Research Paper No. 10102801

California Climate Risk and Response

David Roland-Holst and Fredrich Kahrl

November, 2010

DEPARTMENT OF AGRICULTURAL AND RESOURCE ECONOMICS
207 GIANNINI HALL
UNIVERSITY OF CALIFORNIA
BERKELEY, CA 94720
PHONE: (1) 510-643-6362
FAX: (1) 510-642-1099
http://are.berkeley.edu/~dwrh/CERES_Web/index.html

Research Papers on Energy, Resources, and Economic Sustainability

This report is part of a series of research studies into alternative energy and resource pathways for the global economy. In addition to disseminating original research findings, these studies are intended to contribute to policy dialog and public awareness about environment-economy linkages and sustainable growth. All opinions expressed here are those of the authors and should not be attributed to their affiliated institutions.

For this project on California Climate Risk and Response, we express thanks to Next 10, who recognized the importance of this issue for California's sustainable growth agenda and provided essential intellectual impetus and financial support. Thanks are also due for outstanding research assistance by the following:

Jennifer Baranoff
Sam Beckerman
Shane B. Melnitzer
Drew Behnke
Dana Chadwick
John Chen
Alex Cheng
Henry Ching
Billie Chow
Melissa Chung
Joanna Copley
Elliot Deal
Dave Graham-Squire
Sam Heft-Neal
Shelley Jiang
Maryam Kabiri
Elaine Krikorian
Adrian Li
Tom Lueker
Jennifer Ly
Xian Ming Li
Adrian Li
Vanessa Reed
Cristy Sanada
Mehmet Seflek
Lawrence Shing
Sahana Swaminathan
Michelle Tran
Rainah Watson
Tony Yu

Noel Perry, Morrow Cater, Sarah Henry, John Andrew, Ralph Cavanaugh, Guido Franco, Skip Laitner, and Adam Rose offered many helpful comments. We have also benefitted from the research insights of too many colleagues to list by name here, all of whose dedication is advancing our understanding of climate change and the challenges it presents, and to PIER and other California initiatives who have generously supported much of the research we cite here. We have attempted in all cases to cite original research contributors when their ideas and findings are mentioned in this review, but any omissions will be corrected upon notification. Opinions expressed here remain those of the authors, as do residual expository and interpretive errors, and should not be attributed to their affiliated institutions.

"It is not the strongest of the species that survives, nor the most intelligent, but the one most responsive to change."

– Charles Darwin

Executive Summary

This report provides a multi-sector assessment of long-term Climate Risk and Response for the California economy. It includes a thorough review of the most recent available evidence on potential climate damage, economic assessment of this damage, and a review of options for a comprehensive strategy of Climate Defense for California. From the most general perspective, our review of the evidence on climate risk and response supports four overarching findings:

- At the aggregate level, California has the economic capacity to adapt against foreseen climate risk, but doing so effectively will require better information and strategic policy response. Our estimates indicate that Climate Risk, damages if no action is taken would include tens of billions per year in direct costs, even higher indirect costs, and expose trillions of dollars of assets to collateral risk. Table ES1 below illustrates these costs.
- Climate Response, on the other hand, can be executed for a fraction of these net costs by strategic deployment of existing resources for infrastructure renewal/replacement and significant private investments that would enhance both employment and productivity.
- At the sector level, there will be some very significant adjustment challenges, requiring as much foresight and policy discipline as the state can mobilize. In this context, the political challenges may be much greater than the economic ones. The state's adaptation capacity depends upon flexibility, but divergence between public and private interests may limit this flexibility.
- Despite the extent and high quality of existing climate research reviewed in this document, the degree of uncertainty regarding many important adjustment challenges remains very high. This uncertainly is costly, increasing the risk of mistakes, including deferral of necessary adaptation decisions. To further improve understanding of climate effects may itself be costly and difficult, but policy makers must have better visibility regarding risks and response options.

Thus California can respond to climate risk by developing effective strategies for Climate Response, including defense (against adverse impacts like rising sea level) and adaptation (shifting to more sustainable growth patterns). A real commitment to this would begin immediately by establishing and extending capacity for technical assessment and policy analysis, followed by timely and sustained policy activism. California's historic AB32 initiative is a positive model for this, but only a beginning. The scope of long term climate issues is much wider, and could sustain a longer term agenda for economic stimulus based on Climate Defense.

Table ES1: Economic Damage and Asset Risk Estimates for California

2006 USD Billions	Damage Cost/Year Low	High	Assets at Risk	
Water	NA	0.6	5	
Energy	2.7	6.3	21	
Tourism and Recreation	0.2	7.5	98	
Real Estate	0.2	1.4	900	Water
	0.1	2.5	1,600	Fire
Agriculture, Forestry, Fisheries	0.3	4.3	113	
Transportation	NA	NA	500	
Public Health	3.8	24.0	NA	
Total	7.3	46.6		

Notes: These costs and assets at risk values are intended to be indicative. Annual averages do not represent the actual adjustment process, which will probably be non-linear and dependent on timing of adaptation measures. The absence of a value in this table does not imply that its expected value is zero, but rather that its value might be negative (water in a B1 scenario) or we are not confident of available data needed to estimate it (e.g. costs for transportation). All of the values in this table are drawn from tables and text in the sections on individual sectors. Finally, the total for assets at risk is omitted to avoid double counting.

Like the New Deal or Homeland Security, California can turn adversity into a growth opportunity with the right policy leadership. Pro-active measures such as new and renewed public expenditures on infrastructure (e.g. the new Bay Bridge, rapid rail, etc.) can stimulate local job creation and complementary private investments. Private sector growth can be further accelerated with investment incentives and other promotion for energy efficiency, technologies for climate adaptation, including renewable, carbon capture and storage, energy efficiency, home insulation, etc.

Seven strategic sectors are focal points for California Climate Risk and Response. Our general findings for each are summarized below:

1. Water scarcity in California will increase sharply because of climate change, at least on a seasonal basis. This poses important challenges to the state's physical and institutional capacity for water storage and allocation, and adaptation will add hundreds of millions of dollars to existing renewal and replacement costs. Water conservation is the most cost-effective means reducing these pressures, but it is unlikely to be sufficient to avert more intense rural-urban competition. Because the water economy is seriously distorted by legacy rights, allocation, and pricing policies, this could trigger a complete re-appraisal of rules governing the state's water entitlements and private use.

2. Energy conditions in California depend on the evolution of the electric power and transportation sectors. Electric power will experience significant challenges for climate adaptation, including shrinking hydropower capacity and dramatic potential growth of residential demand. If, as some predict, per capita consumption rises by up to 50% over this century, the state must fundamentally rethink of policies toward electricity production, distribution, and demand. To the extent that supply growth would cause even greater climate damage, more aggressive commitments to renewable energy must be considered, particularly distributed technologies such as photovoltaic. In addition to new supply side polices, projected demand growth would reverse the state's historic progress in energy efficiency and reduce household purchasing power by billions of dollars per year. Demand Side Management policies need fuller consideration. Without this kind of guidance, induced innovation and technology adoption will fall short of California's climate innovation potential.

3. Transportation is vital to the state's diverse but integrated economy, and especially to its national and international economic linkages. California transportation will confront important challenges from climate change. Unfortunately, there has been very little research on this issue, so policy guidance at the present time is very limited. What we do know is that California's port infrastructure has several hundred billion dollars of real asset exposure to changes in sea level, tidal amplitude, and weather induced wave action. This includes many of the state's major airports, which will require fortification or, at dramatically higher cost, relocation. Road systems around the state are also vulnerable to temperature increases in ways that are only beginning to be understood. In addition to asset exposure, the spillover effects of disabling this infrastructure would multiply economic damages significantly.

4. Tourism and recreation are important sources of state income and employment and a large category of services to state residents and visitors. Climate change will hurt some activities in this sector and help others. Thus overall damage and adaptation costs will mask substantial transfer effects, and total economic adjustments will be much larger than net benefits or costs. The winter sport sector, for example will eventually have to leave the state, but water and air temperature increases will open new coastal and montane recreation opportunities. As the state adapts to changing patterns of use in this sector, important opportunities will arise for public and private investment in environmental assets and services. Going forward, the state should give greater recognition to linkages between environmental asset quality (e.g. coastal ecology, forest cover, parks) and willingness to pay for environmental services.

5. Real Estate represents the California's largest climate liability, with up to $2.5 trillion of assets exposed. Direct exposure includes fire and water damage, but a much larger issue is indirect exposure through escalating adaptation costs (higher water, electricity, and other costs) and collateral asset depreciation. A relatively small percent of the state's residential and commercial property faces direct climate damage, but it is concentrated in the most valuable markets. In addition to structures directly threatened, there is significant depreciation risk across all markets linked to forested, coastal, estuarial, or riverine real estate markets. Such linkages far outweigh direct damages. Efficient adaptation to this challenge will depend critically on how the cost is allocated between private and public interests. If the government assumes the costs of climate defense and risk management, this represents a massive transfer of wealth from taxpayers to selected property owners, as well as a moral hazard in insurance and property markets that may drive prices far above more realistic risk-adjusted valuations, further inflating the public's climate liability. Unfortunately there is very little research to support policy guidance on this important climate issue.

6. Agriculture is a politically important sector in California, but its economic significance will be challenged to keep pace with the scarcity value of its underlying land and water resources. Sustained economic growth will increase land prices all over the state, and climate change will raise the scarcity value of agriculture's second most important input, water, to unprecedented levels. For these reasons, we expect dramatic changes in agriculture over the next century. To remain viable, California will have to improve the productivity of diminishing land and water resources available to this sector, at the same time upgrading average product quality to pay much higher prices for those resources. Generally, we expect significant agricultural consolidation around high value and more technology-intensive crops. Agriculture faces other climate adaptation challenges, including temperature induced crop migration and pest evolution, but these are of secondary importance.

7. Public Health effects of climate change are generally negative, with rising risks of heat-induced morbidity and mortality adding hundreds of millions of dollars per year to the human cost of climate change. Public policy can play a significant role in adaptation, mainly through health education and targeted assistance to vulnerable (elderly and low income) groups who will need improved access to mitigating technologies (e.g. air conditioning, refrigeration).

Taken together, these sector impacts portend direct losses of up to tens of billions of dollars per year if no action is taken, far greater indirect costs, and assets exposed to risk valued in trillions of dollars. In the absence of state action, private agency would combine limited defensive investment with long-term asset depreciation, as threatened real estate and other economic interests are abandoned or converted to lower value activities. Some of this is inevitable and perhaps desirable, as the alternative would be state intervention that promotes unsustainable resource use and/or transfers wealth from taxpayers to inefficient private investment. However, public policy still needs to play a prominent role in the adaptation process and, by a combination of forward-looking fiscal and regulatory determination, the state can promote more sustainable growth at lower private cost. A wide array of adaptation policies, supported by more intensive and extensive research of the kind reported here can overcome market failures and provide the support and guidance needed for private agency to effectively share this adjustment burden. These would include, but by no means be limited to:

1. Facilitation of more efficient water allocation within the state, including a comprehensive re-examination of regulatory approaches to efficient water and energy use, including systems of legacy entitlement and public/private cost sharing.
2. More extensive and, where appropriate, intensive promotion of renewable energy technology, including innovation, diffusion, and adoption
3. Investments for climate defense of strategic state infrastructure
4. Investments in state natural landscape and recreational assets, and promotion of public-private partnerships for a new generation of tourism and recreation based on high quality, sustainable environmental services
5. Reassessment of state agricultural policy, with emphasis on knowledge-intensive agricultural innovation, higher value crops, water and land use efficiency, and environmental services
6. An integrated climate action plan for public health, including targeted policies to mitigate risk for the elderly and low income groups

All these measures and more will help the state make its transition to a more climate resilient future, and continue California's legacy of innovative policy solutions that deliver sustained prosperity. Some will be very difficult to achieve politically, but all are necessary to avert higher long-term climate costs. Meanwhile, the present level of uncertainty regarding expected California climate damage is so high that returns to investment in more research could be quite substantial. For the time being, we must emphasis that the estimated annual cost ranges in Table ES1.1 only indicate an average adjustment burden. In reality, year to year costs will fluctuate very significantly, and the state must be prepared for the peaks of this variance. Until more detailed and precise guidance emerges, however, the best strategic option for the state must be: Hope for the best, but prepare for the worst.

CONTENTS

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David Roland-Holst and Fredrich Kahrl[1]

UC Berkeley

Part I – Overview of Findings

Introduction

Average temperatures in the Earth's atmosphere have begun an upward trend that is largely irreversible over the next century, regardless of climate policy options currently under discussion. Whether these trends are moderate or extreme will depend on policy, but in any case extensive environmental change, with attendant economic adjustments, can and should be anticipated. Some areas of the world, particularly with poor majorities living close to sea level, may be catastrophically affected. California, for the opposite reasons, will not be. At the state level, this need not be thought of as an asteroid strike, but more appropriately the challenge of steering a supertanker to avoid a distant collision. Individual economic interests in the state may experience dramatic climate impacts, but the state as a whole has the means to avert large-scale adverse consequences. The extent of success in this will depend on foresight and policy determination.

This report supports pro-active Climate Response with a multi-sector assessment of California Climate Risk and Response. It includes a thorough review of the most recent available evidence on potential climate damage, economic assessment of this damage, and a review of options for a comprehensive strategy of Climate Defense for California.

[1] Contact: Department of Agricultural and Resource Economics, UC Berkeley: dwrh@are.berkeley.edu.

In this part of the report, we provide a very brief summary of major findings and issues relevant to the seven sectors covered in our review. This is then supported with sector by sector policy briefs in Part II and detailed background documentation in Part III. From the most general perspective, our review of research on climate risk suggests three findings:

1. At the aggregate level, California has the economic capacity to adapt against foreseen climate risk, but doing so effectively will require better information and policy determination. Our estimates indicate that Climate Risk, damages if no action is taken would include tens of billions per year in direct costs, even higher indirect costs, and expose trillions of dollars of assets to collateral risk. Climate Response, on the other hand, can be executed for a fraction of these net costs by strategic deployment of existing resources for infrastructure renewal/replacement and significant private investments that would enhance both employment and productivity.
2. At the sector level, there will be some very significant adjustment challenges, requiring as much foresight and policy discipline as the state can mobilize. In this context, the political challenges may be much greater than the economic ones. The state's adaptation capacity depends upon flexibility, but divergence between public and private interests may limit this flexibility.
3. Despite the extent and high quality of existing climate research reviewed in this document, the degree of uncertainty regarding many important adjustment challenges remains very high. This uncertainly is costly, increasing the risk of mistakes, including deferral of necessary adaptation decisions. To further improve understanding of climate effects may itself be costly and difficult, but policy makers must have better visibility regarding risks and response options.

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Like the New Deal or Homeland Security, the government can turn adversity into a growth economy with the right policy leadership. Pro-active measures such as new and renewed public expenditures on infrastructure (e.g. the new Bay Bridge, rapid rail, etc.) can stimulate local job creation and complementary private investments. Also included should be investment incentives and other promotion for energy efficiency, technologies for adaptation including better home insulation, more efficient air conditioners, etc.

Defense and adaptation strategies will entail a combination of hard (infrastructure) and soft (institutional) adaptation. Included in this process will be historic changes public-private resource and risk management partnerships. A process of this importance and complexity requires the best available information to support policy dialog, design, and implementation. This leads to perhaps our most important finding: Much more research is needed to support effective climate adaptation.

1. Water

Essential to all economic activities, water is very unequally distributed across California. In-state water supplies originate in northern weather patterns, yet most water is consumed in the south because it is relatively more arid. Because of this, water re-allocation has been necessary to support extensive development across the state. Meanwhile, the primary functional division in water is between agriculture and residential users, with industry a small user.

Most climate models agree that global warming will increase California's winter precipitation and reduce it at other times. This may not change the state's annual water budget, but warming will dramatically reduce California's second most important water storage facility (after aquifers), the Sierra snowpack, leading to larger and more volatile seasonal disparities in natural water availability. Combined with significant expected population growth, this will lead to considerable stress on existing water storage and allocation systems. Higher water flow variability will also lead to increased risks of flooding, saline intrusion, and drought-induced habitat destruction. Water conservation offers the most cost-effective means of reducing scarcity and its attendant costs, but it is unlikely to offset a substantial part of long-term growth in residential demand.

In the absence of climate defense measures, the potential costs of these climate impacts remain very uncertain, with estimates ranging from a few hundred million to several billion per year. To a significant extent, these differences are due to assumptions about how the state would adapt to scarcity. Initial conditions in the state's water economy are seriously distorted by legacy rights, allocation and pricing policies, so there would seem to be scope for trading systems to achieve more efficient allocation. In particular, urban water users pay about 50 times what agriculture (the major user) pays, suggesting that markets could shift water in the event its scarcity value rises. Indeed, the leading simulation models used to study this assume that trading will significantly mitigate climate induced scarcity. There are also out of state water resources, primarily from the Rocky Mountains, that are assumed to offer a additional water at competitive prices. Finally, state groundwater resources are assumed to offer transitory flexibility to smooth annual water access.

We are concerned that institutional rigidities and Rocky Mountain water scarcity may lead water costs to escalate more sharply in response to climate change. Trading systems are unlikely to operate smoothly with existing patterns of water entitlement and conveyance infrastructure. Indeed, a number of trades worth several hundred million dollars have been offered in recent years, with no takers in the agricultural community. Assuming the Rocky Mountains experience the same snow impacts as the Sierras, it may be unrealistic to rely on this source as a backstop. Finally, California acquifers, the state's primary water storage facility, are not well captured by any existing models, and their entitlement and exploitation characteristics do not suggest competitive allocation opportunities.

Climate adaptation in the water context will require extensive investments in both hard and soft infrastructure. Climate defense or damage mitigation is feasible, largely within renewal and replacement budgets. For longer term adaptation, significant investments in storage, conveyance, and water management institutions are needed. Financing the former can be sustained by public-private partnership, but the latter will break new ground with respect to the public interest in water access and use. We believe that more research may support a simple but challenging conclusion: California water has been too cheap for too long, and a significant rise in its scarcity value could trigger intense rural-urban competition and a complete re-appraisal of rules governing the state's water entitlements and private use.

2. Energy

The electric power sector comprises less than one percent of California GSP, but the services of this commodity are so pervasive it is liked to all economic activity and employment. Climate change will have a threefold impact on California's energy systems. First, changes in the seasonal availability of water would lead to a reduction in the state's hydropower resources, which accounted for 17 percent of California's total system power in 2006. Second, an increase in the number of extreme heat days could lead to a substantial rise in electricity demand for use in air conditioning. Lastly, a rise in winter storm activity might lead to an increase in power outages. All of these impacts can be tempered by both mitigation and adaptation measures, but will require proactive strategies from a variety of state agencies.

The costs of climate change in the energy sector are currently estimated in billions per year for replacement, renewal, and demand-induced capacity increases. On the supply side, compensating for an expected 20% reduction in hydropower capacity is much less important than anticipating climate-induced demand growth. The most reliable estimates indicate that per capita electricity use could increase by up to 50% over this century, which combined with population growth would require enormous commitments to new generation and transmission capacity.[2] Fortunately, these trends annualize to 0.5-1.0% growth, meaning that adaptation is probably feasible but should not be deferred.

Both climate mitigation (AB 32) and adaptation imperatives suggest the need for a radical rethinking of electricity production and distribution in California. Renewable energy can make an important contribution in both contexts, particularly distributed technologies such as photovoltaic. The state can facilitate this with more aggressive renewable standards, but this will still meet only part of the expected growth in demand. In addition to renewables, Demand Side Management policies need fuller consideration. Without this kind of guidance, induced innovation and technology adoption will fall short of California's climate innovation potential.

Actual future electricity demand will depend significantly on the way energy users respond to policy. For example, current electricity pricing is not based on scarcity, so consumers actually consume more per capita as temperatures rise and availability falls. Price reform in this sector should be a high priority. Finally, the residual demand growth, unmet by renewables, will fall to a combination of new in-state and out of state electric power capacity. For the former, it is essential that California promote low and even negative carbon technologies, including Carbon Capture and Storage. A large part of energy adaptation costs will be borne privately, but the state should seriously consider greater public commitments to technical progress in this sector. The benefits of innovation for more effective climate adaptation could be quite significant, both to the state economy and to local public health.

3. Transportation

Transportation is the foundation of the state's spatially diverse but highly integrated economy, as well as its lifeline to the national and global economy. Its ports account for 40% of US container volume and mediate 23% of total foreign trade. Climate change will be an important consideration for transportation planning in California. However, the vulnerability of California and U.S. transportation infrastructure to climate change, both committed and avoidable, is still poorly understood. Only a small amount of research has been done on climate adaptation in the transportation sector. The first federally funded overview of potential impacts of climate change for the transportation sector in the U.S. was published by the National Research Council (NRC) in 2008 (NRC, 2008).

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[2] This estimate is very recent and should be considered preliminary. It also takes only limited account of California's capacity for improvements in energy efficiency.

Climate impacts on the state's transport infrastructure remain very uncertain, but are likely to be concentrated in coastal areas where sea level rise and storm/wave action will threaten maritime facilities, airports, and coastal/fluvial ground transport assets. In the Bay Area, for example, all three major airports are near sea level. They could be raised or barricaded again level rises, but storm/wave action might pose unacceptable risk. Because of easement issues in a dense metropolitan area, the cost difference between fortification and relocation would be one or even two orders of magnitude. [3] Expected costs of maritime and ground transport defense currently range in hundreds of millions per year. These are within range of current public infrastructure budgets, but remain quite speculative. Among other things, these estimates include annualized costs of intermittent disasters, as well as significant uncertainty about the amplitude and frequency of Pacific storm and tidal cycles. Improving these estimates should be a very high priority, however, because the use value of these assets is enormous and their lifespan very long. Thus timing and sequencing of adapting investments is critical.

