the last five decades and on how they may change over the 21st Century. The study indicates that while there are inversions on most days in California, of varying intensity and structure, low frequency variability in inversion strength, along with other inversion characteristics, may have important implications for future changes.

Steiner et al. (2006) evaluated the effects of some anticipated changes in climate variables and ozone precursor emissions for the Central Valley and San Francisco Bay Area. Reductions in anthropogenic emissions of conventional air pollutants by 2050 will reduce ozone levels, assuming there is no change in climate. However, changes in

climate variables, such as higher temperatures and increased natural biogenic emissions, would produce higher ozone concentrations. When these two effects, changes in climate and conventional emission reduction programs, are combined, the benefits of the emission reductions are partially or completely offset by climate change. This off-setting of air quality improvements by climate change-induced temperature and emission changes is sometimes called the "climate penalty."

In a separate study, Millstein and Harley (2008) analyzed in more detail the effects of climate change on ozone concentration in Southern California. They model conditions in 2050, assuming CO_2 levels of twice pre-industrial. They superimposed the effects of emissions and climate-related changes to air quality on a 2005 summer high-ozone episode. They considered the effects of five factors: (a) increased temperature on atmospheric chemical reaction rates, (b) increased temperature on biogenic emissions from plants, (c) increased water vapor concentrations, (d) increased inflow of pollution from the West, modeling an increase in pollution carried in from Asia, and (e) population growth and technology change affecting the emissions of air pollutants within the study area. The authors also differentiated the effects of daytime and nighttime warming. The climate effects (a, b, and c above) lead to ozone concentration increases of up to 11 parts per billion, though the effect on ozone was greatly reduced when the temperature increase occurred at night. Increased inflow pollution also led to ozone increases up to five parts per billion. These climate and inflow-related changes offset some of the anticipated benefits of emission controls within the South Coast Air Basin. (Figure 15)

Figure 15
Projected ozone responses to climate in Southern California, 2050



Source: Millstein and Harley (2008)

1.27

The PM2.5 (particulate matter of less than 2.5 microns) response to global change is more complicated to diagnose because some of the likely trends act in opposite directions. Increased temperature discourages the formation of particulate ammonium nitrate, an important contributor to levels of PM2.5, but rising concentrations of background ozone encourages it. A preliminary study (Kleeman, 2008) suggests that the effect of increased background ozone was especially important during episodes with lower air temperatures. PM2.5 events in the San Joaquin Valley usually occur during the winter months, so the importance of background ozone concentrations at lower temperatures may be especially significant there. Rainy days, wildfires, global dust storms, humidity, and other factors also affect PM and are the subject of ongoing research.

1.2.12 Public Health

Climate change has the potential to significantly impact the health of Californians. Research suggests that the most serious effects will not be primarily related to changes in average climate, but rather to increased frequency of extreme conditions, principally more frequent, longer and more intense heat waves. Heat wave conditions are also associated with weather patterns conducive to increased air pollution formation and wildfire outbreaks, both of which pose risks to public health. In addition, climate change also has the potential to influence asthma symptoms, the incidence of infectious disease, and the potential to affect humans indirectly through impacts on food and water supplies and quality.

A large body of literature published over the past 10 years has consistently shown that the number of observed deaths is greater when temperatures are elevated, and that not all deaths associated with temperature are directly due to hyperthermia or dehydration. Most excess deaths occur in people over 65 years of age who have chronic disease. However, a significant number of cases of death directly attributable to heat are in healthy, relatively young to middle aged people. This group often includes outdoor workers and people engaged in strenuous exercise. Many excess deaths are indirectly related to heat exposure, with the cause of death being cardiovascular or other chronic diseases that are exacerbated by heat exposure. Several studies have also reported that hospitalizations and emergency room visits increase as ambient temperature rises.

Basu and Ostro (2008) provide the first studies investigating heat-related mortality in California. A study of nine counties found that excess mortality resulted from extreme temperatures but also from exposure to generally higher mean temperatures during non-heat wave periods. This study also observed greater effects in Blacks, those over age 65 and those under age one. A follow-up study (Ostro et al. 2008) analyzed the effect of temperature and mortality during the 2006 heat wave and found a higher percent increase in mortality per unit of increase in apparent temperature (nine percent per 10 °F) during that heat wave than during the previously studied non-heat wave

periods (about 2.3 percent per 10 °F). Green et al. (2008) investigated the relationship between temperature and hospitalizations for various causes using the same nine counties as the mortality analyses discussed above. Hospitalizations for directly heat-related causes, such as heat stroke and dehydration, increased as temperature increased. In addition, hospitalizations for ischemic stroke (reduced blood and oxygen flow to the brain), respiratory disease, diabetes, acute renal failure, and intestinal infectious disease also increased as temperatures increased. The results highlight the conclusion that there is an association between temperature and hospital admissions in California, even without extreme temperature events.

A two-week heat wave that impacted most of California in July 2006 led to more than 140 deaths directly attributable to heat exposure. Although daytime temperatures were high during this time period, they were not record-breaking. However, nighttime temperatures during this heat wave were unprecedented and played a key role in the high death count (Gershunov 2007; Gershunov and Cayan 2008). Heat waves, especially those with substantial nighttime warming, have been increasing in recent decades in California. Knowlton et al. (2008) investigated the relationship between hospitalizations and emergency room visits during the 2006 California heat wave. The results showed a significant increase in emergency room visits for heat-related causes. There were also significant increases in hospitalizations for heat-related illnesses, acute renal failure, electrolyte imbalance, and nephritis. Effects were largest in the Central Coast region, which includes San Francisco. This region of California rarely experiences heat waves comparable to the 2006 event. The human toll was likely related to acclimating and adapting to the heat in this region. Ostro et al. (2008) analyzed the full mortality effects of the 2006 heat wave and indicated that the impacts might be two to three times greater than the 140 deaths directly attributed to the heat wave based on the coroner reports.

Climate change will increase the intensity and frequency of wildfires as discussed above. An increase in the number, size and duration of fires will add to the air pollution that already burdens California (Jaffe et al. 2008a; Jaffe et al. 2008b; Spracklen et al. 2007; Spracklen et al. in revision). Wildfires have the potential to significantly impact public health through the contribution of smoke to air pollution. A recent paper (Künzli et al. 2006) investigated respiratory symptoms in children residing in 12 cities in Southern California during the 2003 wildfires, and showed that the number and intensity of respiratory symptoms increased with both the number of days the child smelled smoke and with the PM10 (particles smaller than 10 microns) concentration. However, these results indicate that quantitative estimation of the impacts of future wildfire events is extremely difficult because the health-related impacts of any fire are unique to that event and are influenced not only by the magnitude, intensity and duration of the fire, but also the proximity of the smoke plume to a population.

1.2.13 Crosscutting Issues

The above summary of research suggest that even a relatively modest climate change (such as under the B1 emissions scenario, as described above) could create substantial impacts in each of the examined sectors. Future assessments will begin the challenging work of linking impacts occurring in one sector with those in others by potentially aggregating or using offsets, or responding to new findings.

There are different ways to systematically integrate these impacts across sectors, including through a geographic regional focus such as all impacts affecting a specified area, such as a metropolitan region or a section of the coast; a thematic focus taking into account all impacts from extreme events; or a temporal focus in which all impacts that occur in a specific year. In the 2008 Assessment Report, several studies begin this cross-cutting integration, but future work will need to expand upon it.

One study by multiple authors and coordinated by the San Diego Foundation examines the combined impacts of climate change with other demographic, economic, and social changes anticipated for the San Diego metropolitan area for the next several decades. Sponsors of this multidisciplinary study (San Diego Focus 2050) assume that a recurring assessment of the risks from climate change and incorporation of the best available information into planning will enable San Diego to adapt more readily to the coming changes.

For instance, using a cross integration strategy in San Diego to address climate change means taking into consideration demographic and socioeconomic changes, in addition to environmental issues. Local governments, businesses and individuals will need to be ready to deal with multiple risks and hazards simultaneously, such as sea level rise related to flooding, loss of beaches, water scarcity and water use conflicts, heat waves, rising electricity prices or even shortages, wildfires, increasing air pollution, species movement and losses, and greater public and private expenses.

Another cross-cutting study by Mastrandrea et al.(2008) examined the impacts of extreme events in California such as heat waves, wildfires, droughts, and floods, which have historically caused significant damages to life and property, and are responsible for a large fraction of near-term annual climate-related impacts. Experts expect many extreme events to become more frequent and more intense in the future due to warm temperatures (Figure 16).

Indeed, Trenberth et al. (2007) and Karl et al. (2008) found that some extreme weather events in the United States have already increased in frequency and intensity over the past few decades, with likelihoods ranging from likely (>66 percent likelihood to very likely (>90% likelihood). Observed incidences of extreme weather and changes in the frequency of extreme weather patterns over time in California are consistent with the

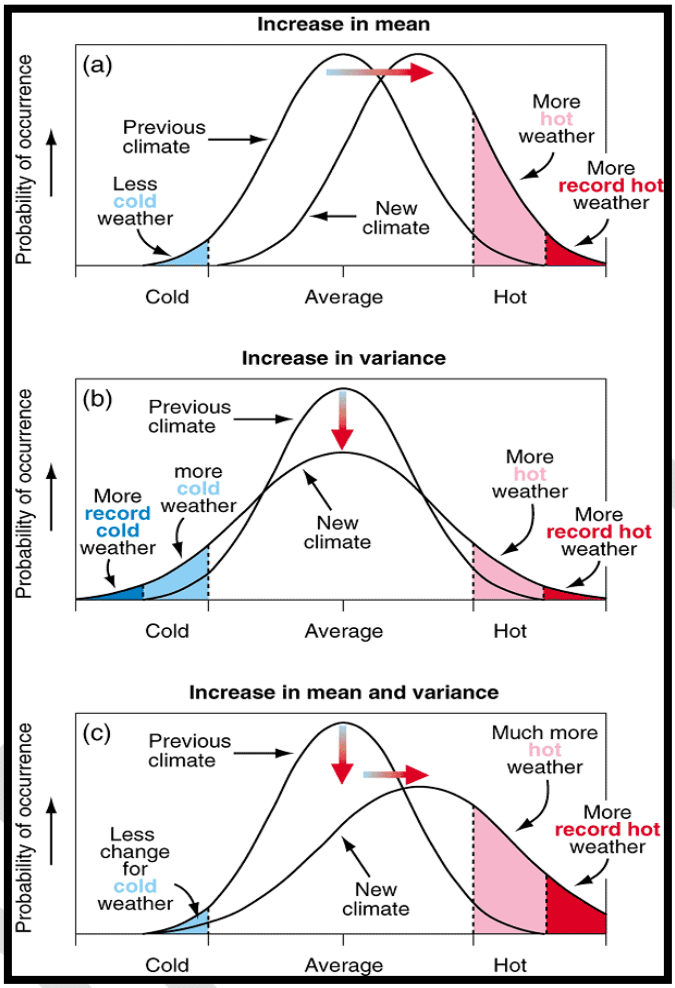
observed national trends. Adapting to extreme weather can be more challenging than adapting to gradual changes in weather conditions. Thus, studies of extreme weather events uniquely impact assessments and adaptation planning.

In their study, Mastrandrea et al. (2008) carefully define what would be considered an extreme weather event based on existing literature and historical experience. The study connects climate conditions (or indicators) to extreme events and tie the impacts experienced in one sector to those in other areas. New projections are made of frequency and intensity of extreme events in the future across climate models, emission scenarios and downscaling methods.

Consistent with other studies, the authors find significant increases in the frequency and magnitude of both maximum and minimum temperature extremes in many areas. The magnitude of change depends on overall temperature increase. For example, in many regions of California, at least a 10-fold increase in frequency is projected for extreme temperatures currently estimated to occur once every 100 years, even under a moderate emissions scenario (B1). Under the higher emissions scenario (A2), these temperatures are projected to occur close to annually in most regions. Also consistent with other studies, they found that projections of precipitation extremes are less spatially correlated and statistically significant than temperature extremes county-by-county, and they are more sensitive to the climate model and downscaling methodology that are employed.

Figure 16
Expected Changes in the Occurrence of Extremes as Climate Changes

DRAFT



Increases in the mean of (a) climate variable may shift toward more extremes on one side of the distribution and fewer extremes on the other; (b) increases in the variance of a climate variable would produce more extremes on both ends of the distribution; and (c) increases in both the mean and variance in a climate variable will produce a skewed shift in extremes: relatively minor shifts in extremes on one end of the distribution but much more change on the other end of the distribution.

Source: Trenberth et al. (2007), based on Houghton et al. (2001)

Mastrandrea et al. (2008) also undertook a comparison of current and future expected frequencies of extreme events comparable to those recently observed, such as the heat wave of July 2006 and the freeze of December 1998). Their exploration suggests

significant changes in the future. Heat waves similar in length and intensity to the 2006 heat wave will become more frequent all across the state. Some simulations suggest that heat waves will be an annual event by the end of this century under a higher emissions scenario. Freezing spells, on the other end, are robustly projected to become less frequent all across the state, even in locations where now they are a yearly event, becoming as rare as a one in 10-year event or less in a large fraction of California.

The study makes important progress in projecting extreme climate conditions and the implications of economic impact analyses, vulnerability assessments, and adaptation planning, though future work will need to refine the approach. Further refinements of information regarding exposure and sensitivity must be assessed to determine the capacity to adapt to specific sectors, regions, and populations, in addition to identifying specific vulnerabilities and strategies to reduce areas of concern.

The state Office of Environmental Health Hazard Assessment (OEHHA), as lead agency for the Environmental Protection Indicators for California (EPIC) Project, has prepared a report presenting indicators of climate change in California (OEHHA, 2008). A total of 27 climate change indicators are presented. The indicators draw upon data collection, monitoring and studies by state and federal agencies, universities and research institutions. Many of the indicators are derived from research studies funded by the California Energy Commission's Public Interest Energy Research (PIER) Program. Taken collectively, the indicators can help the research community in examining the interrelationships between and among climate and other physical and biological elements of the environment, and in identifying gaps in information. Finally, the indicators – particularly those that reveal evidence of the already discernable impacts of climate change – can highlight priority areas for state mitigation and adaptation strategies. Generally, the indicators show that changes occurring in California are largely consistent with those observed globally. There are a number of specific changes that are highlighted by the OEHHA work. Emissions of greenhouse gases have increased since 1990, as have atmospheric concentrations of carbon dioxide, the most important anthropogenic greenhouse gas. Air temperatures in the state have increased over the past century, with nighttime (minimum) temperatures increasing faster than daytime (maximum) temperatures. Water temperatures in Lake Tahoe have increased in the past 30 years, although water temperatures in the southern Sacramento-San Joaquin River Delta have stayed about the same. Sea levels measured at San Francisco and La Jolla have been rising. Over the past century, spring snowmelt from the Sierra Nevada to the Sacramento River has declined, and glaciers have decreased in area. Large wildfires have become more frequent. The lower edge of conifer-dominated forests in the Sierra Nevada has been retreating upslope over the past 60 years. In Yosemite National Park, small mammals are now found at different elevational ranges compared to earlier in the century. Butterflies in the Central Valley have been arriving earlier in the spring over the past four decades. These and the other indicators in the study will continue to be tracked and will provide an ongoing record of the measured impacts of climate change.

Community vulnerability is determined by its ability to anticipate, cope with, resist, and recover from the impact of increased major weather events associated with climate change. Climate change will affect industrial and agricultural sectors, as well as transportation, and energy infrastructure. These shifts may have health and economic consequences for diverse communities throughout California. Climate change may also amplify current as well as future socioeconomic disparities leaving low income, minority, and politically marginalized groups with fewer economic opportunities and more environmental and health burdens. Shonkoff et al. (2008) conducted a literature review exploring disparities in the impacts of climate change and the abilities of different groups to adapt to it and identifies knowledge gaps and future research questions. The literature review concludes that without proactive climate change policies that are sensitive to their economically regressive potential and their distribution of benefits, climate change policies could potentially reinforce and amplify current as well as future socioeconomic and racial disparities.

1.3 Summary of Major Findings

The work summarized in this chapter constitutes ongoing research that will continue for the foreseeable future. It is clear, however, that the science on climate change, impacts, and adaptation needs for California is progressing in important ways. Major advances since the 2006 project have been made, including:

- Downscaling of global climate model outputs to produce greater resolution and thus more realistic climate change projections for the state
- Understanding of the climate and terrestrial influences on global sea level rise and thus improve projections for the 21st century
- Collection and analysis of data to better understand the state's regional and local exposure to changing climate risks such as floods or extreme heat
- Understanding the impacts of climate change on crop yields for important commodities of California's agriculture
- Providing more detailed insights into the complex challenges and costs involved in meeting future energy needs.

Extreme events from heat waves, floods, droughts, wildfires and bad air quality are likely to become more frequent in the future and pose serious challenges to Californians. They pose growing demands on individuals, businesses and governments at the local, state, and federal levels to minimize vulnerabilities, prepare ahead of time, respond effectively, and recover and rebuild with a changing climate and environment in mind.

The next chapter provides some preliminary indications of the cost of climate change impacts under different assumptions, as well as of the cost of adapting to impacts that cannot be prevented or minimized through stringent greenhouse gas mitigation.

1.4 References

Adams, P.N. and D.L. Inman. 2008. "Climate Change and Potential Hotspots of Coastal Erosion Along the Southern California Coast." Draft Paper. 2008 Assessment Report.

Auffhammer, M. and A. Aroonruengsawat, 2008. "Impacts of Climate Change on Residential Electricity Consumption: Evidence from Billing Data." Draft Paper. 2008 Assessment Report.

Basu, R. and B. Ostro. 2008. "A Multi-County Analysis Identifying the Vulnerable Populations for Mortality Associated with High Ambient Temperature in California." Draft Paper. 2008 Assessment Report.

Battles, J.J., T. Robards, A. Das, K. Waring, J.K. Gilless, F. Schurr, J. LeBlanc, G. Biging, and C. Simon. 2006. "Climate Change Impact on Forest Resources." California Energy Commission, PIER Energy-Related Environmental Research Program. CEC-500-2005-193-SF.

Battles, J.J., T. Robards, W. Stewart, and A. Das. 2008. "Projecting climate change impacts on forest growth and yield for California's Sierran mixed conifer forests." Draft Paper. 2008 Assessment Report.

Bonfils, C., P.B. Duffy, B.D. Santer, T.M.L. Wigley, D.B. Lobell, T.J. Phillips, and C. Doutriaux. 2008. "Identification of External Influences on Temperatures in California." *Climatic Change* 87(Suppl. 1): 43-56.

California Energy Commission (CEC). 1989. The impacts of global warming in California. (P500-89-004)

California Energy Commission (CEC). 1991. Global Climate Change: Potential Impacts and Policy Recommendations. California Energy Commission Technology Evaluation Office. P500-91-007VI and P500-91-007VII.

Cayan, D.R., E.P. Maurer, M.D. Dettinger, M. Tyree, and K. Hayhoe. 2008a. "Climate Change Scenarios for the California Region." *Climatic Change* 87(Suppl. 1): 21-42.

Cayan, D.B., P.D. Bromirski, K. Hayhoe, M. Tyree, M.D. Dettinger, R.E. Flick. 2008b. "Climate Change Projections of Sea Level Extremes Along the California Coast." *Climatic Change* 87(Suppl. 1): 57-74.

Chao, B.F., Y.H. Wu, and Y.S. Li. 2008. "Impact of Artificial Reservoir Water Impoundment on Global Sea Level." *Science* 320(5873): 212-214.

Chung, F. and J. Anderson. 2008. “Using Future Climate Projections to Support Water Decision Making in California.” Draft Paper. 2008 Assessment Report.

Costello, C., C. Guo, L. Hannah, L. Ries, and N. Snider. 2008. “The Impact of Climate Change on California Timberlands.” Draft Paper. 2008 Assessment Report.

Franco, G., D. Cayan, A. Luers, M. Hanemann, B. Croes, 2008. Linking climate change science with policy in California. Climatic Change. 87 (Suppl 1):S7-S20

Gershunov, A. 2007. "Intense and Extensive Summer Heat Waves Under Current and Possible Future Climates." Eos Trans. AGU, 88(23), Jt. Assem. Suppl., Abstract A41A-04.

Gershunov, A., and D. Cayan. 2008. Recent increase in California heat waves: July 2006 and the last six decades. CEC-500-2008-XXX. In press.

Gleick, P., M. Heberger, H. Cooley, and P. Herrera. 2008. “The Cost of Adapting to Sea Level Rise Along The California Coastland in the San Francisco Bay.” Draft Paper. 2008 Assessment Report.

Green, R., R. Basu, B. Malig, R. Broadwin, J. Kim, and B. Ostro. 2008. The effect of temperature on hospital admissions in nine California counties. Draft paper. 2008 Assessment Report.

Houghton, J. T., Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, and D. Xiaosu, Eds., 2001. *Climate Change 2001: The Scientific Basis: Contributions of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, 881 pages

Hughes, M., A. Hall, and J. Kim. 2008. *Anthropogenic Reduction of Santa Ana Winds*. California Environmental Protection Agency and California Energy Commission Draft Report CEC-500-2008-XXX, September.

Iacobellis, S., et al. 2008. *Climate Variability and California Low-Level Temperature Inversions*. Draft Paper. 2008 Assessment Report.

Intergovernmental Panel on Climate Change. 2001. *Climate Change 2001: IPCC Third Assessment Report*. United Nations Environment Programme.

———. 2007. *Climate Change 2007: IPCC Fourth Assessment Report*. United Nations Environment Programme.

Jaffe, D., D. Chand, W. Hafner, A. L. Westerling, D. V. Spracklen. 2008a. "Influence of Wildfires on O_3 Concentrations in the Western United States," Environmental Science and Technology, 42(16), 5885-5891, DOI:10.1021/es800084k.

Jaffe, D., W. Hafner, D. Chand, A. L. Westerling, D. V. Spracklen. 2008b. "Interannual Variations in Wildfire PM2.5 in the Western United States," Environmental Science and Technology, 42: 2812-2818. DOI: 10.1021/es702755v.

Kapnick, S. and A. Hall. 2008. *Observed Climate-Snowpack Relationships in California and Their Implications for the Future.* California Environmental Protection Agency and California Energy Commission Draft Report CEC-500-2008-XXX, October.

Karl, T.R., G.A. Meehl, C.D. Miller, S.J. Hassol, A.M. Waple, W.L. Murray. 2008. *Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands*. US Climate Change Science Program, Synthesis and Assessment Product 3.3

Kleeman, M.J. 2008. A preliminary Assessment of the Sensitivity of Air Quality in California to Global Change. Climatic Change. Vol 87. Supplement 1 — March 2nd

Knowles, N. 2008. "Potential Inundation due to Rising Sea Levels in the San Francisco Bay Region." Draft Paper. 2008 Assessment Report.

Knowlton, K., M. Rotkin-Ellman, G. Ing, H. G. Margolis, D. Smith, G. Solomon, R. Trent, and P. English. 2008. The 2006 California Heat Wave: Impacts on Hospitalizations and Emergency Department Visits. *Environmental Health Perspectives*. In press.

Künzli, N., E. Avol, J. Wu, J. Gauderman, E. Rappaport, J. Millstein, J. Bennion, R. McConnell, F.D. Gilliland, K. Berhane, F. Lurmann, A. Winer, J.M. Peters. 2006. "Health Effects of the 2003 Southern California Wildfires on Children." *American Journal of Respiratory and Critical Care Medicine* 174: 1221-1228.

Lee, J. and J. Six. 2008. "Effect of Climate Change on Field Crop Production in the Central Valley of California." Draft Paper. 2008 Assessment Report.
Lobell, D. B. and C. B. Field. 2008. "Estimation of the carbon dioxide (CO2) fertilization effect using growth rate anomalies of CO2 and crop yields since 1961." *Global Change Biology* 14:39-45.

Mastrandrea, M. C.Tebaldi, C.P. Snyder, S.H. Schneider. 2008. "Current and Future Impacts of Extreme Events in California." Draft Paper. 20080 Assessment Report.

Medellín-Azuara, J., J. Harou, M. Olivares, K. Madani, J. Lund, R. Howitt, S. Tanaka, M. Jenkins, T. Zhu, 2008. "Adaptability and Adaptations of California's Water Supply System to Dry Climate Warming." *Climatic Change* 87: 75-90.

Millstein, D.E. and R. A. Harley. 2008. Impact of Climate Change on Photochemical Air Pollution in Southern California. To be submitted to *Journal of Geophysical Research*.

Nakicenovic, N., and R. Swart (eds.). 2000. *Special Report on Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 599 pp.

OEHHA (2009). *Indicators of Climate Change in California*. January 2009. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, Sacramento, CA.

Ostro, B., L. A. Roth, R. S. Green, R. Basu. 2008. "Estimating the mortality effect of the July 2006 California heat wave." Draft paper. 2008 Assessment Report.

Rahmstorf, Stefan. 2007. "A Semi-Empirical Approach to Projecting Future Sea-Level Rise." *Science* 315(5810): 368-370.

SFEP (San Francisco Estuary Project). 1993. *Comprehensive Conservation and Management Plan*. Oakland. http://www.abag.ca.gov/bayarea/sfep/reports/ccmp/ccmp-index.html.

Sanstad, Alan H., H. Johnson, N. Goldstein, G. Franco. 2008. "Long-Run Socioeconomic and Demographic Scenarios for California." Draft Paper. 2008 Assessment Report.

Shaw, M.R., L. Pendleton., D. Cameron, B. Morris, D. Bachelet, K. Klausmeyer, J. MacKenzie, D. Conklin, G. Bratman, J. Lenihan, E. Haunreiter, C. Daly. 2008. The Impact of Climate Change on California's Ecosystem Services. Draft paper. 2008 Scenario Report

Shonkoff, S.B, R. Morello Frosh, M. Pastor, J. Sadd. 2008. "Environmental Health and Equity Impacts from Climate Change and Mitigation Policies in California: A Review of the Literature." Draft paper. 2008 Assessment Report.

Spero, J. 2006. "California Timber Yield Tax Volume and Value Trends: Historical BOE Timber Harvest Data by Species, County, Ownership." California State Board of Equalization. http://www.boe.ca.gov/proptaxes/timbertax.htm

Spracklen, D. V., J. A. Logan, L. J. Mickley, R. J. Park, R. Yevich, A. L. Westerling, and D. Jaffe. 2007. "Wildfires drive interannual variability of organic carbon aerosol in the western U.S. in summer," Geophysical Research Letters, 34, L16816. DOI:10.1029/2007GL030037.

Spracklen, D. V., L. J. Mickley, J. A. Logan, R. C. Hudman, R. Yevich, M. D. Flannigan, A. L. Westerling. In revision. "Impacts of climate change from 2000 to 2050 on wildfire

activity and carbonaceous aerosol concentrations in the western United States,"Geophysical Research Letters, in revision.

Steiner, A.L.; Cohen, R.C.; Harley, R.A.; Tonse, S.; Goldstein, A.H.; Millet, D.; Schade, G. 2008. "VOC Reactivity in Central California: Comparing an Air Quality Model to Ground-Based Measurements." *Atmospheric Chemistry and Physics* 8, 351-368.

Thuiller, W. 2003. "BIOMOD—Optimizing Predictions of Species Distributions and Projecting Potential Future Shifts Under Global Change." *Global Change Biology* 9(10): 1353-1362.

Trenberth, K. et al. 2007. Observations: Surface and Atmospheric Climate Change. In: *Climate Change 2007. The Physical Science Basis*. Contribution of WG 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [S. Solomon et al., eds.], Cambridge University Press. Cambridge, U. K., and New York, NY, USA, 235-336.

United States Global Change Research Program. 2001. *Our Changing Planet*. A Report by the Subcommittee on Global Change Research, Committee on Environment and Natural Resources of the National Science and Technology Council. A Supplement to the President's Fiscal Year 2002 Budget. 83 pages.

———. 2002. *Our Changing Planet*. A Report by the Subcommittee on Global Change Research, Committee on Environment and Natural Resources of the National Science and Technology Council. A Supplement to the President's Fiscal Year 2003 Budget. 132 pages.

Vicuna S., Leonardson, R., Dale, L., Hanemann M., Dracup, J. 2008. "Climate Change Impacts on High Elevation Hydropower Generation in California's Sierra Nevada: A Case Study in the Upper American River." *Climatic Change* 87(Suppl. 1): 123-138.

Westerling, A.L., B. P. Bryant, H.K. Preisler, H G. Hidalgo, and T. Das. 2008. "Climate Change, Growth, and California Wildfire." Draft Paper. 2008 Assessment Report.

CHAPTER II

2 Economic Impacts of Climate Change on California

2.1 Introduction

This chapter summarizes the recent assessments of economic impacts of climate change on California. The assessments focus on the economic valuation of the physical impacts described in the previous chapter.. Consequently, this chapter is organized by those sectors, with an emphasis on putting dollar values on the changes anticipated under the A2 and B1 climate change scenarios discussed above. The A2 scenario represents a higher greenhouse gas (GHG) emissions scenario that may be described as "business as usual" and the B1 scenario is a lower emissions scenario resulting in far lower emissions by the end of the century (see Figure 1 in Chapter I).
By putting a dollar value on the physical impacts of climate change, we start to understand in economic terms the cost associated with climate change if no corrective actions are taken versus the value of global action to reduce greenhouse gas GHG emissions.
These assessments are in the early stages of development and are expected to evolve as improved data and methods are developed. Nevertheless, this current assessment demonstrates that climate change poses significant monetary risks for California. The value of reducing global emissions is substantial. Even when levels of emissions drop, the monetary impacts remain significant, highlighting the need for effective adaptation policies as part of the State's response to the climate change challenge.

An overview is given of the methodology used to determine the monetary value of the physical impacts of climate change, the economic impact assessments from various sectors, and other areas that remain to be assessed.

2.2 Economic Valuations

The concept of economic valuation, representing the consequences of climate change through a monetary measure, has been the subject of significant research and also some controversy both technically over appropriate measures and methodologies, and philosophically. For example, some ecologists argue that it is not proper to equate economics with morality and that "[i]n fact, we should not take costs into account in setting environmental (or other) objectives, but we should take costs into account when considering how to implement moral objectives and policies".[4] There is a limited amount

[4] Roughgarden (1998).

of funds, however, to spend in combating climate change. The monetary value of avoiding actions to reduce greenhouse gas emissions versus taking initiatives to reduce emissions are undertaken in this report.

Economic valuation measures in monetary terms the value that people place on things. The value is characterized through a monetary amount that is equivalent, in terms of its effect on the person's wellbeing, to the item in question. There are two ways to formulate what is equivalent: the most that the person would be willing to pay (WTP) to obtain the item, known as the WTP measure of equivalence; and the minimum compensation that the person would be willing to accept (WTA) to forego the item, known as the WTA measure of equivalence.

The physical impacts of climate change may create changes in markets for suppliers and consumers of goods and services. Conceptually, there are four possible types of change: a change in income; a change in the price of commodity or input; a change in the quality of a commodity or input; and or in availability. A heat wave in an agricultural area that damages or kills crops could be conceptualized as a loss of income for farmers and farm workers; an increase in prices of crops for consumers; a reduction in quality (grapes are still available but the heat harmed their quality); or a reduction in quantity of grapes available for the market.

Climate change may also produce impacts that are not reflected in markets, such as effects on human health and mortality, the loss of amenity from the environment, and impacts on ecosystems and species. While there may also be market effects associated with these changes, by themselves the items are not things that can be purchased in a market.

Replacement cost must also be considered, particularly for non-market impacts. In some cases it is possible to take actions to replace the non-market items lost. For example, if a population of birds is injured or killed, it may be possible to protect an existing threatened and declining population of a similar bird so that its population grows. Or it may be possible to create a new habitat at another location to increase its population.

The concept of replacement cost needs to be treated with care. In many cases it may not be possible to replace the non-market item lost; hence, there has arisen the notion of "replacement of like kind" – the replacement is something that is different, but similar. However, similarity is in the eye the beholder, and what is a meaningful replacement of that which is lost is a matter of judgment.

When assessing damage, a common principle in law is that the appropriate compensation is the lesser of the value of the item damaged and the cost of replacing it. If it can be replaced inexpensively – if the replacement cost is the lesser of the two – then it is appropriate to provide the cost of replacement as the means of making the item's owner (e.g., society) whole. If the item cannot readily be replaced, or the cost of replacement is the greater of the two, then the appropriate compensation is the value the owner places on the lost item. In the context of damages from climate change, it is not clear how readily it will be possible to replace the non-market damages; therefore, the empirical relevance of replacement costs is an open question.

In summary, as applied in this report, the economic cost of climate change may be thought of as the lesser of the replacement cost and the monetary value of the impact.

When the impact is a direct change in income, the change in income is itself the monetary value. For any other change, whether involving a market or non-market effect, the monetary value is based on the willingness to pay for the item or willingness to accept to forego the item.

2.3 Sectoral Economic Impacts [5]

This section summarizes what is known about potential economic impacts of climate change in California and describes the economic studies being conducted for the 2008 Assessment Report.[6]

The authors who prepared the economic evaluations for this report worked closely with the scientists conducting the impact studies. For example, Richard Howitt and Josué Medellín-Azuara (UC Davis) are using the estimated changes in crop yields reported in Chapter I in their economic valuations for the agricultural sector. Peter Gleick (Pacific Institute) and colleagues are using Noah Knowles' sea-level rise projections and flood-related inundation to estimate economic impacts of future flooding on San Francisco Bay urban areas, while Linwood Pendleton (UCLA) and colleagues are using beach width loss projections along various erosion hotspots (developed by Adams and Inman) to estimate impacts on beach going-related economic expenditures along Southern California beaches.

The assessment uses two global GHG emission scenarios commonly used in climate impact studies to estimate the potential physical and economic impacts of climate change on California. Most studies conducted for this assessment used the higher A2 (business-as-usual emissions) scenario and the B1 (low emission scenario) (see Figure 1 in Chapter I). The A1Fi scenario would have been an even higher emissions scenario, bracketing even more of the plausible future emissions pathways, but the Intergovernmental Panel on Climate Change (IPCC) did not require model runs using the A1Fi scenario from the different research groups maintaining global climate models for the 2007 IPCC Fourth Assessment. Therefore, detailed climate projections are not available for that scenario from most modeling groups and thus could not be downscaled to California.

[5] The reader should be aware that Chapter II summarizes a series of technical papers in the final stages of peer-review and, therefore, final results may differ from what is presented in this chapter.

[6] This chapter refers to an exploratory study released in 2003 and funded by the Energy Commission's Public Interest Research (PIER) Program, a study which investigated the potential economic impacts of climate change in California. For simplicity, this study is referred in this chapter as the 2003 Assessment (Wilson et al. 2003).

The B1 scenario (low emission scenario), while not explicitly reflecting global climate policies, has been used in past studies as a proxy for a "policy" scenario in which policies are assumed to be implemented with the goal of substantially reducing GHG emissions at the global scale. Some explicit policy scenarios have been developed but unfortunately, again, modeling groups have not been required to run such an alternative lower emissions "policy" scenario. For this reason, the 2008 Assessment uses the B1 scenario as a proxy to estimate impacts assuming the implementation of strong programs designed to reduce global GHG emissions.

As indicated in Chapter I, Scripps developed 12 climate change scenarios using the outputs from six global climate models covering both the A2 (business as usual emissions) and B1 scenarios. Considering the resources required for the different impact studies, the researchers in charge of the different studies used a subset of the 12 available climate scenarios. In addition, some studies focused on specified time periods, such as 2050 or the end of this century. For this reason, the reported economic impacts do not cover the entire range of potential scenarios and timeframes.

2.3.1 Economic Impacts on Agriculture

Agriculture is not only the most heavily studied sector in the climate economics literature, but also the most controversial in terms of the range of divergent impact estimates. Most studies in the past suggest that climate change would benefit this sector of the U.S. economy, while some more recent studies suggest that this may not be the case. One factor contributing to the divergence in estimates is the sheer complexity of the interactions between climate and crop growth; these interactions involve temperature, carbon dioxide; crop water needs, pests, weeds and ozone.

Temperature influences crop growth through its impact on photosynthesis, respiration, and serves as a controlling factor for key plant development processes, such as blooming and fruit setting.[7] It affects both crop yield and crop quality. The effects are not unidirectional. Yield generally increases at first as temperature rises but then both yield and quality decline. Moreover, different crop processes react to different aspects of temperature. Photosynthesis, by which a plant manufactures carbohydrates, occurs during daylight hours and increases with daytime temperature (i.e., daily maximum temperature). Respiration, which consumes plant carbohydrates, occurs during day and night, and therefore increases with nighttime temperature (typically, the daily minimum temperature). If the latter increases more than the former, the net effect can be a reduction in yield.[8] For some perennial crops, a beneficial consequence of warming is

[7] Besides crops, livestock are also affected by temperature. For example, high temperature stresses dairy cows, reducing milk production and reproductive success.

[8] Since 1980, nighttime temperature has increased about three times as much as daytime temperature, and in some areas there has been a reduction in yield over this period for some

the reduced probability of frost damage. But the opposite effect also can occur with fruit trees, which typically need a certain number of hours of winter chill each year for flowering and for fruit to set.

CO_2 itself is the prime substrate for photosynthesis. For most plants, photosynthesis increases when the atmospheric concentration of CO_2 rises. However, the amount of this fertilization effect is still uncertain: it has been well demonstrated in controlled environments such as growth chambers, but there are few studies in more realistic field settings. Some recent research suggests that the yield increase under fully open air conditions at an agronomic scale may be only one-third to one-quarter as large as assumed in many previous climate impact assessments (Long et al. 2005, 2006).[9] For some crops, it is not certain whether the increase in growth translates into a corresponding increase in the yield of the economically valuable product of the plant, such as the seeds or the fruit. Some crops, such as strawberries, may benefit in quality from an increase in CO_2. For others, there may be a reduction. For instance, a decrease in the bread-making quality of wheat.[10]

Climate also affects a plant's need for water. Higher levels of atmospheric CO_2 induce plants to close the small leaf openings through which water vapor is released, thus reducing the need for water. However, higher temperatures can increase a plant's water requirement.

In addition to the direct effect on the plant, climate affects the biotic environment surrounding the desirable crop, including weeds that compete with the crop for sunlight, water and soil nutrients, and insect pests and microbial pathogens such as viruses, bacteria, and fungi that influence plant growth. In some cases, the carbon fertilization effect will benefit weeds more than the crop itself, leading to a net reduction in yield (and/or increasing cost to the farmer fighting the growing weed or pest problems). Changes in temperature and precipitation may affect the range of plant pests, leading to an impact on yield.[11]

---

crops such as wheat, maize and barley (Peng et al. 2004; Lobell and Ortiz-Monasterio 2007; Lobell and Field 2007).

[9] Based on this work, Cline (2007) suggests a weighted average increment in global agricultural yield from carbon fertilization of 9% at 550 ppm, and 15% at 750 ppm, which is the level associated with the A2 emission scenario by 2100. Tubiello and Fischer (2007) argue that Long et al. (2006) overstate the difference between their findings and the previous literature. Cline's estimate of the yield effect is consistent with the preferred crop model cited by Tubiello and Fischer, but is lower than most estimates in the existing literature.

[10] Pritchard and Amthor (2005).

[11] A recent study in California suggests that range expansion of plant pests is likely to be more significant than range contraction. An example is pink bollworm, a major cotton pest. The pink bollworm's range is limited by winter frosts that kill over-wintering dormant larvae. As

Another environmental factor is groundlevel ozone, which is formed through the action of sunlight on volatile organic compounds in the presence of nitrogen dioxide. High ozone levels are harmful to crop plants, and ozone is likely to increase with higher summertime temperatures.[12]

In short, the potential effects of climate change on agricultural production are complex, non-linear, and multidimensional. Perhaps not surprisingly, the impact has been treated in a fairly simplified manner in most of the existing economic analyses.

In California, the first study of the potential impact of climate change in the agricultural sector was conducted by Howitt et al. (2003) as part of the 2003 Assessment. He used an earlier version of his Statewide Agricultural Production (SWAP) optimization model modified to consider potential gains in yields due to technical progress in the 21st century and econometric relationships between crop yields and growing season temperatures. His study also considered the effect of water availability as suggested by the CALifornia Value Integrated Network (CALVIN) model. He concluded that economic impacts would be relatively modest assuming that farmers are able to switch from such low-value high water demand crops (e.g., alfalfa) to high-value crops (e.g., vegetables) and are enticed to sell some of their water "rights" to urban centers. The statewide assessment, however, masked some large regional differences in expected impacts. For example, farm income goes down substantially in Palo Verde[13] and in some counties in the Sacramento Valley according to this study.

For the 2008 Assessment, three methods are being used to estimate economic impacts given the complex nature of this problem. The assessment used as much as possible improved estimated changes in yields provided by Lee et al. (2008) (see Chapter I) for annual crops and Lobell and Field (2008) for perennial crops (see Chapter I). An advantage of the new yield estimates is that the researchers are now considering not only the effect of temperatures during the growing season but also additional meteorological parameters that are known to affect yields, such as low temperatures in the winter and spring for perennial crops such as almonds.

The first study, by Costello et al. (2008), involved the use of annual county-level data on agricultural profits and crop yields to estimate the impact of weather and climate change on agricultural sector production in California. The basic methodology involves two distinct steps. In the first step, they developed statistical models relating profits and yields to weather across counties and years. Special attention is devoted to fitting models that allow for nonlinearities and for the diverse agricultural practices in California (e.g., perennials and annual crops). In the second step, they used the estimated

---

temperatures rise, winter frosts will decrease, greatly increasing the survival and subsequent spread of the pest throughout the state (Gutierrez et al. 2008).

[12] Elevated ozone levels are also harmful to human health, especially for asthma.

[13] Palo Verde is an agricultural region in Imperial County, California.

statistical models to project the impacts of climate change on the agricultural sector. In principle the model takes into account the effect of increased temperatures on pest control, farmers' behavior adapting to higher temperatures, and other factors already implicitly accounted for in the historical data sets. Because the models are estimated based on historical variations in weather data, they cannot, however, capture the potential impacts of persistent changes in meteorological conditions that would be expected under climate change. For example, the implications of sustained elevated ozone levels or expanded ranges of pests and plant disease due to climate change are not reflected in the historical data.

According to Costello et al. (2008), the aggregate economic impacts of the production changes are positive and the magnitude of the impacts grows with the time horizon of the projection. Over the 2010-2039, 2040-2069, and 2070–2099 periods, the projected impact are +$0.5, +$1.5, and +$2.3 billions of dollars (2006 dollars), respectively for the A2 scenario as simulated with downscaled outputs from the National Center for Atmospheric Research's (NCAR) global Community Climate Model (CCSM) . The corresponding estimates for the B1 scenario are +$0.6, +$0.8, and +$1 billion dollars. The authors noted that their results are contingent on the assumption of continued availability of irrigation water in the 21st century, as the analysis does not consider potential future water supply constraints or increased costs of irrigation.

The second study, by Howitt et al. (2008), explored the likely statewide economic costs of climate-related agricultural yield changes in California by 2050, using the SWAP Model. The SWAP model assumes farming units in California aim to maximize net profits from agricultural production. As indicated before, evidence from other studies reported in Chapter I suggests a warmer-drier climate in California may reduce crop yields over the long run. Yield losses estimated in these studies are used in SWAP to calculate losses for selected crop groups in California. The base regional cropping pattern is established using geo-referenced data on land use from the California Department of Water Resources. In addition, average production cost information from the University of California Agricultural Cooperative Extension was used. SWAP also takes into account estimates of agricultural land conversion to urban uses, technological change, and expected crop prices by year 2050. An offsetting effect may result from agricultural crop price increases as a result of decreased production and reduced yields which are considered by the SWAP model. However, for crops traded on a global market such as grain, rice, and corn, shifts in demand can be directly related to changes in world prices, which are exogenous to SWAP.

To consider the availability of water for the agricultural sector, the researchers used results from Medellín-Azuara et al. (2008). Medellín-Azuara et al. simulated the water system in California with the CALVIN model driven by the climate projections generated by the Geophysical Fluid Dynamics Laboratory (GFDL) global climate model under the A2 global emission scenario (warm-dry scenario, see Chapter I). According to Howitt et al., there would be significant reductions in irrigated acres, ranging regionally from 14 percent to 28 percent, and 8.9 percent to 15.3 percent reductions in revenues due to partial offsets from price and crop changes. According to SWAP, total California

agricultural revenues in 2050 would be $22.6 billion, down from $25.5 without climate change (a net loss of about $3 billion per year in 2006 dollars). Table 1 shows the estimated percent changes in price, production, and revenues in 2050 as estimated by the SWAP model. The results reflect crop substitution in response to climate change, a type of adaptation to changing conditions. Large reductions occur in pasture and rice--water intensive activities that have seen recent declines in California. As would be expected, the crops most heavily affected are water-intensive or low-value.

Table 1

Percentage Change in Price, Production, and Revenue in 2050

(From Historical to Future Conditions under Climate Change: GFDL A2 scenario)

Crop Group	% Change Price ($/Ton)	% Change Production (Tons)	% Change Revenues
Alfalfa	-5.56%	9.39%	3.94%
Citrus	18.51%	-25.47%	-7.55%
Corn	0.02%	-24.31%	-23.65%
Cotton	1.54%	-22.32%	-19.90%
Field	0.06%	-46.01%	-44.31%
Grains	0.06%	-39.79%	-40.10%
Grapes	4.05%	-11.16%	-7.77%
Orchards	22.14%	-21.68%	-4.11%
Pasture	0.04%	-87.79%	-87.78%
Rice	1.80%	-31.36%	-27.45%
Tomato	-0.24%	0.71%	0.45%
Truck	3.13%	-14.20%	-11.33%

Source: Howitt et al. (2008)

The third study by Joyce et al. (2008) makes use of the results generated by Chung et al. (2008) using the CalSim-II model to estimate the availability of surface water to agricultural users in the Central Valley and urban users in the South Coast hydrological region. Unlike the other studies, the analysis of these data is explicitly probabilistic. The time series of outputs generated by CalSim-II are not treated as deterministic but, instead, as realizations of a random variable from which an empirical probability distribution can be derived.

For the analysis of agricultural users in the Central Valley, the economic metric used is net revenue (profit), as opposed to gross revenue. By 2085, the median annual net revenue of Central Valley agricultural producers is projected to decline by $128 million annually under the GFDL A2 scenario, compared with $72 million under the GFDL B1

scenario. With the PCM A2 scenario, it is projected to decline by $14 million annually, while with the PCM B1 scenario it is projected to increase by $8 million. In some of the lower decile years, the reductions in net revenue are more pronounced.

Table 2 summarizes the estimated statewide economic impacts for this sector using the results of the more complete study of Howitt et al. (2008). However, since this study only simulated the A2 scenario; impacts for the B1 scenario were estimated using the results from Hanemann et al. (2008), which suggest a halving of costs under the B1 scenario. The A2 impacts would represent a contraction of about 11 percent from the no climate change conditions in the agricultural sector in 2050.

Table 2

Potential Revenue Losses to the Crop Sector ($billion/year)

Climate Scenario	2050	2085
A2	3.0	>3.0
B1	1.5	>1.5

Scenario A2 estimates from Howitt et al. (2008).

Scenario B1 estimates are 50 percent of the A2 estimates based on Hanemann et al. (2008).

Estimates include crop substitution in response to changing conditions over time, but exclude impacts on livestock. Estimates also do not consider impacts due to sustained increases in ozone levels, or expanded ranges of pests and crop diseases.