In light of expected population growth, less intensive use would not appear to be an option for adapting the state's transport infrastructure. Although there has been virtually no research in this area, the remaining options should certainly include more stringent design standards for new structures and retrofits to existing structures. Both would likely require some increase in costs, but engineering solutions of this kind are in most cases likely to be cheaper than relocation. In any case, foresight will again save money by avoiding irreversible misallocation and parallel capacity losses from extreme events, but early action must be better informed.

More generally, the infrastructure decision-making process needs to be completely overhauled and potentially combined with life cycle assessment to ensure that adaptation isn't putting undue stress on the state (or the world) to mitigate. For example, the GHG implications of large public works (esp. cement intensive construction) need to be assessed in concert with contributions to adaptation.

Soft adaptation options could also be important for reducing climate damages, both inside the transport sector and more broadly. Transportation shapes land use, migration/population growth, and economic development patterns, and more adaptive transportation planning decisions could have a significant influence on property-related climate damages. Policies that discourage settlement in high risk areas, for example, will reduce the state's long-run Climate Defense costs. In the truest sense, these linkages reveal the extent to which the climate issues are lifestyle issues.

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[3] The latest SFO scale "green field" airport, in Hong Kong, cost $20 billion.

4. Tourism and Recreation

Tourism is a major activity and source of income and employment in the California economy. Because the majority of people classified as "tourists" in the state are actually residents, we consider Tourism and Recreation as one sector for the analysis. Many of California's top tourism destinations are outdoors, including beaches, ski resorts, state and national parks, and golf courses. Climate change is expected to affect all of these venues and their appurtenant activities, but in different ways. If the earth's climate is actually stabilized, not all the climate impacts on this sector will be negative. In some industries, such as recreational gold mining, lower levels of warming will be beneficial. In others, such as the winter sports industry, any warming will be negative. Similarly, even as some areas lose revenue from tourism, other areas will gain. Thus, the net effect of climate change on California's tourism and recreation sector will likely mask large distributional shifts.

The primary sources of damage relate to snow, water, and heat tolerance. Under most climate scenarios, the California ski industry is threatened with extinction. Water sports will likely be attenuated somewhat on an annual basis and shift more strongly on a seasonal basis. Heat intolerance will reduce the appeal of outdoor activities generally, but those in natural environments in particular. The cumulative cost estimates for these impacts still vary considerably, between hundreds of millions and billions annually. More important, however, may be the distributional impacts, which shift income and employment around the state and between very different activities. People who can't ski may still take holidays in California, but this industry currently represents $500 million in direct revenue annually.

For this sector, the financial burden of adaptation will be relatively evenly divided between public and private stakeholders, at least according to existing patterns of asset ownership and use. Adaptation options differ for each of the three main categories of recreation (beaches, winter sports, and other outdoor). Most of the states recreational beach capacity can be sustained or substituted with "nourishment" strategies. For winter sports, artificial snow making can extend useful facility life, but this appears to be part of an end-game process that should include non-winter use diversification that could be significantly facilitated by public investments. Other outdoor activities can best adapt with strategies that combine diversification with ecosystem development to improve the recreational capacity of public and private lands.

5. Real Estate and Insurance

In the industrialized world, the economic implications of climate change will be dominated by asset valuation of real property. Whereas in many parts of the developing world other concerns, such as the spread of disease, may take precedence, in California the dominant climate issues will likely be related to demographics, land use, and real estate. Deeply implicated in the same discussion is the insurance industry, whose risk exposure will increase dramatically, offering new market opportunities and a central role in market guidance for both mitigation and adaptation.

Taken together, these two sectors represent the largest economic climate risk for the state, although they are among the least studied to date. Because of relatively frequent natural disasters — earthquakes, fires, and floods — many parts of California are intrinsically risky places to live and work. Despite the deterrent effect of such risks, California has an estimated $4 trillion in residential real estate assets, large portions of which are built in fire prone areas and zip codes along the coastline. Natural disasters have historically taken their toll on California's homes and businesses. The state suffered a total of $6.2 billion (2006$) in damages from hazardous weather from 1997-2006. Climate change may increase the frequency and severity of these adverse events, and climate-induced sea level rise will threaten coastal real estate. An increase in the frequency and severity of wildfires will further threaten homes and businesses across the state. Depending on the extent of defensive measures, real estate asset exposure in the coastal areas could vary from billions to hundreds of billions. In montane and other fire vulnerable areas, the vulnerability range is less than ten percent of this, but still quite significant.

Adaptation strategies for real estate and insurance are very complex, both from a material and behavioral perspective. As fixed assets, property values are highly vulnerable to changing local conditions. Residents and values in risk-prone areas should to a significant extent internalize such risks, but if history is any guide they will use political means to resist that. However, the geographic concentration of flood and fire vulnerabilities means that defense and adaptation policies are inherently distributional, using scarce public funds to secure the wealth of some residents but not others. Also, moral hazard in this context may undermine the insurance industry's capacity to price risk accurately, increasing exposure and the ultimate risk of costly public bailouts. Despite these reservations, our general conclusion is that defensive investments will be made in coastal areas because initial property values are very high, while public defensive investment in fire prone areas is less likely. Finally, an important distinction needs to be made between defense of private property assets, where markets can offer options for private financing, and public property. Adaptation and climate defense needs for the latter will necessarily be addressed with public resources.

6. Agriculture, Forestry, and Fishing

Although agricultural activities represent a small percent of GSP, they are politically very important and are linked deeply to a resource base (water, land) that is threatened by climate change. Climate change will mean significant changes for agriculture, forestry, and fisheries in California. In lower warming scenarios, some of these changes will be beneficial for agriculture and forestry, although there is still a debate about net impact. Both higher and likely lower warming scenarios, even if they cause no net economic impacts, will lead to a gradual but substantial change in the composition and location of agricultural, forest, and fish production. Agriculture will experience at least seasonal and perhaps annual water scarcity, spatial changes in crop eligibility, higher yields and pest activity, and greater vulnerability to energy prices (agro-fuel and chemicals). Forestry will experience high yields, but also higher fire risk and drought vulnerability. Fishery changes are less predictable, but rising sea temperatures may displace coastal fisheries.

The nets costs of these effects are generally agreed to be positive, with adjustment or transactions costs by far the largest component. Direct impacts range from hundreds of millions to billions annually, while very little has been done to estimate the very extensive costs of sector displacement, food source substitution, and surplus land effects on related property markets. Structural change in this sector is expensive because of high fixed asset and fixed cost proportions. For this reason, higher quality information can play an essential role in limited adjustment costs. There are many activity-specific options open to agricultural operators, but they need reliable guidance to commit to these. Forestry is a regional activity in the state, and over the time horizon considered demographic trends will probably exert more influence in this area than climate change. For fisheries, better quality information or insurance is again essential to facilitate adjustment.

In the end, however, these sectors are quite important for policy, but small relative to the states' overall economy and even the state budget. This suggests that public-private partnerships can meet significant elements of the adjustment challenge. Other sector adaptation discussed in this study, particularly water, will exert collateral influence on this one, but it must be recalled that California has a very high-value portfolio of crops, including wine and specialty fruits and nuts. Thus it is better positioned to make investments needed for climate defense and adaptation.

7. Public Health

Those who justly admire California for its progress in energy efficiency and emissions standards may be surprised to learn that it has the worst average air quality of all 50

United States. Air pollution leads to respiratory and cardiovascular disease that cause thousands of residents to die prematurely every year, with the number of California deaths from air pollution currently on par with those due to traffic fatalities (ARB, 2004). In addition to air quality, heat-related mortality is becoming an increasing concern for California policymakers.

Climate change has already begun to create new public health risks around the world, and in California most of these will be tied to air quality and temperature rather than malnutrition or pandemic diseases. Official estimates of the public cost of current air pollution are high, at about $70 billion annually. Most of this is actuarial valuation of premature death, but over $2 billion per year are spent on air pollution related hospital visits, and no account has yet been taken for an estimated 4.7 million and 2.8 million days of missed school and lost work (respectively). Climate change will increase all these amounts, which we estimate under a variety of climate scenarios to average in the range of $3-13 billion annually. It must be emphasized, however, that no other estimation work of this kind has been done yet, so these estimates must be seen as highly uncertain.

Effective government intervention could significantly reduce health-related impacts from climate change. Controlling criteria pollutant emissions is the most powerful option for reducing the pollution-related impacts of climate change. Relatively simple strategies could significantly reduce mortality during heat waves in California. These include early warning systems, public education, cooling centers, and air conditioning. As with other sectors described in this report, however, developing the capacity to deal with current problems will be the first step in an adaptation strategy.

Longer-term solutions for air quality may instead require a host of other considerations, from transportation and land use planning to fuel choices to greater attention to environmental justice issues. Among older and poorer groups, adaptive capacity is also significantly lower than in the population at large. Given the potentially high rates of risk and relatively low costs of intervention there is an obvious role for state agencies in reducing heat-related mortalities.

Part II – Sector Reviews

The direct impacts of climate change will be concentrated in seven economic sectors: water; energy; transportation; tourism and recreation; real estate; agriculture, forestry, and fisheries; and public health. While there are significant linkages among these sectors, the adjustment challenges faced by each will be different. For each sector, we provide a synopsis of the potential physical impacts of climate change faced by that sector, an assessment of the economic cost of these impacts, an indication of the distribution of these costs, and an overview of adaptation options.

1. Water: Agricultural, Urban, and Environmental Use

Overview

California's water resources are very unequally distributed across time and space. Most of the state's water supply arrives as precipitation falling in the northern region. By contrast, water demand is highest in the southern part of the state during late spring and summer. Overcoming this gap between the timing and geography of supply and demand requires an extensive system of water storage and conveyance, much of which was designed and built more than a half century ago.

The environment (e.g., maintaining ecosystems) has historically been the largest water user in California (48 percent), with agriculture a close second (41 percent) and urban users a distant third (11 percent) (AIC, 2006). Growth in urban water use, in particular, will require adjustments to these shares, with one study projecting that the share of urban water use will increase by more than 50 percent over its current level by 2050 (Medellin et al., 2006). Climate change will increase pressures on California's water supply by reducing the amount of water available in late spring and summer.

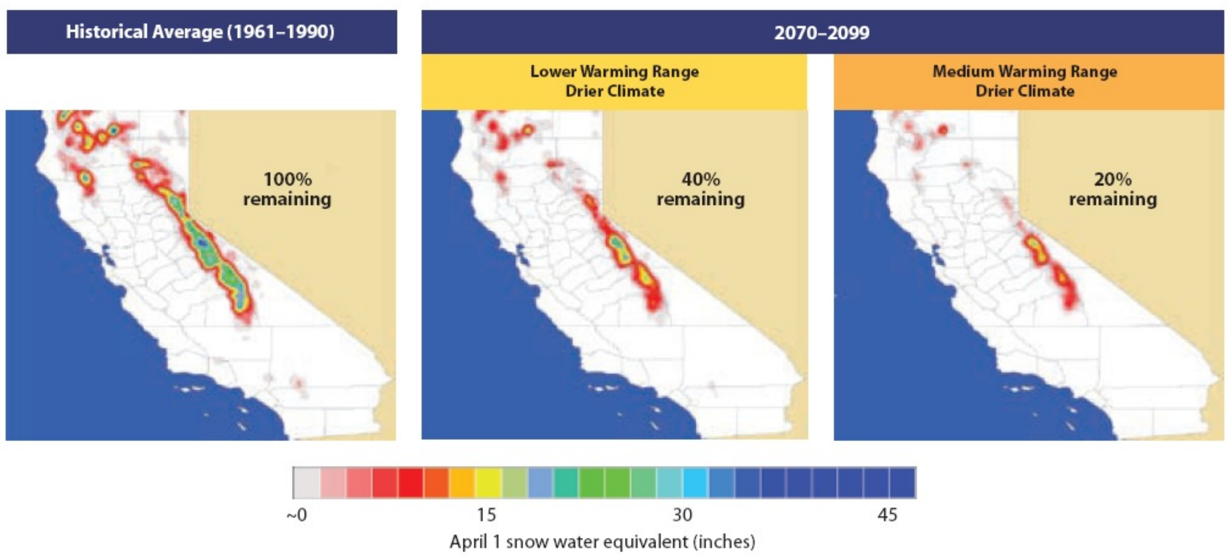
Climate Impacts

Climate change is expected to increase the amount of water flowing into California's rivers in the winter, and reduce water flows in late spring and summer. Despite often major differences in their other results, this pattern is common to all climate models and modeled emissions scenarios. The intuition is straightforward: Rising temperatures increase the amount of winter precipitation falling as rain rather than snow, decrease the extent and cause earlier melting of the Sierra snowpack, and, as a result, reduce runoff in late spring and summer for river systems that are heavily dependent on snowmelt.

This shift in California's hydrological regime is expected to lead to a broad range of water-related changes in California, including:

- decreases in the availability of water stored in the Sierra snowpack;
- increases in the frequency and severity of drought and floods;
- a higher probability of levee failure;
- salinity intrusion via the Sacramento-San Joaquin Delta and other coastal sloughs and estuaries;
- alterations to river hydrology;
- habitat changes from reduced summer flows.

Figure 1.1: Reduction in the Sierra Snowpack by 2070-2099 under Lower and Higher Warming Scenarios



Notes and Source: "Lower Warming Range Drier Climate" is based on an GFDL B1 scenario; "Medium Warming Range Drier Climate" is based on a GFDL A2 scenario. Luers et al., 2006.

Even in the more optimistic B1 scenario, the Sierra snowpack is projected to shrink by more than 30 percent by 2070-2099 (Cayan et al., 2008). In dry higher warming scenarios, as much as 80 percent of the snowpack could disappear by 2070-2099 (Cayan et al., 2008) (Figure 1.1), with far-reaching implications for the state's economy and demography. As we discuss below, even with models that assume a high degree of flexibility in the movement of water around the state, larger fluctuations in the seasonality of California's water supply lead to a significant decrease — as high as 27 percent statewide and 41 percent in Southern California (Medellin et al., 2006) — in annual average water availability in the state.

Under high emissions scenarios in "dry" climate models (e.g., PCM and GFDL), the frequency of droughts is projected to dramatically increase, with the number of critically dry years in California increasing by as many as a factor of three (Luers et al., 2006). In "wetter" climate models (e.g., HadCM3), droughts are not as significant a problem. Even with more critically dry years, winters in California will be wetter as more precipitation falls as rain. California's current water systems were not designed to handle higher winter stream flows; without investments in flood control in areas like the Central Valley, higher winter flows would likely lead to an increase in the number of floods (Luers et al., 2006).

Higher winter stream flows, in tandem with sea level rise, increase the probability of levee failure. The myriad natural and man-made channels that make up the Sacramento-San Joaquin Delta are protected by an extensive system of levees, much of which is over a century old. California's levees were designed to contain a 100-year flood at current sea levels; a 12 inch (0.3 m) rise in sea levels could reduce the return period for the 100-year flood to 10 years (Luers et al., 2006). If sections of the levee system are breached, brackish water from the San Francisco Bay could flood agricultural land and rapidly enter into California's freshwater supply, decreasing water quality. Because a significant portion of California's water supply comes from the Delta, levee failure could affect water supplies across the state.

A drop in summer stream flows would similarly allow more water from the Pacific Ocean to "intrude" into California's freshwater supplies. Holding back this salinity intrusion would require higher freshwater flows in estuarine areas in the summer months to flush brackish water back out to sea, which would increase pressure on already scarce resources. Reduction of summer stream runoff would additionally increase pressure on estuarine and river habitats, which require minimum flows of water to sustain. As we discuss in greater detail in the section on *Tourism and Recreation*, when minimum flows are not maintained the impacts on fish populations can be considerable.

Costs Associated with Climate Change

Because of its fundamental importance, water is perhaps the most studied of all of the sectors that will be impacted by climate change in California. Researchers have used a number of models to project changes in California's water resources in response to climate change. Two of those models in particular have been used extensively in PIER research: the California Value Integration (CALVIN) model and the CALSIM model. CALVIN is an economic-engineering optimization model; CALSIM is a water resources simulation model, whose outputs can be used for economic analysis. Neither model is completely comprehensive in geographical scope, but both cover major population centers and agricultural areas and the results do capture the most important changes to California's hydrology.

Cost estimates based on the two models are substantially different, as their assumptions, techniques, and constraints are different. Two distinctions in particular are of note. Studies based on CALVIN (Medellin-Azuara et al. and Tanaka et al. in Table 1.1) allow water transfers, while studies based on CALSIM (Hanemann et al. in Table 1.1) presently do not. In addition, the CALVIN-based estimates include both operational costs (e.g., the variable cost of running the pumps, treating water, expanding supply through efficiency and desalinization) and scarcity costs (i.e., the cost of receiving less than an economically optimal amount of water); the CALSIM-based studies only include scarcity costs.

Table 1.1: Potential Climate Change Impacts on California's Water Supply

Source	Timeframe	Scarcity Costs	Operational Costs
Medellin-Azuara et al., 2008	**2050**	**$121 million/year (2008$)**	**$369 million/year (2008$)**
Tanaka et al., 2006	**2080-2099**	**$147 million/year (2006$)**	**$1,663 million/year (2006$)**
Hanemann et al., 2006	**2070-2099**	**$580 million/year (2004$)**	

Notes: Medellin-Azuara et al., 2008 estimates are based on GFDL A2; Tanaka et al., 2006 estimates are based on a dry PCM A2; Hanemann et al., 2006 estimates are based on GFDL A2.

Though based on similar climate model scenarios, the costs listed in Table 1.1 are not strictly comparable because they cover different regions and users. The Medellin-Azuara et al. and Tanaka et al. estimates include the entire region modeled under CALVIN; the Hanemann et al. estimate includes only impacts on agriculture in the Central Valley Project region and on urban water users in the Metropolitan Water District (MWD) service area in Southern California.

Ultimately the key difference between the Hanemann et al. (2006) and Medellin-Azuara et al. (2008) and Tanaka et al. (2006) scarcity cost estimates may lie in the extent to which water users have the ability to trade. Importantly, neither approach includes capital costs, which in this case will be dominated by the need for more water storage and conveyance infrastructure. Although capital costs spread over a century are somewhat diluted by time, the required investments could be considerable. For State Water Project (SWP) contractors, for instance, in 1999 46 percent of their expenses went toward repaying bonds that funded the project (DWR, 2008).[4]

[4] Department of Water Resources (DWR) website, "SWP Contractors Payments," http://www.water.ca.gov/swp/docs/swppayments.pdf.

In addition to the direct impacts of climate change on California's water systems, researchers have also estimated the economic consequences of an increase in the severity and frequency of floods on the state's water supplies. Vicuña et al. (2006) estimated the cost of levee failure to agricultural users in the Central Valley and urban users in Southern California, depending on whether the flood occurred before a drought, after a drought, or during a wet year. Importantly, the order of magnitude difference in the cost estimates shown in Table 1.2 stems not from the timing of levee failure but from whether Southern California water users are able to import water from outside of the Sacramento-San Joaquin Delta. If imports are restricted, costs rise by a factor of nearly five.

Table 1.2: Potential Climate Change Impacts on Flooding in California

Source	Timeframe	Total Cost
Vicuña et al., 2006	**2070-2099**	**$2 billion -$14 billion**

Notes: These estimates are based on GFDL A2 sea level rise conditions; the loss of net revenues to agricultural users is an order of magnitude less than the loss of consumer surplus to urban users.

An increase in less catastrophic floods could also be an important climate impact. The Central Valley is particularly at risk, as it has limited river channel capacity and is experiencing rapid population growth. Major floods in the Central Valley occurred at a rate of 2 per decade from 1980-2000 at a cost of roughly $600-700 million (2005$) per decade (Hanemann et al., 2006). Because trends in floods are highly dependent on local context and climate models are unable to forecast at such high resolution (Field et al., 1999), there are currently no estimates of potential economic damages in California from increased floods as a result of climate change.

Despite differences in scope, assumptions, and focus among the different models described above, each provides important insights into both the potential damages to California's water sector from more severe climate change, and potential adaptation measures to reduce the potential impacts of committed warming on the sector. Three insights are particularly important:

- The economic impacts of climate change on California's water supplies will be highly heterogeneous across both sectors and counties.
- Population is a major, if not the key, driver behind pressures on California's water system.
- Inflexibility in the state's water systems, particularly in terms of storage and conveyance, could dramatically increase the costs of climate impacts.

Most of the burden for climate-induced changes in California's hydrology will fall on the agricultural sector. If water transfers are allowed, urban water users in theory could face little scarcity because their willingness to pay is much higher than agricultural users and they can simply buy more water from agricultural users to meet their needs. Although some if not all of the losses to individual growers can be offset by the revenues from selling water, a scale-up of water transfers would have negative externalities for both other growers and the downstream food industry as a whole, and would likely lead to a larger contraction in the state's agricultural sector. The scale of water transfers in California is currently restricted because of concerns about broader sector impacts (DWR, 2005).

Medellin-Azuara et al. (2008) project that most of the increase in climate-related agricultural water scarcity will be north of the Tehachapi Mountains, concentrated in the Sacramento, San Joaquin, Tulare Basins. Even in dry climate model scenarios, Southern California agriculture is unaffected by warming because of its ability to import from the Colorado River. Nevertheless, in the Medellin-Azuara et al. analysis Southern California agriculture still faces the largest total increase in scarcity of all four major regions because of its competition with urban water users. In all of the CALVIN-based scenarios that allow for regional flexibility, urban users do not face significant water scarcity.

Medellin et al. (2006) illustrate the challenges that population growth will entail for water management in California. Indeed, their analysis suggests that the population growth-induced scarcity costs ($118 million/year) on California's water resources could be of a similar magnitude to the scarcity costs caused by a dry, high temperature increase climate scenario ($120 million/year). Modeling over a longer timeframe, Tanaka et al.'s projections are a more substantial $784 million/year. This possibility suggests, as we discuss below, that a major adjustment process in California's water sector will likely be necessary even if the earth's climate can be successfully stabilized.

All of the afore-mentioned studies indicate the sizeable costs of rigidness in the mobility of California water, and in particular the combined effects of population growth, climate change, and an inflexible infrastructure can lead to high scarcity costs. Medellin et al. (2006), for instance, estimate the additional costs of inflexibility in interregional water transfers at $145 million/year, or roughly one-fourth of total estimated scarcity costs. Sufficient storage and conveyance infrastructure is critical to allow for greater flexibility; if water conveyance is already stretched to capacity, an increase in water supply is not necessarily meaningful unless the supply of water can be moved to the source of demand. For instance, in 2003 the Metropolitan Water District of Southern California (Los Angeles, Orange, San Diego, Riverside, San Bernardino, and Ventura Counties) purchased water from growers in Sacramento but was unable to actually obtain the water because conveyance systems in the Sacramento-San Joaquin Delta were already operating at full capacity (DWR, 2005).

Estimating the costs of water-related climate impacts in California is a non-trivial exercise. Large uncertainties exist in the results of climate models, how California's hydrological systems will respond to changes in climate, and how California's policymakers, engineers, and citizens will respond to changes in hydrological systems. Many of the key limitations of the modeling results presented here are admittedly difficult to address. Economic-engineering optimization models, such as CALVIN, tend to give a "best case" scenario where there are no transaction costs, information is free and abundant, foresight is perfect, and water resources are thus allocated in an optimal fashion. In the case of CALVIN, its assumption of "frictionless" water trading is extremely optimistic, particularly given historical resistance to water trading (Howitt and Sunding, 2007).

Analyzing the results of water resources simulation models ex post, alternatively, makes it difficult to account for interactions between human and physical systems, such as the ability of water transfers to reduce scarcity. Both approaches omit the effect of prices on behavior, both positively by inducing innovation in, for instance, water saving technologies and negatively through higher water prices. The effects of rising relative prices for water, while perhaps not realistic to account for in a long-range forecast, are likely to raise economy-wide costs significantly over the estimates presented in Table 1.1.

As a final note on the limitations of optimization models to completely capture the economics of shifts in water supply under climate change scenarios, we highlight the strong possibility that losses averaged over 30 years will mask huge annual shocks in years where water is scarce. For instance, Hanemann et al. (2006) estimate that the cost of water scarcity to agriculture increases nearly three-fold in years where water supply is at the lowest 15 percent of its availability distribution. If California's water supply system continues to be rigidly supply constrained, these shocks could be socially, politically, and economically debilitating.

Distribution of Costs

Climate change will have huge distributional implications for agricultural, environmental, and urban water users. Although efficiency improvements may prove effective in lowering per capita water needs among urban users, population growth will ultimately require a greater share of water resources transferred to urban users, even as those resources become scarcer with climate change. Growing attention to maintaining minimum environmental flows will mean that the water supplies needed to meet urban demand will have to come from the agriculture sector. While a seamless transfer of water from agriculture to urban users, as assumed in the CALVIN model, might be possible, this transfer would require significant investments in the state's water infrastructure and fundamental changes in the politics of water in California.

California's aging water infrastructure was designed for a world where demand for water is fixed and perfectly inelastic. Upgrading California's water systems to deal with the challenges of population growth and climate change would require a massive infusion of resources into the state's hard and soft water infrastructure. Capital investment would be required in the form of storage to replace the natural storage of the Sierra snowpack, levee improvements designed to withstand increased stream flow and higher sea levels, and expanded conveyance capacity to facilitate interregional water transfers. However, it is not clear that "hard" investments in conventional water infrastructure (e.g., dams) will be the most effective and efficient way of providing water storage, flood protection, and water distribution services. In complex ecosystems like the Delta, for instance, new institutions and processes will be needed to improve decision-making about water resources (Norgaard et al., 2008).

The state's two largest water infrastructure projects — the Central Valley Project (CVP) and the State Water Project (SWP) — were built to serve the Bay Area and transfer water from northern California to the Central Valley, Central Coast, and southern portions of the state (Figure 1.2) The CVP and SWP are critical to ensuring water supplies; more than 20 million Californians (roughly 60 percent of the state's 2006 population) rely on these two projects for drinking water (DWR, 2005), and agriculture in many parts of the state would be impossible without them. The CVP, the largest federal water project in the U.S., is a product of a different era, and new conveyance infrastructure will likely have to look elsewhere for funding. An emphasis on cost recovery in new conveyance infrastructure could have a significant impact on the distribution of water prices.

CVP farmers represent about 20 percent of all water use in California, more than two-thirds of which was consumed by the largest 10 percent of farms (Sharp, 2004). Heavily subsidized, the average price paid by CVP farmers in 2002 ($17.14/AF) was 2 percent of what Los Angeles residents paid for water ($925/AF), 3 percent of what San Francisco residents paid ($625/AF),and 13 percent of the price paid by the Environmental Water Account ($129.48) (Sharp, 2004). The average price by SWP farmers in 2002 ($50.92/AF), though 3 times higher than the price paid by CV farmers, is still an order of magnitude lower than prices paid by urban residents. Higher costs for urban users reflect both the cost of treatment and often larger delivery costs. Nevertheless, the price differential between urban and agricultural water users is huge, and this discrepancy in prices will likely be unsustainable in the face of climate-induced pressures on water supply.

Distributional issues are also likely to unfold between agricultural producers and agriculture producing regions, even in a scenario where the earth's climate can be stabilized. While most of California's agricultural value is created by fruit and vegetable producers (Table 1.3) most of the state's agricultural water is consumed by field and fodder crops (Howitt and Sunding, 2007). Similarly, although most of the state's agricultural production by value occurs in the Central Valley, higher value agriculture is concentrated in Monterey and along the Southern California coast (Figures 1.3 and 1.4). Water allocation between farmers and regions will be an intensely political process that can be at least tempered by preparation.

Table 1.3: Value of California Agricultural Products by Category, 2006

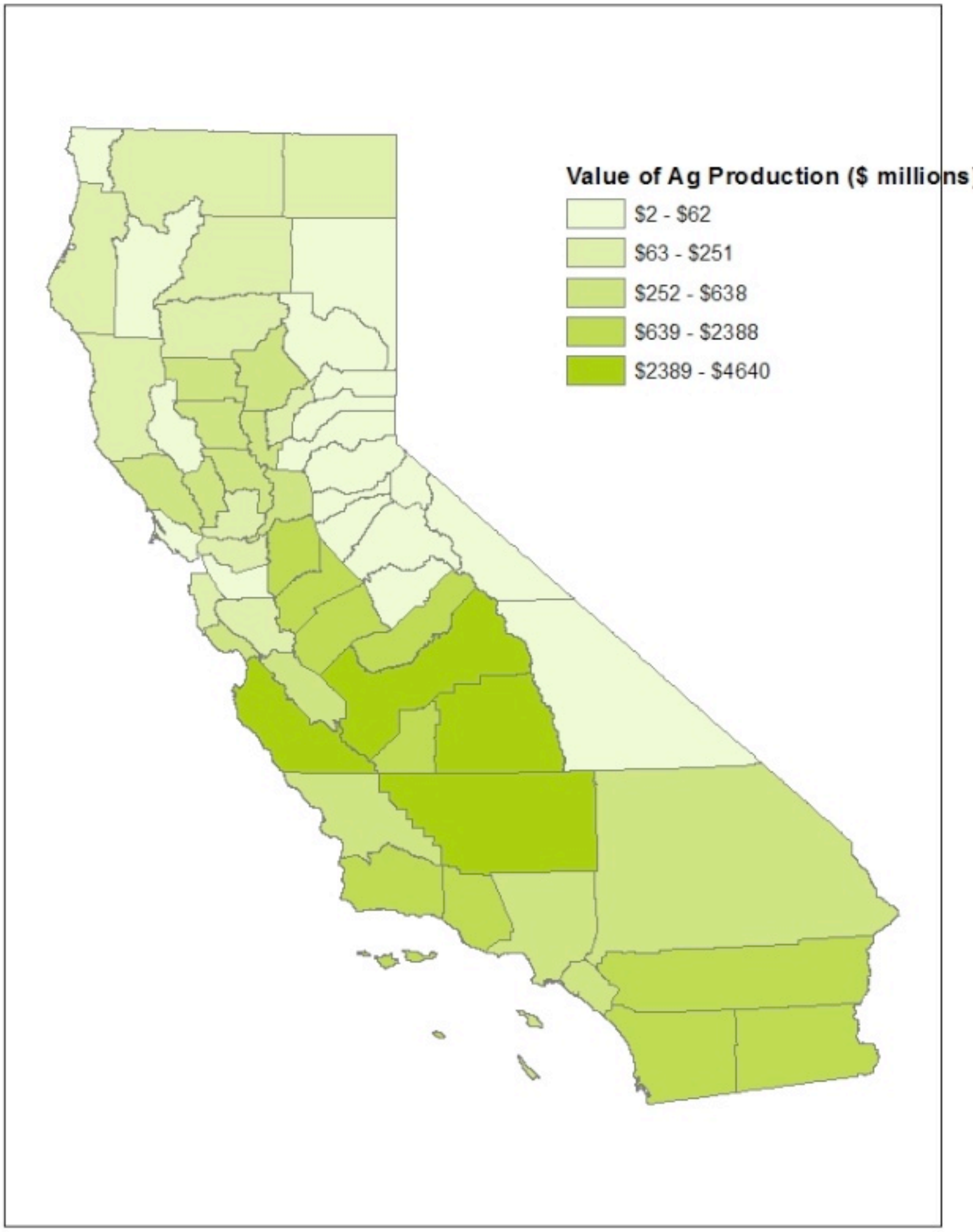
Products	Value in Billions
Fruits and Nuts	$10.24
Livestock and Poultry	$7.61
Vegetables and Melons	$6.96
Greenhouses, Nurseries and Floriculture	$3.80
Field Crops	$2.78

Source: CDFA, 2007.

Figure 1.2: California's Water Conveyance Infrastructure

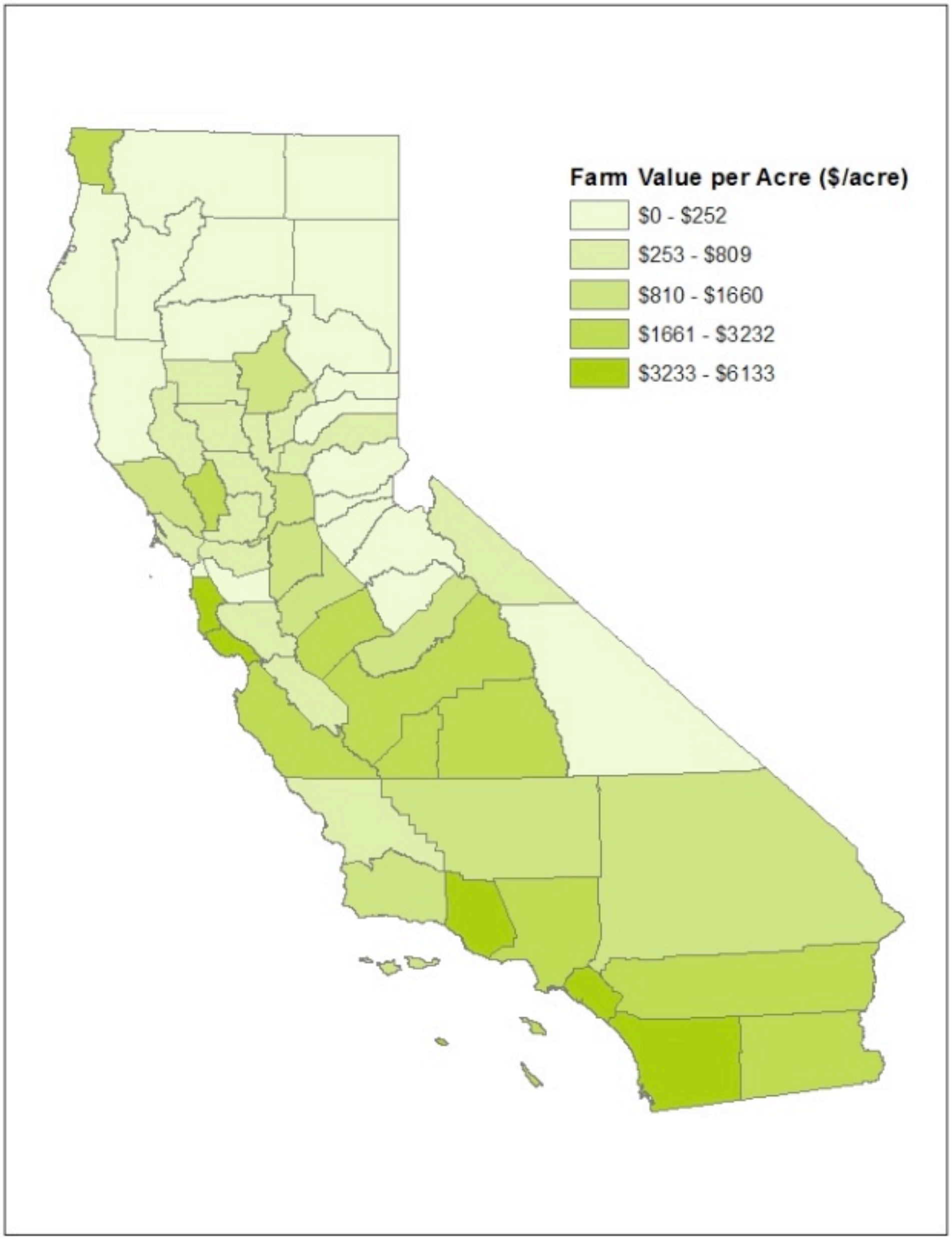
Source: Wilkinson, 2002.

Figure 1.3: Value of Agricultural Production, 2006



Source: California Department of Finance County Profiles

Figure 1.4: Per Hectare Value of Agricultural Production, 2006



Source: California Department of Finance County Profiles

Adaptation Options

Even if more severe climate change is avoided, California's water systems will have to "adapt" as population growth and a greater emphasis on maintaining environmental flows strain the current allocation of water among agricultural, environmental, and urban users. Climate change will add further pressure on water management systems as water supplies become scarcer in summer months. To deal with the impacts of population growth and climate change, the California Department of Water Resources has identified four key strategies: integrated regional water management (IRWM) to expand supply; improving conflict resolution mechanisms to avoid disputes; leveraging existing infrastructure to minimize costs; and developing water supply alternatives to ensure availability (DWR, 2005).

At some level, adaptations that minimize scarcity in the water sector require an expansion of supply. There are numerous options available for expanding the supply of water in California, ranging from options that are potentially less expensive, such as water use efficiency and water transfers, to more expensive strategies such as desalinization. As Table 1.3 shows, even within options there is high variability in costs, often depending on context-specific factors. Desalination remains a backstop technology, but with technological and cost innovations has reached a point where it is now a practical option in Southern California on a limited scale. The Department of Water Resources expects the use of desalination to increase from current levels of around 0.2 percent (0.08 MAF) of water supply to around 2 percent of the state's water supply (0.5 MAF) by 2030 (DWR, 2005).[5] Desalination, while a useful pressure relief valve, is by far the most energy intensive of the options in Table 1.3.

Table 1.3: Selected Adaptation Strategies in California's Water Sector

Adaptation Strategy	Potential Cost Range
Water Transfers	$75-$185/acre-foot
Urban Efficiency	$227-$522/acre-foot
Agricultural Efficiency	$35-$900/acre-foot
Conjunctive Management	$10-$600/acre-foot
Desalination	$250-$2000/acre-foot

Source: DWR, 2005.

All of these adaptation strategies face technology, institution, and information barriers. Water transfers have high cost and institutional barriers, for instance. Buyers must pay the cost of conveyance, storage, and treatment, which limits the cost-effectiveness of

[5] Percentages are assuming a total water supply of 30-35 million acre feet by 2030.

transfers. The cost of conveyance can be as high as the cost of actual water (DWR, 2005). The institutional limitations to water transfer are less clear, and require further research. Efficiency has high potential as a means of supply augmentation in both urban use (Gleick et al., 2003) and agriculture water use (Cooley et al., 2008). Estimates of the potential water savings from urban use efficiency range from 1-2 million acre feet (MAF), or roughly 3 percent of California's total developed water supply (DWR, 2005). As in the electricity sector, financing and incentives have been a perennial obstacle to encourage efficiency in water use. For example, it often proves difficult to encourage efficiency investment through rate increases as many households are still not charged based on the volume of water that they actually use.

Groundwater management is one of the most complex, and potentially one of the cheapest, water adaptation strategies. If groundwater and surface water can be managed in tandem ("conjunctive management" in Table 1.3), with groundwater acting as storage for surface water to be used during periods of water scarcity, the overall scarcity of California's water supply system can be minimized. The institutional politics of managing this kind of a system make conjunctive management less straightforward than it might seem at face value, particularly because California has historically not had strong groundwater management regulations. While all of the barriers mentioned above suggest the need for strong public sector coordination and intervention, they also illustrate the primacy of institutions in determining water management outcomes and the unlikelihood that these outcomes will resemble what single state-wide water planner might consider optimal.

2. Energy

Overview

Energy, and particularly electricity, is a key sector in considering climate change adaptation in California. The electricity sector itself is a small part (around 1 percent) of GSP, and electricity is a small part (around 1 percent) of average household and business expenditures in California.[6] However, because of its universality as an input into production and as part of the household consumption basket, changes in electricity rates can have far-reaching social and economic implications. California residents and businesses spent $33.7 billion on electricity in 2006.[7]

Climate change will have a threefold impact on California's energy systems. First, changes in the seasonal availability of water would lead to a reduction in the state's hydropower resources, which accounted for 17 percent of California's total system power in 2006.[8] Second, an increase in the number of extreme heat days could lead to a substantial rise in electricity demand for use in air conditioning. Lastly, a rise in winter storm activity might lead to an increase in power outages. All of these impacts can be tempered, both through mitigation and adaptation measures, but will require proactive strategies from state agencies.

Climate Impacts

Climate change will impact California's hydropower supplies through changes in the timing and variability of hydrological flows. More winter precipitation falling as rain rather than snow could increase total hydropower generation, provided that reservoir capacity is sufficient to store it. Alternatively, the shrinking of the Sierra snowpack would decrease the amount of water available for hydropower production in the late spring and particularly the summer months, when electricity demand tends to be highest. This scaling back of the snowpack would have particularly deleterious effects for California's 156 high-elevation hydropower stations, which are dependent on snowpack for their water supplies (Madani et al., 2008). High-elevation reservoirs account for a disproportionate share of hydropower generation; facilities above 3,000 feet have historically accounted for 14 percent of reservoir capacity but produce 25 percent of the state's hydropower (AEG and M.Cubed, 2005). Whereas lower elevation hydropower

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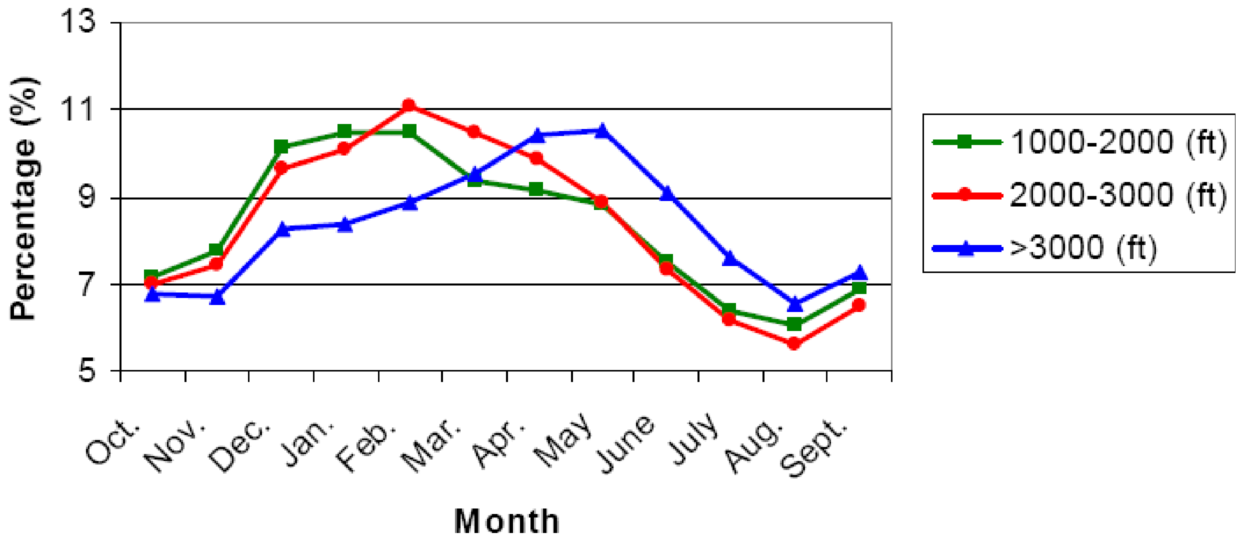
[6] Both of these estimates are based data in a 2003 social accounting matrix (SAM) for California.
[7] Data are from the Energy Information Administration's (EIA's) State Electricity Profiles.
[8] California Energy Commission (CEC) website, *California Energy Almanac.* In 2007 hydropower fell to 9 percent of total system power (TSP), but, because historically hydropower has been closer to 20 percent of TSP the 2006 number is more representative. This share includes both large and small hydro.

generation peaks in the winter months, higher elevation hydropower generation peaks in the summer (Figure 2.1)

Figure 2.1: Monthly Hydropower Generation at Different Altitudes



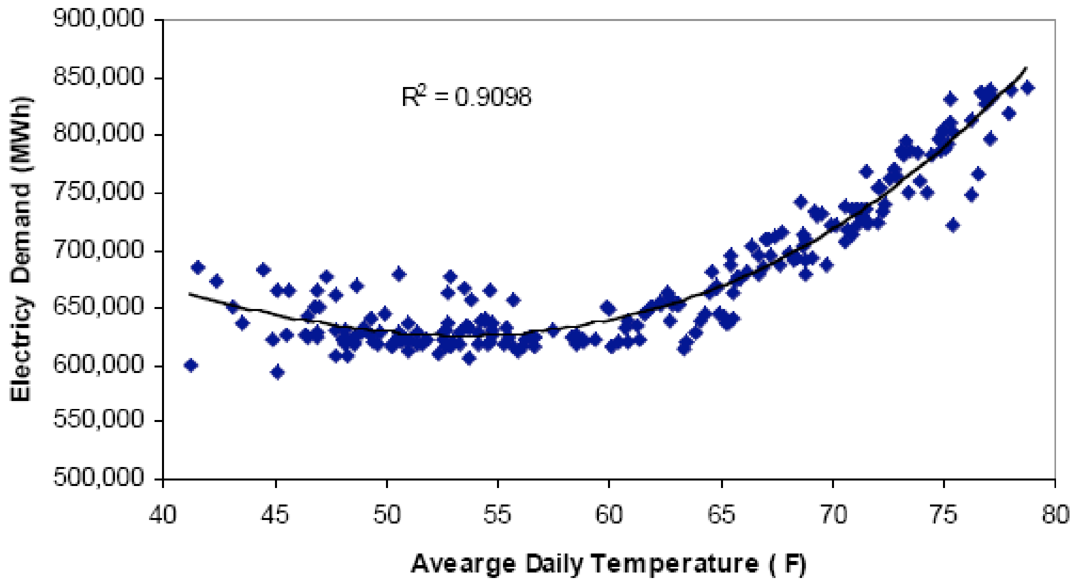
Source: Madani et al., 2008.