There are several caveats to the results presented in Table 2. For example, potential increases in costs to combat the effects of pests are not included. Reductions in revenues to dairy production or animal operations due to reduced productivity with higher temperatures and possible cost for adaptive measures were also not estimated. It is also reasonable to expect transition costs, such as those incurred when shifting perennial crops to new areas. But they were not considered in these estimates.

2.3.2 Economic Impacts on Forestry

Early studies on the potential impacts of climate change in the U.S. timber industry suggested that timber growth would be reduced with subsequent economic losses to U.S. producers and landowners (Perez-Garcia et al. 1997). However, a subsequent study by Sohngen et al. (2001) concluded that under the assumption of “perfect

adaptation"[14], landowners would switch to different timber species to accommodate a changing climate, thereby continuing to produce economic benefits. The net result would be a positive outcome for relatively small increases in temperatures in B1 scenarios, but negative for larger climate changes, as in A2 scenarios. For the Southwest, a region that includes California and other states, the net effect seems to be positive for landowners under these adaptation assumptions. The authors cautioned that the results are limited by the fact that the study did not consider the impact of changes in global timber markets on consumers. These impacts are important to consider because some studies suggest that future global timber prices are likely to be heavily influenced by timber production outside the United States. If global timber prices go down, consumers benefit, but US timber producers may register declines in revenue. Mendelsohn (2003b) performed a similar study for California for the 2003 Assessment Report. His study relied on an ecological model to predict changes in ecosystems from transient climate scenarios (Lenihan et al. 2003). For each climate scenario, a dynamic vegetation model predicted changes in productivity and vegetation patterns.

Mendelsohn used these projected changes to estimate how forest composition and productivity would change at a county level. Forest changes, in turn, were used to predict the impact on harvesting and planting of softwood forests in each county from 2000 through 2100. The study suggests that, at first, climate change increases harvests by stimulating growth in the standing forest. In the long run, these productivity increases are offset by reductions in the size of the area where productive softwoods can grow. Mendelsohn assumed that there would be large global timber price reductions leading to economic losses to California timber producers of more than $1 billion.

The 2008 Assessment Report included two economic studies conducted for the forest sector. The first study, by Hannah et al. (2008a), built and improved upon the approach used by Mendelsohn (2003b). Among the innovative features of their study are the use of species range shift models that have been under development for the last three years at UC Santa Barbara (Hannah et al. 2008b) coupled with a process model known as 3-PG (Physiological Principles for Predicting Growth), a general forest productivity model (see Chapter I) and dynamic optimization within the economic model.

Hannah et al. (2008a) found that "climate change will result in an overall decline in the value of harvested timber in the state, with decreases of [between] 4.9 percent [and] 8.5 percent, depending on climate change scenario and management option." An important driver of their findings is that in addition to impacts on tree growth, climate change is expected to cause downward pressure on global timber prices. As a result, future timber prices are forecast to increase more slowly under climate change as compared to a no climate change baseline (see Figure 1). In some California locations, strong losses in timber revenue coincide with projected pressure for land conversion to other uses, such as housing. These spatial effects are more significant than statewide averages, and

[14] Perfect adaptation means perfect foresight, perfect information, and everybody responding like an economic rational person.

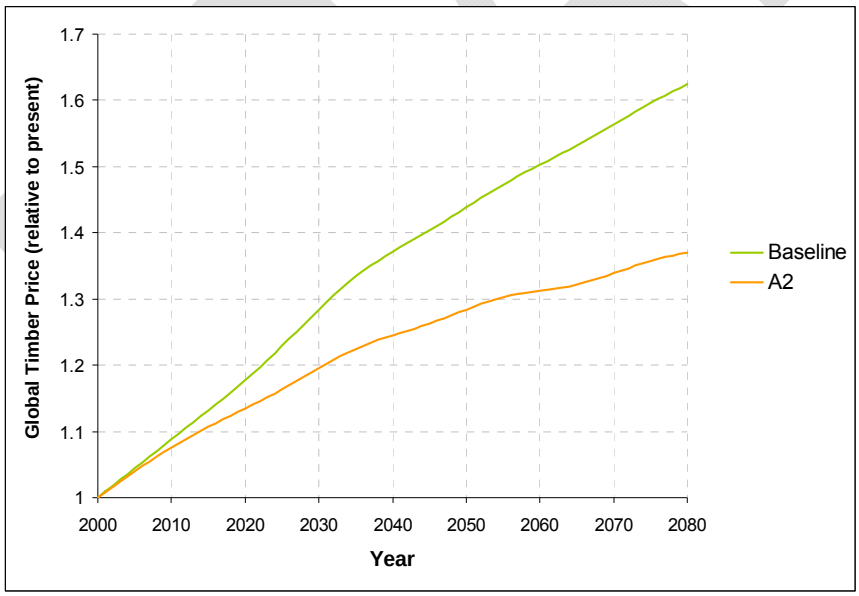
may result in loss of timberland to competing uses. Policy intervention to retain timberlands for production and recreation might include carbon pricing, which would soften the potential revenue declines in all areas.

The reported impacts represent statewide averages, which range from significant gains to major losses depending on global timber price responses to climate change. A significant decrease in the rise in global timber prices is expected due to increased global productivity with warming, especially in high latitude forests. This results in revenue losses in California by the end of the century based on the A2 scenario.

In the absence of price effects of climate change, most timber producing locations in California would see net benefits. In the B1 scenario, prices are assumed to be closer to the baseline (unaffected by climate change) case, resulting in revenue gains across the state, due to rising productivity. This is in principle in agreement with the findings from Battles et al. (2008) who simulated growth of a commercial pine plantation during a 50-year management cycle for 18 climate realizations and predicted increases in yield as measured in total tree volume. It supports the assumption that under more severe climate change, global timber productivity would rise, depressing prices.

Figure 1

Potential Relative Global Timber Prices



Adapted from Sohngsen et al., 2001

The second study, by Bryant and Westerling (2008) provides estimates for the potential effect of changing wildfire patterns for populations and households throughout California. By linking spatial scenarios for climate-related changes in wildfire probability to spatial scenarios for population growth, the researchers generated scenario-specific

expected values and estimated bounds on the damages from wildfires. Bryant and Westerling used the increased fire risks that they developed for the 2008 Assessment (see Chapter I) to estimate the expected number of housing structures likely to be damaged by future wildfires, and (more tenuous but illustrative estimates) of monetary losses associated with housing destruction. Their findings suggest that there may not be much of a discernable difference in damages between the A2 and B1 scenarios until the second part of this century with the range of results (minimum and maximum values) reported in Table 3. A substantial portion of the increased economic loss is driven by the assumed increase in exposed value due to population growth and development in fire-prone areas.

Table 3 presents the results for this sector (Hannah et al. and Bryant and Westerling) where economic losses are in relation to the revenues that land owners would realize in the absence of climate change.

Table 3

Loss in Undiscounted Cumulative Net Revenue from Timber Production in California
and
Annual Damages from Forest Fires on Housing Units

(Loss in Undiscounted Cumulative Revenue in $billion; Fire Damages in $billion/year)

Climate Scenario	Impact	2050	2085
A2	Timber Revenue	-0.4 to 3.4	4.2 to 8.0
	Forest Fires	0.2 to 2.3	0.7 to 14
B1	Timber Revenue	- 2.2 to -1.3	
	Forest Fires	0.2 to 2.5	0.5 to 11

Negative numbers represent gains.

Estimates for undiscounted cumulative timber revenue from Hannah et al., (2008). Losses calculated from 2000 through 2050 or 2080.

Estimates for annual damages from forest fires from Bryant and Westerling (2008) for 2050 and 2085.

Estimates do not include impacts from expanded ranges of pests or disease.

Forest fires damages reflect only potential impacts on housing units.

2.3.3 Economic Impacts on Water

Three quarters of the fresh water used in the United States comes from surface water rather than groundwater and, therefore, depends directly on current precipitation. One might thus be inclined to assume that, with climate change, water supply will change by whatever is the change in total annual precipitation. This assumption, however, is overly simplistic because in some regions temperature increases and accelerating sea-level rise affect water supply additionally or even more profoundly than precipitation. Temperature affects both the timing and volume of runoff. In mountain areas, including California and the Pacific Northwest, it affects whether precipitation falls as rain or snow, whether it runs off immediately or is stored as snow, and when the snow melts. It also affects the ground cover in a watershed, which in turn influences runoff. In forested areas, for example, the combination of higher temperature and dryer soil could cause more frequent or intense wildfires, reducing forest cover, lowering moisture retention, and accelerating runoff. Because of the water consumed by ground cover, Nash and Gleick (1993) found that, if the temperature in the Colorado River Basin increased by 4 °C (7.2 °F) with no change in precipitation, this would reduce the mean annual runoff there by nearly 20 percent.

What matters economically, however, is not just total runoff but also its timing. For agriculture in rainfall areas, the key variables are the available soil moisture at the time of planting plus precipitation during the growing season.

At the national level, there are both positive and negative estimates of the economic impact of climate change on U.S. water supply. For example, a negative figure comes from Hurd et al. (1999) who estimated an annual loss of about $15 billion by 2100. A more positive potential outcome is represented by Frederick and Schwarz (1999) who projected negligible economic impact in part because one of their climate scenarios assumed substantial increases in precipitation and water supply for most of the United States.

The 2003 assessment included a study by Lund et al. (2003) applying the CALifornia Value Integrated Network (CALVIN) model to the Hadley Climate Model (HadCM2) and NCAR's Parallel Climate Model (PCM 2) simulations of the IS92a[15] emissions scenario. The PCM model estimates were distinctly drier than the Hadley model estimates, and thus resulted in some significant water scarcity by 2100 under that scenario. The CALVIN model makes several assumptions which can be regarded as best-case adaptive responses to climate change. It assumes perfect foresight regarding future streamflow and water supply over the stretch of years simulated, and it assumes well quantified and totally fungible water rights, so there is no legal or institutional impediment to water market exchanges. Because the marginal willingness of urban water users to pay for water exchanges is much higher than that of agricultural water

[15] IS92is a global emissions scenario that was developed for the Intergovernmental Panel on Climate Change in the early 1990s.

users, the model handles all shortages by assuming water markets re-allocate water to urban uses, leaving only agricultural use unfulfilled.

For the present report, Medellín-Azuara and collaborators applied the CALVIN model to analyze water supply adaptation strategies under two climate change scenarios and 2050 levels of development. The first scenario explored a warmer-drier climate with high greenhouse g emissions levels (A2 scenario) and low precipitation levels as estimated by the Geophysical Fluid Dynamics Laboratory (GFDL) global climate model. The second climate scenario (warmer-only) resembles historic overall levels of precipitation but includes seasonal shifts as suggested by the GFDL model. Results suggest that significant adaptations will be necessary in both the warmer-drier scenario and the warmer-only scenario.

Increased water scarcity is expected to occur due to the drier climate in the warmer-drier scenario, with increasing competition among water uses. Early snowmelt and peak storage characterize both scenarios in California. In the warmer-only scenario, water scarcity costs are projected to be significantly less than for the warmer-drier scenario. However, significant losses to high-elevation hydropower may also occur under the warmer-drier scenario. Wider ranges of groundwater and surface water storage levels for the warmer-drier scenario suggest conjunctive use operations may be a promising adaptation strategy for some regions of California. The combination of perfect foresight and perfect markets would minimize the projected economic loss from river runoff shifts induced by climate change. Thus, in the drier GFDL scenario, perfect adaptation keeps the annual cost down to $243 million. This should be compared with the estimated annual cost of $83 million, taking into account only urban development without changes in climate. Therefore, the net economic loss due to climate change is a modest amount, about $160 million ($0.16 billion) annually.

Hanemann et al. (2008) conducted an analysis of impacts on urban water users in the South Coast region. Their study started by noting that population growth is expected to be the major driver of change over this century. With the population growth anticipated by 2085 and no improvement in urban water use efficiency, urban water use in the South Coast region would more than double, from 4.2 million acre-feet (MAF) in 2000 to 8.7 MAF in 2085. If per capita urban water use fell from the present level of 208 gallons per capita per day (gpcd) to 160 gpcd through increased use of efficiency measures, urban water use in 2085 would still be more than 50 percent larger than it is today, at 6.7 MAF. Rather than projecting the absolute level of urban water use with and without climate change, their analysis focused on the differential impact of climate change, assuming that the region has secured adequate supplies to meet the needs created by future population growth.

Because of hydrologic uncertainty and physical and institutional limits to the amount of water that can be transferred from agriculture on a spot market basis, it is likely that drought emergencies and water shortages will not be eliminated in the South Coast region. The analysis was calibrated to a no-climate change baseline of shortages

occurring with a probability of 16 percent, or 13 times in 81 years. By 2085, without additional supplies, the probability of a shortage increases to 51 percent under the GFDL A2 scenario, and 42 percent under the GFDL B1 scenario. By contrast, it increases to 21 percent with PCM A2, but under PCM B1 declines to 15 percent. Generally, it is assumed, however, that the region will obtain additional supplies to reduce the occurrence of severe drought. Under the scenarios considered, the region increases its permanent supply at an annual cost of $354 million. The economic metric of loss from water shortage in the South Coast region is the loss of short-run consumer surplus. The expected loss without climate change is $135 million per year. Under the GFDL A2 scenario in 2085, this annual loss rises to $562 million, an increase of $427 million (~$0.4 billion) per year. Under the GFDL B1 scenario, it increases by $135 million (~$0.14 billion) per year.

The California Department of Water Resources (DWR) and the Department of Fish and Game (DFG) have been charged by Assembly Bill 1200 to estimate the potential impacts of levee failures on water supplies. The Delta Risk Management Strategy (DRMS) team has been formed to provide, among other things, cost estimates for levee repair and maintenance, as well as economic cost estimates associated with hazardous events such as earthquakes, and impacts from climate change and a rise in sea level. DRMS issued a preliminary report in June 2007 and a final report was issued very recently – too recently for the information to be incorporate here. The information from the final report will be used in a future analysis to estimate the costs associated with a failure of the Sacramento-San Joaquin Delta levee system due to increased flood (hydrologic) risk from climate change impacts—sea level rise and changes in seasonal runoff.

In summary, the three studies commissioned for the 2008 Assessment Report describe relatively modest impacts of climate change on the water sector when perfect foresight and adaptation are assumed. This is a surprising result given the expected substantial changes in snow pack in the Sierra Nevada and the shift of river runoff timing with more natural runoff occurring in the winter and less in the spring and summer seasons. Part of the explanation may lie in the fact that the changes in streamflow projections from the current downscaled climate scenarios are significantly smaller than they were in the projections used in the 2006 scenarios project. The result may also reflect the flexible water infrastructure in California that is able to store water in the winter time for use in the dry hot months of the years and transport the water where it is needed.

The added risk of a major failure of the levee system in the Sacramento/San Joaquin Delta due to accelerated sea level rise, however, increases the potential negative economic impacts, as shown in Table 4 below.

Table 4

Potential Economic Costs to the Water System[16]

($billion/year for Water Supply and $billions due to the Failure of the Delta System)

Climate Scenario	Impact	2050	2085
A2	Water supply Delta failure	<0.16	<0.4
B1	Water supply Delta failure		<0.14
Water supply impacts assume perfect foresight and adaptation. Delta failure costs are per failure event.			

The economic impacts reported in Table 4 do not consider the potential economic losses due to inland flooding. This may be a significant shortcoming because even under climate scenarios that show overall reductions in precipitation levels, winter runoff conditions are expected to exceed historical levels, increasing the probability of flooding.

2.3.4 Economic Impacts on Coastal Regions

Besides agriculture, the most extensive economic analysis of impacts of climate change in the United States is for sea level rise. The first analysis of the potential cost of sea level rise was conducted by Schneider and Chen (1980). Barth and Titus (1984) conducted an integrated analysis of two U.S. cities, incorporating adaptation strategies and examining decision-making following coastal disasters. Yohe (1989) and Smith and Tirpak (1989) built on this early work. The economic methodology was subsequently refined by Yohe et al. (1996) and Yohe and Schlesinger (1998). This methodology has become a commonly used framework for assessing the economic impacts of sea-level rise.

Schneider and Chen (1980) estimated the market value of taxable real property located in the coastal areas of the United States that would be inundated during a rise in sea level. This estimate subsequently was characterized as an assessment of vulnerability

[16] The numbers for water supply come from Hanemann et al. (2008) with the exception of the value for 2050 of $< $0.16 billion/year, which is derived from Lund et al. (2008) for the A2 scenario.

rather than damage because it ignores the possibility of adaptation, namely the construction of sea walls and other structures to prevent inundation or other measures (such as retreat) to reduce the risk from inundation to structures. Barth and Titus (1984) conducted an integrated analysis, combining climate change and sea-level rise scenarios to estimate physical impacts due to inundation and storm surge, and economic impacts on property. The cost and benefits of adaptation using erosion control, beach nourishment, and shoreline protection were examined, along with alternative development strategies. Their methods enabled them to estimate the economic value of anticipating sea level rise in development and shore protection investments.

The economic analysis of Yohe et al. (1996) assumed that sea walls would be constructed where and when this is economically justified. Where sea walls are constructed, the authors assumed that the construction would occur just when the sea level reaches the property at risk, and the only economic cost is the cost of this construction; this assumes that there is no flood damage either before or after the sea walls are constructed.. If a sea wall is not constructed, then the economic cost is the loss of the land and the damage to structures.

A consideration omitted from most analyses of damage from coastal inundation is the damage to infrastructure located along the coast. The coast is the location for a huge amount of infrastructure, including wastewater sewer and treatment plants, water supply (drinking water treatment and desalination facilities), utilities (natural gas, electricity and telephone lines), roads, airports, harbors, and other transportation infrastructure. This infrastructure is vulnerable to both storm surges and sea level rise. Hurricane Katrina destroyed, disabled, or damaged 172 wastewater treatment plants and about 1,000 water supply systems in Louisiana, Mississippi, and Alabama, with 90 percent of those systems still affected two weeks after the hurricane. Furthermore, even if sea walls are constructed, some of the coastal infrastructure will still need costly modifications to accommodate a higher sea level. For example, storm water and combined sewer outfalls will have to be modified to avoid sea water inflows that would disable wastewater treatment systems. None of these infrastructure costs are factored into existing economic assessments of the costs of climate change.

Another omitted consideration is environmental impacts. For example, Hurricane Katrina caused numerous petrochemical releases, and more than 7 million gallons of oil were spilled. In addition, a 40-mile chain of barrier islands was largely destroyed. Some of the environmental impacts of storm surges and sea level rise also have direct economic implications, such as the increased erosion of cliffs and beaches. Beach erosion may necessitate replenishment of the sand, which can be a substantial expense. Few studies have begun to estimate the cost and economic impact of beach loss and replenishment. Moreover, in the immediate aftermath of a storm event, before the sand has been replenished, there can be a heightened risk to coastal land and property and some curtailment of beach use, which itself entails a loss of economic value in the form of the public's willing to pay (WTP) for beach recreation.

As part of the 2003 Assessment, Neumann et al. (2003) performed a very limited study about the potential impact of climate change on coastal properties assuming the implementation of perfect adaptation strategies. The study estimated the cost of protecting low-lying developed coastal areas plus the value of land that is allowed to be inundated. No impacts were assumed at California's coastal cliffs or other coastal infrastructure. The authors examined scenarios where sea level rises linearly to 33 cm (~1 foot), 50 cm (~1.5 feet), 67 cm (~2 feet), and 100 cm (3.3 feet) by 2100, capturing a wide range of potential changes. The authors found that most of the low lying and exposed urban coastline has sufficiently high value to justify protection by sea walls.

The undiscounted cost of protecting vulnerable areas over the next 100 years was estimated to be approximately $700 million for a 50 cm (1.5 feet) sea level rise and $4.7 billion for a 1 m (3.3 feet) sea level rise.

The Neumann et al. (2003) study has several limitations, including the use of simplistic methods to estimate the cost of inland areas that would be affected by inundation, the assumption that cliffs will not be affected by sea-level rise, the failure to include valuation of ecological damages or infrastructure impacts, and the assumption that coastal properties would be protected as needed just in time. In addition, the authors used a rate of $935 per linear foot (in constant 2000 dollars) for sea wall protection in Southern California; however, the actual cost there today is already on the order of $6,000 per linear foot and may well increase further over the considered time period.

For the 2008 Assessment two coastal economic impacts studies were commissioned in an attempt to address some of the limitations of the prior studies mentioned above.

The first study by Heberger et al. (2008) made use of the detailed inundation maps generated by Knowles (described in Chapter I) for the San Francisco Bay to update a study that the Pacific Institute conducted in 1990. In addition, they produced similar, if less detailed inundation maps for the open coast areas. This study examined the site-specific economic costs of a 100-year flooding event before and after a 140 cm (4.6 feet) sea level rise above 1990 levels (the high-end scenario of the estimated range produced for the 2008 Assessment Report)[17]. The GIS-based analysis used land use data, land and structural value inventories to project the areas and structures exposed to increased flooding if left unprotected by levees or if other adaptation strategies were not implemented. The study concludes that a 140 cm (4.6 feet) sea level rise will put 480,000 people at risk of a 100-year flood event, given today's population. A socio-economic analysis of those affected suggests that there is the likelihood of a disproportionate impact on low-income communities and those of color. A wide range of critical infrastructure, such as roads, hospitals, schools, emergency facilities, wastewater treatment plants, power plants, and more will also be at increased risk of

[17] An economic assessment for the B1 scenario was not undertaken in this study. The study assumed a linear increase in flood elevation levels by the projected 1.4 m (4.6 ft) of sea-level rise, though historical evidence suggests that mean higher high water (MHHW) has increased more than mean sea level.

inundation, as are vast areas of wetlands and other natural ecosystems. In addition, the cost of replacing property at risk of coastal flooding under this sea level rise scenario is estimated to be $100 billion (in 2000 dollars). An overwhelming two-thirds of that property is concentrated within the San Francisco Bay, indicating that this region is particularly vulnerable to impacts associated with sea level rise. Their study did not attempt to quantify the economic impact from economic and social disruption, such as interruption of traffic in ports or along coastal roads and highways, lost days at work, health impacts, impacts on migratory bird habitat, or other higher-order impacts to the economy and the environment, which can be serious during flooding events. Protecting vulnerable areas from flooding by building seawalls and levees will cost at least $14 billion (in 2000 dollars), with added maintenance costs of another $1.4 billion per year. Continued development in vulnerable areas will put additional areas at risk and raise protection costs.

Large sections of the Pacific coast are not vulnerable to flooding, but are highly susceptible to erosion. The study finds that a 140 cm meter sea level rise will accelerate erosion, resulting in a loss of 41 square miles (over 26,000 acres) of California's coast by 2100. A total of 14,000 people currently live in the area at risk of future erosion.

Additionally, significant transportation-related infrastructure and property are vulnerable to erosion. Statewide flood risk exceeds erosion risk, but in some counties and localities, coastal erosion poses a greater risk.

The second study, by Pendleton et al. (2008), builds on Adams and Inman's (2008) analysis described in Chapter I to examine the economic impact of climate change and sea-level rise on Southern California beaches (Los Angeles and Orange counties). The authors combined the estimates of beach width changes with a model of beach-going (using various socioeconomic and demographic scenarios) to assess the non-market and market impacts of beach loss. The beach visitation model used as inputs data on beach attributes, including width, travel costs, income, and demographic characteristics. The study compared the effects of gradual, cumulative beach width loss on the beach going public due to current rates of sea level rise and after accelerated sea level rise (up to 1 m or 3.3 feet) by 2100, as well as the effect of punctuated beach width loss from a year characterized by extreme erosional events (as predicted by Adams and Inman 2008). The authors also projected the costs of beach nourishment needed to mitigate these impacts, a likely first response to climate-related beach erosion, and compared the net benefits of inaction to the potential cost of attempts to counteract the effects of climate change on beaches. Their study found that the gradually increasing sea level by itself would cause a relatively small reduction in the total number of beach visits (if population and demographics are held constant at year 2000 levels). While sea-level rise could cause an *overall* reduction of the economic value in beach attendance, some beaches would experience increased visitation and value while others would lose value. They also found that the potential annual economic impacts, and the economic costs of adaptation through beach nourishment, are likely to be many times greater for wave-driven erosion events, especially from extreme storms, than if gradual sea level

rise over time is considered alone. The effects on one year of beach visitation caused by an extremely stormy year is likely to be similar in magnitude to the annual effects caused by a full meter of sea level rise. The economic impacts of both inundation and storm-related erosion are distributed unevenly across the region.

The estimated reduction of beach attendance is 600,000 people with reductions of annual expenditures by beach visitors $15 million and reductions of consumer surplus[18] of $63 million (year 2000 dollars) for a 1 m (3.3 feet) of sea level rise (total annual cost of $78 million or about $0.08 billion). If higher high tides result in stormier winters, the most important impact of sea level rise on the beach going economy may result from increased wintertime erosion. The authors estimate that a single extremely stormy year could result in a loss of $9 million in the first year following the stormy winter, with a loss reaching $25 million at some highly affected beaches. The loss in consumer surplus could equal $37 million for the region. If this analysis were done for all important coastal beach recreation areas in California, the total costs for the State would increase.

Table 5 below summarizes the findings described above.

DRAFT

[18] Many local visitors are able to enjoy the beach at little or no cost, but they still derive economic benefit from this "free" or at least "low cost" resource. Even though these beachgoers may not spend much on their beach visits, they still enjoy considerable economic benefit from the beach. This benefit beyond what people do pay is called the consumer surplus or non-market value of beaches and represents the willingness to pay to visit beaches, beyond what people actually do pay.

Table 5

Estimated Replacement Value of Property at Risk along all California Coasts due to Flooding ($billion) and Beach Recreation in Los Angeles and Orange Counties ($billions/year)

Climate Scenario	Impact	2050	2085
A2	Flooding: San Francisco Bay property at risk	36*	62**
	Flooding: Open coast property at risk		37**
	Southern California Beach Recreation annual loss	< 0.08	> 0.08
B1	Flooding: San Francisco Bay property at risk		49***
	Flooding: Open coast property at risk		
	Southern California Beach Recreation annual loss	<0.08	<0.08

* Estimate is based on a sea-level rise of 50 cm.
** Estimate is based on a sea-level rise of 140 cm.
*** Estimate is based on a sea-level rise of 100 cm.
The estimates for flooding in the San Francisco Bay come from Table 22 in Heberger et al. (2008). The open coast flooding estimate for 2085 comes from Table 21 in Heberger et al. 2008.
Pendleton reports a total cost of about ~$0.08 billion/year for 1 meter (3.3 ft) sea-level rise. To extrapolate this number, this analysis assumed that in 2050 sea level would always be below 1 meter (3.3 feet) for both the A2 and B1 scenarios. At the end of this century, sea-level rise would be higher than 1 meter for the A2 scenario and lower than 1 meter for the B1 scenario. Flooding estimates do not include potential costs of accelerated erosion, damage to infrastructure, or environmental impacts.

2.3.5 Economic Impacts on Energy

In the United States, space heating and cooling accounts for 54 percent of all energy used by residential and commercial users. Global warming has a mixed effect: it reduces the need for heating while raising the need for cooling. Whether the cost from increased cooling outweighs the savings from reduced heating is an empirical question that varies with location and depends on whether the energy affected is baseload or peak power and also the degree of warming. A key issue is how heating and cooling demand vary with temperature. For the United States, researchers have analyzed this

issue in different ways and have reached different conclusions, but the majority of the studies find increases in energy demand (cooling and heating) and energy expenditures. A recent study by the U.S. Climate Change Science Program confirms this overall finding for the nation.

In addition to the effect on demand, climate change can also affect the supply of energy when extreme weather events occur. During the 2003 heat wave in Europe, energy production in France's nuclear power stations fell because the river water was too hot for adequate cooling. In the United States, power plants discharging cooling water often face restrictions on the temperature of the discharge water and sometimes have to limit operations when the ambient air and water temperature become too high, notably along the Gulf of Mexico, but also in the Great Lakes Region. Extreme heat also lowers the carrying capacity of electricity transmission lines. Hurricanes, storms, and extreme weather conditions can disrupt the production and distribution of energy; Hurricanes Katrina and Rita in 2005 damaged about 50 pipelines and destroyed more than 100 offshore oil platforms, including a major platform out of production for eight months.[19]

The 2003 Assessment included a study by Mendelsohn (2003a) that used a cross-sectional analysis (which makes use of different geographical areas with different climates to estimate potential responses) to estimate potential changes in net energy expenditures in California. Mendelsohn used data for different regions in the United States including portions of California. He used total energy expenditures as he did not have separate expenditure data for cooling and heating. His results project that net energy expenditures would increase most in California and in the southeastern desert areas. The northern maritime and high alpine counties have the smallest projected changes in energy expenditures.

Mendelsohn (2003a) estimated that by 2100 residential net energy expenditures could increase from $1.6 billion (a 4 percent increase) to $10.2 billion (a 17 percent increase over his baseline) because of climate change. Increases in net energy expenditures are a result of the estimated increases for air conditioning that more than offset the decreases in expenditures for heating.[20]

The 2008 Assessment Report focused mainly on two economic impacts to the energy sector: 1) changes in electricity demand, and 2) potential changes in hydroelectricity generation. Other impacts, such as reduced costs due to lower heating demand during the cooler season of the year are not addressed.

As indicated in Chapter I, Auffhammer and Aroonruengsawat (2008) combined four years of residential billing data for California's three largest utilities with daily temperature, pricing information, and socio-economic data to estimate per-household

[19] http://www.nola.com/katrina/pdf/091806_lra_ritareport.pdf

[20] It should be noted that, in California, the energy used for wintertime heating is generally baseload power, while the energy used for summertime cooling is generally peak power, which is more expensive than baseload power.

temperature consumption response functions by climate zone for the residential sector (however, the resolution is at the level of U.S. mail zip code zones). The main advantage of this study is the use of California-specific data, which avoids the use of expenditure data from outside California as these states may not have the same level of energy efficiency requirements. The researchers only reported A2 and B1 scenario data for the National Center for Atmospheric Research's (NCAR) Parallel Climate Model (PCM). The authors estimated the changes in energy demand using the baseline population projections reported by Sanstad et al. (2008) and assuming constant per capita electricity consumption until the end of the century.[21] Under these conditions, total incremental annual electricity expenditures in the residential sector changed by -$0.3 and +$3.5 billion by 2050 and 2100, respectively under the B1 scenario. For the A2 scenario these costs were +$1.6 and +$15 billion, respectively.[22]

Hydropower generation in California comes from units associated with relatively large reservoirs (low elevation units) and units in high-elevations. Medellín-Azuara et al. (2008) reported very negligible changes in annual electricity generation from low-elevation units in part due to the fact that surface water reservoirs (behind dams) seem to be able to dampen the changes in the seasonal runoffs. For high-elevation hydropower units, Medellín-Azuara et al. (2008) reported up to 20 percent decreases in annual electricity generation for approximately 150 high-elevation hydropower units available in California. Total annual generation is a strong function of the amount of precipitation falling in California. As shown in Figure 4 in Chapter I, most global climate models used for this assessment suggest reductions in precipitation levels. If we assume a cost of generation of about five cents per kilowatt-hour, a reduction of 20 percent of electricity generation from high-elevation units would translate to an annual loss of about $1 billion.[23] Of course, the cost of electricity generation by the middle and the end of this century is highly uncertain so this number is, again, just an order of magnitude estimate.

[21] From Table 3 in Auffhammer et al. (2008) we selected the results from the BCSD downscaling model for the scenario with increase prices of electricity of 30 percent by 2020 and constant prices after that for the rest of the century.

[22] The econometric relationships developed by Auffhammer and Aroonruengsawat include electricity rates as one of the independent variables. If electricity prices remain constant, in real terms, over the course of this century, demand for electricity would be even higher.

[23] The average hydroelectricity generation in California from 1996 to 2006 was about 39.7 Gigawatt-hours. This study conservatively assumed that about 50 percent of this generation comes from high-elevation units (Medellín-Azuara et al. (2008) report that this number is roughly 74 percent).

Table 6 summarizes the estimated economic costs for the energy sector.

Table 6

Estimated Incremental Costs to the Residential Sector and Estimated Costs for the Purchase of Electricity to Compensate for the Reduction of Hydropower Generation ($billion/year)

Climate Scenario	Impact	2050	2085
A2	Electricity demand	1.6	15
	Hydropower generation		1
B1	Electricity demand	-0.3	3.5
	Hydropower generation		<1

Electricity demand impacts from Auffhammer and Aroonruengsawat (2008).

Hydropower generation impacts form Medellín-Azuara et al. (2008).

Negative numbers represent cost reductions (i.e., economic gains).

Estimates do not include potential increases in electricity demand for additional urban or agriculture groundwater pumping or for desalination or wastewater recycling in response to reduced surface water deliveries. Nor do they reflect any changes in the price for electricity.

2.3.6 Economic Impacts on Air Quality

Ozone levels vary from day to day depending on meteorological conditions. Increasing future temperatures due to global warming are expected to exacerbate the state's serious ozone problems. Recent studies by Steiner et al. (2006) and Millstein and Harley (2008) examined the impact of climate change on ozone in four major air basins (Sacramento Valley, San Francisco Bay Area, San Joaquin Valley, South Coast) in California, concluding that globally driven climate changes lead to ozone increases throughout the study areas. Both studies used an air quality model to predict the effects of future temperature perturbations and emission control on high-ozone episodes during the summer. Future temperature changes were predicted at high spatial resolution in

California for a scenario of doubled pre-industrial CO_2 concentrations (280 to 560 ppm) using results from a global and regional climate modeling study by Snyder et al. (2002).

Future emissions were predicted starting from the baseline emissions inventory, factoring in expected population growth and likely advances in future emission control technologies. The effect of the temperature changes on biogenic hydrocarbon emissions were estimated using a vegetation model. Increases in background levels of ozone, methane, and carbon monoxide were also estimated.

The two studies conclude that, by 2050, the effects of climate change may partially or completely offset the benefits of the Air Resources Board (ARB) and local district emission control programs on ambient levels of ozone, especially in the San Francisco Bay Area. This off-setting of air quality improvements by climate change-induced temperature changes is known as the "climate change penalty."

The Steiner et al. (2006) and Millstein and Harley (2008) studies used emission scaling factors to estimate 2050 man-made emissions relative to present-day conditions. Using the same emission scaling factors, ARB staff estimated that additional reductions of 900 tons per day of reactive organic gases (ROG) emissions and 500 tons per day of nitrogen oxides (NO_X) emissions, in excess of the 2007 State Implementation Plan (SIP) requirements, would be needed in these four heavily populated regions of the state to attain the federal eight-hour ozone standard. While ozone levels in other regions of California are also likely to be impacted by climate change, it was not possible to estimate the additional emission reductions required for those regions.

To assess the climate change penalty in these four regions, ARB staff assumed that the ozone episodes modeled were reasonably representative of ozone design values that drive SIPs. The per-unit cost and cost effectiveness of additional emission reductions needed to meet the Federal ozone standard in 2050 would be the same as those estimated for the 2007 SIP. The cost-effectiveness estimates used for the most recent SIP analysis averaged $12,500 per ton of ROG emissions reduced and $21,000 per ton of NO_X emissions reduced for the state and federal strategies (in 2006 dollars). By multiplying these cost-effectiveness estimates by the amount of emissions to be reduced, the total annual control costs of the additional reductions needed because of climate warming is estimated at about $8 billion per year by the middle of this century.

Climate change may also increase ambient levels of particulate matter (PM) in California. Additional research is underway to assess the impacts of future climate change on ambient PM in California.

2.3.7 Ecological Services

The study of the economic value of ecosystem goods and services emerged and matured over the past two decades, but economic impacts assessments on the

environment under different climate scenarios is still in its infancy. Only a few ecological services were examined by Shaw et al. (2008) for the 2008 Assessment but economic damage estimates due to the significant loss of species and biodiversity were not reported given the enormous scientific obstacles that have to be overcome to produce credible estimates. Thus, the expected results most likely severely underestimate the ecological impacts of climate change on economic activity in California and on quality of life.

As discussed in Chapter I (see Figure 10 there), Shaw et al. (2008) used a dynamic ecological model to estimate changes in above-ground carbon stocks in vegetation in California. The results are mixed: using the climate output produced by one climate model, the authors found an increase in carbon stock while estimating reductions when using the output from the other two climate models. The sequestration of carbon generates a direct market value, through the constructed markets for carbon emissions, as well as an indirect economic (and societal) value due to the fact that sequestered carbon does not contribute to climate change and thus generates a savings in foregone future damages. Shaw et al. (2008) reports a wide range of estimated economic impacts depending on what is assumed to be the cost of carbon in a future carbon market. Table 7 below views vegetation in California as a stock of carbon and summarizes the economic impacts on this stock as estimated from this study, assuming the price of carbon is $89.20 per metric ton($24.32 per ton of carbon dioxide), which is in agreement with recent prices (2008) in the European Union Emission Trading Scheme.

Table 7

Projected Economic Penalties due to Changes in Above-ground Carbon Stock ($billion/year)

Climate Scenario	2050	2085
A2	-2.3 to 11	-6.3 to 22
B1	-2.5 to 13	-8 to 11.8
Estimates from Shaw et al. (2008) include value of changes in carbon stock in forested ecosystems. Negative numbers are gains.		

2.3.8 Other Impacts Not Considered

Several impacts have not been considered here, such as the potential benefits from reduced energy demand for winter heating or the adverse economic impact on the ski industry due to the loss of snowpack. In addition, not considered was the impacts of climate change induced shifts in marine ecosystems and their impacts on California's recreational and commercial fishing industries, or the effects of extreme weather events on the transportation and construction sectors. No estimates are yet available for the small business sector in California or elsewhere on climate change impacts. The value of human health impacts is not included, such as the economic cost of heat-related morbidity and mortality. Several studies on human health impacts and the costs of climate impacts associated with heat events and particulate matter pollution are expected to be complete by the summer of 2009.

2.4 Summary and Caveats

As indicated in the beginning of this chapter, the understanding of the economic valuations of potential impacts due to climate change is uncertain and continues to evolve. This chapter updates our current understanding of the potential impacts of climate change on California and the direct economic costs. The basic conclusion is that climate change will impose substantial costs to Californians in the order of tens of billions of dollars annually, but that costs will be substantially lower if global emissions of greenhouse gases are curtailed to levels suggested by the B1 or an even lower emissions scenario.

Adaptation costs have only begun to be assessed. In some sectors they are significant, even for the B1 scenario, and increase substantially for the higher emissions scenario. While for other sectors, direct adaptation costs seem to be less costly. However, the full costs of climate change impacts and adaptation need further study. Moreover, the economic assessments undertaken to date do not consider indirect impacts of climate change or the cost of undesirable side effects of different adaptation options. For example, coastal armoring to protect coastal properties is a relatively low-cost option compared to the loss of property that would occur if sea levels were allowed to inundate developed land, but the ecological and distributional impacts have not been fully analyzed. In this case, years of further research both in the physical and economic sciences are needed, in addition to financial support.

2.5 References

Adams, P. and D. Inman (2008). Climate Change and Potential Hotspots of Coastal Erosion along the Southern California Coast. California Energy Commission, PIER Energy Related Environmental Research Program. CEC-500-2009-XXX. Forthcoming.

Auffhammer, M. and A. Aroonruengsawat, 2008. "Impacts of Climate Change on Residential Electricity Consumption: Evidence from Billing Data." Draft Paper. 2008 Assessment Report.

Barth, M. and J. Titus (eds.), 1984. *Greenhouse Effect and Sea Level Rise, A Challenge for This Generation*. Van Nostrand Reinhold Company, New York, 1984. Available for download at: http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsSLRChallenge.html.

Battles, J., T. Robards, A. Das, and W. Stewart, 2008. Projecting Climate Change Impacts on Forest Growth and Yield for California's Sierran Mixed Conifer Forests. California Energy Commission, PIER Energy Related Environmental Research Program. CEC-500-2009-XXX. Forthcoming.

Bryant, B. and A. Westerling, 2008. Potential effects of Climate Change on Residential Wildfire Risk in California. California Energy Commission, PIER Energy Related Environmental Research Program. CEC-500-2009-048-D.

Cayan, D., M. Tyree, M. Dettinger, H. Hidalgo, T. Das, E. Maurer, P. Bromirski, N. Graham, and R. Flick, 2008. Climate Change Scenarios and Sea Level Rise Estimates for the California 2008 Climate Change Scenarios Assessment. California Energy Commission, PIER Energy Related Environmental Research Program. CEC-500-2009-014-D.

Chung, F. and J. Anderson. 2008. "Using Future Climate Projections to Support Water Decision Making in California." Draft Paper. 2008 Assessment Report.

Cline, W.R. 2007. *Global Warming and Agriculture: Impact Estimates by Country*. Center for Global Development, Peterson Institute for International Economics. 186 pp.

Costello, C.J., O. Deschênes, and C.D. Kolstad. 2008."Economic Impacts of Climate Change on California Agriculture." Draft Paper. 2008 Assessment Report.

Delta Risk Management Study (DRMS), (2007). (to be provided).

Drechsler, D.M. ; Motallebi, N. ; Kleeman, M. ; Cayan, D. ; Hayhoe,K. ; Kalkstein, L.S. ; Miller, N.L. ; Jin, J. ; VanCuren, R.A., 2005. Public Health-Related Impacts of Climate Change in California, California Climate Change Center

Frederick, K.D. and G.E. Schwarz, 1999. "Socioeconomic Impacts of Climate Change on U.S. Water Supplies." *Journal of the American Water Resources Association* 35(6): 1563-1583.

Gutierrez, A. P., L. Ponti, T. d'Oultremont and C. K. Ellis, 2008. Climate change effects on poikilotherm tritrophic interactions. *Climatic Change* 87, Supplement 1 / March.

Hanemann, M., S. Stratton, N. Bush, and L. Dale, 2008. Climate Change Impacts to Urban and Agricultural Sectors in California. California Energy Commission, PIER Energy Related Environmental Research Program. CEC-500-2008-XXX. Forthcoming.

Hannah, L., C. Costello, C. Guo, L. Ries, C. Kolstad, N. Snider, 2008a. The Impact of Climate Change on California Timberlands. California Energy Commission, PIER Energy Related Environmental Research Program. CEC-500-2008-XXX. Forthcoming.

Hannah, L., G. Midgley, I. Davies, F. Davis, L. Ries, W. Thuiller, J. Thorne, C. Seo, D. Stoms, N. Snider, 2008b. BioMove - Improvements and Parameterization of a Hybrid Model for the Assessment of Climate Change Impacts on the Vegetation of California. California Energy Commission, PIER Energy Related Environmental Research Program. CEC-500-2008-060.

Heberger, M., H. Cooley, P. Herrera, P. Gleick, and E. Moore, 2008. The Impacts of Sea Level Rise on the California Coast. California Energy Commission, PIER Energy Related Environmental Research Program. CEC-500-2009-024-D.

Howitt, R., M. Tauber, and E. Pienaar, 2003. Appendix X: Impacts of Global Climate Change on California's Agricultural Water Demand. In *Global Climate Change and California: Potential Implications for Ecosystems, Health, and the Economy*. California Energy Commission, PIER Energy-Related Environmental Research. 500-03-058CF.

Howitt, R. and J. Medellín-Azuara. 2008. "Measuring Economic Impact of Agricultural Yield Related Changes." Draft Paper. 2008 Assessment Report.

Hurd, B., N. Leary, R. Jones, J. Smith, 1999. "Relative Regional Vulnerability of Water Resources to Climate Change." *Journal of the American Water Resources Association* 35(6): 1399-1409.

Joyce, B. V. Mehta, D. Purkey, L. Dale., M. Hanemann, M. Kiparsky, J. Dracup. 2008. "Climate Change Impacts on Water Supply and Agricultural Water Management in

California's Western San Joaquin Valley and Potential Adaptation Strategies." Draft Paper. 2008 Assessment Report.

Karlstad et al. (2008). (to be provided).

Lee, J., S. De Gryze, and J. Six. 2008. Effect of Climate Change on Field Crop Production in the Central Valley Of California. California Energy Commission, PIER Energy Related Environmental Research Program. CEC-500-2009-XXX. Forthcoming.

Lenihan, J.M., R. Drapek, R. Neilson. 2003. Appendix IV: Climate Change Effects on Vegetation Distribution, Carbon Stocks, and Fire Regimes in California. *In* Global Climate Change and California: Potential Implications for Ecosystems, Health, and the Economy. California Energy Commission, PIER Energy-Related Environmental Research. 500-03-058CF.

Lobell, D.B., and C.B. Field, 2008. "Estimation of the Carbon Dioxide (CO_2) Fertilization Effect Using Growth Rate Anomalies of CO_2 and Crop Yields Since 1961." *Global Change Biology* 14(1): 39-45.

Lobell, D.B., and C.B. Field, 2007. "Global Scale Climate—Crop Yield Relationships and the Impacts of Recent Warming." *Environmental Research Letters* 2(1): article number 014002.

Lobell, D.B., and J.I. Ortiz-Monasterio, 2007. "Impacts of Day Versus Night Temperatures on Spring Wheat Yields: A Comparison of Empirical and CERES Model Predictions in Three Locations." *Agronomy Journal* 99(2): 469-477.

Long, S.P., E.A. Ainsworth, A.D.B. Leakey, and P.B. Morgan, 2005. "Global Food Insecurity. Treatment of Major Food Crops with Elevated Carbon Dioxide or Ozone Under Large-Scale Fully Open-Air Conditions Suggests Recent Models May Have Overestimated Future Yields." *Philosophical Transactions of the Royal Society B—Biological Sciences* 360(1463): 2011-2020.

Long, S.P., E.A. Ainsworth, A.D.B. Leakey, J. Nosberger, and D.R. Ort, 2006. "Food for Thought: Lower-than-Expected Crop Yield Stimulation with Rising CO_2 Concentrations." *Science* 312(5782): 1918-1921.

Lund, J.R. et al., 2003. Appendix VII: Climate Warming and California's Water Future. *In* Global Climate Change and California: Potential Implications for Ecosystems, Health, and the Economy. California Energy Commission, PIER Energy-Related Environmental Research. 500-03-058CF.

Medellín-Azuara, J., C. Connell, K. Madani, and J. Lund. 2008. "Water Management Adaptation with Climate Change." Draft Paper. 2008 Assessment Report.

Medellín-Azuara, Josué, Julien Harou, Marcelo Olivares, Kaveh Madani, Jay Lund, Richard Howitt, Stacy Tanaka, Marion Jenkins, Tingju Zhu, 2008. "Adaptability and Adaptations of California's Water Supply System to Dry Climate Warming." *Climatic Change* 87: 75-90.

Mendelsohn, R., 2003a. Appendix XI: The Impact of Climate Change on Energy Expenditures in California. *In* Global Climate Change and California: Potential Implications for Ecosystems, Health, and the Economy. California Energy Commission, PIER Energy-Related Environmental Research. 500-03-058CF.

Mendelsohn, R., 2003b. Appendix XII: A California Model of Climate Change Impacts on Timber Markets. *In* Global Climate Change and California: Potential Implications for Ecosystems, Health, and the Economy. California Energy Commission, PIER Energy-Related Environmental Research. 500-03-058CF.

Millstein D.E. and R. A. Harley, 2008. Impact of Climate Change on Photochemical Air Pollution in Southern California. To be submitted to *Journal of Geophysical Research*.