How climate change ultimately effects hydropower generation in California will be depend on reservoir storage capacity, the flexibility of reservoir systems, and actual changes in precipitation in different regions of the state. Based on their analysis of an 11-reservoir, high-elevation hydroelectric system in the Upper American River Basin, Vicuña et al. (2008) provide a useful synopsis of the facilities that are most at risk: hydroelectric systems that currently lack sufficient storage capacity and are located in river basins where inflows are highest in summer months. If storage capacity is sufficient, impacts on hydro generation can be minimized. Using a water resources model for California (CALVIN), Madani et al. (2008) highlight the importance of precipitation for projections of hydropower generation. For a dry, high warming climate modeling scenario, Madani et al. estimate a 19.3 percent reduction in hydroelectric generation vis-à-vis a 1984-1998 baseline. For a wet, high warming climate, generation increases by 4.8 percent.

As hydropower resources potentially fall in late spring and summer, rising temperatures over the same period will increase demand for electricity, as electricity use is positively correlated with average daily temperature above about 60°F (Figure 2.2). Intuitively, air conditioning is the largest driver behind this effect. Using results from a range of climate models and scenarios and assuming that the functional form in Figure 2.2 roughly holds, Franco and Sanstad (2006) project that annual electricity consumption would increase by 5.3 percent (PCM) to 11.0 percent (GFDL) against a 1961-1990 temperature baseline in an A2 scenario by 2100, and by 3.1 percent (PCM) to 5.8

percent (GFDL) in a B1 scenario by 2100. Miller et al. (2007) project similar, though slightly higher, percentage increases in demand derived from their analysis of five major Californian cities. Based on an analysis of detailed household billing data and assuming constant electricity rates, Auffhammer (2008) estimates a much larger increase in demand, by 61 percent in an A2 scenario and 29 percent in a B1 scenario (both with PCM), by 2100.

Figure 2.2: Electricity Demand as a Function of Average Daily Temperature in the CalISO Service Area, 2004



Source: Franco and Sanstad, 2005.

A final potentially important but often overlooked energy-related impact of climate change is electric power outages. Storm damage to transmission lines can lead to the loss of electricity service, which leads to lost revenues and repair costs on the supply side and lost productivity for commercial customers. Little research has been done on the vulnerability of California's grid to changes in weather patterns, and how future improvements to the grid might integrate climate change considerations.

Costs Associated with Climate Change

In dealing with a loss of hydropower resources, the state essentially has two options: replace hydropower with another generation source, or expand storage capacity. The economic costs of replacing hydropower generation for California are difficult to assess because of the importance of timing in the electricity sector and ambiguities in the word 'cost.' Although hydropower is typically a "baseload" resource (i.e., it is one of the first resources to be dispatched), the seasonal peak cycle of hydropower generation coincides with peak electricity demand in California. During the summer, air conditioning pushes electricity loads higher, straining the capacity of generators to produce enough electricity and making electricity scarcer and thus more expensive.

Electricity prices are currently determined as part of a rate-making process in California, which means that Californians only pay higher rates for higher average use, rather than for higher use at times when electricity generation is in short supply. With a more price responsive electricity system, such as through real time metering, the fall in demand as higher peak prices curtail use could offset some of the loss of hydropower generation. If this is insufficient, more generating capacity would be required to cover the shortfall. The effect on electricity producers and the grid is difficult to gauge, and has yet to be analyzed with electricity models.

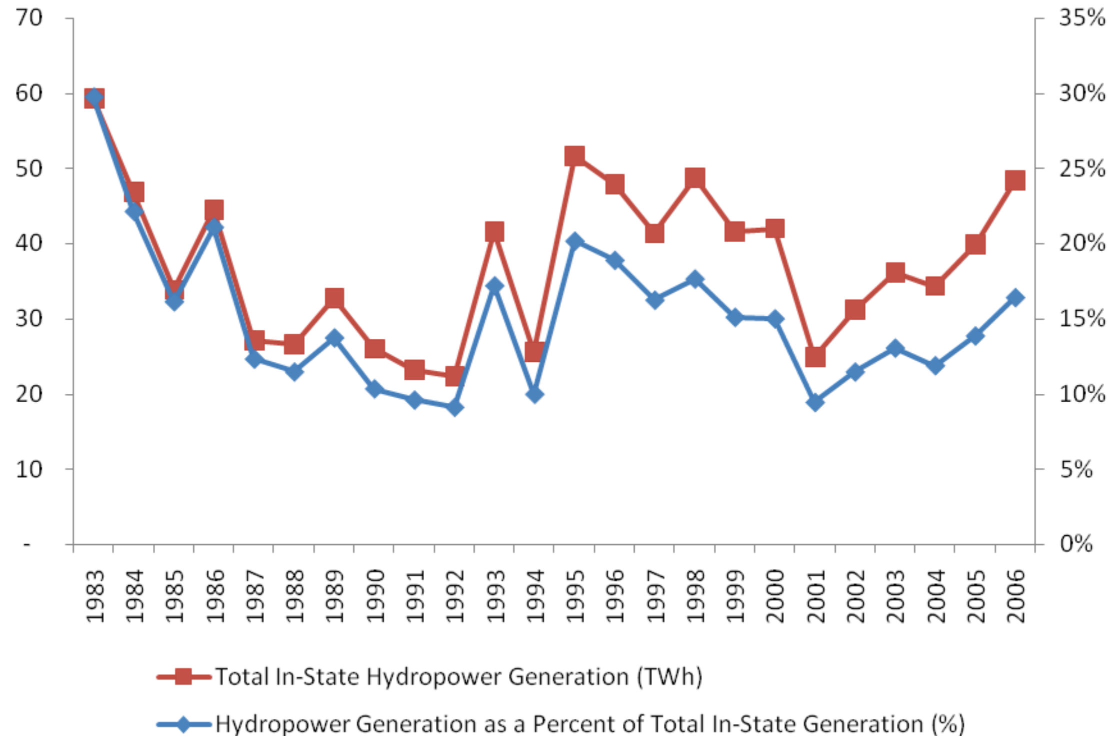
Inter-annual fluctuation in hydropower generation is normal; in-state hydropower generation in 2007 (23 TWh) was nearly 50 percent less than in 2006 (43 TWh), from 1990-2006 hydropower's share of total in-state generation in California fluctuated by as much as 20 TWh and more than a factor of 2. More important is the timing of these shortfalls. In off-peak periods, shortfalls in hydropower generation can be made up by existing, idle natural gas power plants. In on-peak periods, the system is already constrained, and new generating capacity would be required to make up shortfalls. Without more detailed modeling, it is unclear how much additional capacity would be needed.

We take a more heuristic approach here, using Madina et al.'s A2 scenario result of a 19.3 percent (4.3 TWh) annual reduction in hydropower generation. As A2 is a fossil fuel-intensive scenario and 4.3 TWh would be a fraction of a percent of 2100 generation in California,[9] we assume that this shortfall is made up with natural gas-fired generation. Based on a levelized cost for large hydro of \$0.05/kWh, if all of this generation had to be made up by a natural gas combined cycle power (NGCC) plant (\$0.1022/kWh), this would amount to a net increase in system costs of \$220 million per year, a capital investment of \$618 million, and an increase of 1.6 million metric tons CO_2 ($mmtCO_2$).[10] Because the cost of generating electricity during summer peak hours is much higher than the rest of the year, this situation is not particularly realistic but it does provide a useful anchor point. The California Public Utility Commission's (CPUC's) longer-term market price referent (about \$0.12/kWh) is also close to the levelized cost of NGCC (CPUC, 2007).

[9] 4.3 TWh is 1.4 of California's 2007 gross system power. If gross system power grew by 0.5 percent per year, for instance, by 2100 4.3 TWh would be 0.9 percent of total system power.

[10] All cost and emission factor estimates are drawn from or based on Klein and Rednam (2007).

Figure 2.3: Total In-State Hydropower Generation and Hydropower Generation as a Percentage of Total In-State Generation, 1983-2006.



Notes and Source: That the trends in Figure 2.3 roughly match illustrates that the share of hydropower generation in California is indeed driven by water availability rather than by changes in other generating sources. All data are from the CEC's Energy Almanac.

Alternatively, if hydropower generation is uniformly distributed throughout the day during Madina et al.'s projected shortfall in May (1.2 TWh), June (1 TWh), and July (0.5 TWh), and peak hours from 2 pm to 6 pm are supply constrained hours, a total of 450 MWh/year (around 10 percent) would have to be met with, for instance, more expensive simple cycle natural gas ("peaker") plants ($0.5996/kWh). If the remainder is met by load following NGCC plants elsewhere in the system, combining 3.85 TWh from NGCC and 0.45 TWh from peaker plants would lead to a net system cost increase of $450 million per year, a total capital investment of $1.0 billion, and an increase of 1.7 mmtCO_2. To put these numbers in context, $450 million is equivalent to 1.3 percent of total electricity sales in California in 2006 ($33.7 billion),[11] $1.7 billion is less than 1 percent of annual investment spending in California, and 1.7 mmtCO_2 is equivalent to 0.4 percent of California's 2004 greenhouse gas emissions.[12] More likely, shortfalls in

[11] Total sales data are based on EIA electricity sales data (MWh) multiplied by average electricity prices ($/kWh) for California, drawn from the EIA website's State Electricity Profiles.
[12] GHG emissions data are from CEC, (2006).

hydropower production would be met through a mix of different energy sources, rather than natural gas alone, but natural gas does reflect the cost differences of meeting peak and off-peak demand in the current electricity system.

Table 2.1: Hypothetical Costs of Replacing 4.3 TWh of Hydropower Generation in California with Natural Gas

	Net Increase in System Costs (2008$)	Required Capital Investment (2008$)	Increase in CO_2 Emissions (mmt)
If met with all NGCC	$220 million	$618 million	1.6
If met with NGCC and NGSC	$450 million	$1 billion	1.7

Notes and Source: These costs are not intended to be forecasts, but rather the costs of a hypothetical scenario. NGCC is combined cycle natural gas, NGSC is simple cycle natural gas, or "peakers"; Capacity factors, capital costs ($/kW), levelized costs, and emissions factors are all from Klein and Rednam (2007).

Heat-driven increases in electricity demand during hot summer months could potentially have a much larger economic impact on California's electricity sector. Auffhammer's (2008) constant-price estimate of a 61 percent increase in residential electricity consumption above 2000 levels (79.2 TWh) would require a 48.3 TWh increase in electricity generation by 2100. As in the case of hydropower shortfalls some of this increase in demand could be checked through higher electricity prices. Auffhammer (2008) demonstrates that a rise (30 percent) in electricity rates in 2020 and 2040 would reduce electricity consumption increases to 28 percent in the A2 scenario and 3 percent in the B1 scenario. In addition, much of the rise in heat-driven electricity consumption is expected to be in the Southern California Coast and Central Valley; expanding transmission capacity between these regions and less supply constrained areas could obviate the need to build more power plants to meet additional peak demand.

As Franco and Sanstad (2006) show, much of the increase in heat-driven electricity demand would be during on-peak hours. In a business as usual A2 scenario where the majority of this new demand is met with higher cost simple cycle natural gas plants, the increase in system costs would be on the order of $15-25 billion annually by 2100. A more realistic scenario would assume that, with technological innovation, some amount of peak smoothing is possible. If that is the case, at the CPUC's 2020 20-year market price referent of roughly $0.12/kWh (CPUC, 2007), increasing generation by 48.3 TWh would mean an increase in system costs of $5.8 billion per year by 2100. If met by building out advanced NGCC plants, it would require 9.2 GW of new capacity and a $7.6 billion capital investment. If, alternatively, these needs were met with a 20 contribution of concentrating solar PV, biomass, geothermal, natural gas, and wind, at current capital costs required investment would skyrocket to $41.8 billion, reflecting both the higher capital costs of renewable energy vis-à-vis natural gas at present. At 91 MW/year (NGCC case) and 123 MW/year (5 sources case), the heat-driven expansion in electricity generating capacity would be equivalent to 9-12 percent of California's average annual capacity additions between 1960 and 2007 (1,069 MW/year).[13]

Table 2.2: Increase in System Costs and Required Investment under High Estimates for Heat-Induced Changes in Electricity Demand

	B1	A2
Increase in system costs at CPUC market price referent (2007)	**$2.7 billion/year**	**$5.8 billion/year**
Required investment in NGCC case	**$3.6 billion**	**$7.6 billion**
Required investment in "5 sources" case	**$19.9 billion**	**$41.8 billion**

Notes: "5 sources" here refers to 20 percent of solar concentrating (CS) PV, wind, geothermal, natural gas, and biomass, NGCC refers to natural gas combined cycle. We use high capital cost for CS here; a reduction to more reasonable levels (e.g., $3,000/kW) could reduce required investment by 30 percent.

Even in a B1 (stabilization) scenario, heat-driven increases in electricity demand would require a substantial build out of generation capacity, as Table 2.2 shows. Although a 23 percent increase in demand over 100 years (0.2 percent annual growth) might go unnoticed, a 23 percent increase of peak demand would be less likely to. The coincidence of temperature rises and inland population growth warrants new thinking about how electricity is distributed and stored. For instance, new energy storage technologies could allow peaks in electricity use to be met without substantially increasing system costs.

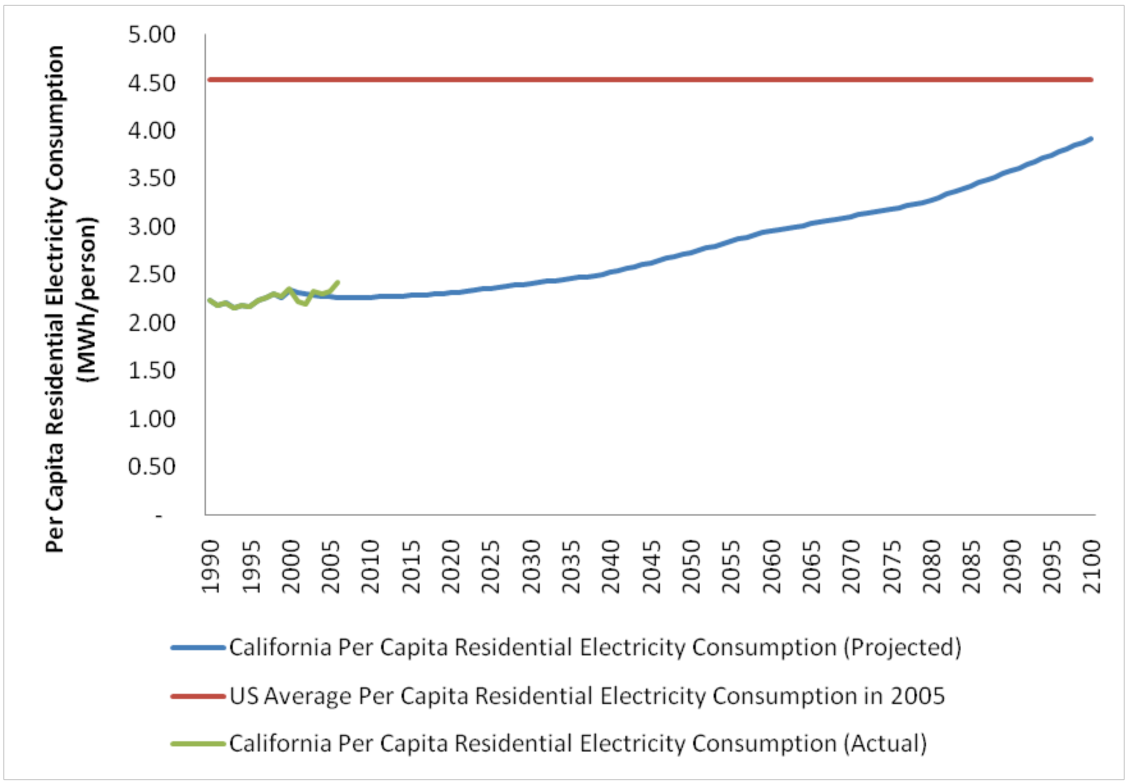
There are several things to point out about these estimates. First, although a 61 percent increase is certainly enormous, on an annual basis the increase in demand would be 0.5 percent. Climate change is only one factor affecting California's electricity sector, and over the course of the century population growth will likely be a much larger driver of electricity demand than temperature increases. Auffhammer (2008) estimates that, in a high population growth (1.47 percent annual growth) low warming scenario (B1), residential electricity consumption alone could grow by more than four-fold by 2100. If, hypothetically, residential electricity demand in 2100 is still 34 percent of California's

[13] Capacity information is from the California Energy Commission's *Energy Almanac*. We assume in this calculation that major power plants are still online.

total electricity use, a total addition of 737.1 GWh, or nearly three times 2006 consumption, would be required in a *climate stabilization* scenario by 2100.[14]

Second, it is important to note that, of all of the impacts discussed here, only power outages necessarily represent real "costs" in a strict macroeconomic sense. More generation capacity to offset losses in hydropower capacity and meet higher summertime demand would only influence real income and employment through its opportunity cost, and through its impact on electricity rates and interest rates. Over such a long timeframe, it is not realistic to meaningfully model these effects.

Figure 2.4: Per Capita Residential Electricity Consumption in California under a Medium Population Growth Scenario and an A2 Emissions Scenario



Sources: Population and electricity consumption data for 1990-2006 are from the Department of Finance and the Energy Information Administration, respectively. This figure assumes a 0.88 percent population growth and Auffhammer's electricity demand projections for an A2 scenario.

Lastly, increases in demand along the lines projected by Auffhammer (2008) would reverse a 20-year trend of flat growth in per capita residential and total electricity consumption in California. Using Auffhammer's electricity preliminary demand and population projections, an A2 scenario would lead to a more than 50 percent increase in

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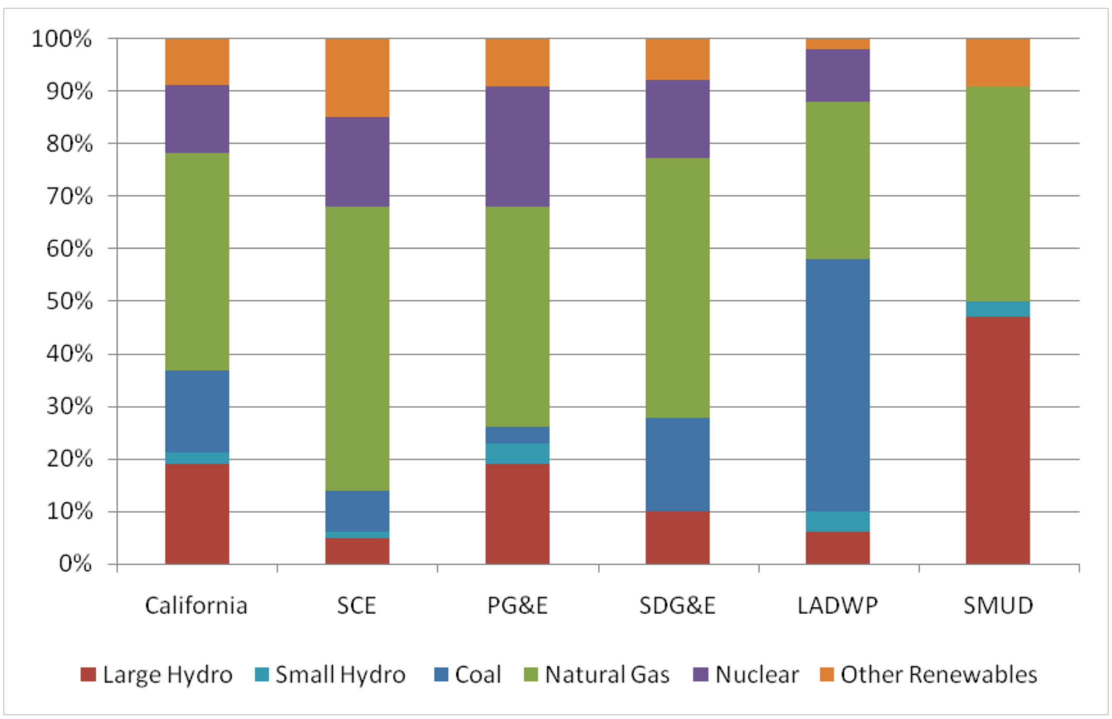
[14] A 423% increase in 2000 residential electricity sales is equivalent to 335.1 TWh; if this is 34% of total generation in 2100, total generation would be 981.1 TWh, which is equivalent to a 737.1 TWh increase on 2006 total retail electricity sales (263.0 TWh). All data are from the Energy Information Agency's State Electricity Profiles.

per capita residential electricity consumption, although it would still be below 2005 levels for the greater U.S. Such a turn of events would put pressure on the state to meet its longer-term climate goals.