Nash, L. and P. Gleick, 1993. "The Colorado River Basin and Climate Change." Rep. EPA 230-R-93-009, United States Environmental Agency, Washington, D.C.

Neumann, J.E., Hudgens, D.E., Leber Herr, J., Kassakian, J., 2003. Appendix XIII: Market Impacts of Sea Level Rise on California Coasts. *In* Global Climate Change and California: Potential Implications for Ecosystems, Health, and the Economy. California Energy Commission, PIER Energy-Related Environmental Research. 500-03-058CF.

Pendleton, L., P. King, C. Mohn, D. Webster, R. Vaughn, and P. Adams, 2008. Estimating the Potential Economic Impacts of Climate Change on Southern California Beaches. California Energy Commission, PIER Energy Related Environmental Research Program. CEC-500-2009-033-D.

Peng, S.B., J.L. Huang, J.E. Sheehy, R.C. Laza, R.M. Visperas, X.H. Zhong, G.S. Centeno, G.S. Khush, K.G. Cassman, 2004. "Rice Yields Decline with Higher Night Temperature from Global Warming." *Proceedings of the National Academy of Sciences of the United States of America* 101(27): 9971-9975.

Perez-Garcia, J., L.A. Joyce, C.S. Binkley, A.D. McGuire, 1997. "Economic Impacts of Climatic Change on the Global Forest Sector: An Integrated Ecological/Economic Assessment." *Critical Reviews in Environmental Science and Technology* 27: S123-S137.

Prichard, S.G. and J.S. Amthor, 2005. *Crops And Environmental Change: An Introduction to Effects of Global Warming, Increasing Atmospheric CO_2 And O_3 Concentrations, and Soil Salinization on Crop Physiology and Yield.* Philadelphia: The Haworth Press. 421 p.

Roughgarden, J. (1998). Can economics protect biodiversity? In "*The Economics and Ecology of Biodiversity Decline.*" Edited by T. M. Swanson. Cambridge University Press.

Sanstad, Alan H., H. Johnson, N. Goldstein, G. Franco. 2008. "Long-Run Socioeconomic and Demographic Scenarios for California." Draft Paper. 2008 Assessment Report.

Schneider, Stephen H. and Robert S. Chen. 1980. "Carbon Dioxide Warming and Coastline Flooding: Physical Factors and Climatic Impact." *Annual Review of Energy* 5: 107-140.

Shaw, M.R., L. Pendleton., D. Cameron, B. Morris, D. Bachelet, K. Klausmeyer, J. MacKenzie, D. Conklin, G. Bratman, J. Lenihan, E. Haunreiter, C. Daly. 2008. The Impact of Climate Change on California's Ecosystem Services. Draft paper. 2008 Scenario Report

Smith, J.B. and T.A. Tirpak, 1989. Appendix B: Sea Level Rise. *In* The Potential Effects of Global Climate Change on the United States. Report to Congress. United States Environmental Protection Agency, Policy, Planning, and Evaluation, PM-221, EPA-230-05-89-050.

Snyder, M. A., J. L. Bell, L. C. Sloan, P. B. Duffy, and B. Govindasamy. 2002. "Climate responses to a doubling of atmospheric carbon dioxide for a climatically vulnerable region." *Geophysical Research Letters* 29 10.1029/2001GL014431.

Sohngen, B., R. Mendelsohn, and R. Sedjo, 2001. "A Global Model of Climate Change Impacts on Timber Markets." *Journal of Agricultural and Resource Economics* 26(2): 326-343.

Steiner, A. L., S. Tonse, R. C. Cohen, A. H. Goldstein, and R. A. Harley. 2006. "Influence of future climate and emissions on regional air quality in California." *Journal of Geophysical Research-Atmospheres* 111:D18303, doi:10.1029/2005JD006935.

Steiner, A.L.; Cohen, R.C.; Harley, R.A.; Tonse, S.; Goldstein, A.H.; Millet, D.; Schade, G., 2008. VOC Reactivity in Central California: Comparing an Air Quality Model to Ground-Based Measurements. *Atmospheric Chemistry and Physics* 8, 351-368.

Tubiello, F.N. and G. Fischer, 2007. "Reducing Climate Change Impacts on Agriculture: Global and Regional Effects of Mitigation, 2000–2080." *Technological Forecasting and Social Change* 74(7): 1030-1056.

Wilson, T., L. Williams, J. Smith, R. Mendelsohn, 2003. Global Climate Change and California: Potential Implications for Ecosystems, Health, and the Economy. California Energy Commission, PIER Energy-Related Environmental Research. 500-03-058CF.

Yohe, G.W., 1989. "The Cost of Not Holding Back the Sea – Economic Vulnerability." *Ocean and Shoreline Management* 15: 233-255.

Yohe, G.W. and M.E. Schlesinger, 1998. "Sea-Level Change: The Expected Economic Cost of Protection or Abandonment in the United States." *Climatic Change* 38(4): 447-472.

Yohe, G.W., J. Neumann, P. Marshall, H. Ameden, 1996. "The Economic Cost of Greenhouse-Induced Sea-Level Rise for Developed Property in the United States." *Climatic Change* 32(4): 387-410.

DRAFT

Chapter 3

3 Climate Change Research in California

3.1 Introduction

Scientific research is critical for understanding the causes and impacts of climate change, making informed decisions to mitigate human effects on climate, adapting the natural and built environments to climate impacts, and developing new strategies and technologies for adaptation and mitigation. A broad international scientific research effort has been invaluable for understanding climate change on a global scale. However, understanding the nature and potential consequences of climate change on a regional scale, and developing regional adaptation and mitigation approaches, has fallen to state and local governments.

In California, state-funded research has illuminated regional impacts of climate change, shown cost-effective means of emissions mitigation, and highlighted adaptation issues, providing a scientific basis for California's leadership in climate change policy. An ongoing coordinated research program in California is improving our understanding of the causes of state- and regional-scale impacts of climate change, and identifying potential corrective actions. This critical research is helping to reduce scientific uncertainty associated with climate change.

Identifying and implementing robust policies will require a series of evaluations, including estimating existing conditions, predicting changes and consequences under a variety of scenarios, exploring alternative strategies to manage or reduce impacts, and carefully monitoring the results of decisions for unintended consequences. Climate change research and policy-making are mutually dependent. California State agencies have recognized the need to be closely engaged in designing and supporting research that will help guide critical decision making as they fulfill their core missions.

A number of California State agencies have been, and continue to be, considering the impacts of climate change in strategic planning. For example, the Department of Water Resources began addressing climate change in 2005 and plans to have specific recommendations in its 2010 State Water Plan. The Air Resources Board's *Strategic Plan for Research: 2001 to 2010* (April 2003 update) identifies greenhouse gas (GHG) emissions regulation as a driver of the agency's research program. Since 2003, the California Energy Commission (Energy Commission) has considered the implications of climate change in its "*Integrated Energy Policy Report."* The Department of Fish and Game's 2007 report titled "*California Wildlife Action Plan"* specifically identifies climate change as a major issue to address. The Department of Forestry and Fire Protection considered the effects of climate change in the 2003 Fire and Resource Assessment Report and will do so again in its 2009 update. The California Coastal Conservancy's 2007 *Strategic Plan* incorporates 13 objectives that require consideration of the best

available science on climate change in the design, siting and management of infrastructure, and natural resource projects.

The greenhouse gas mitigation strategies developed under the requirements of the Global Warming Solutions Act (AB 32) rely on research sponsored by the State. Additionally, the Resources Agency recently initiated a long-range planning effort for adapting to climate change. To support this work, research must assess climate change impacts on energy demand and generation, water resources, ecosystems, coastal resources, regional air quality, and the California economy. These comprehensive scientific research assessments are helping agency decision-makers design the most appropriate strategies to adapt and mitigate increasingly complex multi-sector issues.

The need for coordination and common planning assumptions has increased with the growing recognition of the interdependency between efforts to develop and protect infrastructure, conserve natural resources, and protect public health. For example:

- The potential impacts to the snowpack from climate change have serious implications for water supply and the availability of hydroelectricity. Thus, working with the Energy Commission, the Department of Water Resources is developing regional climate models designed to allow strategic planning for water availability and related planning for electricity supply.
- The increased reliance on renewable energy as a GHG reduction strategy, including increased use of biomass-to-energy, fosters joint research between the Department of Forestry and other agencies to develop analytical tools to balance forest health with the removal of fuel for fire protection and bio-energy. Although there are clear benefits to this removal, the methods and amounts must be consistent with the protection of sensitive species and habitats and the adaptation of the forests to future climate conditions.
- Rising sea levels are predicted to have serious impacts to critical infrastructure, and to coastal and bay resources. The Ocean Protection Council is coordinating the development of adaptation strategies to address these impacts and needs more information to support vulnerability assessments to target these efforts most effectively. Research will be important for agencies responsible for planning and maintaining critical infrastructure (e.g., Department of Transportation, Energy Commission, and Department of Water Resources), the agencies responsible for regulating development in the coastal and bay regions (e.g. State Lands Commission, Coastal Commission and Bay Conservation and Development Commission) and agencies working on public access to beaches and protection and restoration of coastal resources (e.g. Coastal Conservancy, Wildlife Conservation Board).
- Land-use planning to encourage less driving and more walking, bicycling, and use of public transportation has been shown to improve public health (Frumkin et al., 2004) as well as significantly reduce GHG emissions. The Department of Public Health, the Office of Planning and Research, and local and regional governments need additional research on ways to promote these behaviors for integration into general planning throughout the state.

These examples illustrate the importance of the integration of analysis, which will increase with time as activities relating to climate change increase within these agencies.

For California, much is at stake, and coordinated scientific research is needed to make informed policy choices. Increasingly, research is focused on sustainable development in which natural resources are used to meet human needs while preserving the environment so that these needs can be met into the future. Thus, this research is critical to the State's ability to respond to the local effects of a global issue and to ensure that optimal solutions to these highly complex issues are identified. Beyond the impacts to health, well-being, and the environment, the cost of inaction—failing to address climate change vulnerabilities—could be in the billions of dollars (as partially enumerated in Chapter 2 of this report.) That is why the Climate Action Team places a high priority on research. The following sections provide an overview of federal and state-sponsored research programs, and describe future research needs for California.

3.2 Overview of Research Programs

Climate change is the focus of intense national and international research designed to improve understanding of human-induced climate change, its observed and projected impacts, and options for adaptation and mitigation. State agencies actively monitor this research and use it as a framework for identifying research gaps and possible collaboration[24].

3.2.1 National climate change research Programs and Funding

3.2.1.1 Overview of federal programs

Two interagency working groups coordinate most federal climate change research. The goal of the Climate Change Science Program (CCSP) is to support informed discussion of climate change science and to guide future research. The CCSP publishes Synthesis & Assessment Reports. The Climate Change Technology Program (CCTP) seeks to accelerate the development and deployment of technologies that reduce net GHG emissions. Key programs funded by the federal government:

- *The Integrated Earth Observation System* seeks to provide a single framework for collecting and maintaining data on Earth systems for use in scientific research and policy–making;
- *The Global Climate Observing System, Global Ocean Observing System, and Global Terrestrial Observing System* provide infrastructure needed for

[24] As an example of collaboration, with funding from the Energy Commission, the Scripps Institute was able to run regional climate models on the "Earth Simulator," a supercomputer in Japan.

- *The Solar America Initiative (SAI)* accelerates the development of photovoltaic (PV or solar electricity) technologies with the goal of making solar electricity from PV cost competitive with conventional grid electricity by 2015;
- *The Solar America Cities Partnership* is working to accelerate the adoption of solar energy technologies. The goal is to power municipalities with clean, safe, reliable energy by developing a sustainable solar infrastructure that removes market barriers and encourages the adoption of solar energy by residents and businesses;
- *Freedom CAR* is a government-industry partnership to develop a personal transportation system free of air pollution and dependence on imported oil, possibly through hydrogen vehicles;
- *Clean Automotive Technology* is a U.S. Environmental Protection Agency (USEPA) program that works on cost-effective, high fuel economy, low-emissions vehicles;
- *The Generation IV Nuclear Energy Systems Initiative* investigates advances in reactor and fuel-cycle systems which may lead to dramatically improved economic performance, safety, and reduced risk of proliferation;
- *The Carbon Sequestration Program* is the U.S. Department of Energy (DOE) program to develop the potential to capture and sequester the CO_2 emissions of large point sources in geologic formations;
- *The Greenhouse Gas Reduction Through Agricultural Carbon Enhancement Network* measures and predicts sequestration and emissions at 30 agricultural sites with different agricultural, soil, and climate contexts;
- *ITER (originally, International Thermonuclear Experimental Reactor)* is an international project to design and demonstrate a fusion energy facility;
- *Building America* is a private/public partnership that develops energy solutions for new and existing homes.

3.2.1.2 Federally funded programs in California

California benefits from federal research funds for climate-related research through several agencies and programs. Some of these agencies are not solely or primarily focused on climate change, but provide some funds for climate and otherwise relevant research and outreach. In addition, not all of these funds or programs are directed to California-specific issues and may be more global in focus.

Federal funding comes to the state, for example, through some 40 national research laboratories based in California. Some of the laboratories conduct important policy-relevant climate change and energy research; e.g., DOE's Lawrence Berkeley and

Lawrence Livermore National Laboratories, NASA's Jet Propulsion Laboratory, and Sandia National Laboratories (CCST, 2006).

Several federally funded research programs in California include:

- Climate, weather, hydrology, agricultural and other monitoring stations are included in the Integrated Earth Observation System and other networks;
- *West CARB*, administered by the Energy Commission, is one of DOE's Regional Partnerships assessing the potential for geologic and terrestrial carbon sequestration;
- *CALFED* is a collaborative program of several state and federal agencies focused on the management of the San Francisco Bay-San Joaquin Delta region that has been giving increasing attention to climate change in its planning activities and science program;
- *The National Oceanic and Atmospheric Administration (NOAA)* funds a regional integrated sciences and assessment (RISA) center at Scripps Institution for Oceanography. The RISA is organizationally tied to the California Climate Change Center. Other NOAA funding supports coastal management research, increasingly focused on climate change impacts, which includes the work with the state's Coastal Commission, San Francisco Bay Conservation and Development Commission, and Coastal Conservancy. NOAA also provides support for the development of decision support tools in the face of climate variability and change that are currently being tested and refined for northern California reservoir management (INFORM Project). The Southwest Fisheries Science Center is a NOAA program that researches the impact of climate change on state fisheries;
- *The U.S. Department of Interior* provides federal funds for climate change impacts research through 1) the U.S. Geological Survey, for studies of sea level-rise inundation and beach and cliff erosion of the San Francisco Bay; 2) the National Park Service; and 3) the Fish and Wildlife Service, for research and outreach about climate change to visitors to California National Parks or Preserves;
- *The U.S. Department of Agriculture (USDA)* supports some climate change research and an emerging planning effort with the Forest Service, including national forest areas in the Sierra Nevada Mountains and elsewhere in California. The USDA climate change strategy is organizing climate change research into four areas: effects, adaptation, mitigation, and decision support tools.

While these programs yield benefits to California, their results do not necessarily address important regional issues related to climate change. For example, there are only three monitoring stations in California related to the federal climate change monitoring programs, an insufficient number to understand impacts in our many climate zones. In addition, most federal modeling of climate change does not have detailed enough resolution to address the state's diverse regions. California-specific environments and resources like the Sierra snowpack, diverse agricultural crop

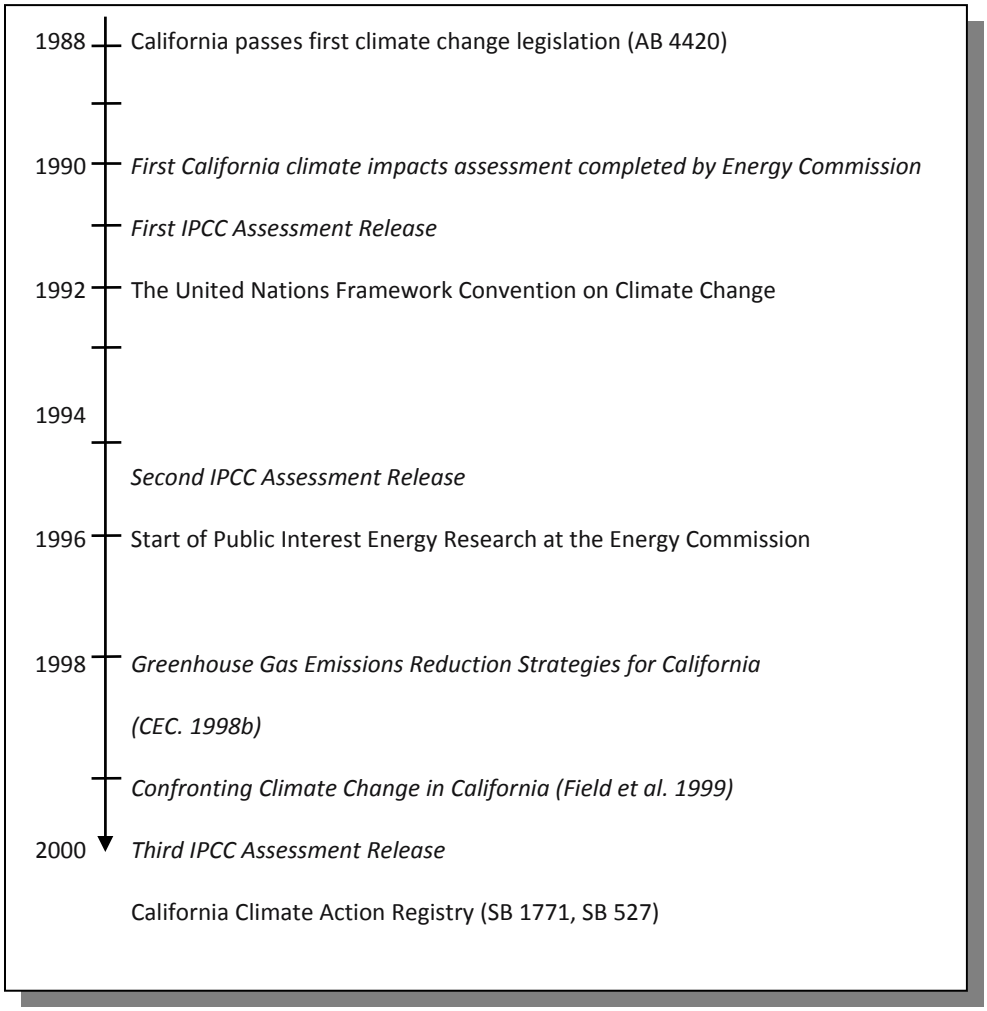
production, and the Pacific coastline are not sufficiently addressed in the federal program.

3.3 California state-sponsored and directed climate change research

California-sponsored and -directed climate research is designed to complement national and international efforts by focusing on regional distinctions critical to informed State climate change policy (e.g., down-scaling global climate modeling outputs).

California-sponsored climate change research started in 1988 with the adoption of AB 4420 (Sher, Chapter 1506, Statutes of 1988) which assigned the Energy Commission to assess the potential impacts of climate change on California and options for reducing GHG emissions in the state. The 1988 law led to two high-profile climate reports: "The Impacts of Global Warming on California," (CEC, 1989) and "Climate Change Potential Impacts and Policy Recommendations" (CEC, 1991). The political discussion generated from these reports helped pave the way for implementation of policies to address climate change (Figure 1).

During the late 1980s and 1990s, a number of significant coordinated research efforts and research programs that laid the foundation for future climate action were initiated. A series of high profile federal- and state-sponsored assessment reports highlighted for California policymakers the severity of the risks posed by unabated



3.6

climate change and helped raise public support for climate action.
In 1999, the publication of *"Confronting Climate Change in California: Ecological Impacts on the Golden State: A Report by the Union of Concerned Scientists and the Ecological Society of America"* focused California policy-makers' attention on the potential impacts of climate change, and the need for decisive action on mitigation and adaptation.

At the same time that the U.S. Global Change Research Program published the first National Assessment (USGCRP, 2002) and NOAA established the RISA program, California initiated its own state-supported integrated climate research program via the Energy Commission's Public Interest Energy Research (PIER) Program. Under this program, the Energy Commission has developed roadmaps for research including regional climate modeling, GHG inventory methods, water resources, carbon sequestration, renewable energy, and energy efficiency. These roadmaps are designed to identify research gaps of high importance for California that are not adequately covered by existing research programs at the national or international levels. Technical staff from state agencies and researchers from California institutions participate in the development and review of these roadmaps. In addition to creating a broad foundation for technology development, this effort culminated with an integrated Strategic Climate Change Research Plan released at the end of 2003 and aimed at addressing the following policy-relevant questions:

- How is climate changing in California and what are plausible climate change scenarios?
- How would the physical impacts of climate change affect California's environment and economy?
- What are the merits of different mitigation and adaptation strategies?
- How would climate change affect energy supply and demand?
- How would climate change policies affect the economy?

To implement this research plan, the Energy Commission created a virtual research center, the California Climate Change Center, with core research at the University of California, Berkeley; the University of California, San Diego (Scripps Institution of Oceanography); and other research institutions[25]. This research center is remarkable for being one of the first state-sponsored climate research programs in the United States. An important underpinning of its research is its use of ongoing national and international research efforts as the foundation for defining complementary research needs for California. Research results generated have been used to prepare the official statewide inventory of GHG gases in the state (CEC, 2002; CEC, 2006) and to identify preliminary mitigation strategies in different policy forums (CEC, 2005; CAT, 2006).

Among the many high-impact products produced from the various coordinated research programs were those highlighting the potentially severe threats that climate change

[25] The Center engages researchers at a variety of institutions including other UC campuses, private universities, national laboratories, and research institutes.

posed to California's water resources. This threat was first brought to the attention of the scientific community when the chief hydrologist for the California Department of Water Resources (DWR) released a study (Roos, 1987) showing that annual runoff occurring in the spring and summer months has been on the decline since records began in the early 1900s. This study, and other complementary studies, raised the awareness of water managers in California of the potential serious effects of a warming climate on water resources. The emergence of data like this with increasing levels of detail about potential climate change impacts in the region helped create the momentum necessary for meaningful climate policy formulation in California.

In June 2005, California once again demonstrated its leadership on climate issues when Governor Schwarzenegger signed Executive Order S-3-05 establishing GHG emissions targets for California. The Executive Order also mandated the preparation of a biennial science report describing the impacts climate change would have on water supply, forestry, public health, agriculture, and the coastline, and discussing coping and adaptation strategies that the state should consider.

Today, many state agencies conduct, support, or direct research related to climate change, and there is increased coordination among agencies in this research. Agencies routinely collaborate in research efforts by: 1) participating in each other's research review committees and research planning efforts; 2) partnering through interagency agreements; 3) leveraging research funding with project co-sponsorship from federal and nonprofit research institutions; 4) holding periodic interagency coordination meetings, and; 5) participating in the annual multiagency-sponsored climate change conference.

In the context of their mandated responsibilities, agencies are engaged in climate change research that addresses issues specific and often unique to California. For example, the Energy Commission has sponsored direct research on climate change since 2001 and has a longer history of sponsoring energy technology research (like renewable energy and energy efficiency programs) that indirectly help reduce the GHG impacts of energy. ARB's climate change-related research and responsibilities have increased to support implementation of AB 32 as well as achievement of long-term emissions reductions of 80 percent by 2050 (1990 baseline). Other state entities also have research programs and projects relating to climate change that apply to the mission of the specific agency. The research programs for many state departments are identified in Table 1.

Further details about these agency programs can be seen in the Climate Research Project Catalog and white papers on climate research priorities from the various agencies. The catalog and white papers will be included as an appendix to the final CAT Report. The Climate Research Catalog shows the diversity of climate change research efforts in California. While there are a number of direct and indirect research projects underway, there is very little duplication in the state research portfolio.