Distribution of Costs

The impacts of both a loss of hydropower resources and an increase in summer demand for electricity will not be uniformly distributed across the California's electricity system, and changes in electricity rates and expenditures that accompany these changes may not be as well. Most of the state's hydropower is concentrated in the north. Large hydro is a significant portion of total generation for both Pacific Gas & Electric (PG&E) and particularly the Sacramento Municipal Utility District (SMUD). SMUD is particularly vulnerable, as hydropower accounted for 50 percent of its generation in 2006. Hydroelectric facilities most likely to be affected by climate change are in the Sacramento, Feather, San Joaquin, and American River systems, which have large hydropower to storage capacity ratios and changes in projected runoff are large relative to current storage capacity (AEG and M.Cubed, 2005).

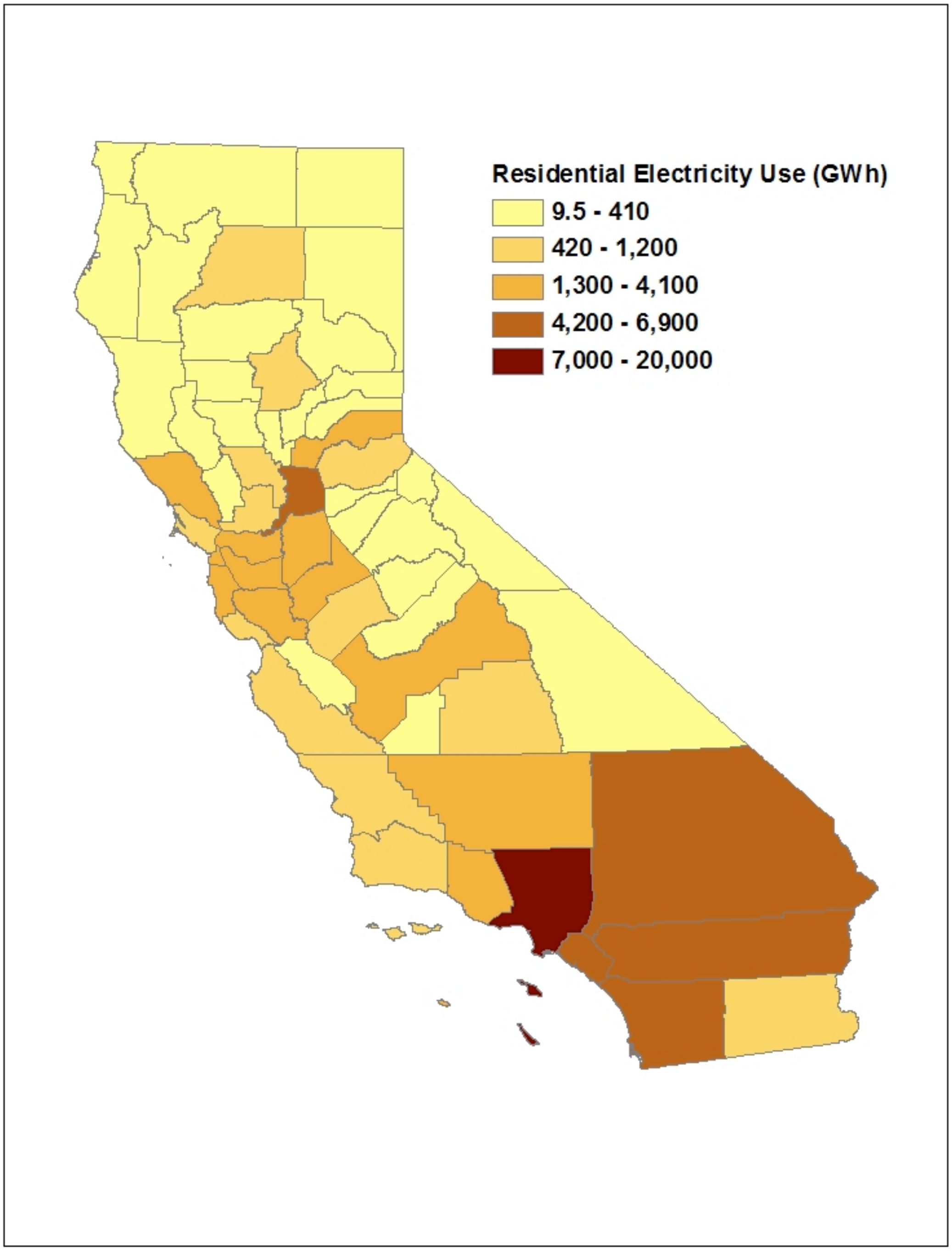
Figure 2.5: Sources of Electricity Generation for California's Major Utilities, 2006



Source: California Energy Commission, Energy Almanac, http://energyalmanac.ca.gov.

Heat-driven increases in electricity demand will also be regionally concentrated. Most of this increase will be in the Central Valley and Southern California (Auffhammer et al., 2008), which experience higher summer temperatures. This projection approximates the current pattern of residential electricity use in California, where a significant portion of consumption occurs in the South Coast, Inland Empire, and Sacramento Metro areas (Figure 2.6). Although regionally focused increases in electricity demand will further strain the state's electricity grid, regional disparity in demand increases suggests the possibility that some of these increases could be met with transfers from other regions if transmission capacity can be expanded.

Figure 2.6: Total Residential Electricity Use by County, California, 2006 (GWh)



Source: California Energy Commission, Energy Almanac, http://energyalmanac.ca.gov.

Adaptation Options

Planning for future hydropower resources will be part of a larger effort to adapt the state's water resources to climate change. A key decision will be whether to expand the storage capacity of existing reservoirs, to build new storage capacity, or to simply relinquish current hydropower resources and replace them with another generation source as water supplies become scarcer. Storage capacity is capital and materials intensive, and whether hydropower is cost- or CO_2-effective will depend on the value of generation at on-peak hours, and on how CO_2 intensive reservoir construction or expansion is. If innovations in electricity grid transmission and storage can reduce the cost of peak load, "protecting" hydropower resources might not be cost-effective. Similarly, it is conceivable that, for materials-intensive reservoir projects, a life cycle assessment (LCA) would favor alternatives to hydropower.

In the near term, demand-side management (DSM) programs that encourage reductions in peak load could be an effective strategy for reducing the economic and environmental implications of an increase in summer demand for electricity. In the longer-term, and particularly in more extreme climate scenarios, this strategy will prove insufficient. In addition, considering the public health, greenhouse gas, and economic implications of peak electricity demand California, the state is in fairly urgent need of innovations that separate the timing of electricity demand from the severity of social, environmental, and economic impacts. Both climate mitigation (AB 32) and adaptation imperatives suggest the need for a radical rethinking of electricity production and distribution in California.[15]

[15] For an overview of the physical and institutional challenges and options for restructuring the U.S. electricity system, see DoE (2003); for a more grid-specific overview, see Fox-Penner (2005).

3. Transportation

Overview

California is critically dependent on its transportation infrastructure. Trade is an important part of the California economy, and the importance of trade has grown in tandem with Asia's economic rise over the past two decades. In 2004, the ports of Los Angeles, Long Beach, and Oakland accounted for more than 40 percent of U.S. container shipping by volume (in TEUs), and more than 23 percent ($425.5 billion) of the total foreign trade through the nation's top 50 international freight gateways (BTS, 2005). Within the state, air, rail, water, truck transportation accounted for $19.1 billion (1 percent) of California's GSP in 2006.[16]

California is also an automobile dependent society; many state residents would have their mobility radically constrained without the roads, bridges, and other publicly provided transportation services. As we describe below, much of this infrastructure is in a state of disrepair, and in the coming decades California will have to make difficult decisions about how to design and finance transportation infrastructure in the future in such a way that will improve the quality of life of its residents and enhance its economic competitiveness.

Climate change will be an important consideration for transportation planning in California. However, the vulnerability of California and U.S. transportation infrastructure to climate change, both committed and avoidable, is still poorly understood. Only a small amount of research has been done on climate adaptation in the transportation sector. The first federally funded overview of potential impacts of climate change for the transportation sector in the U.S. was published by the National Research Council (NRC) in 2008 (NRC, 2008).

Climate Impacts

As with other sectors, the impacts of climate change on California's surface, water, air, and marine transportation infrastructure can be separated into potentially avoidable impacts that will occur several decades from now, and nearer-term impacts that are likely unavoidable. For transportation, however, the extent of both physical and economic impacts is closely tied to the continual cycles of infrastructural retirement and renewal. New, long-lived infrastructure will have to be built under a tremendous amount of uncertainty about operating conditions. Existing infrastructure may require significant

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[16] of 2006 GSP ($1.742 trillion)

and expensive upgrades — for instance, elevating large sections of coastal highways — to adapt it to a changing climate, or may be prematurely retired.

Table 3.1: Estimated Average Lifetimes of Selected Transportation Infrastructure

Mode	Infrastructure	Lifetime
Surface Transportation	Pavement	10-20 years
	Bridges	50-100 years
	Culverts	30-45 years
	Tunnels	50-100 years
	Railroad tracks	50 years
Aviation	Runway Pavement	10 years
	Terminals	40-50 years
Marine	Docks and port terminals	40-50 years
Pipelines	Pipelines	100 years

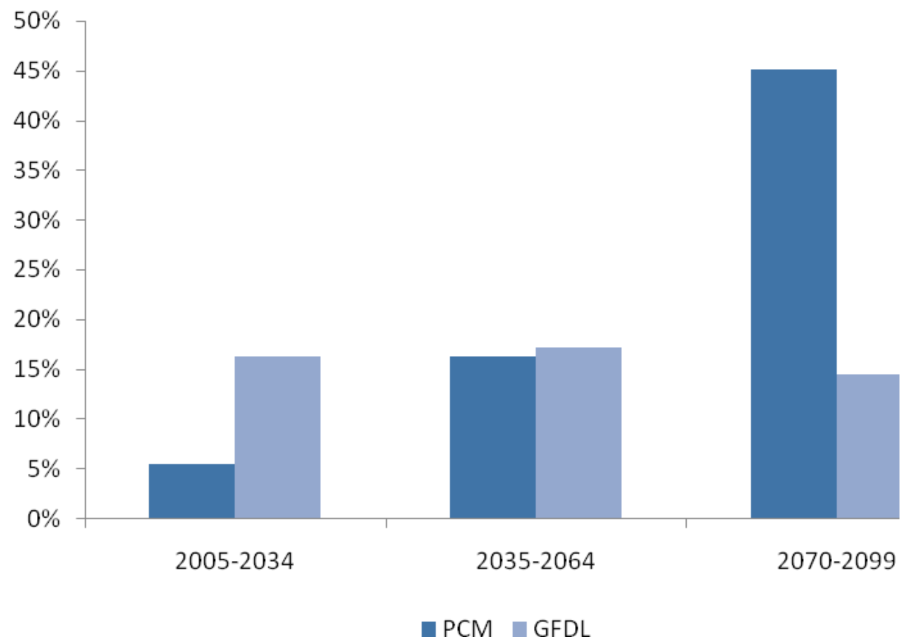
Source: Drawn from NRC (2008).

Table 3.1 shows average lifetimes for different kinds of transportation infrastructure. For pavement of roads and runways, shorter turnover times provide sufficient time to develop and use new construction materials. For longer-lived infrastructure, such as bridges and ports, "climate proofing" will have to be done largely by retrofitting existing infrastructure. Although the figures in Table 3.1 are averages based on designed lifetimes, in reality most infrastructure operates long beyond what it was designed for.

Changes in extreme weather and sea level rise will be the two largest climate-induced impacts on California's transportation infrastructure. Although these two categories of impact are not entirely separate because of their interactive influence on coastal erosion through changes in tidal and wave patterns, for expositional purposes we treat them separately here. Extreme weather here includes the effects of changes in the frequency and intensity of Pacific storms and extreme heat days on the design and operation of transportation infrastructure. The effects of sea level rise include the permanent inundation of that infrastructure.

El Nino Southern Oscillation (ENSO) events are a particular concern for the transportation sector. ENSO is a natural weather phenomenon driven by a warming of Pacific surface waters that occurs once every two to seven years. Its impact on California is highly variable; in strong ENSO years, such as 1982-1983 and 1997-1998, storm damage can be considerable. In other years, ENSO events can result in drier weather for California (Wilkinson, 2002). ENSO patterns are complicated to model, and climate models tend to disagree about the results. Timmermann et al. (1999) argue that ENSO events will increase in frequency as temperatures warm, but there is still considerable debate within the scientific community on how climate change might affect ENSO. Using the PCM and GFDL models, Cayan et al. (2008) find little change in the frequency or severity of ENSO-related weather anomalies vis-à-vis historical averages for California. For extreme precipitation more broadly, Figure 3.1 shows Cayan et al.'s projected change in 99th percentile extreme precipitation occurrences for Northern California, which highlights both the generally modest changes and substantial disparities between climate models.

Figure 3.1: Change in 99th Percentile Precipitation Occurrences, PCM and GFDL Models, A2 Scenarios



Source: Cayan et al., 2008.

Precipitation has a disproportionate impact on surface transport and aviation operations. During the ENSO event of 1997-98, interstate highways and smaller roads were repeatedly washed out and forced to shut down. A flood-induced surge on the Ventura River led to significant damage to Union Pacific railroad trestle (duVair et al., 2002). The aviation industry is extremely sensitive to weather conditions; inclement weather is responsible for 70 percent of all flight delays in the U.S. (Kulesa, 2002). Changes in storm intensity and frequency can also damage physical infrastructure. Higher wind speeds during winter storms could lead to damage on bridges that were not built to withstand them. Ports may suffer damage from wave intensities and tidal forces they were never imagined to encounter.

Warming temperatures and particularly an increase in extreme heat days can similarly damage transportation infrastructure that was not designed to withstand changing weather conditions. Road and runway pavement expands and cracks as it absorbs heat; during a previous heat wave in California high temperatures caused an eight-lane highway to buckle (Wilkinson, 2002). Warming temperatures and changes in precipitation might also affect soil moisture, threatening the structural integrity of roads, bridges, and other structures.

Inundation and coastal erosion are of particular concern for California's surface transportation system because a small but important portion of its roads and railroad tracks are on or near the coast. The Pacific Coast Highway (State Route 1) already experiences frequent mudslides, high waves, and closures as a result; an increase in storm activity along the coast might force the highway to close permanently (Wilkinson, 2002). Coastal erosion could force parts of the highway to be protected or moved. Of potentially greater concern is that two of California's major airports are less than 15 feet above mean sea level. San Francisco International Airport (SFO), which was the world's 23rd busiest airport in 2007 with more than 35.8 million travelers,[17] is 13 (4.0 m) feet above mean sea level. Oakland International Airport (OAK), which saw 14.6 million passengers in 2007,[18] is 9 feet (2.7 m) above mean sea level.[19] The Bay Conservation and Development Commission (BCDC) argues pictorially that a substantial part of both airports would be vulnerable to inundation from a one meter rise in sea level,[20] although the scope of this claim has yet to be verified and quantified.

Costs Associated with Climate Change

As in many other sectors reviewed in this report, California's transportation infrastructure will be strained by population growth over the next century. Already, transportation in California is underperforming and facing financial shortfalls. California's roads are of significantly poorer quality than the U.S. average (Figure 3.2), and nearly 30 percent of its road bridges, though at the U.S. average, are structurally deficient or functionally obsolete (BTS, 2005). The American Society of Civil Engineers (ASCE) gives the state a below average rating in both aviation and surface transportation infrastructure, and estimates that nearly $20 billion per year would be required to bring the state's transportation infrastructure up to a "B" rating. To put this number in context,

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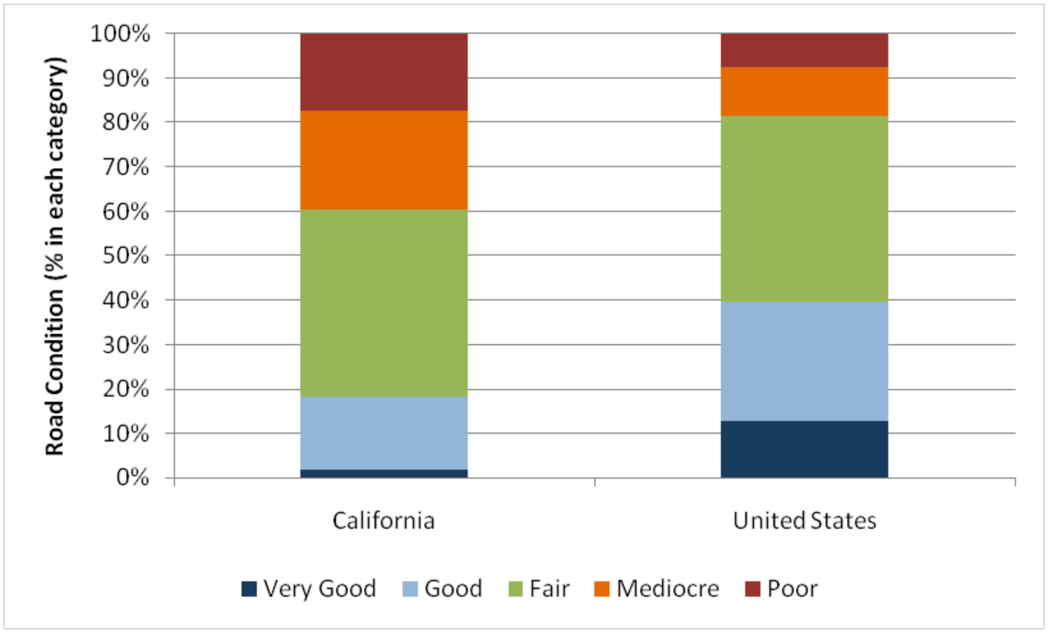
[17] Airports Council International website, "Passenger Traffic 2007 Final," http://www.airports.org/cda/aci_common/display/main/aci_content07_c.jsp?zn=aci&cp=1-5-54-55_666_2__.
[18] Oakland International Airport website, "Statistics," http://www.oaklandairport.com/airport_stats_yearend_stats.shtml.
[19] Sea level figures are from Airport IQ 5010 website, http://www.gcr1.com/5010web/default.cfm.
[20] Bay Conservation and Development Commission website, http://www.bcdc.ca.gov/planning/climate_change/climate_change.shtml.

California's 2008-09 budget allocates about $14.5 billion for transportation infrastructure spending out of a total budget of $144.5 billion.[21]

Figure 3.2: Road Conditions, California and U.S. Average, 2004



Source: BTS (2005).

Table 3.2: American Society of Civil Engineers Report Card for California Transportation Infrastructure, 2006

	ASCE Grade	Proposed Investment
Aviation	C-	$0.5 billion/year
Surface Transportation	D+	$17.9 billion/year
Ports	C+	$1.2 billion/year
Total		$19.6 billion/year

Source: ASCE, 2006.

The cost of ENSO events to California's transportation infrastructure is difficult to assess, and indeed assessing the total damage from storms is a non-trivial exercise. For California as a whole, we found three estimates of damages for ENSO events over the past two decades. Changnon (1999) reports estimates for both the 1982-83 ($2 billion in 1998$) and 1997-98 ($1.1 billion in 1998$) storms, but in both cases these are drawn from either newspaper reports or personal communications. For the 1982-83 event, the original damage estimate was $265 million in 1983 dollars, which when

[21] Based on the *Governor's Budget 2008-09* website. We include all entries in line item 26 in this calculation.

adjusted to 1998 dollars should have been a much lower $392 million. The National Climatic Data Center (NCDC) reports $550 million in damages for the 1997-98 ENSO, but does not give a source.[22] Using National Weather Service data, Pielke et al. (2002) report that the public assistance costs in California for the 1997-98 ENSO were $316 million.

Repair to damaged transportation infrastructure may be a significant portion of total ENSO damages, but there are no available data to substantiate this assumption. Preparation costs by Caltrans do, however, give some indication of the scope of transportation impacts. In preparation for the 1997-98 ENSO Caltrans spent more than $200 million, most of which went toward fixing storm damage from the previous winter.[23] Unless Pacific storms increase in severity or frequency beyond scenarios suggested by Cayan et al. (2008), the incremental, climate-induced cost of these storms on the transportation sector is unlikely to be significant. A 20 percent increase in the frequency of 10-year weather events that cost $200-300 million each, for instance, would lead to two additional events and a total additional cost of $400-600 million over the course of a century.

For extreme weather events, it is likely that an increase in frequency would be more costly an increase in intensity, within reasonable limits for the latter. Increases in storm intensity can be designed for, at a cost, but cost-effectively if potential damage justifies the investment. The New Zealand government, for instance, estimates that the cost of redesigning and retrofitting its bridges for climate change raised initial costs by 10 percent, but over the life of the structures this additional cost amounted to only a 1 percent increase because of avoided damage (Savonis et al., 2008). Increases in the frequency of extreme weather events, alternatively, may not have these same kinds of technological fixes. Such an increase would almost certainly have an impact on transportation operations, but even order of magnitude estimates of what these impacts might be is beyond the scope of meaningful analysis.