Air Resources Board	ARB has initiated a suite of research projects to support AB 32 implementation as well as realization of long-term goals of 80 percent emissions reductions by 2050. These studies include projects in greenhouse gas emissions, mitigation support, policy and economic impacts analysis, climate change impacts on public health and regional air quality, and community/business tools and strategies.
California Coastal Commission	The Commission relies upon mitigation and adaptation research from NOAA, the Energy Commission and others for application in regulatory and land use planning decisions; the Commission helps disseminate climate change information to local and regional governments and other interested parties. Climate change efforts are done as part of the Commission's ongoing regulatory and land use planning work.
California Coastal Conservancy	Research projects have focused on incorporating sea level rise and other climate change projected impacts into modeling and project design for coastal and bay wetland restoration projects; evaluating climate change impacts on Bay Area upland habitats; and measuring carbon sequestration in tidal wetlands.
Department of Conservation	Research projects related to geologic sequestration potential in California and impacts of recycling programs and conversion of agricultural lands on climate change are being conducted by the Department.
California Energy Commission	The Public Interest Energy Research program sponsors direct climate change research in the areas of climate modeling, emissions monitoring, impacts assessment, and carbon sequestration. Additional research is conducted in advanced generation, alternative transportation, renewables, energy efficiency, and other areas that relate to achieving reduced climate impacts from energy use.
California Environmental Protection Agency	Cal/EPA funds interdisciplinary climate research to support policy decision-making. Recent examples include determination of indicators of the effects of climate change on human and natural systems, and expanding capacity in environmental justice and climate change.
Department of Fish and Game	Fish and Game is actively involved in collaborative research efforts related to wildlife corridors and sensitive species.
Department of Food and Agriculture	The Department has sponsored research on carbon sequestration in agricultural soils, research on emissions from dairy operations, and management practices for vineyards to reduce carbon footprint.
Department of Forestry and Fire Protection	In conjunction with the Energy Commission, ongoing Department projects have helped establish the impact of forest management practices on GHG emissions and potential for carbon storage in wild-land and urban forests. Research is also ongoing to develop a

	risk rating system to assist in evaluation of the climate benefits of fuel hazard reduction treatments.
California Integrated Waste Management Board	A number of the Board's research projects are focused on reducing GHG emissions of California's waste stream. These include reducing methane emissions from landfills and better quantification of landfill collection efficiencies; developing green technologies that use landfill gas, municipal solid waste, food waste and other organic wastes to produce renewable fuels and electricity; conducting a life cycle assessment on organic materials management alternatives; completing economic analyses for recycling waste materials as resources; and developing best practices for composting.
California Ocean Protection Council	Since its formation in 2004, OPC has provided for research on assessing vulnerability to sea level rise and other coastal/ocean climate change impacts and on modeling adaptation planning options.
California State Parks	Projects have focused on impact of climate change on California parks including animal and vegetation migration due to climate change, establishing resiliency through landscape linkages, and determining geographic hotspots of species evolutionary change.
Department of Public Health	The Department has allocated staff time and received federal support from the Centers for Disease Control and Prevention to study increases in heat-related illness and death in communities and workplaces. The studies identify vulnerabilities that need to be reduced or eliminated. The Department shares evidence and experience with local jurisdictions to create healthy general plans that tie together transportation, energy, land use, food production, and community design for smart growth and sustainability.
California Public Utilities Commission	Under direction of the CPUC, the California Investor Owned Utilities (IOUs) operate a ratepayer-funded technology research program that directly focuses on climate change and two additional indirect programs. These programs include a two-year direct research study on geologic carbon sequestration and indirect technology and policy research for IOU energy efficiency programs and the California Solar Initiative.
Department of Transportation	Caltrans sponsors research related to improving transportation and transportation planning towards increased efficiency and reduced emissions. A number of indirect research studies have implications for climate change.
Department of Water Resources	The Department uses information that may be available from sources such as research sponsored by NOAA and the Energy Commission for understanding how climate impacts California's water resources. The Department collaborates extensively with NOAA's RISA centers to keep informed of the latest developments
State Water Resources Control Board	The water boards have research projects related to the impact of climate change on coastal areas and technology for water re-use.

The Climate Research Project Catalog is a key effort of the CAT research working group, as part of its mission to coordinate and prioritize climate change research. As part of this ongoing effort, The research working group will continue to update project information and include other linkages to make the catalog more useful to technical staff and other interested parties

Recent state-sponsored research has yielded notable successes. Some highlights from successful California programs in climate change research include:

- ARB-funded research ongoing at UC Davis is illuminating the impact of climate change on meteorology and regional air quality in California, with a focus on particulate matter;
- The Energy Commission has sponsored a series of studies to identify the utility investments in transmission upgrades essential to support renewable energy resources (wind, solar, biomass, etc.) for reaching renewable generation and 2020 GHG reduction goals. Importantly, these studies found that with significant expansion of transmission by 2020, it is feasible to operate the electricity system with 33 percent renewables. Transmission system upgrades are a key to efficient operation of tens of billions of dollars worth of new remotely located renewable power plants and require effective planning and coordination between power plant developers and utilities;
- The Energy Commission and Department of Forestry and Fire Protection sponsored a number of early research projects in the forest sector identifying an initial carbon stock baseline, set of carbon supply curves, and the effects of management practices on forest carbon stocks. The results of this effort were utilized in the development of the first industry-specific carbon accounting protocols adopted by the California Climate Action Registry and ARB. This work continues to be influential in the current protocol updating process.

State-sponsored and -mandated research is complementing national and international efforts and has provided a scientific framework for informed climate change policy in California. These research programs are beginning to address state-specific adaptation issues and developing optimal approaches to meet GHG reduction goals. Additionally, this research is highly valuable because of the dialogue between scientists and decision makers that it has fostered.

3.3.1 Regional climate modeling

Regional climate modeling is a major focus of climate change research being sponsored by the Energy Commission. This modeling is foundational and a key for understanding the impacts of climate change on our local California environments. Figure 2 shows down-scaled temperatures on a grid of about 12 by 12 kilometers (7.5 miles). These high-resolution results are being used for the impact studies reported in Chapters II and III of this report.

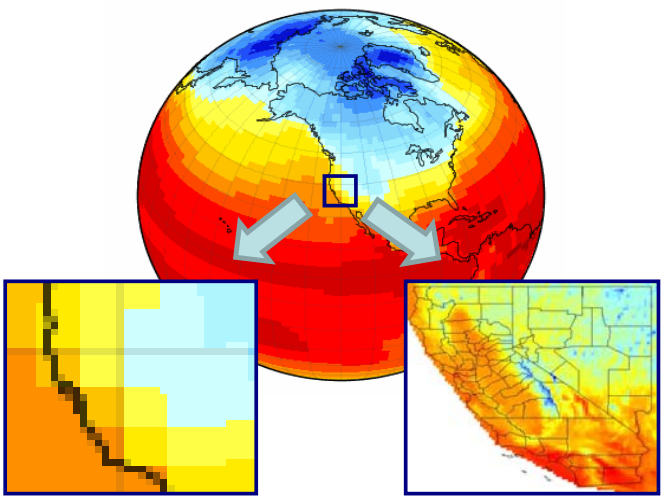


Figure 2. Comparison of outputs from a Global Climate Model and scaled outputs for California

Note: Color scale indicates maximum daytime temperature. The global model (center and lower left) has resolution of 500 km,

Several studies have shown that California is getting warmer due to increased concentration of GHG emissions in the atmosphere. At the same time, other factors, such as urbanization and agricultural irrigation, have affected local temperatures, with urbanization increasing temperatures and agricultural irrigation partially reducing the warming that would have occurred otherwise. The temperature signal is only one of the factors used to determine whether climate in California is changing. Other factors include hydrological signals such as the early melting of snow. In addition, other reports suggest changes in vegetation patterns and distribution of native fauna in California in the 20th century that is highly compatible with observed temperature trends. The climate change signal is emerging in California, but further advances in detection and attribution studies will come from more sophisticated global and regional climate models.

The long-term goal of climate modeling research is to provide insights on 1) how climate is changing in California and the reasons for these changes, and 2) how climate may change in the 21st century. The ability to more accurately model these and other topics will inform policy makers as they plan for the medium- and long-term future of the state. Key areas for future research include:

- Developing regional climate projections (including temperature and precipitation) based on newly developed downscaled regional climate models;
- Fundamental research to support a new generation of regional climate models under development. For example, this research includes improved understanding of the impact of snow reflectivity in the Sierra Nevada, i.e. darkening of snow due

to air pollution, which may be a factor contributing to the already observed trend of early snow melting[26];

- Exploring how changes in vegetation patterns may affect the hydrological cycle with exploratory coupling of vegetation and atmospheric models;
- Improving reliability of precipitation forecasting. Further research is needed to develop the capability to predict seasonal to inter-annual climate patterns and, by extension, precipitation outlooks.

3.3.2 Impact and adaptation studies

As climate change has emerged as a critical policy priority in California, research programs have investigated potential climate change impacts, vulnerabilities, and response strategies. California must pursue a balanced approach to managing its climate risks: both reducing the drivers of climate change, and minimizing its impacts. The State's goal is to ensure public safety and welfare, ecological integrity, continued economic vitality, and a rich and functional natural environment on which people and the economy depend.

Though research is ongoing, there is significant uncertainty about many aspects of climate change impacts. Further research is needed in:

- *Heat Waves and Public Health*
    - The relationship between temperature, air pollution episodes, and several health endpoints, to protect vulnerable subgroups;
    - Changes in atmospheric chemistry that change human exposure to certain air pollutants;
    - Differential risk to populations that are vulnerable due to physiological, socioeconomic, or occupational factors.
- *Energy supply, demand, and delivery*
    - Availability of energy resources and fuels:
        - Electricity generation, including hydroelectricity and other renewable resources;
        - Mid- to long-term, to supply alternatives to petroleum for transportation;

[26] The Energy Commission has other projects addressing this issue and a major field program proposed for 2009/2010 as a coordinated research effort supported by ARB, NOAA, and the Energy Commission.

        - Long-term planning capability and to investment guidance in emerging energy technologies.

- *Wildfires*
    - The increased risk of wildfire impacts on sensitive species and natural communities, especially ecosystem conversions and adaptation strategies. Climate change has been linked to an increased risk of wildfires in California which result in significant ecosystem changes and large increases in respiratory emergency room visits (SDADIC, 2007);
    - The types of human health conditions and priority interventions for sensitive populations, such as those with pre-existing respiratory or cardiovascular disease, smokers, the elderly, and children, during wildfire events.
- *Sea level rise*
    - Analytical techniques to evaluating coastal storm surge and flooding. They must operate at multiple scales, for the entire California coast, for a range of future sea level rise scenarios, and for a number of different tidal data, such as mean sea level and mean high water;
    - Implementing a statewide, systematic program to identify and mark maximum overtopping, run-up heights, and locations on sandy beaches during large wave/storm events to determine which areas are most vulnerable to sea level rise;
    - Development and evaluation of effective sea level rise adaptation strategies to minimize impacts to coastal development and ecosystems.
- *Ecosystem Impacts*
    - Monitoring and modeling on a bio-region scale to identify impacts to ecosystems (e.g., the effects of early snow melt on alpine forests);
    - Establishing adaptation measures, which should be designed to minimize the number of at-risk species and protect biodiversity;
    - Ecosystem restoration, including support for decisions on restoration processes and on where and when to restore;
    - Increasing resilience of ecosystems, as well as how to develop and adapt landscape reserves to support biodiversity and the migration of species in response to changing climatic conditions;
    - How climate change will influence the integration of habitat connectivity and wildlife corridors into land use planning and management.
- *Floods and Droughts*
    - Prediction of storm events with the potential to generate major regional flooding;

- Increases in risk of flooding and repeated drought/flooding cycles due to extreme variability in rainfall patterns and more-rapid spring snowmelt, which can impact both the natural environment and agricultural productivity;
- Extreme weather swings that can affect the dynamics of disease transfer between animal and human populations. (Droughts reduce water quality, and subsequent flooding can cause sewer overflows and microbial contamination (Tibbets, 2007), as well as an increase in the growth in rodent and mosquito populations.) To understand disease risk, more research is necessary in:
  - Assessment of innovative techniques for improving flood risk evaluations;
  - Regional analysis of the vulnerability of drinking water systems to contamination, especially in areas in flood plains and near potential levee breaks;
  - Analysis to determine which populations in California are most vulnerable to water borne disease outbreaks (e.g., elderly, immuno suppressed populations);
  - Analysis to decrease outbreak events for diseases not limited to water borne events;
  - Analysis of capacities of local and state public health departments to conduct rapid surveillance and response during water contamination events;
  - Analysis and future scenario modeling of impacts of continued droughts and reduced snowpack melt on drinking water quality.

- *Air quality/respiratory health*
  - The relationship between predicted ecological shifts and the potential for increased pollen production, which could result in worsening allergy symptoms in vulnerable populations. Studies should identify the geographic regions where impacts would most likely occur.
- *Community design and land use*
  - Assessment of how land-use decisions influence the amount of GHGs generated by a community and affect local climate; for example, how transportation routes, school siting, waste management options, and food production decisions influence community vulnerability to temperature, hydrologic and other climate change impacts.
- *Health behaviors/communication*
  - The policies/incentives that encourage more walking, bicycling, and use of public transportation;
  - Ways to incorporate health impact assessments into land use planning.

- *Surveillance*
  - Determining key environmental and health indicators that need to be monitored on an ongoing basis for trends in the effects of climate change on human and ecosystem health.
- *Mapping*
  - GIS mapping capability to identify regions and populations most vulnerable to various climate change impacts as a planning tool for local agencies;
  - High resolution mapping in coastal and bay regions to support sea level rise vulnerability assessments and evaluation of adaptation options for sea level rise and storm impacts on shoreline development and ecosystems.

3.3.3 Greenhouse gas inventory methods

The Intergovernmental Panel on Climate Change (IPCC) has issued guidelines on how GHG emissions should be estimated for regional and national inventories (IPCC, 2006). In the United States, USEPA is responsible for producing the annual national inventory that is submitted to the United Nations in accord with its Framework Convention on Climate Change (UNFCC). In California, ARB is responsible for producing the official state inventory. ARB released its first inventory in November 2007 (ARB, 2007). California has been producing time-series GHG inventories since 1990 (CEC, 1990; CEC, 1998; CEC, 2002; CEC, 2006). Estimated emissions have changed over time due to several factors, such as improved activity data, identification of new sources, and improvements to inventory methods and models. Research is needed to further reduce remaining uncertainty.

ARB and the Energy Commission have complementary and collaborative ongoing and planned studies to refine fuel consumption estimates and resolve discrepancies between energy consumption data from different sources. Mandatory reporting of major sources of GHG emissions will also be used to update the inventory.

Additional research is needed to support improved estimates of emissions and sinks from land use, land use change, and forestry. The prevailing scarcity of information to characterize these emissions sources is such that some important categories are omitted from the current California inventory (e.g., soils CO_2 fluxes and GHG emissions attributable to land use change).

Research by the CIWMB on organic materials will provide lifecycle assessment information and regional and statewide infrastructure models to provide a systems approach to optimizing GHG emission reductions for solid waste management and recycling. ARB, the U.S. Forest Service and the Department of Forestry and Fire

Protection are undertaking an effort to update the "Forest Inventory Assessment" for California to reduce the uncertainty in determining emission from forestlands. Ongoing research at ARB will improve the GHG inventory by reconciling non-CO_2 emissions calculated using 'bottom-up' and 'top-down' approaches. Discrepancies between bottom-up and top-down inventories for individual GHGs may point to un-inventoried or unknown sources of the GHG in question.

3.3.4 Greenhouse gas emissions reduction: Emerging technologies and strategies

Research on GHG mitigation strategies is essential for effective implementation of AB 32 and other climate change policies. The 2020 goal set by AB 32 will establish California as a leader in climate change policy and was informed by research specific to California's economy, environment, and vulnerabilities. However, long-term stabilization of climatic effects on Earth's life support systems requires further mitigation in line with the Governor's goal (Exec. Order S-3-05) of 80 percent reductions in GHG emissions by 2050.

California's GHG emissions come mostly from transportation, utilities (electricity and natural gas), and other industries such as refining, cement, manufacturing, forestry, and agriculture. Meeting these goals will require new policies and technological advances. Emissions in all sectors of the economy must shrink dramatically, through sustainable practices in which the land and natural resources used and the resulting pollution loading from air, water, and toxic and solid waste streams do not create significant impacts to already damaged ecosystems, water basins and air basins in California, the United States, and around the world. Achieving the 2050 goal will depend on the development and deployment of technologies that are currently not cost effective, or often do not yet exist. Research gaps that are critical to meeting the state's climate goals are identified below for each of these sectors.

3.3.5 Transportation

Transportation accounted for approximately 40 percent of total California GHG emissions in 2004. About 80 percent of that came from road transportation. Since 1990, total emissions associated with the transportation sector have increased from 150 to 182 million metric tons of CO_2 equivalents (MMT CO_2e), an increasing share of the state's overall GHG emissions. This trend must be reversed to achieve AB 32 goals and dramatically reduce GHG emissions from transportation to reach California's 2050 goal.

3.3.5.1 Vehicle and Fuel Technologies

Critical research needs with regard to California's fuels and vehicles include:

- Technical and economic analysis of low-carbon fuel production, distribution technologies and strategies (including hydrogen, cellulosic biofuels, natural gas, and electricity);
- Improved lifecycle modeling of transportation fuel pathways including direct and indirect land-use effects;
- Evaluation of other sustainability metrics associated with transportation fuel pathways including effects on food prices, water quality and availability, and natural habitat;
- Vehicle-to-grid infrastructure and management technologies and strategies, and strategies to support and evaluate smart recharging of electric vehicles and plug-in hybrid electric vehicles, e.g., time-of-day pricing;
- Vehicle and fuel market demand studies to support deployment efforts and effective market segmentation;
- Demonstrations of promising innovative mobility services, including integration of services with neighborhood electric vehicles and bus rapid transit;
- Effectiveness and implementation of road pricing models.

3.3.5.2 Land use and smart growth

To meet California's target of 80 percent GHG emissions reductions by 2050, the transportation sector must move beyond vehicle and fuel technologies. While often focused on transportation, land use and smart growth research also encompasses and complements research needs described later for building and community-scale energy efficiency. Effective climate policy must engage land-use strategies, transit infrastructure, pricing signals, and transportation conservation programs, including:

- Development of advanced travel and land use modeling to support regional planning in evaluating the effects of land use, transit, and pricing strategies and monitoring GHG reduction targets;
- Identification and evaluation of critical lessons associated with alternative policies for bringing about changes in land use, including local, regional, and state policy approaches, and incorporation of these lessons in the application of travel, land use, and emission models to support "best practices" recommendations, future monitoring and GHG enforcement;
- Development of methods for identifying priority conservation areas that will both discourage sprawl and minimize the number of species that are projected to become extinct due to climate change;
- Quantification of uncertainty in projections made by advanced travel and land use models;

- Development of cost effective methods of collecting vehicle-miles-travelled (VMT) data in California at regular intervals to support model development efforts, model validation efforts, and monitoring and enforcement of GHG reduction targets;
- Investigation of the "self-selection" bias in empirical analyses of the relationship between land use and VMT, moving beyond cross-section designs and employing more sophisticated quasi-experimental approaches;
- Development and validation models to identify, quantify, evaluate, and verify GHG impacts of planning practices and designs. Using life cycle studies or system analysis, identify the costs, benefits and the GHG impacts of alternative community designs.

3.3.6 Electricity and natural gas

Reductions in GHG emissions from electricity and natural gas use come in two forms: consuming less energy and reducing the GHG intensity of energy sources. Energy use can be reduced by energy efficiency by the user, producer or distributer, or reduced demand by the user. Net demand can be reduced by users by process changes such as recycling of aluminum and other waste materials. GHG emissions from electricity generation can be reduced by from coal to renewable energy resources, natural gas, nuclear, or other low GHG energy sources, or sequestering the emissions from fossil fuel power plants. Although current knowledge and technology support large increases in energy efficiency and renewable energy, more research is needed to improve the performance and cost effectiveness of current and emerging technologies. Research is also needed to improve capability to predict the effects of climate change on the supply and demand for energy services.

3.3.6.1 Demand response and energy efficiency

Since the 1970s, California's distinguished efforts in developing energy efficiency have led to no net increase in per capita electricity consumption despite growth in per capita income. Research to support a climate-friendly buildings sector must extend beyond past and current initiatives, which, with notable exceptions, can be loosely characterized as emphasizing incremental component-level improvements. Reducing electricity and natural gas consumption through decreasing demand for energy services (e.g., turning off the lights) requires behavioral research for public outreach and education. However, technology research also has a key role. Key ongoing and future research needs include the following:

- Improvements in energy efficiency and zero-carbon energy supply, addressing both new and existing buildings.
- Systems integration to boost energy efficiency and energy management systems, to facilitate use of distributed renewable energy technologies.

- Tools for benchmarking, measuring impacts of, and improving voluntary and standards-based initiatives.
- Improved GHG emissions and emissions reductions tracking at the building and end-use levels from various building types: commercial, residential, school, industry, and government facilities.
- Continuation of studies investigating the relationships between building efficiency and indoor environmental quality.
- Improved information and informational networks to convey carbon "footprints," and opportunities to reduce them, to emitters and intermediaries.
- Technology and management systems driven with real-time data (e.g., weather, and occupancy) and able to account for changes in climate and weather.
- Advanced meters and other tools that provide consumers information about their energy use and energy costs. These may lessen unproductive energy use, especially when combined with automated ways to respond to this information.
- Enabling technologies for "smart grids" capable of integrating energy efficiency and renewable energy at a community scale.

3.3.6.2 Renewable energy and reduced carbon energy sources

California is increasing renewable energy and other low-GHG energy sources, but technology and science research is required to achieve policy objectives in this sector, including:

- Continued support for development of renewable and low-GHG advanced generation technologies.
- Integration of renewable energy resources and advanced energy efficiency to produce zero net-energy residential and commercial buildings.
- Improved understanding of how to increase use of intermittent renewable energy sources without overreliance on inefficient fossil fuel generators, which inadvertently creates incentives for inefficient generators.
- Enabling technologies to accommodate increased levels of intermittent and variable renewable generation while maintaining operational stability and local area reliability requirements of the electricity system. For example: strategic location of other low-GHG generation sources such as a dispatchable or complementary renewable generators; energy storage technology; renewable heating and cooling technologies; and energy consumers that can reduce

demand in response to real-time or forecast grid conditions, such as compressor loads for chillers in large commercial buildings[27].

- Detailed modeling of the effects and response to climate changes for energy infrastructure including transmission and demand centers.
- Continued development of a full lifecycle cost/benefit analysis for renewable energy and fossil fuel energy sources.
- Continued development of commercial-scale technologies that produce renewable energy from waste materials and byproducts rather than agricultural sources.

The strategies presented above describe GHG reduction opportunities within the electricity and natural gas sectors. As noted in the AB 32 scoping plan, all sectors of the state economy must participate in a comprehensive GHG reduction strategy for California. Policymakers need a rational means for prioritizing these different strategies in deciding how and when to allocate effort to each strategy.

3.3.7 Low greenhouse gas technologies for other sectors

Other sectors may offer other non-energy options for reducing GHG. These options need to be better quantified to identify potential reductions. Some areas where further research is needed to make performance improvements are:

- *Cement*: Alternative cement and concrete products and processes to reduce CO_2 emissions;
- *Forestry*: Additional research on forest management and technology to improve terrestrial carbon storage and reduce wildfire risk;
- *Agriculture and Landscaping*: Better emissions quantification, best practices evaluation, and development of ways to reduce GHG emissions associated with conventional fertilization and irrigation;
- *Water Resources*: Continue research on improved efficiency in water distribution, end use, and cleanup;
- *Recycling and Waste Management:* Life cycle models to identify GHG reductions associated with the development, manufacturing, use, and disposal of consumer products. Improved methods for community-scale assessment of indirect GHG emission reductions for alternative waste treatment (e.g., recycling).

3.3.8 Carbon Sequestration

[27] For further information on this topic, see the research recommendations for renewable energy in the California Energy Commission's Committee Draft 2008 IEPR Update, p. 36-37. For discussion of the CA ISO's interest in variable compressor loads for chillers, see p. 21.

Carbon sequestration has the potential to substantially lower or offset California's CO_2 emissions. There are two classes of technologies applicable to the state: terrestrial and geologic.

3.3.8.1 Terrestrial Sequestration

Terrestrial sequestration refers to carbon stored in plants and soils. California can improve carbon storage in the state's forests, rangelands, wetlands, and agricultural lands through changes in land management practices that increase carbon uptake and/or reduce CO_2 emissions from these ecosystems. Because terrestrial sequestration removes CO_2 that is already in the air, it can help offset emissions from other sectors. Studies have shown that afforestation (tree planting) and agricultural soil management offer significant terrestrial storage opportunities in California. Research needs for terrestrial sequestration in California include:

- Forest management approaches, including incentives, to help reduce CO_2 emissions from wildfires;
- Agriculture management approaches for sequestration in annual and perennial crops and quantification of lifecycle CO_2, N_2O, and CH_4 emissions impacts for these practices;
- How projected changes in climate will affect existing carbon stocks and terrestrial sequestration options in the state;
- Effects of urban development on terrestrial sequestration; policy options to minimize GHG emissions; research on the role of urban forests and greenscapes in providing mitigation opportunities and other co-benefits to public health, water management, and energy savings;
- Carbon sequestration rates in habitats other than forests, including wetlands and perennial grasslands; geographic sensitivity, species composition, and management options for increasing carbon sequestration in these habitats;
- Potential impacts of expanded terrestrial sequestration on climate change (e.g., albedo effects), sensitive species and habitats and water use/availability.

3.3.8.2 Geologic Sequestration

Geologic sequestration, also known as CO_2 capture and storage, involves modifying industrial facilities to remove CO_2 from process or exhaust gases before emission and injecting it into secure geologic formations for long-term storage.

Large industrial facilities such as power plants, refineries, and cement plants constitute California's second largest source of CO_2 emissions. Initial screening of potential

geologic storage sites and estimates of geologic storage capacity indicate that California's deep sedimentary basins, particularly those underlying the Central Valley, could store hundreds to thousands of years' worth of the state's industrial CO_2 emissions.

Critical areas of research for developing geologic sequestration in California include:

- More detailed mapping and characterization of the state's sedimentary basins to qualify storage sites and refine capacity estimates;
- New or improved technologies for reducing the cost of capturing CO_2;
- Technology validation and demonstration projects that serve as a basis for formulating regulations for commercial projects.

3.3.9 Economic impacts and considerations

Understanding the economic aspects of climate change is crucial for reaching emission reduction goals both in California and globally. One research gap in the economics of GHG mitigation is in the area of induced technological innovation. Economic theory predicts that if a market mechanism puts a price on GHG emissions, then the economy will find ways of reducing the cost of getting the needed emission reductions. There are multiple examples of the role of government in induced technology innovation, but in general, these effects are not captured by macroeconomic models used for developing policy. Technological innovation involves a complex interaction between engineers, managers, financiers, and policymakers. Research is needed to develop next generation sector and macroeconomic modeling capability, including:

- The impact of pricing of GHG emissions on technological innovation on key industries (e.g., energy efficiency and alternative fuels);
- State government policies to encourage induced technological innovation;
- Leveraging state incentives for research and development for promising technologies;
- Incentives to stimulate widespread use of emerging technologies to support the state's renewable energy and GHG emission reduction goals.

Another area of needed research is in GHG mitigation strategy evaluation. An extension of life cycle cost analysis is needed, one which takes into account the value of co-benefits such as air pollution emission reductions, water pollution reduction, solid waste reductions, and the adaptive value of a strategy.

Finally, the State needs to continue to fund research on the economic impact of the effect of ongoing and future climate change on California. As other research efforts produce clearer understanding of climate change impacts, policy makers need to understand the costs of this impacts and the costs of adapting to them.

3.3.9.1 Social science to support implementation, education, and outreach

Social science research is crucial for effective implementation of climate change policy. Education and outreach are needed to educate the public on the risk posed by climate change, to develop a green workforce, to foster effective management practices among the state's professionals, and to inform the businesses, households, local governments, and schools whose decisions help determine California's GHG emissions and adaptive capacity. Social science research is needed to guide development and implementation of educational programs. Further social science research, including investigation of legal and administrative structures, may be needed to help the State cope with adaptation, promote robust laws and institutions, and partner with entities beyond California's jurisdiction.

The national Climate Change Science Program named "decision support" a priority in its 2003 strategic plan and re-emphasized the importance of decision-supporting social sciences in its 2008 revision to the research plan (CCSP, 2003; CCSP, 2008). In California the CPUC, in partnership with the California Institute for Energy and Environment, has commissioned a series of white papers on consumer behavior and energy consumption, which will inform development of a strategic plan to guide the CPUC's research, development, and demonstration. Among the social science research gaps that need California-specific investigation to support effective climate strategies are:

- The role of lifestyles and behavior (versus technological factors) in forecasting studies (e.g., fuel switching, comfort and lighting control, and telecommuting);
- Identification and improvement of models and assumptions that are sensitive to behavioral components;
- Education, outreach, and social/behavioral change strategies so that voluntary and outreach programs can be compared to conventional regulatory and emerging market mechanisms;
- How residential energy efficiency is affected by decisions of home builders, home equipment manufacturers, mortgage lenders, rental housing owners and managers, heating and cooling system contractors, and appliance retailers and repair personnel.

3.3.10 Environmental justice impacts and considerations

Climate change is an issue of great importance for human rights, public health, and social equity because of its potential disproportionate impact on vulnerable and socially marginalized populations. Without proactive policies to address equity concerns, climate change could reinforce and amplify current and future socioeconomic disparities, leaving low-income, minority, and politically marginalized groups with fewer economic

opportunities and more environmental and health burdens. The incidence of mortality and morbidity associated with mounting physical and biological impacts and economic consequences will increase. Moreover, community vulnerability to climate change is determined by its ability to anticipate, cope with, resist, and recover from the impact of major weather events (Blakie et. al., 1994). Therefore, to understand concerns regarding climate justice, it is critical to explore disparities in the costs and benefits of climate change and the abilities of different groups to adapt to it.

To better inform the mitigation and adaptation strategies as they relate to environmental justice concerns and communities, additional research is needed and should include consideration of the following (adapted from Pastor, 2008):

- *Co-pollutants:* Develop methods for determining the relationship between CO_2 and various co-pollutants in terms of both the co-benefits of cleanup and any potential worsening of pollution under climate change or climate policies. These assessments should look at pollution sources and both immediate and regional impact areas;
- *Displacement:* Vulnerability assessments and GIS capability for identifying where populations may be displaced due to sea-level rise, increased flood threat, water availability, and other potential impacts of climate change;
- *Jobs:* Where job losses and gains will occur, geographically and in which industries and job markets;
- *Capacity to adapt:* How multiple stressors (e.g., rising energy expenses and job losses) affect the ability to adapt to climate change, one of many stressors felt by low-income residents.

3.4 Conclusion: Research and the 2050 challenge

The ambitious goal of reducing emissions to 80 percent below 1990 levels by 2050 may yield tremendous benefits in energy diversification and the creation of a green economy in California, but will also require new policies and technological innovation. Accomplishing the goal will require the state economy to transition to become almost carbon-free. It will also require scientifically validated policies that reflect the true costs and benefits of emissions and emissions reductions. Adaptation, planned or not, will also be well under way by 2050. Investments to adapt to the coming impacts of climate change will be most effective if they are guided by scientific research and monitoring necessary to support effective adaptive management. These three threads of research—climate change impacts, new technologies, and the analysis needed to guide policy decisions—are the subjects of ongoing coordinated research that must continue to expand in order to reach the 2050 goal.

Advancement and diffusion of technologies will play a decisive role in achieving GHG emissions reductions. Technologies for reducing the energy burden of the built environment, increasing the role of renewables and carbon capture in the energy sector,

and new technologies and fuels in the transportation sector are all areas that require research focus.

Up-to-date scientific research is needed by State and other public agencies, policy makers, land managers and the general public to make short term, mid-term, and long-term decisions about the most effective ways of mitigating and adapting to climate change impacts. Accessibility of this information will facilitate rapid incorporation of emerging science into management and funding decisions, and will assist State agencies in identifying research gaps, critical needs, and in avoiding duplication of funding specific projects. Integrated assessment of economic, social, ecological, public health, and environmental justice impacts will be needed to support decision-making. Continued State-sponsored and directed climate change research will help California protect its citizens and environment and create a secure future for 2050 and beyond. The Climate Action Team will continue ongoing activities to support and enhance coordination and collaboration of State-sponsored climate change research.

3.5 References

Air Resources Board (ARB). 2007. *California's Greenhouse Gas Emissions Inventory (covering years 1990 to 2004)*. Available at: http://www.arb.ca.gov/cc/inventory/inventory.htm

ARB. 2008. *Climate Change Proposed Scoping Plan.* California Air Resources Board. October 2008. Available at: http://www.arb.ca.gov/cc/scopingplan/document/scopingplandocument.htm

American Association for the Advancement of Science (AAAS). 2008a. *Guide to R&D Funding Data - Historical Data.* AAAS: Washington, D.C. Available at: http://www.aaas.org/spp/rd/guihist.htm.

AAAS. 2008b. *AAAS R&D Funding Update on R&D in Climate Change Science Program.* AAAS; Washington, D.C. Available at: http://www.aaas.org/spp/rd/ccsp08p.htm.

Blaikie, P., et al. 1994. *At Risk: Natural Hazards, People's Vulnerability, and Disasters.* Routledge, New York.

California Council on Science and Technology (CCST). 2006. *California's Federal Laboratories: A State Resource*. CCST: Sacramento and Riverside, CA, Available at: http://www.ccst.us/publications/2006/2006labs.php.

California Energy Commission (CEC). 1990. *1988 Inventory of California Greenhouse Gas Emissions.* Final Staff Report, California Energy Commission. October 1990.

CEC, 2006. *Inventory of California Greenhouse Gas Emissions and Sinks: 1990 to 2004*. (P600-2006-013-SF). Available at: http://www.energy.ca.gov/2006publications/CEC-600-2006-013/CEC-600-2006-013-SF.PDF

CEC. 1989. *The impacts of global warming in California.* (P500-89-004).

CEC. 1991. *Global climate change: potential impacts and policy recommendations*. (P500-91-007).

CEC. 1998. *Appendix A: Historical and Forecasted Greenhouse Gas Emissions Inventories for California.* Publication # P500-98-001V3. January 1998. California Energy Commission, Sacramento. Available at: http://www.climatechange.ca.gov/publications/97GLOBALVOL3.PDF

CEC. 2002. *Inventory of California Greenhouse Gas Emissions and Sinks: 1990-1999.* (P600-02-001F). Available at: http://www.energy.ca.gov//reports/600-02-001F/2002-09-14_600-02-001F.PDF

CEC. 2005. *Development of Energy Balances for the State of California.* (P500-2005-068). Available at: http://www.energy.ca.gov/pier/project_reports/CEC-500-2005-068.html

Climate Action Team (CAT). 2006. *Climate Action Team Report to Governor Schwarzenegger and the California Legislature.* California Environmental Protection Agency. March 2006. Available at: http://www.climatechange.ca.gov/climate_action_team/reports/index.html

Climate Change Science Program (CCSP). 2003. *Strategic Plan for the Climate Change Science Program*. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research. Washington, D.C: CCSP.

CCSP. 2008. *Revised Research Plan for the U.S. Climate Change Science Program*. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research. Washington, D.C: CCSP.

Franco, et al. 2007. *Linking Climate Change Science with Policy in California.* Climatic Change 87 (1). Springer, Netherlands.

Frumkin, H., L. Frank, and R. Jackson. 2004. *Urban Sprawl and Public Health: Designing,*

International Panel on Climate Change (IPCC). 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Prepared by the National Greenhouse Gas Inventories Program, Eggleston HAS., Biennia L., Miwa K., Negara T. and Tanabe K. (eds). Published: IGES, Japan. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm

Moser, S.C. 2008. *Building California's Climate-Related Decision Support Capacity and Fostering Social Science Contributions*. CEC PIER-EA Discussion Paper, Sacramento, CA.

Pastor, M. 2008. USC Department of Geography, personal communication.

Planning, and Building for Healthy Communities. Island Press.

Roos, M. 1987. *Possible Changes in California Snowmelt Runoff Patterns.* Fourth Annual Pacific Climate (PACLIM) Workshop, Pacific Grove, California.

USEPA. 2008*. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006. United States Environmental Protection Agency.* EPA 430-R-08-005. Washington D.C. Available at: http://www.epa.gov/globalwarming/publications/emissions

Weart, S. 2003. *The Discovery of Global Warming*. Cambridge, MA: Harvard University Press. Available at: http://www.aip.org/history/climate/index.html.

Wilkinson, R. et al. (eds.). 2002. *The Potential Consequences of Climate Variability and Change for California. The California Regional Assessment*. A Report of the California Regional Assessment Group for the U.S. Global Change Research Program. Washington, D.C.: USGCRP.

3.6 White Papers from CAT Research Sub-Group

Air Resources Board. 2008. *Climate Change Research at California's Air Resources Board (ARB).*

California Energy Commission. 2008. *An Overview of Climate Change-Related Research and Future Needs at the California Energy Commission*.

California Energy Commission. 2008. *Summary of PIER Program Research and Accomplishments to Date on Public Health Impacts on Climate Change.*

California Integrated Waste Management Board. 2008. *Climate Action Team Research Subgroup – Research White Paper.*

California Public Utilities Commission. 2008. *CPUC Submission to CAT R&D WG.*

California State Parks. 2008. *Climate Change and Research Considerations*.

California Water Boards. 2008. *Water Boards - Climate Action Team Research.*

Department of Conservation. 2008. *Climate Research Subgroup - Current and Needed Research.*

Department of Fish and Game. 2008. *Climate Change-Related Research Considerations.*

Department of Public Health. 2008. *Research Section*; *Climate Action Team Report to Governor.*

Department of Transportation. 2008. *Transportation and Climate Change - Potential Areas of Research.*

Department of Water Resources. 2008. *2008 Climate Action Team Report - Research Needs Appendix.*

San Francisco Bay Conservation and Development Commission. 2008. *Climate Change Research Needs for the San Francisco Bay Coastal Sector.*

Chapter 4

4 State Efforts to Adapt to Current and Future Effects of Climate Change

4.1 Introduction

The first three chapters of this report show California has been, and will be, at greater risk to climate change in the foreseeable future than it has been in the past. Unfortunately, public and private entities are not prepared to address a potential eight-fold increase in sea levels rising in the next century compared to the last century, or a decrease in overall precipitation and snow pack, or greater extreme temperature events. We can no longer plan for the future using historical information since climate change is changing at such a fast and unpredictable scale.

A new, more comprehensive planning effort is required that *links* new and rapidly growing climate change science with new and existing infrastructure, human health, and environmental planning policies and funding. With this in mind, Governor Schwarzenegger issued Executive Order S-13-08, the "Climate Adaptation and Sea Level Rise Planning Order" that provides clear direction for how the State should plan for future climate impacts, as discussed below.

As climate change science continues to improve, so will our need to plan for expected climate change impacts. All current planning efforts recognize society is at the beginning of understanding the scale and extent of how climate change is impacting our communities, state, nation, and planet. Implementing low-cost (or revenue-generating), high-return strategies now will benefit our long-term efforts to reduce California's vulnerability to current and future climate change impacts while providing long-term health and cost savings.

4.1.1 Executive Order S-13-08: the Climate Adaptation and Sea Level Rise Planning Directive

On November 14, 2008, Governor Arnold Schwarzenegger issued Executive Order (EO) S-13-08 (http://gov.ca.gov/press-release/11035/) calling for the State to implement a number of actions to reduce vulnerability to climate change. In particular, there are four key actions including:

(1) Initiate California's first statewide Climate Change Adaptation Strategy (CAS) that will assess the state's expected climate change impacts,

identify where California is most vulnerable and recommend climate adaptation policies;

(2) Request the National Academy of Science establish an expert panel to report on sea level rise impacts in California in order to inform State planning and development efforts;

(3) Issue interim guidance to State agencies for how to plan for sea level rise in designated coastal and floodplain areas for new and existing projects; and

(4) Initiate studies on critical infrastructure projects, and land-use policies, vulnerable to sea level rise.

Article 7 of the Governor's order states the overall structure of the CAS as follows:

> *By June 30, 2009, the California Resources Agency, through the Climate Action Team, shall coordinate with local, regional, State, and federal public and private entities to develop a state Climate Adaptation Strategy. The strategy will summarize the best known science on climate change impacts to California (led by CEC's PIER program), assess California's vulnerability to the identified impacts, and then outline solutions that can be implemented within and across State agencies to promote resiliency. A water adaptation strategy will be coordinated by Department of Water Resources with input from the State Water Resources Control Board, an ocean and coastal resources adaptation strategy will be coordinated by the Ocean Protection Council, an infrastructure adaptation strategy will be coordinated by the California Department of Transportation, a biodiversity adaptation strategy will be jointly coordinated by the California Department of Fish and Game and California State Parks, a working landscapes adaptation strategy will be jointly coordinated by the California Department of Forestry and Fire Protection and the California Department of Food and Agriculture, and a public health adaptation strategy will be jointly coordinated by the California Department of Public Health and the California Air Resources Board, all as part of the larger strategy. This strategy will be facilitated through the Climate Action Team and will be coordinated with California's climate change mitigation efforts.*

Article 7 continues in explaining the overall goal of the CAS:

> *"The goal of State climate adaptation planning efforts is to help State agencies and stakeholders better understand the rate, scale, and timing of*

known and unknown climate change impacts, develop preliminary strategies to reduce the State's vulnerability to these impacts, and to prioritize actions the State can and should complete in the near term to ultimately reduce fiscal, health, and environmental risks.

4.1.2 California's Dual Climate Strategy: Mitigation and Adaptation

Climate change mitigation efforts, through reductions in greenhouse gas emissions, are the foundation for eventually reaching a stable level of greenhouse gases in the atmosphere. If greenhouse gas emissions continue at the current pace, the consequences and impacts could be disastrous, and eventually beyond our capacity for effective adaptation without severe costs and sacrifices. Chapter 2 of this report provides an initial set of assessments for the costs of climate change impacts in California. The basic conclusion reached from these assessments is that climate change will impose substantial costs to Californians on the order of tens of billions of dollars annually, but that costs will be substantially lower if global emissions of greenhouse gases are curtailed to levels suggested by lower GHG emissions scenarios.

Accordingly, California has undertaken a number of aggressive initiatives to reduce greenhouse gas emissions in the state, including implementation of the Global Warming Solutions Act (AB 32), the Renewable Energy Portfolio Standard, and the Low Carbon Fuel Standard. These measures, if matched by the rest of the nation and the global community, will continue to provide the best defense against long-term climate change consequences and ensure that greenhouse gas emissions never reach critically dangerous levels resulting in catastrophic outcomes.

Regardless of how successful these actions prove in limiting greenhouse gas emissions, however, some impacts of climate change have already occurred and will continue to occur inevitably occur as a result of past or current greenhouse gas emissions. Even if all greenhouse gas emissions were stopped today, temperatures would continue to rise through the rest of the century, inevitably resulting in some degree of climate change. As detailed in Chapter 1 and 2, California's impacts from climate change are likely to include shifting precipitation patterns, increasing temperatures, sea level rise, increasing severity and duration of wildfires, earlier melting of snow pack, and effects on habitats and biodiversity.

To ignore these unavoidable impacts of climate change would place California's economy, natural resources, and infrastructure at risk, as well as the health and well-being of people and communities across the state. Consequently, a pro-active climate change plan must include the development of parallel efforts that

both mitigate climate change through emissions reductions and prepare for existing and anticipated impacts through adaptation planning.

Mitigation and adaptation efforts can also be mutually beneficial, as illustrated in the adoption of forestry management practices that reduce the risk of wildfires, thereby protecting forest lands and limiting greenhouse gas emissions that result from considerable wildfires. In other cases, mitigation and adaptation goals could potentially work at cross purposes. The increased use of air conditioning, for example during heat waves, would help stave off some health effects associated with extreme heat, while at the same time it would increase energy usage and associated emissions of greenhouse gases.

Similarly, compact and mixed land-use strategies--while helpful in reducing emissions from a reduction in vehicle miles traveled--could in some cases lead to increased residential and commercial developments concentrated in neighboring floodplains. Moving development out of at-risk floodplains on the other hand, could potentially increase sprawl and related emissions. These examples point to the need for continuing collaboration between agencies, boards, and departments involved in both efforts at State and local levels of government working on both climate change mitigation and adaptation strategies.
Through these parallel climate change actions, the State will continue working to prevent the most severe impacts of climate change while also acknowledging and preparing for known impacts already beginning to occur, with the aim of providing the maximum benefit to California in both the short- and long-term.

4.2 Development of a Climate Adaptation Strategy

The CAS effort, as outlined in EO S-13-08, is being led by the California Natural Resources Agency and coordinated across five State agencies and numerous departments. The CAS will work toward developing the first comprehensive State strategy to address climate impacts while understanding that a more in-depth assessment will be needed once complete.

The CAS is expected to summarize what we know about current climate change impacts to California, use State agency policy expertise to understand what strategies could be implemented, and to assist in prioritizing near- and long-term actions. The science summary is utilizing research sponsored by the California Energy Commission's Public Interest Energy Research (PIER) program, much of it highlighted in Chapter 1 of this report. The strategy efforts are being led by a host of departments, as listed in Article 7 of EO S-13-08 as listed in this report, and include:

Box 4.1: Agencies and Departments Responsible for Developing 2008 CAS

• California Environmental Protection Agency
• California Business, Housing and Transportation Agency
• California Health and Human Services Agency
• California Natural Resources Agency
• California Department of Food and Agriculture
• Department of Water Resources
• State Water Resources Control Board
• Ocean Protection Council
• Department of Public Health
• Air Resources Board
• Department of Forestry and Fire Protection
• Department of Fish and Game
• State Parks
• California Energy Commission

4.2.1 CAS Components: Science, Policy and Action

The development of the CAS involves three major components: a review of the latest science, identification of policy strategies, and a listing of short- and long-term actions. Strong scientific data will serve as the foundation for understanding how climate change will affect the state and ensure that the appropriate adaptation efforts are undertaken. A major component of this scientific data is garnered from the 2008 Climate Change Assessment and its underlying studies prepared and sponsored by the California Energy Commission. This information will be used to assess the risks that California is facing in regard to its natural resources, economic assets, and the protection of vulnerable populations. Future scientific research will attempt to identify the degree of vulnerability as well as the State's ability to respond to potential impacts.

The main objective of the CAS is the development of a comprehensive set of strategies that will address the impacts of climate change in California. These strategies will include a wide range of approaches, including proposals for specific projects, new policies, updates to existing policies, potential legislation, regulations, and future recommendations for scientific research.

The first CAS will serve as a guidance document with a primary focus on State-level strategies while including preliminary policies that can be adopted by local jurisdictions. Future versions will need to fully integrate local, regional, State, and federal adaptation strategies to ensure the greatest coordination possible, and the elimination of barriers that may arise from multiple goals, rules, and regulations. The CAS will include a diverse set of strategies to account for the

foreseeable uncertainties that relate to projections of when, where, and how climate impacts will become apparent in specific regions and locations. In addition to sector-specific strategies, the CAS will outline those cross-sector measures designed to reduce the risks from climate change.