The most important climate-induced cost for California's transportation sector could be the cost of protecting or moving infrastructure. Protecting ports, for instance, could require raising entire port terminals. Given their locations and difficulties with acquiring land, moving San Francisco and Oakland airport runways is likely out of the question; elevating them could be more realistic, but would be expensive if needed. Physically moving the entire airports would require repositioning them in a peri-urban area at significant monetary and logistical cost. As an upper bound, moving the two airports "offshore" would require an engineering feat on the scale of Hong Kong's Chek Lap Kok

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[22] National Climatic Data Center (NCDC) website. California Flooding and Florida Tornadoes, February 1998, http://www.ncdc.noaa.gov/oa/reports/febstorm/february98storms.html#CALIF
[23] California Resources Agency website. California El Nino Information, "Lead El Nino Agencies in California," http://ceres.ca.gov/elnino/arar/bth.html.

Airport, which was built on a landfill at a cost of roughly $20 billion in 1998. Closing or re-engineering parts of the Pacific Coast Highway could have substantial monetary and logistical costs as well. In all of these cases, the scope of vulnerability and potential damage, the range of possible adaptive responses, and the cost of those responses are still highly uncertain, despite their importance for longer-term planning (Savonis et al., 2008).

In summary, because of the large recurrent commitments already made to transport investment in California, the net cost of adaptation is highly uncertain. To a significant extent, adaptation needs will be met by re-programming of existing commitments to replacement and renewal. The adjustment costs and new costs arising from this will obviously depend on the timeliness and reliability of policy expectations regarding adaptation needs, however, so it would be advisable for the state to invest in better information about these issues.

Finally, the question of exposed assets remains open. No significant accounting of this kind has yet been undertaken for California, but we can impute rough estimates from OECD research on US coastal and maritime transport assets at risk from climate damage (Nicholls et al: 2008). By these standards, the average asset exposure over 2010-2100 would be about $500Billion.

Distribution of Costs

Climate change should be integrated in a broader discussion of how transportation infrastructure is designed, where and whether it is built, retrofitted, or re-built, and how it is financed in California. The state's transportation infrastructure is already aging and overburdened, and continued population growth over the next 40 years will strain local and regional transportation systems without a substantial commitment of human and financial resources. As Henton et al. (2008) note, infrastructure constraints present California with both a challenge and an opportunity.

Many of the most severe threats from climate change — either in a stabilized or a significantly warming climate — would not materialize until later in the century. However, as we noted at the outset, transportation infrastructure is typically long-lived. Building or retrofitting a major bridge in 2010 would essentially require an educated guess about what operating conditions will be like 40 years into the future. Building or retrofitting all infrastructure to withstand the worst case IPCC scenario is not cost-effective if worst case conditions do not materialize, but insufficiently building or retrofitting infrastructure to account for new risks could have grave consequences. As the Bay Bridge retrofit demonstrates, the costs of bringing transportation infrastructure up to new construction standards can be non-trivial (Box 3.1).

This confluence of required infrastructure improvements, high expected rates of population growth and infrastructure expansion, and greater concern about climate change impacts presents California with an opportunity to conduct long-term, visionary planning about its transportation future. Much of this discussion will likely involve the politics of land use and the pricing of mobility, both of which are tied to climate change impacts. Less development in high risk areas could limit the damage to transportation infrastructure from storms, sea level rise, and coastal erosion. Pricing climate change risks into infrastructure upgrades through user fees could, in theory, internalize some of the costs of adaptation. How decisions in these two arenas are made will determine who shoulders the cost of climate impacts.

Box 3.1: Financing Toll Bridge Seismic Retrofits

ne 1989 the Loma Prieta Earthquake drew attention to the seismic vulnerability of alifornia's bridges. Subsequent analysis demonstrated that 7 of the 9 state-owned toll idges in California, including the East Span of the San Francisco-Oakland Bay Bridge, quired seismic work. To bring bridges up to a higher seismic standard, the state overnment created the Toll Bridge Seismic Retrofit Program (TBSRP) in 1997. Only the ay Bridge remains to be retrofitted. Retrofitting and indeed replacing parts of the Bay ridge's East Span make it the largest public works project in California history.[A]

ne TBSRP had a total budget of $8.7 in 2008 (Q2), of which the dominant project by far is e Bay Bridge retrofit ($6.5 billion total). The cost of retrofitting the 6 other bridges in the ogram ranged from the Vincent Thomas ($58.5 million) to the Richmond-San Rafael idge ($914.0 million) at an average cost across bridges of roughly $100 million per mile xcluding the Bay Bridge, and $340 million per mile including it.[B]

ost of the funds for the TBSRP are expected to be generated from an additional rcharge of $1 to the Bay Area bridge toll and revenues from the San Diego-Coronado nd Vincent Thomas Bridge toll accounts; together these are projected to finance 65 ercent ($5.7 billion) of the TBSRP budget. The remainder of the project's finance comes om a combination of general obligation bonds ($789 million), state transportation funds 1,085 million, including spillover revenues and funding from the Motor Vehicle Account), deral transportation funds ($600 million), and a $900 million contingency funded by otentially taking funds from other sources.[C]

ne huge amount of funding required for the TBSRP does not appear to have influenced e Bay Area Toll Authority's (BATA's) credit rating,[D] although California's credit rating has enerally deteriorated since the end of the 1990s for unrelated reasons.[E] In addition, trofits do not appear to have required a significant diversion of state budgetary resources. ne broader economic impact of the TBSRP — and by extension climate change-induced frastructure retrofits —is thus difficult to assess. In the latter case, if project design and nance is done prudently, negative economic impacts may be negligible.

an Francisco-Oakland Bay Bridge Project Information Site, http://baybridgeinfo.org/.
esults Group, 2005, "Historical Review of San Francisco-Oakland Bay Bridge East Span Seismic Retrofit Cost Increases," al Project Report to the California Business, Transportation and Housing Agency. Bridge lengths were taken from the y Area Toll Authority website, http://bata.mtc.ca.gov and California Department of Transportation website, p://www.dot.ca.gov/.
oll Bridge Program Oversight Committee, 2008, Toll Bridge Seismic Retrofit Program Report, Second Quarter Report.
Fitch: Comment on Recent Legislation Regarding Bay Area Toll Bridge System," *BusinessWire*, July 25, 2005.
alifornia State Treasurer website, http://www.treasurer.ca.gov/ratings/history.asp. The downturn in California's credit ing after 2000 had other causes, including the 2000-2001 electricity crisis.

Adaptation Options

Adapting California's transportation infrastructure to climate change will require a rigorous assessment of vulnerability and potential risks, possible responses and costs, and an evaluation of trade-offs. This kind of analysis has yet to be carried out, either at a state level in California or at the Federal level (NRC, 2008). Both of the two main adaptation options for transportation infrastructure — more stringent design standards for new structures and retrofits to existing structures — would likely require some increase in costs. On the design side, more probabilistic planning that accounts for greater weather variability and stronger materials could reduce project vulnerability. For existing structures, we argue that for major infrastructure nodes the cheapest option may be the engineering-intensive solution rather than trying to relocate them. Moving a major road, bridge, port, or airport in the U.S. would likely cause significant logistical and economic dislocation and, more importantly, the contiguous land to do so might not be procurable at reasonable cost.

"Softer" transportation adaptation options could also be important for reducing damages from climate change, both on the sector itself and more broadly. Transportation shapes land use, population growth, and economic development patterns, and more adaptive transportation planning decisions could have a significant influence on property-related climate damages.

4. Tourism and Recreation

Overview

Tourism and recreation are a major part of the California economy. The California Travel and Tourism Commission (CTTC) estimates that total direct travel spending was $96.7 billion in 2007 (5 percent of 2007 GSP), and supported nearly 925,000 jobs (4 percent of California's 2007 labor force).[24] Travel spending is also a significant source of local ($2.2 billion) and state government ($3.6 billion) revenues. The vast majority of the travel and tourism in California is actually in-state; of the 352 million "visitors" to the state in 2006, 299 million (85 percent) were local residents.[25] To account for the fact that such a large percentage of California's "tourists" are in fact state residents, we emphasize that recreation is an important component of travel and tourism in California by explicitly recognizing it in the title of this section.

Many of California's top tourism destinations are outdoors, including beaches, ski resorts, state and national parks, and golf courses. Climate change is expected to affect all of these venues and their attendant activities, but in different ways. Particularly in a world where the earth's climate is stabilized, not all of these effects will be negative and, for the U.S. as a whole, the net economic effect may indeed be positive (Mendelsohn and Markowski, 1999; Loomis and Crespi, 1999). In some industries, such as golf, lower levels of warming will be beneficial. In others, such as the winter sports industry, any warming will be negative. Similarly, even as some areas lose revenues from tourism other areas will gain. Thus, the net effect of climate change on California's tourism and recreation sector will likely masks huge distributional shifts.

Climate Impacts

Climate change will affect California's tourism and recreation industry through its impacts on natural systems. Pressures on natural ecosystems in California are not new. Since the first European settlement in California in 1769, California has lost as much as 91 percent of its original wetlands, mostly through conversion to agricultural land (USGS, 1996). Most of the state's valley grasslands have disappeared, with the remainder dominated by non-native species; fire suppression has fundamentally changed the character of California's unique forests and shrublands (Field et al., 1999).

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[24] State GDP and total employment are from the Bureau of Economic Analysis (BEA) website, www.bea.gov. California GSP was $1.813 trillion and total employment was 21,238,947 in 2007.

[25] All of the travel and tourism statistics in this paragraph are based on a series of three studies carried out for the CTTC by D.K. Shifflet and Associates (2006), Dean Runyan Associates (2008), and CIC Research (2008).

California has second largest number of threatened and endangered species among U.S. states (USFWS, no date). At some level, much of this ecological alteration has historically been population driven and population growth will continue to put pressure on ecosystems in California, even as these play an important part in the state's economy. Climate change could in many cases exacerbate the impacts of population growth.

California beaches are one of the state's more vulnerable natural resources. Sandy beaches are inherently unstable, as sand is deposited on the beach from river sediment, eroding bluffs, and migrating sand from other beaches, and removed or inundated by a host of natural processes that include wave activity and sea level rise. Over the course of the 20th century, the building of dams, reservoirs, and, to a lesser extent, coastal infrastructure in California have significantly reduced the volume of sediment reaching the state's coastline, and played a major role in the erosion of California's beaches (King, 2001). Human intervention has also been instrumental in restoring beaches and protecting them from erosion by dredging sand from elsewhere and placing it on existing beaches, or what is typically known as 'beach nourishment.'

Climate change will impact California beaches primarily through inundation as a result of sea level rise and accelerated erosion through an increase in Pacific storm activity and attendant changes in wave patterns. Using a detailed beach model for Los Angeles and Orange Counties, Pendleton et al. (2008) project that a one meter rise in sea levels would lead to an average 33 foot (10 meter), and a 26 percent, reduction in beach width. Reductions in beach width would be highly variable among beaches in these two counties, however, ranging from a 5 percent reduction at Humboldt State Beach to a 100 percent reduction at Las Tunas.

A major reduction in the Sierra snowpack would have profound implications for California's ski industry. Ski resorts require a minimum snow depth to begin the ski season, with a typical ski season in California historically (1961-1990) lasting from late November to late June (around 200 days).[26] Under all modeled climate scenarios, Hayhoe et al. (2004) found that the ski season shortens considerably, by 71 (B1) to 132 (A1fi) days using the PCM model; using the Hadley model, under an A1fi scenario the ski season ceases to exist. (Hayhoe et al., 2004). Shortening of the ski season under these scenarios happens at both ends; the onset of the ski season is delayed by the fact that temperatures are not cold enough, while the season ends sooner because of earlier snowmelt.

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[26] In their supporting online material, Hayhoe et al. (2004) report the length of the ski season from 1961-1990 as late November to late June, and the minimum snow depth to be 1-2 feet. As of the time of writing of this report, most ski resorts were advertising a ski season from mid-December to mid-April.

California is home to an extensive system of state and national parks, including America's first national park at Yellowstone,[27] that attract millions of visitors annually. National parks in particular have an important symbolic role in climate policy discourse in the U.S. because, as Saunders et al. (2006) note, Congress is tasked with protecting them for future generations. California's state and national parks cover a range of diverse ecosystems, and because of this diversity climate change will have different impacts on different parks. At higher warming levels, some of these impacts could be devastating; others could be benign or even positive.

For the western region as a whole, Saunders et al. (2006) list 11 potential impacts of climate change on national parks, including: loss of glaciers and snowfields, changes in vegetation, wildlife extinction, historical and archaeological losses, parks closed due to fire, loss of beaches, intolerable heat, overcrowding, loss of boating, loss of fishing, and loss of winter recreation. In California, many of these impacts could be overlapping. For instance, sea level rise could lead to flooding and coastal erosion along Point Reyes National Seashore, destroying both recreational space and the 120 known sites that are evidence of the 5,000 year-old Coast Miwok Indians.[28] Perhaps the most ignominious climate-induced impact on California's national parks would be the complete loss of Joshua trees from Joshua Tree National Park.

Considering outdoor recreation more broadly, negative climate change impacts will likely be driven by changes in hydrology, temperature, and coastal erosion. Changes in water availability and water temperatures could have a major impact on fish habitats. In 2002, lower than average water levels and higher temperatures in the lower Klamath River may have contributed to the disease that caused a massive die-off of more than 33,000 salmon and steelhead trout (Lynch and Risley, 2003). Williams (2006) argues that, in higher warming scenarios, the Chinook salmon will be unlikely to survive in the Central Valley because of higher water temperatures. Coastal erosion and inundation in wetlands and estuaries could destroy the habitats of numerous bird species cherished by birdwatchers (Skikne et al., 2008).

Climate change could potentially have a positive impact on the golf industry due to an increase in the number of days in the year conducive to golf (Scott, 2006). However, although the number of days suitable to golf might increase, an increase in weather variability might offset these benefits. Additionally, in water stressed regions golf, at least in its current form, could become untenable because of the inability to maintain greens. Climate change is already having an impact on the golf industry across the U.S. For instance, in a study of weather patterns from 1977-2006 by WeatherBill Inc. (2007) found that while the number of golf playable days (GPD, defined as 45-105°F and less

[27] National Park Service website, http://www.nps.gov/yell/.
[28] National Park Service website, http://www.nps.gov/pore/naturescience/climatechange_culturalresources.htm.

than 0.25 inches rainfall) in the U.S. — and for 5 of 8 cities examined in California — has increased over the past three decades, so has the variability in weather outcomes. This added uncertainty makes planning more difficult for golf course owners.

Costs Associated with Climate Change

The largest potential climate impact to California's tourism and recreation sector will be through its beaches. Of the total travel spending in California, nearly 44 percent is in the three coastal destinations of Los Angeles ($22 billion), Orange ($8 billion), and San Diego ($10.5 billion) Counties (Dean Runyan Associates, 2008). The National Survey on Recreation and the Environment (NSRE) estimates that 13.1 million Californians (39 percent of all residents)[29] visited coastal beaches and non-beach waterways in 1999-2000 (Leeworthy, 2001). King (1999) estimates that the total (direct, indirect, induced) national benefits of California's beaches was $73 billion in 1998, generating $14 billion in direct revenue for California and contributing $2.6 billion in federal tax revenues. The Woods Hole Oceanographic Institution (2003) reports the direct revenue generated by beach recreation in California at $13 billion in 2001. Needless to say, the state's beaches are an important part of both California's and the U.S. economy.

Pendleton et al. (2008) predict that the economic effects of a one-meter sea level increase on changes in beach width would on the whole be negative, but sea level rise would create winners and losers. Huntington City, for instance, would see a $16 million increase in beach travel-related expenditures. Laguna, alternatively, would experience a $14.6 million reduction in such expenditures. The net impact would be negative, with an annual $12 million loss in expenditures, a $63 million loss in consumer surplus, and a cost of beach nourishment of $4 billion. Extreme weather events, including storm and wave generated erosion, could have a much more significant economic impact on beaches than sea level rise alone, dramatically increasing beach nourishment costs (Pendleton et al., 2008). As an extreme upper bound, King and Symes (2003) estimate that the complete disappearance of beaches would lead to a total annual economic loss of $8.3 billion to California.

Curiously, there have been no valuations carried out to determine the economic consequences of climate change on the ski industry. The California Ski Industry Association estimates that winter sports in California generate $500 million and employ 15,000 people.[30] Skiing and snowboarding account for the bulk of revenue generation

[29] California's population in 2000 was 33.7 million; data are from the California Department of Finance website.
[30] This estimate is reported by the California Ski & Snowboard Safety Organization (CSSSO website: http://www.calskisafety.org/reports.html) as a result from a study published by the California Ski Industry Association. Although these numbers are widely cited online, no report or date for the estimates was

from winter sports in California, and for the sake of argument we assume that all of this revenues comes from the ski industry. If the entire ski industry were to collapse, as in the Hayhoe et al.'s (2004) most extreme scenario, this entire $500 million would be lost. A more likely scenario, again drawing on Hayhoe et al.'s estimate for changes in the ski season, would be that the ski season shortens by half, with a loss in revenue of roughly $250 million. Even in a B1 scenario, with a shortening of the ski season by roughly one-third, a loss in revenues could be between $150 and $175 million.

This approach significantly understates potential damages to the broader California economy from a decline in ski industry output for three reasons. First, the $500 million generated by the winter sports recreation includes only direct revenues; the ski industry supports accommodation, dining, and other service industries, and the total impact from a decline in ski resort revenues could be twice as high as the direct impact.[31] Second, changes in the ski season are likely to have a much larger impact on ski resort profits than on their revenues. Most of the expected shortening of the ski season results from earlier snowmelt, reducing the number of days at the tail of the season. However, a later onset of the ski season may be more difficult for ski resorts to overcome (Hayhoe et al., 2004) because of travel season and capacity considerations. Snow-making would be one option for lessening impacts on revenues, but would still reduce ski resorts' margins. Third, the ski economy is extremely local, and, as we discuss later, a decline in the ski industry could have disproportionate impacts on town economies that are based exclusively on skiing.

According to the Fish and Wildlife Service's 2006 *National Survey of Fishing, Hunting, and Wildlife-Associated Recreation*, 8.3 million residents and nonresidents fished, hunted, or watched wildlife in California in 2006, contributing $7.4 billion in expenditures to the state's economy (FWS, 2007). Of these, wildlife watching was by far the largest activity, accounting for 76 percent of participants and 56 percent of expenditures (FWS, 2007). State and national parks are a significant part of these wildlife watching activities. NPCA (2003) estimates the total visitor spending resulting from visits to California's 23 national park sites at $1.2 billion in 2001. Recreational fishing, which is possibly the most at risk of outdoor activities, generated $2.4 billion in expenditures by 1.7 million anglers in 2006 (FWS, 2007). Ultimately, however, it is not clear how climate change will affect outdoor activities.

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found as part of this study. At the 7.2 million skier visits reported by CSSSO in 2007-2008, $500 million would equate to $69.44, which is close to the NSAA's (2006) estimate of $68.18 in revenue per ski visit.

[31] For instance, Millsaps and Groothuis (2003) estimate a ski multiplier of 1.77 for North Carolina.

Table 4.1: Climate Impacts on Winter Sports and Beaches

	B1	A2
Winter Sports	$150 million	$250 million
Beaches	n/a	$75 million

Notes: These estimates are intended to indicate order of magnitudes only. For the winter sports industry we only include direct costs here; including indirect costs would roughly double these estimates (see Footnote 7). Beach estimates are based on estimates of direct costs, and this approach allows for comparability. Pendleton et al. argue that the storm-induced costs of beach nourishment may increase the above costs several fold because of a rise in beach nourishment costs, but final estimates are pending and the above only includes the effects of sea level rise. The lack of an estimate for beaches in a B1 scenario does not mean there will be no cost, but rather than we were not able to find an estimate.

Distribution of Costs

Climate change is unlikely to deter demand for outdoor recreation, but it is likely to change the geography of the tourism and recreation sector. In the case of beaches, a reduction of beach width and a loss of revenues in one area may mean more revenues for another area. Thus, while the overall net effect may be small, as Pendleton et al. describe in the case of beaches climate change has the potential to create large swings between winners and losers. Because the tourism and recreation industry is often highly localized, these shifts may have calamitous consequences for towns that are dependent on tourism.

Adaptation Options

California's tourism and recreation sector can be crudely classified into beaches, winter sports, and outdoor recreation. Each of these has distinct adaptation options. For beaches, for instance, the most immediate option is to scale-up beach nourishment. The state's beach nourishment was funded to the tune of $10 million per year in 2000-2001 (Kildow and Colgan, 2005), and is complemented by a smaller contribution of federal funds. Pendleton et al. (2008) estimate that sea level rise alone would require increasing program funds by 40 percent over current state expenditures, but that the combined effects of sea level rise and storms could require increasing funds by an order of magnitude. To some extent, required levels of funding may depend on how moneys are spent. If beach nourishment is poorly timed, for instance, newly added sand may be swept out to sea. Neumann et al. (2003) suggest that there may be a trade-off between protecting beaches and protecting property; they assume that sea level rise over 30.5 cm would require armoring, which in some cases would mean abandoning beaches. Other options for protecting beaches may be less direct. For example, it is unclear to what extent changes in upstream river management would have on the amount of sediment reaching beaches.

For ski resorts, the most immediate adaptation option is snow-making to make up for lost snow at the beginning and end of the ski season. In its study on climate change in the Alps, the OECD (2007) notes that artificial snow-making has proved cost-effective as a means to make up for some of these losses. However, as the ski season continues to shorten, snow-making will no longer be cost-effective, and more fundamental changes in the industry may be required. Simply moving the ski industry to other areas of the western U.S. will likely not be feasible because other resorts will be facing similar reductions in snow availability; Hayhoe et al. (2004) project that the Cascades and Columbia River Basin will experience loss in snowpack along similar lines as in California. Ski resorts' most cost-effective strategy may be to support mitigation efforts; thus far, the California Ski Industry Association has been an important supporter of California's climate mitigation efforts.[32]

For outdoor recreation, adapting to climate change requires greater attention to ecosystem management. Climate change is already affecting ecosystems in California, and through its effects on natural systems climate change will have long-term implications for outdoor recreation in California. National parks may need to purchase and protect habitat corridors as they change, and will need to modify their land stewardship practices (OHMVR, 2007). Greater adoption of best practices for ecosystem management in recreation areas has the benefit of reducing current stresses and making ecosystems more resilient to climate change (Julius and West, 2008). If temperatures are restrained within a "coping range" (Luers and Moser, 2006), many of the worst impacts on ecosystems can be avoided, but increasingly there is a need to develop approaches to valuing ecosystems in a policy context. Although healthy ecosystems are an important part of the state economy, they are often given short shrift in economic assessments.