The third and final component of this climate adaptation analysis is the development of specific actions that will be implemented in priority areas. The nature of climate change, and the considerable degree of uncertainty remaining in many projections of climate change impacts, requires that the State work within a risk management framework. Because of climate change, policymakers and planners can no longer rely on historical records to predict future weather conditions related to average and extreme weather events.

While the scientific and economic analyses conducted to inform the CAS provides an important foundation for the development of adaptation strategies, uncertainty may remain in regard to precise magnitudes, timing, and effects of climate change impacts. Effective adaptation planning will require action based on probabilities and risk assessments that provide the best measurements and estimates of how climate change will impact California.

4.3 Sector Working Groups

Development of the CAS is structured around six Climate Adaptation Working Groups, each representing a major sector of California that will be impacted by climate change, as outlined in Article 7 of the Governor's executive order. These working groups form the core of a bottom-up process that drives the CAS, bringing together experts from across State agencies and departments and drawing on the input from stakeholders. Numerous opportunities have been provided for public comment and feedback. It should be remembered that this CAS is considered an early effort to understand how the State should plan for future climate change impacts. It is expected future CAS efforts will be much broader in scope, and include even greater scientific and stakeholder input to the process.

Each working group is responsible for assembling relevant information synthesized into the final CAS report. With the assistance of advisors from the California Energy Commission and the Resources Agency, each working group is completing a preliminary risk assessment for impacts related to their sector. The working groups will propose and prioritize multiple adaptation strategies to prepare for these impacts. This will include a complete assessment of policy mechanisms and resources required for the implementation of these strategies. In addition, the working groups will provide information on the potential barriers to implementation, as well as recommendations for future research needs. These findings will be summarized in white papers from each working group which will

be compiled into the complete CAS to be released in February 2009 for public comment.

4.3.1 Water

California's water sector faces significant impacts from climate change. These will exacerbate the stresses on an already stressed state water system. A projected reduction of the Sierra Nevada snowpack by at least 25 percent by 2050[28] will pose severe water supply challenges for California, which relies on the proper timing and quantity of the spring melt in order to provide a reliable water source throughout the summer and fall. Changing precipitation patterns will result in longer and drier droughts and decreased groundwater levels, coupled with a higher frequency and severity of extreme flooding events. Sea-level rise will add additional complications to an already critical situation in the Sacramento-San Joaquin Delta by placing additional pressure on an already vulnerable levee system, and magnifying sea-level rise driven saltwater intrusion into coastal groundwater resources in the face of decreasing freshwater recharge. The Public Policy Institute of California estimates that a single occurrence of catastrophic levee failure in the Delta could result in economic damages of up to $16 billion and significantly disrupt water supply throughout the state[29]. The devastating nature of these expected impacts clearly demonstrates the need for careful planning and aggressive action to improve resiliency and limit vulnerability to climate change in the water sector.

The Department of Water Resources, in collaboration with other departments and stakeholders, has initiated a number of projects to begin climate change adaptation planning for the water sector. The recent incorporation of climate change impacts into the California Water Plan is an essential step in ensuring that all future decisions regarding water resources management address climate change. Central to these efforts will be the implementation of Integrated Regional Water Management (IRWM) plans, which address regionally appropriate management practices that incorporate climate change adaptation. These plans will evaluate and provide a comprehensive, economical and sustainable water use strategy at the watershed level for California.
The Department of Water Resources also plans to promote and pursue the following:

[28] Scenarios of Climate Change in California: An Overview. FINAL report from California Energy Commission, Public Interest Energy Research (PIER) Program, California Climate Change Center, publication # CEC-500-2005-186-SF, posted: February 27, 2006 - This is taken from this paper: "In the Sierra Nevada by the 2035–2064"

[29] Comparing Futures for the Sacramento-San Joaquin Delta. Jay Lund, Ellen Hanak, William Fleenor, William Bennett, Richard Howitt, Jeffrey Mount, and Peter Moyle. PPIC. July 2008

- Aggressive water conservation programs, including updated urban water management plans, wider use of recycled water where appropriate, and incentives for water-efficient appliances and systems;
- Increases and improvements in both surface and groundwater storage capacity, including the protection of groundwater recharge areas and feasibility studies for reservoir expansion;
- Integrated flood management programs, including improved emergency preparedness and recovery plans as well as structural and non-structural projects for flood protection that account for climate change impacts;
- Preservation and enhancement of ecosystems to preserve biodiversity and also improve flood management and water supply functions;
- Expansion of monitoring and data collection capabilities, in order to better track and understand climate change impacts to the water sector;
- Plan for anticipated sea-level rise; and
- Fund research studies on climate impacts and system vulnerabilities.

4.3.2 Transportation

Climate change will have significant impacts on California's transportation and energy infrastructure. Given the long timeframes involved in many construction projects in this sector, early planning efforts are essential for effective adaptation. Major impacts include sea-level rise, an increase in the frequency and severity of heat events and changes in hydrologic patterns. Sea-level rise could potentially inundate California's major transportation infrastructure, including San Francisco and Oakland airports and neighboring communities. A sea-level rise of merely one foot would result in "100-year" flood events as occurring on average every ten years[30]

The anticipated regional or microclimate changes facing transportation infrastructure in California could have variable impacts on the economy, environment, and transportation infrastructure and operations due to increased temperatures, sea-level rise, and changes in the timing, intensity, and variability of precipitation. The degree of vulnerability or risks for transportation infrastructure depends on regional and local characteristics–natural, built, and human environment--as well as location, types and function of transportation facilities or assets.

[30] Our Changing Climate. Assessing the Risks to California. CEC-500-2006-077.

Impacts may include flooding of tunnels, coastal highways, runways, and railways; buckling of highways and railroad tracks; submersion of dock facilities; drainage and hydrological facilities; and shifts in demand for transportation. Increased frequency of precipitation, storms, extreme events, and wave run-up could disrupt system operations and services and the safety of transportation. Highway capacity and throughput is reduced during storm or rain, lowering speed and impeding mobility. The emergency and evacuation routes could be vulnerable to climate extremes, particularly in low-lying coastlines.

California has over 1,100 miles of coastline and 1,000 miles of enclosed bay with variable regional, micro climate environments that serve to provide major economic activities, tourism and recreation. Gradual changes in sea level or waterways, particularly at high tide during storm events, or increases in extreme events given potential wave run-up will threaten transportation operations and will damage low-lying coastal infrastructure. Rising sea level could also erode beaches and wetlands, increase flooding from storm surges and rainstorms, and enable saltwater to advance upstream. Rises in the water levels of inland waterways may also affect transportation and shipping into and out of the ports and may necessitate more frequent dredging of channels. Many coastal airports built on wetland are vulnerable to flooding. This includes Oakland and San Francisco airports that were built on bay fill.

These prospects could have strategic security as well as transportation implications. They require transportation agencies to recognize the prospect of climate change and have proper organizational structure and tools for assessing risks and economic costs, and initiate strategic planning in addressing adaptation that satisfy climate change concerns.

4.3.3 Oceans and Coastal Resources

This sector comprises the state's ocean resources as well as coastal land areas along California's 1,100 miles of open ocean coast and another 1,000 miles along San Francisco Bay, including its bays, lagoons, estuaries and wetlands. In addition to the extensive recreational, economic, and cultural resources located along the coast, these areas are home to a large number of vital ecosystems and species. All of these resources including infrastructure, human environments and communities, and natural habitats are at considerable risk from climate change impacts. These include inundation from sea-level rise, increased flooding and erosion, higher storm surges, loss of coastal habitats such as beaches and wetlands, salinity changes, increased ocean acidity, and biodiversity reduction due to species loss. Given the tremendous value of these coastal resources to the state and the potentially devastating consequences of climate change, adaptation planning is of utmost importance in this sector.

The Ocean Protection Council and the San Francisco Bay Conservation and Development Commission, along with several groups and stakeholders, have worked to propose adaptation strategies in the coastal sector which fall into several major categories. The first involves strategies for existing development, including existing infrastructure and other resources located in potentially vulnerable areas. Strategies for addressing climate change impacts include rolling easements, relocation incentives from high-risk areas, government purchase of vulnerable property, seawalls and levees to protect critical infrastructure, planned retreat (gradually moving buildings and other structures) and rebuilding restrictions for those structures located in vulnerable areas following climate-related disasters.

The second major category involves strategies for new development. Adaptation strategies for new development include the use of new building materials, an increasing emphasis on design for climate resiliency, the encouragement of smart growth and clustered development in low-risk areas, mandatory setbacks to restrict development within a certain distance of vulnerable areas, required "warning" notices to developers and buyers on the potential impacts from future climate change, and the development of expendable or movable structures in high-risk areas.

The third major category targets ecosystems and habitat and includes beaches, wetlands, subtidal habitats, and fisheries. Strategies to protect and preserve these ecosystems in the face of climate change include regional sediment management planning to help restore natural sources of coastal sediment, beach nourishment to replace areas lost to sea-level rise or erosion, creation of additional "buffer zones" to allow for wetland migration as the climate changes, creation of new wetlands to replace lost areas, fishery management plans that set catch limits with future climate change in mind, subtidal habitat enhancement, and the creation of Marine Protected Areas. In addition to these major concerns the Ocean Protection Council will address insurance-related policies that encourage responsible development in vulnerable areas; additional legislative and funding opportunities to further adaptation planning; and strategies for the coordination between local, State, and federal governments.

4.3.4 Forestry

California's forests face significant vulnerability to climate change impacts, including changes in water supply and timing of snowmelt runoff, upward shifts in the distribution of wildlife and vegetation, more frequent and intense wildfires, longer fire seasons, more frequent outbreaks of pests and diseases, and changes in growth rates and productivity of forest trees and vegetation.

In order to adapt to these changes and increase resiliency of California's forest resources, the Department of Forestry and Fire Protection and the Board of Forestry (BOF), in coordination with other agencies and stakeholders, plan to implement a new vision for California forest management that will include a strong framework for climate change adaptation.

While forests will "adapt" in some fashion to climate change, management actions may increase the likelihood of achieving desired conditions by enhancing the resiliency of existing forests, establishment of future stands, and improving the ability to cope with disturbance and related impacts to climate change. In addition, land-use decisions and management actions can also have adverse effects that create environmental stress and weaken the resiliency of ecosystems. Actions taken to reduce the current stress on forest and range ecosystems can also improve chances for successful adaptation (e.g. unintended adverse impacts on current forest health from fire suppression). In some cases, environmental effects from climate change have already been observed in California forest and rangelands. This includes shifts in species ranges, changes in the frequency of disturbance from wildfires and pests, and effects on forest productivity.

Rapid climate change may challenge the capacity of forest species and habitats to adapt. Temperature and precipitation changes can affect regeneration, tree growth and vigor, and forest health and productivity. In addition, temperature, drought, and forest health can interact to enhance the level or occurrence of disturbances such as fire and pests. Human uses of the land (e.g. forest management and fire suppression), along with population growth and development, create additional stress that affects forest health and may increase vulnerability to impacts from climate change. It is this vulnerability assessment that is essential when proposing actions that lead to climate resiliency. There are no standard methods for assessing vulnerability from climate change, but given the increasing body of knowledge and the nature of forests and their impact on many long-lived species, a flexible or adaptive management plan is an integral part of any adaptation strategy.

Adaptative management of forests should prioritize the management of forests and range lands for resilience, restoration, and recovery while promoting adaptation in land use, public safety, and economic infrastructure that leads to the identification of private and public investment considerations. Certainly the continued funding of research models that allow for experimentation and feedback are also beneficial when it comes to thoughtful adaptative management planning and the encouragement of forest health and monitoring activities.

The introduction of prioritized planning efforts that identify geographic "hot spots" and develop contingencies to monitor, assess, and react to abrupt climate change is instrumental in preparedness planning.

Adaptative land-use planning should also be encouraged in order to prevent or decrease the impacts of climate change disturbance, and assist with recovery. This

should include improving land-use planning and implementation to reduce conversion and wildfire risks and include regional readiness to respond to disasters, improvements in local land-use planning, and by working with local agencies to decrease risk and hazards and increase public safety options. It is also important to include climate change into planning for fire protection services and encourage other agencies to incorporate adaptation principles into permitting programs for land conversions, forest practice general plans, and individual development projects. Improved rangeland management that supports private sector efforts by identifying economic opportunities for low carbon footprint, biofuel production, and riparian forest restoration are also important as climate coping mechanisms for California.

The improvement of analytical tools for assessment, strategic planning, and tactical planning should be developed in order to facilitate long-term planning, and provide decision support guidance that will help government agencies and landowners prepare for climate change and make informed decisions. This includes modeling capacities, improvements in the existing scientific knowledge base, establishment of assessment criteria, and collaborative efforts that address indicators of forest and range health that are sensitive to climate change, as well as ongoing work with reporting agencies to establish standardized reporting procedures and formats.

4.3.5 Agriculture

The California Department of Food and Agriculture has identified, with stakeholder input, climate change impacts including changes in average and extreme temperatures and precipitation patterns which influence crop yields, pest and weed ranges, and the length of the growing season. Extreme events, such as heat waves, floods, and droughts, may be among the most challenging of impacts on agriculture since they can result in significant economic losses. It is also anticipated that water deliveries to agriculture will be reduced due to overall drier conditions concurrent with increased urban demand.

Agriculture will be directly affected by increased warming: some crop yields may increase, while other yields may decrease. Higher average temperatures can also cause increases in mortality and reproduction, and decreases in the productivity of livestock, leading to declining meat, egg, and dairy production unless adaptive measures are taken to reduce heat stress on animals. The ability of fruit and nut crops to set fruit is influenced by the number of chill hours in the winter. An increase in average temperatures reduces the numbers of chill hours; and without a sufficient number of chill hours in a growing season, these crops will have decreased fruit quality and economic yield.

Impacts on agriculture are further complicated by difficulties in introducing new management practices, the potential need for increased irrigation, and crop

switching. Agricultural production also may need to relocate to other regions, due for instance to sea-level rise and saltwater intrusion increasing the salinity of soils and groundwater, or when higher temperatures do not allow certain crops to be grown in the regions where they had been previously.

Warmer winters, longer growing seasons, and higher temperatures overall will encourage the proliferation and survival of pathogens and parasites, affecting both crops and livestock. Therefore, efforts sponsored by the State will be necessary to support research and the identification of crop varieties capable of adapting to climate change and to guide grower crop and livestock selection. Efforts to alter planting, thinning, and harvesting practices in order to adapt to new and expanded crop pests and diseases may be needed to prepare for and manage climate change impacts.

A number of climate impacts can be addressed through farm management practices that prevent erosion, build soil fertility, and increase the water-holding capacity of soils, such as conservation tillage, crop rotations, manure management, fallowing, cover crops, and more efficient use of fertilizers. Many of these practices serve both adaptation and mitigation purposes. Other measures will need to address water availability through irrigation and new crop regimes.

4.3.6 Habitat and Biodiversity

California's unique natural ecosystems and species make the state an area of exceptional biodiversity. The state has long had a strong commitment to preservation of natural landscapes and wildlife, but these efforts face considerable challenges due to the changing climate. Most climate impacts, including sea-level rise, water availability and water quality changes, extreme weather events and more severe wildfires, will have a significant effect on both individual species and entire ecosystems in the state. Moreover, climate change will interfere with ecosystem functions, migration patterns, and species interactions as seasonal timing of life cycles and natural processes become disrupted. Habitat loss and the increased prevalence of invasive species and disease-causing organisms may also be dramatically impacted by climate change.

The Department of Fish and Game and California State Parks, together with other departments and stakeholders, are working to outline strategies to best preserve California's natural landscapes and biodiversity and facilitate adaptation components in all State plans given changing climatic conditions. The Department of Fish and Game has assembled a climate change task force that will coordinate all climate adaptation efforts within the department. The Department of Fish and Game has initiated stakeholder outreach and hosted workshops to discuss potential climate impacts and adaptation strategies for each of the state's nine bioregions.

A primary goal of climate analysis for habitat and biodiversity is the recent update the California Wildlife Action Plan. Primary areas of focus include landscape level conservation efforts, aggressive measures to control invasive species, assurance of adequate water supply and quality and recommendations for future research within each bioregion. Early strategies include improved monitoring of ecosystem health, identification of indicator species that could provide early warning of climate change impacts, and improved modeling that will serve to predict shifts in ecosystem function and composition following climate change.

State Parks has also begun incorporating climate change considerations into all of its planning and operations. In the face of potentially severe impacts from climate change that result in unavoidable species loss, the department has acknowledged that the previous approach of protecting individual species must be set aside in favor of a new paradigm based on protecting large reserves that represent California ecosystems. State Parks will focus on adding a number of large reserves that increase size and connectivity, which promotes the survival and adaptability of species within protected areas. State Parks will acquire those areas that have high numbers of endemic species, are evolutionary hotspots, or are highly diverse and heterogeneous in wildlife, vegetation, soil type, elevation, and other factors. By considering these important factors in the creation and expansion of reserves, State Parks will ensure the maximum ability for ecosystems to evolve and adapt to climate change while minimizing the risk and loss of functionality. With climate change as a priority concern, State Parks will continue to increase its understanding of wildfire impacts, beach and shoreline issues, and water management.

4.3.7 Public Health

A changing climate will undoubtedly affect public health across the state, requiring updates to existing emergency and preparedness response plans in order to minimize climate impacts as it relates to public health and safety. A major impact of a climate change will be an increased frequency, duration, and severity of heat events. The heat wave that occurred in California in July 2006 was the longest on record since 1948, and resulted in approximately 140 heat-related deaths. These occurrences are likely to increase with climate change and will disproportionately affect the elderly, infants, the infirmed, outdoor workers, and other vulnerable populations. Public health impacts from climate change also include increases in other extreme weather events such as droughts, flooding, increased particulate matter, frequent wildfires, increased allergens, spread of water- and vector-borne diseases, and the availability and quality of adequate food and water supplies. These multiple impacts have the potential to increase

morbidity and mortality, chronic diseases, communicable diseases, and psychological distress.

Potential strategies for reducing risks and vulnerabilities from these impacts include providing better access to health care, expanding and building upon existing surveillance and modeling capabilities to better understand and track public health hazards, and updating emergency plans to better deal with extreme climate events.

4.4 Cross-Sector Interactions

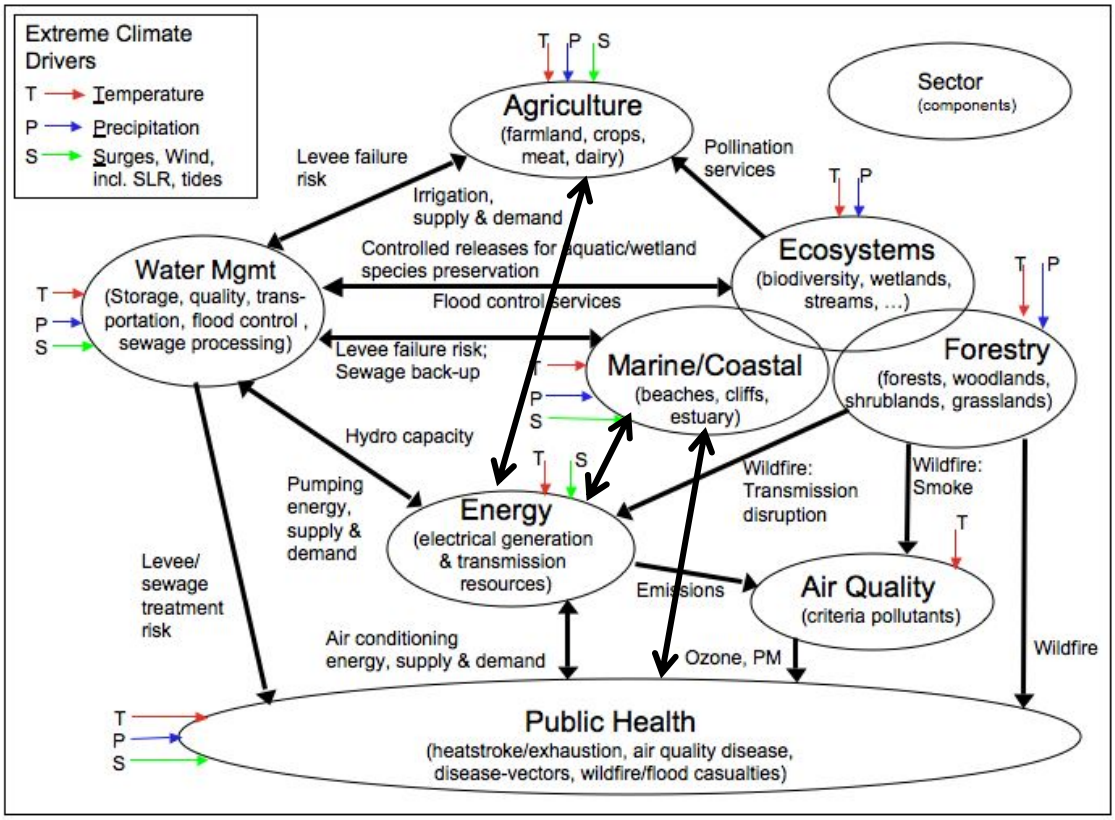
Climate change impacts, as well as adaptation strategies, may overlap between two or more sectors, requiring cross-sector coordination and collaboration in order to identify benefits for both sectors. It should also be noted that adaptation strategies proposed by one sector may also compete with, or complicate proposed actions of, another sector.

In order to facilitate cross-sector communication, representatives from each working group of the Climate Adaptation Strategy reviewed the strategies of all other sectors and met to discuss implications on their strategies in preparation of the CAS.

In order to maximize the overall benefits to all sectors, it is essential that the adaptation analysis addresses any potential “unintended consequences” of individual department actions. As such, cross-sector collaboration should continue for long-term adaptation planning.

Here is an illustration showing connections between different sectors, as an example of the complications of linking different sectors.

Figure 3: Cross Sector Adaptation Strategy Links



4.5 Early Actions - Climate Adaptation Efforts

Throughout the CAS development process, the Climate Adaptation Working Groups will continue to look for early action adaptation strategies that can be introduced in the short term, while long term strategies are investigated further. Examples of early actions include, but are not limited to the following:

- Executive Order (EO) S-13-08 requires the development of the first California Sea-Level Rise Assessment Report, to be completed no later than December 1, 2010. The result of this study will be used to develop coastal management planning guidance for sea-level rise through the state's coastal management agencies, offices, and commissions, thereby ensuring preservation of terrestrial and aquatic species in coastal areas;

- The California Ocean Protection Council will coordinate with the Coastal States Organization to continue to ensure climate change adaptation is a priority for State and federal partners;

- The California Department of Fish and Game has identified climate change as a key threat in its core planning document, *the State Wildlife Action Plan*, and is actively working to determine the climate impacts faced by their managed lands and the species residing on those lands. All of California's land management agencies will adjust plans and expenditures based on updated climate science;

- The Department of Water Resources has completed the 2008 State Water Plan Update that will guide water expenditures and planning for the next century and has climate change as a major planning priority

4.6 Climate Adaptation Tools for Stakeholders

Individuals, organizations, or State agencies interested in planning for future climate change impacts can access a number of tools and reports to help. The following organizations provide useful resources for stakeholders interested in learning more about adaptation planning.

ICLEI	http://www.iclei-usa.org/programs/climate/Climate_Adaptation
Pew Center for Climate Change: State Adaptation Plans	http://pewclimate.org/node/5860
Centers for Disease Control	http://www.cdc.gov/climatechange/
2007 IPCC Report on Impacts, Adaptation, and Vulnerability	http://www.ipcc.ch/ipccreports/ar4-wg2.htm
Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments	http://www.cses.washington.edu/db/pdf/snoveretalgb574.pdf
Adaptation Wizard – UK Climate Impacts Programme (UKCIP)	http://www.ukcip.org.uk/resources/tools/adapt.asp