[32] See, for instance, "California Ski Industry Association Works to Curb Global Warming," http://www.californiasnow.com/green_programs_csia_works.asp

5. Real Estate

Overview

In the industrialized world, the economic impacts of climate change will be preponderantly a matter of property. Whereas in many parts of the developing world other concerns, such as the spread of disease, may take precedence, in the U.S. the dominant issue will likely be the economics and politics of demographics, land use, and real estate. Deeply implicated in this discussion is the insurance industry, which stands to see its risk exposure increase dramatically as a result of climate change. For that reason, the insurance industry can play an important role in both mitigation and adaptation.

Because of its penchant for natural disasters — earthquakes, fires, and floods — many parts of California are intrinsically risky places to live and work. California has an estimated $4 trillion in residential real estate assets, large portions of which are built in fire prone areas and zip codes along the coast.[33] Natural disasters have historically taken their toll on California's homes and businesses; the state suffered a total of $6.2 billion (2006$) in damages from hazardous weather from 1997-2006.[34] Climate change may increase the frequency and severity of these disaster events, and climate-induced sea level rise will threaten coastal real estate. An increase in the frequency and severity of wildfires would further threaten homes and businesses across the state.

Climate Impacts

For California, there are essentially three major climate change impacts that have implications for real estate:

1. Increases in the frequency and severity of wildfires, which burn property;
2. Sea level rise and coastal erosion, which permanently inundate property; and
3. Increases in the frequency and severity of Pacific storms, which destroy or temporarily inundate property through, for instance, coastal flooding.

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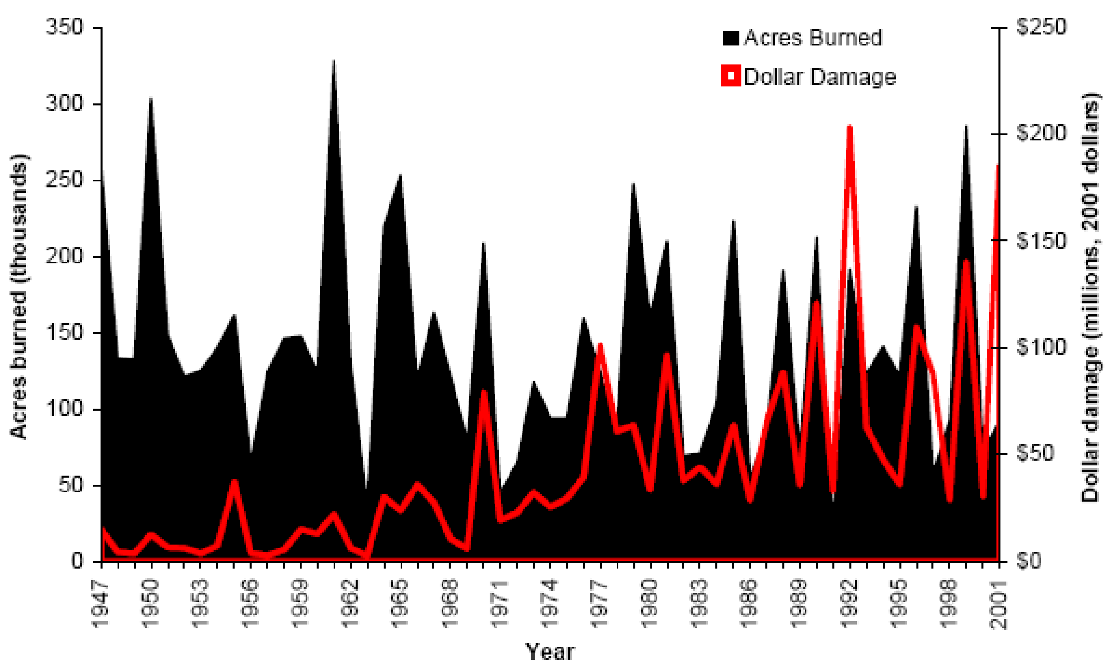
[33] We estimate this number using the total housing stock for California in 2006 (13,138,670), multiplied by the average home sales price for California for 2002 ($326,414). Housing sale prices data are from Rand California's Business and Economic Statistics database, and the data are from the California Association of Realtors. California housing stock data are from the California Department of Finance's California County Profiles.

[34] Data are from the National Weather Service's (NWS's) Natural Hazard Statistics database (http://www.nws.noaa.gov/om/hazstats.shtml), and were adjusted to 2006 dollars using the IMF's deflator for the U.S.

The magnitude and scope of these impacts are not static; they are conditioned by demographics, economics, and policy. Put simply, more people living in more high risk areas means more damage. Disincentives, for instance, in the form of higher risk premiums, can discourage some risky development, but if insurance premiums are subsidized by the federal government acting as an insurer of last resort risk prices may not be appropriately conveyed. For floods more specifically, Pielke et al. (2002) describe these interactive forces as the "independent and interdependent influences of climate, population growth and development, and policy on trends in damage." Much of the increase in hurricane damage over the last two decades is attributable to increasing population density in high risk areas rather than an increase in the intensity of storms (Pielke et al., 2008). For California, the California Department of Forestry and Fire Protection (CDF) notes that while wildfires have shown a longer-term upward trend, the trend in acres burned is more ambiguous (Figure 5.1).

Figure 5.1 Acres Burned and Dollar Damage on State Responsibility Areas, 1947-2001



Source: CDF, 2004.

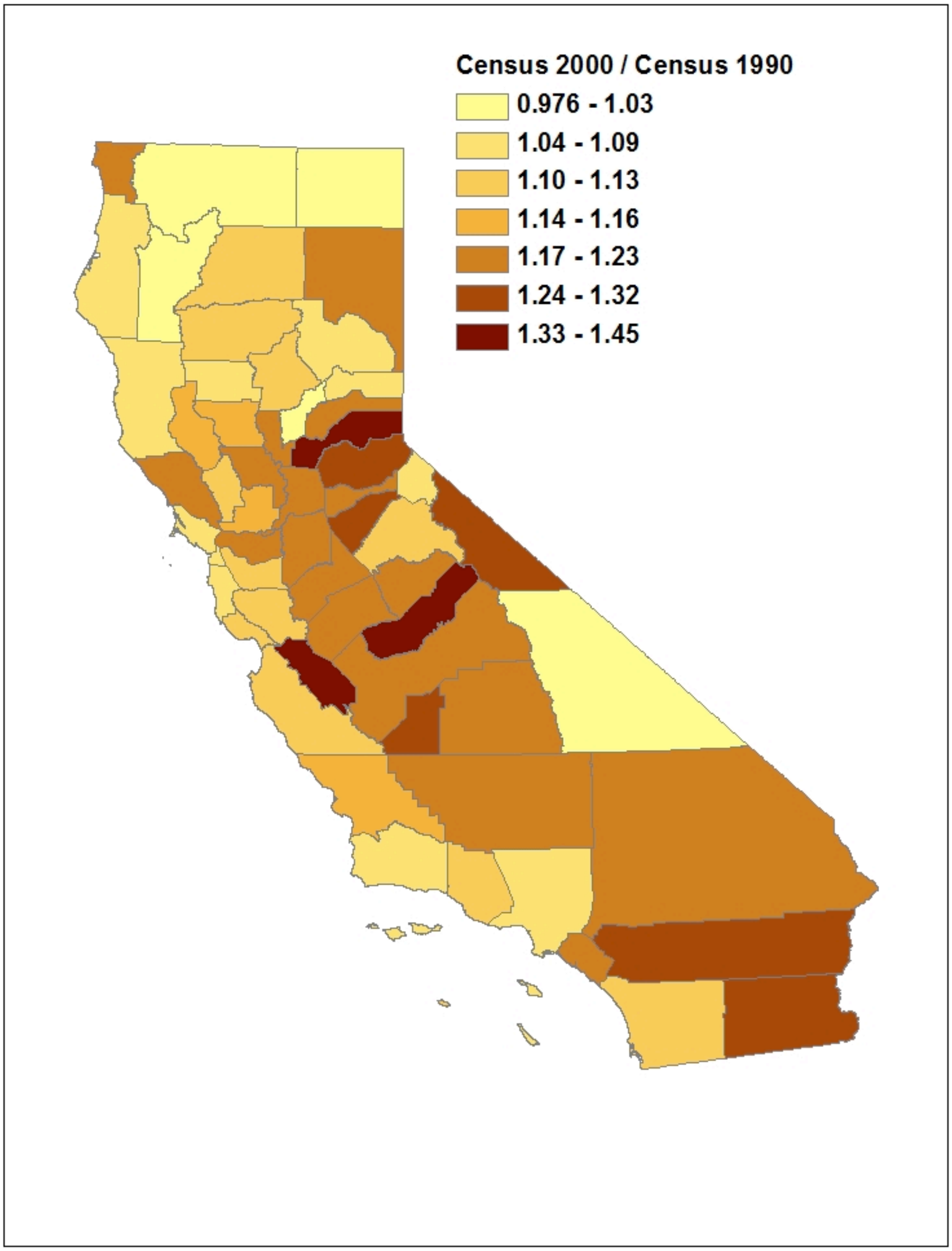
California's shifting demographic profile over the next century will similarly shift its exposure to natural hazards. Interestingly, although in absolute terms the number of people living in high disaster prone areas in California will likely continue to rise, in relative terms the share of the state's population living in these areas may decrease. In a trend that has taken shape in recent decades (Figure 5.2) and is expected to continue, much of California's population growth is occurring in inland regions, and in particular in the Inland Empire, Sacramento Metro, and the San Joaquin Valley (Johnson, 2002). Population in "near shore" areas grew more slowly than the state average (13.7%) between the 1990 and 2000 census, while population in inland areas grew (22.7%) much faster than the state average, albeit from a smaller base (NOEP, 2004). Inland areas are in theory less at risk to climate impacts, including sea level rise, coastal storms, and, in the case of the Central Valley and much of the Inland Empire, to wildfire.

Wildfire is a primary climate-related concern for California because such a large portion of its residential real estate is located in high risk fire zones. Wildfires also create conditions conducive to erosion and landslides. Much of California's fire risk is concentrated in the foothills of the Sierra Mountains and along the southern coast (Figure 5.3), but large portions of the state are at risk. California's most damaging fire in the past two decades occurred in Oakland, which is generally not thought of as being a high fire risk area. As of 2004, 4.9 million homes were located in a region with high or greater fire threat (CDF, 2004). These homes were equivalent to about 38 percent of the state's housing stock and an estimated $1.6 trillion in property value.[35]

Changes in moisture availability that will accompany climate change in California could have a number of effects on the state's wildfire regime. California's vegetation has two extremes in terms of its susceptibility to fire: energy limited regimes and moisture limited regimes (Westerling and Bryant, 2008). In energy limited regimes, where weather is typically wetter and cooler, dryer conditions and warmer temperatures increase the risk of fire. In dryer and hotter moisture limited regimes, high precipitation in a year before a fire leads to high vegetative growth, providing more fodder for the fire once weather has become dry and hot again. These distinctions are important for California because they describe the state's two main fire regions: Northern California around the Central Valley but particularly in the foothills of the Sierra Mountains tends to be more energy limited, while Southern California tends to be more moisture limited.

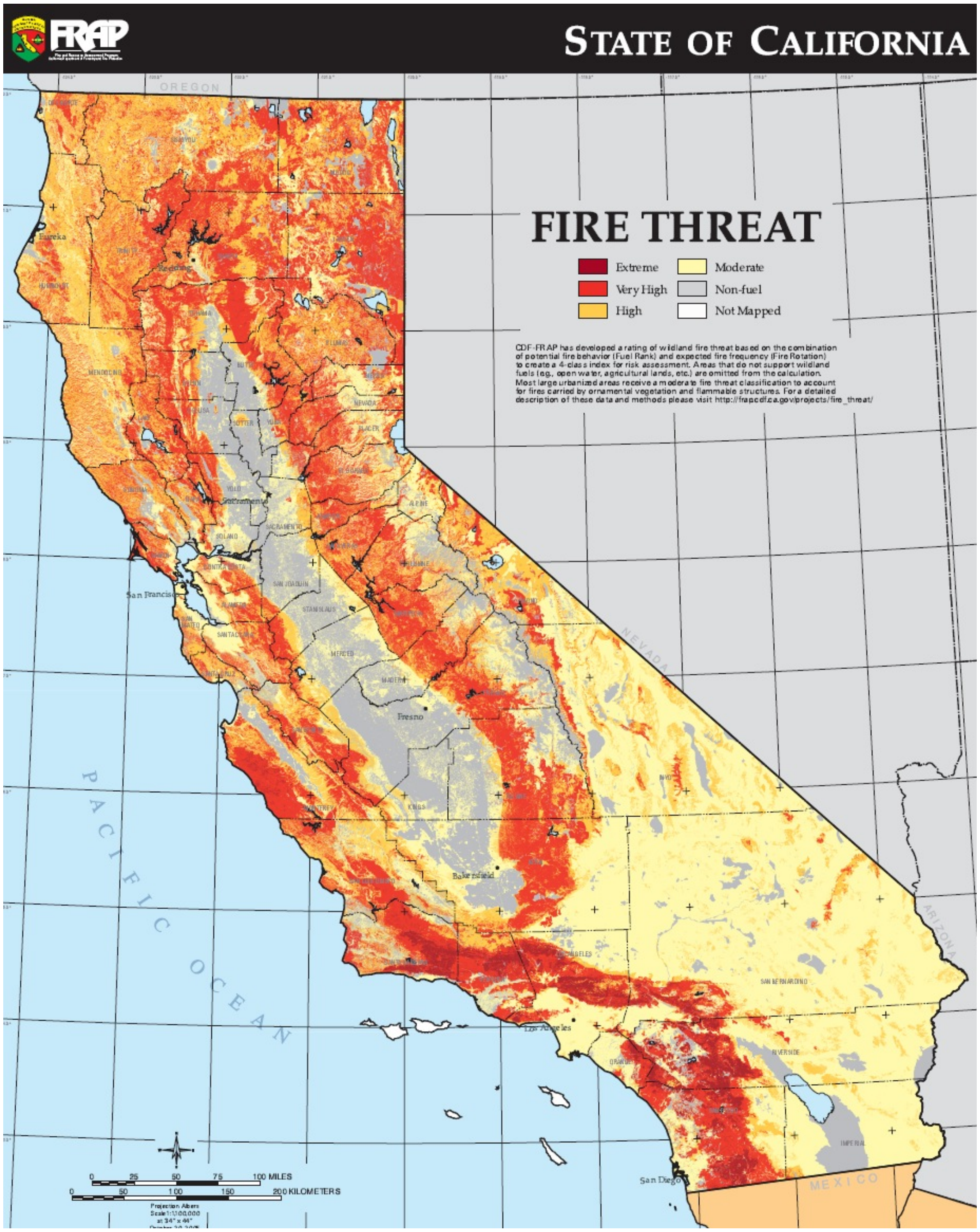
[35] California had an estimated 12.9 million homes in 2004. This estimate assumes that housing stock grew at a roughly constant rate from 2000 (12.2 million homes) to 2006 (13.1 million homes). Data are from the Department of Finance's (DoF's) California County Profiles. Property values are estimated using the CDF's estimate for homes in high risk areas (4.9 million) and the estimated average home sales price described in footnote 30.

Figure 5.2: Population Growth in California, 1990 to 2000 Census (Census 2000 Population Normalized to Census 1990 Population)



Source: California Department of Finance website, population data are from the 1990 and 2000 U.S. Census

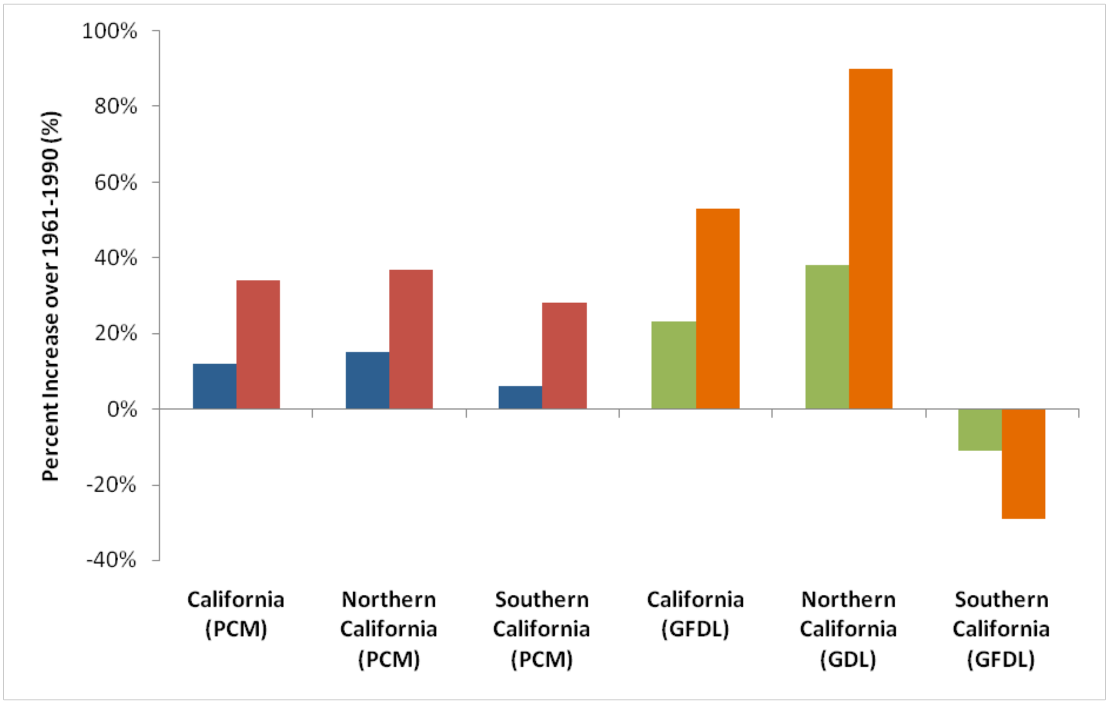
Figure 5.3: Fire Risk in California



Source: California Department of Forestry and Fire Protection, Fire Resources Assessment Program website, http://frap.cdf.ca.gov/.

B1 scenario is the left column
A2 scenario is the right column

Figure 5.4: Increased Risk of Large Fire under Different Climate Scenarios (% Increase over 1961-1990 by 2070-2099), California State-wide, Northern California, and Southern California

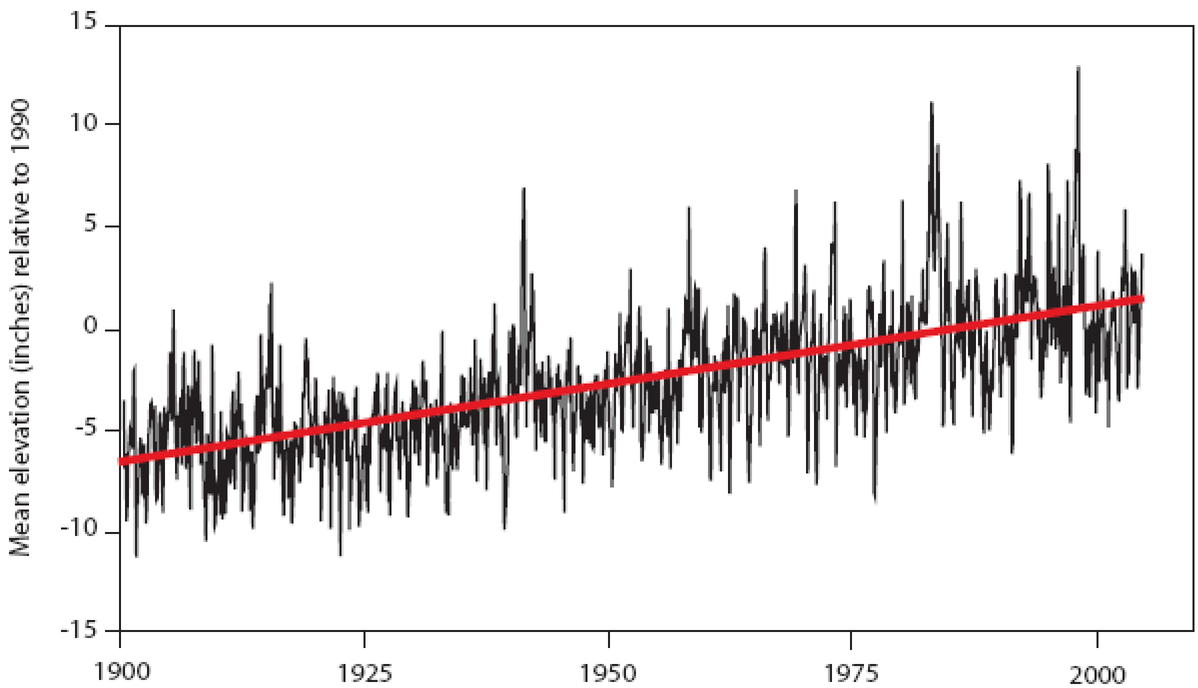


Source: Based on Westerling and Bryant (2008).

Precipitation is a major factor in determining how wildfires in California respond to changes in climate, but there is little consensus among climate models on how climate change might affect precipitation in the state over the next century (Cayan et al., 2008). As a result, the effects of climate change on Northern California are estimable with relatively greater certainty than the effects on Southern California, where fires are moisture limited and thus precipitation is a larger factor. Based on a simulation model of the Western region, Westerling and Bryant (2008) project that the number of large fires in California as a whole would increase by 12-53 percent, depending on the model and scenario, but that the impacts could be highly uneven between Northern and Southern California. Using the PCM model, Westerling and Bryant predict roughly comparable risk increases between north and south; using the GFDL model, Northern California experiences a 90 percent increase in large fires, while Southern California sees a nearly 30 reduction in risk (Figure 5.4).

Sea level rise and coastal erosion have particular importance for California because so much of the state's population and property is located along its 1,100 mile coastline. According to statistics from the last U.S. Census (2000), 14 percent of California's population and 16 percent of its housing stock lived and were located "near shore."[36] Sea levels in the San Francisco Bay have risen by about 7 inches (0.2 m) over the past century (Figure 5.5), although the rate of sea level increase has not accelerated (Cayan et al., 2006). As the earth's oceans warm and expand and as glaciers melt, climate models predict an increase in global mean ("eustatic") sea level of between 0.4-2.8 inches (0.1-0.7 m) by 2070-2099, depending on models and modeling scenarios (Cayan et al., 2007). In the two scenarios that we focus on here (B1 and A2), average projected sea level rise ranges from 0.3-0.4 m (Cayan et al., 2007). Higher sea levels worsen the eroding effects of high tides, surge, and waves from winter storms and amplify the impacts of flooding.

Figure 5.5: Rises in Sea Level in the San Francisco Bay



Source: Luers et al., 2006.

The effects of sea level rise and coastal erosion will be uneven across the California coast. As Figure 5.5 shows, most of the areas that the US Geological Survey (USGS) classifies as "very high" risk are concentrated around the state's major bays, including the Humboldt, San Francisco, and Monterey Bays. Areas around Los Angeles and San Diego are also at very high risk. Most of California's coast, alternatively, is at "low" to

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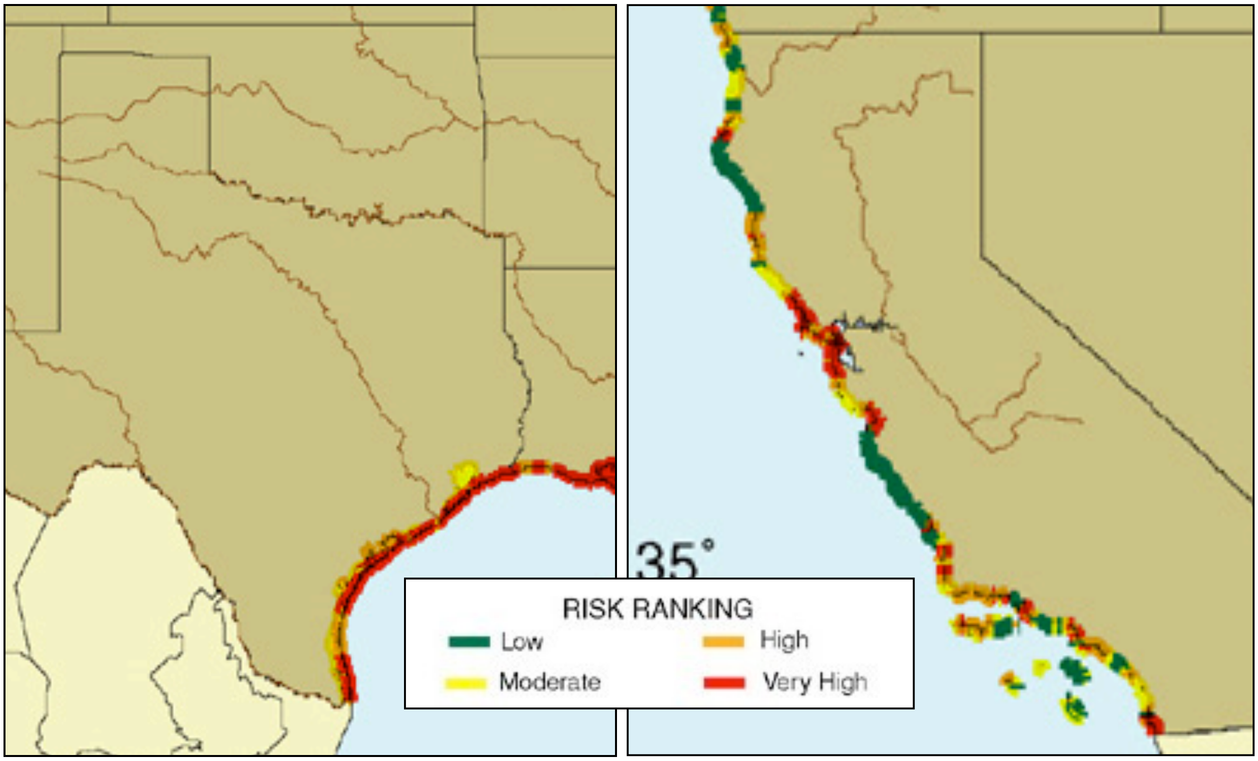
[36] Data on population and housing stock are from the National Ocean Economics Program (NOEP) Population and Housing Data database, using 2000 U.S. Census data. NOEP defines 'near shore' as "establishments or population located in a zip code that is immediately adjacent to an ocean, Great Lake, or included river or bay," NOEP website, http://noep.mbari.org/Market/.

"moderate" risk, a situation which contrasts sharply with states like Texas, where much of the coastline is at very high risk to sea level rise (Figure 5.6).

Figure 5.6: Coastal Vulnerability Index for California and Texas



Source: Adapted from USGS Woods Hole Science Center website, http://woodshole.er.usgs.gov/project-pages/cvi/.

Pacific storms are California's most recurrent natural disaster, averaging more than 8 major storms per decade over the last 40 years (see Table 5.1, below). Severe storms lead to flooding, landslides, and mudslides that damage property. As we describe in greater detail in the section on *Transportation*, the relationship between rising temperatures and Pacific storms is complex and still not well understood. Cayan et al. (2008) project a modest increase in extreme precipitation events for Northern California by 2070-2099. As with sea level rise and coastal erosion, the climate-induced impacts from increased storm activity may be concentrated in a few regions.

Costs Associated with Climate Change

The extent of climate-induced damage to property depends on where property is concentrated. As a rule, fires and extreme weather events that strike near urban areas are the most costly. Additionally, population growth in high risk areas increases the potential for climate-induced damage. All of the estimates we discuss below are thus conditional on where natural disasters occur and how many people are living there a century from now.

Table 5.1: Billion Dollar Disasters in or Involving California

Type	Lott and Ross (2006) Description	Year(s)	Deaths	Damage (billion 2006$)
Fire	Southern California Wildfires	2003	22	$2.7
	California Wildfires	1993	4	$1.7
	Oakland Firestorm	1991	25	$4.8
Winter Storms	West Coast Flooding*	1996-1997	36	$4.2
	California Flooding	1995	27	$4.6
	Western Storms and Flooding**	1982-1983	45	$3.9

* West Coast Flooding includes damages to California, Washington, Oregon, Idaho, Nevada, and Montana.
** Western Storms and Flooding includes damages to Washington, Oregon, California, Arizona, Nevada, Idaho, Utah, and Montana.

Notes and Source: All estimates are from Lott and Ross (2006). We assume that damage estimates are in current dollars, and convert them to 2006 dollars using the IMF's GDP deflator for the U.S. Lott and Ross's list includes three "Western Fire Seasons" (2002, 2000, and 1994), with $6.0 billion in total damages, that are likely to involve California.

From 1980-2005, California itself experienced four instances of billion dollar disasters, and the state was involved in at least three others (Table 5.1). Pacific storms are the most regular of California's climate-related natural disasters, but are likely not the worst in terms of damage. As a first order approximation, we estimate the damage from Pacific storms in California to be between $2 billion and $4 billion per decade, or around $200-400 million per year.[37] California's most expensive non-earthquake natural disasters since 1980 were the flood season in 1995 and the Oakland Hills fires in 1991.

[37] This estimate is based on matching NWS's Natural Hazard Statistics database and FEMA's disaster history for California (see Table 5.2) and assuming that federally declared disasters account for most of NWS damage estimates. In 2005, for instance, California had two declared federal disasters, both of which were severe storms. According to NWS estimates, total property damage in 2005 from natural hazards was $884.9 million, which would translate to an average of roughly $450 million/storm. In 2006 a similar situation occurred, with the average at roughly $300 million/storm. This pattern approximately holds for the ENSO event in 1997-1998 as well, giving a range of between $300 million/storm and $450 million/storm. At an average of 8.2 storms per decade, this leads to an order of magnitude estimate of $2-4 billion per decade.

From 1985-1994, the CDF estimates annual damages to residential real estate at $210 million (2006$), or $2.1 billion over the course of the decade (CDF, 1996). As Table 5.1 implies, there is potentially an inconsistency between this estimate and those of Lott and Ross, as their damage estimate of the Oakland Hills fires is more than twice that. Using the Lott and Ross estimates and assuming that large fires are significantly more costly than the average fire seasons, wildfires have over the last three decades cost the state $2-5 billion per decade if they occurred once per decade, and $4-6 billion per decade if they occurred twice per decade.[38] As Table 5.2 shows, in the last two decades the latter has been the case.

Table 5.2: Number of Federally Declared Natural Disasters by Decade, California, 1960-2007

	Forest Fires	Severe Storms	Levee Failure / Flooding	Earthquakes	Total
2000-2007	2	4	1	2	10
1990-1999	2	8	0	2	16
1980-1989	1	10	1	2	14
1970-1979	1	10	1	2	14
1960-1969	1	9	1	0	12
Decadal Average	1.4	8.2	0.8	1.6	13.2

Source: Federal Emergency Management Authority (FEMA) website, "California Disaster History," http://www.fema.gov/news/disasters_state.fema?id=6.

Using Westerling and Bryant's (2008) prediction of a 23 and 53 percent increase in the frequency of large fires under a GFDL (i.e., dry) B1 and A2 scenario, respectively, we estimate that climate change might increase the number of large fires from 5 per a 3 decade time period during 1960-1999 to 6-8 per 3 decades by 2070-2099. At a conservatively high estimate of $4 billion in property damages per large fire, climate-induced additional damages would be $1.3-4 billion per decade, or $130-400 million annually. Again, these are order of magnitude estimates that are useful conceptual anchors but are not intended to be forecasts. While we do use a high damage coefficient to account for population growth and increasing property values, this might

[38] California experienced major fires in 2003 and 2007. Risk Management Solutions estimates that the 2007 fires caused between $900 million and $1.6 billion in 2007 (www.rms.com/newspress/PR_102507_CAwildfire.asp), which, assuming that half of damaged property was insured, would lead to a total damage estimate of $2-3 billion for 2007, or a $6 billion cost for both the 2003 and 2007 fires.

still be an underestimate of the scale of potential damages depending on demographic patterns.

California has an estimated $900 billion in residential real estate that is located "near shore," [39] and potential impacts on coastal property will be one of the most important, and likely most contentious, effects of climate change in California. The huge value of this property, nearly half of the state's GSP, suggests that protecting coastal real estate will likely take precedence over other options, such as "retreat" (i.e., abandoning the property). The calculus may not be quite so straightforward, as we discuss in more detail below, but the notion that coordinated coastal protection will be more economically efficient than retreat is at least an often used assumption.

In what is still the only analysis of the economics of sea level rise on coastal property in California, Neumann et al. (2003) estimate the costs of either protecting (beach nourishment and armoring) or retreating from the coast. Although their model allows for the option of retreat, given the high value of coastal real estate this option is never used in any of their scenarios. The present value of a coastal protection strategy ranges from $14 million with 0.3 m sea level rise and a discount rate of 5 percent, to $635 million for a 1 m sea level rise and a 3 percent discount rate.[40] Undiscounted annual costs range from $57 million per year for a 0.3 m sea level rise, to $1.04 billion per year with a 1 m sea level rise. Notably, damages increase non-linearly with sea level rise increments; the annual costs of protection increase from $303 million per year with 0.7 m sea level rise to $1.04 billion per year with 1 m sea level rise. While these estimates do account for increases in the value of real estate and population growth, they do not include the value of wetland inundation.

Changes in the frequency and severity of Pacific storms might add to the already substantial costs of storm damage in California. However, we argue that projections of Pacific storm activity are not sufficiently robust to provide an order of magnitude estimate here. As an upper bound, if the increase in storm frequency is less than 50

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[39] We estimate this value using average housing sales prices for coastal counties for 2002, multiplied by total housing stock data for California in areas designated "near shore" by the National Ocean Economics Program (NOEP) using housing data from the 2000 Census. California median housing prices increased significantly between 2000 and 2006, and this number is therefore likely to be somewhat of an underestimate but a useful anchor point given recent volatility in real estate markets. Housing sale prices data are from Rand California's Business and Economic Statistics database, and the data are from the California Association of Realtors. California housing stock data are from the California Department of Finance's California County Profiles and the NOEP Population and Housing Data database. This estimate is almost certainly an underestimate as near shore property would intuitively be more valuable, but it is nonetheless a useful starting point.

[40] In this case, present value can be interpreted as the amount of money that would have to be set aside today at a given interest rate to make future investments in coastal protection. As a rule, a higher discount rate reduces the scale of future damages and costs.

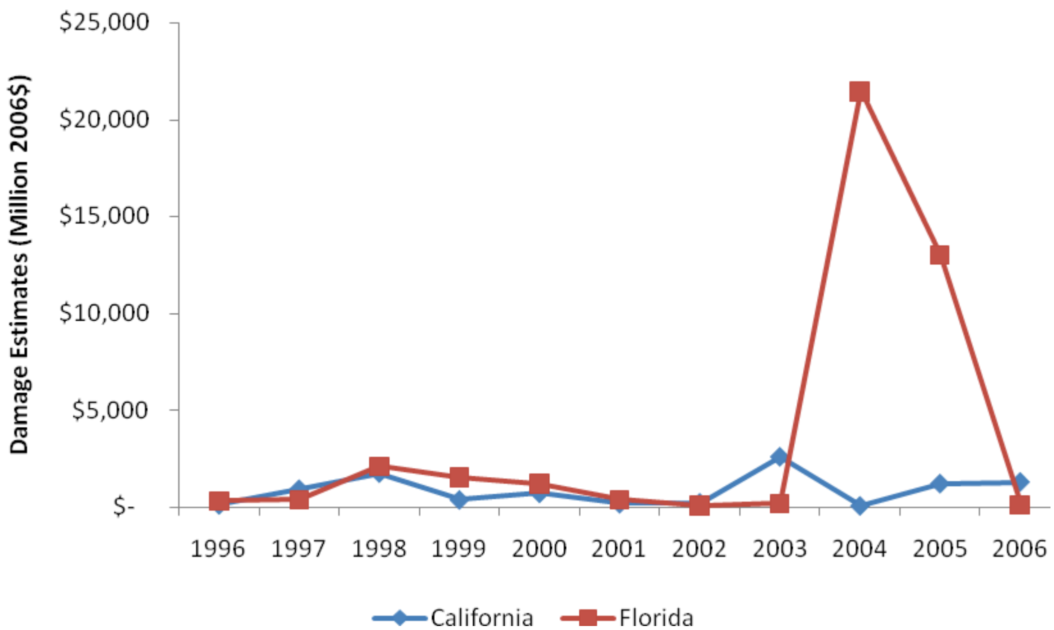
percent, California would experience an increase in damages of at most $1-2 billion per decade and $100-$200 million annually.

Table 5.3: Representative Costs of Climate Impacts on Real Estate

	B1	A2
Wildfires	$130 million/year	$400 million/year
Seal Level Rise	$50 million/year	$300-1,000 million/year

Notes: We report Neumann et al.'s estimates as a range for 0.7 to 1 m sea level rise rather than as a probability-weighted estimate. We do not provide an estimate for Pacific storms for reasons cited in the text.

Figure 5.7: Hazardous Weather Damage Costs, 1996-2006, California and Florida



Source: National Weather Service website, "Natural Hazard Statistics," http://www.nws.noaa.gov/om/hazstats.shtml. Damages were deflated to 2006 $ using an IMF deflator for the U.S.

It is important to emphasize that, at their most severe, the damage from Pacific storms in California is not on the same order of magnitude as powerful hurricanes in the Gulf Coast. By some metrics, the 1997-98 ENSO event was the strongest on record (McPhadden, 1999). The National Weather Service reports that the property damage from hazardous weather, which includes ENSO-related damage, in California during 1997 and 1998 was a combined $900 million. As we describe in the *Transportation* section, total cost estimates for the ENSO event itself have a median value of around

$500 million. By contrast, in Florida 7[41] hurricanes during the 2004 and 2005 seasons cost nearly $33 billion in property damage (Figure 5.7). At their most severe, the damage disparity between Gulf Coast hurricanes and Pacific storms is even larger. Damages from Hurricane Katrina, the costliest hurricane in U.S. history, have been estimated at more than $100 billion (Johnson, 2006).

For one California region, the map below gives an indication of inundation risk. Areas with hatch marking are within two meters of sea level, and currently protected by relatively low dikes or even level embankments. These include quite significant commercial and residential real estate assets.

Figure 5.8: Bay Area Elevations within Two Meters Above and Below Sea Level

Source: Gilliam (1969)

[41] See, for instance, FEMA website, "Florida Disaster History," http://www.fema.gov/news/disasters_state.fema?id=12.

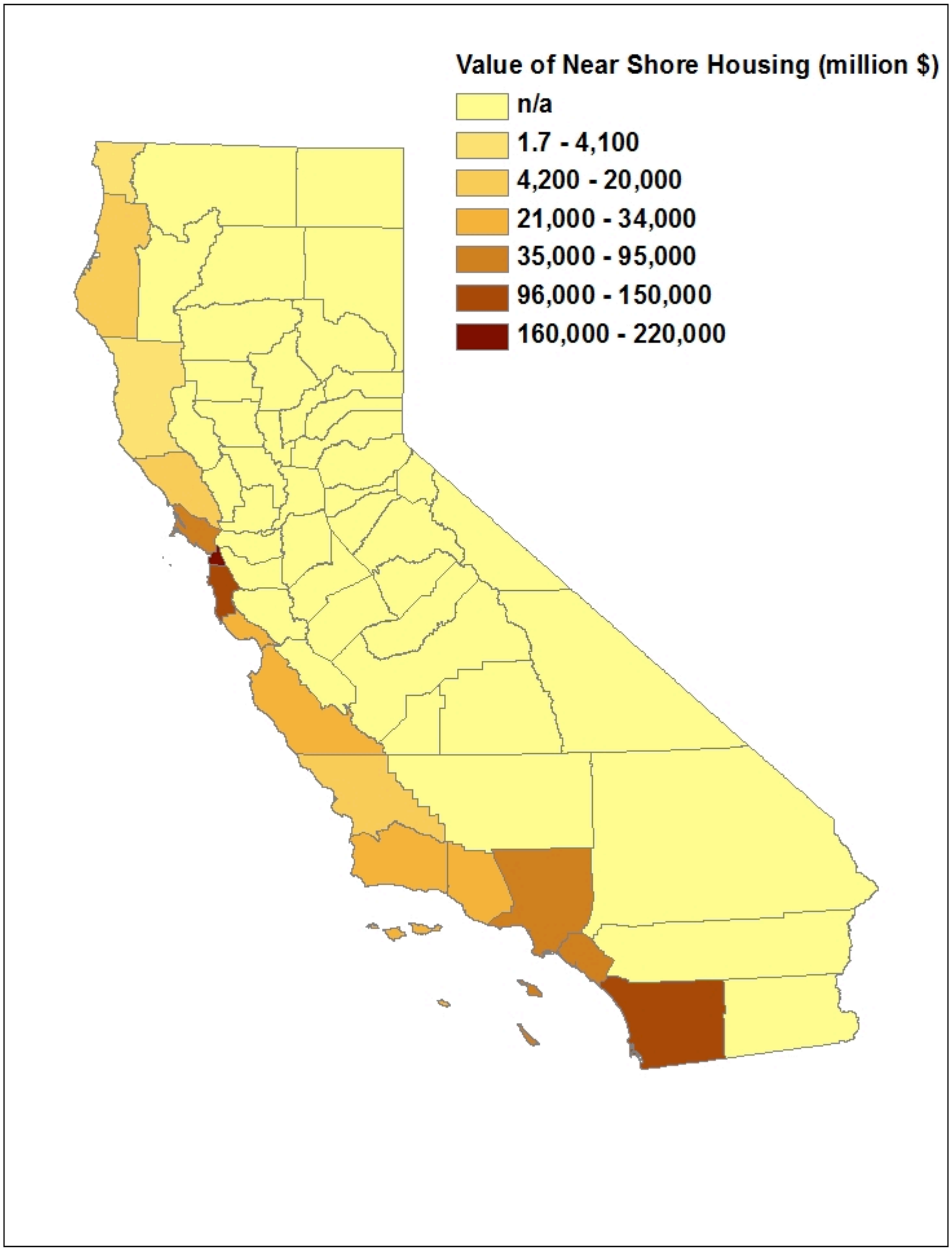
Distribution of Costs

While the insurance industry will play a significant role in climate change adaptation, ultimately it is the federal government that will determine who pays for both adaptation strategies and damages. The federal government acts as the final arbiter in the insurance industry, both in its role as a backstop insurer through, for instance, the Federal Flood Insurance Program (FFIP), and in its role as an industry regulator.

Insurance premiums play a dual role in allowing policy holders to smooth consumption, but also to ensure that they internalize risks. The federal government's role as an "insurer of last resort" has historically created huge distortions in insurance markets by effectively depressing insurance premiums in high risk areas and thereby encouraging people to live there. Allianz and WWF (2006), in a joint report, argue that a major component of climate adaptation must be to let insurance markets work in order to discourage high risk behavior and reduce potential damages. This issue is particularly relevant to wildfires and sea level rise in California, but could also become an even more relevant issue if Pacific storms increase.

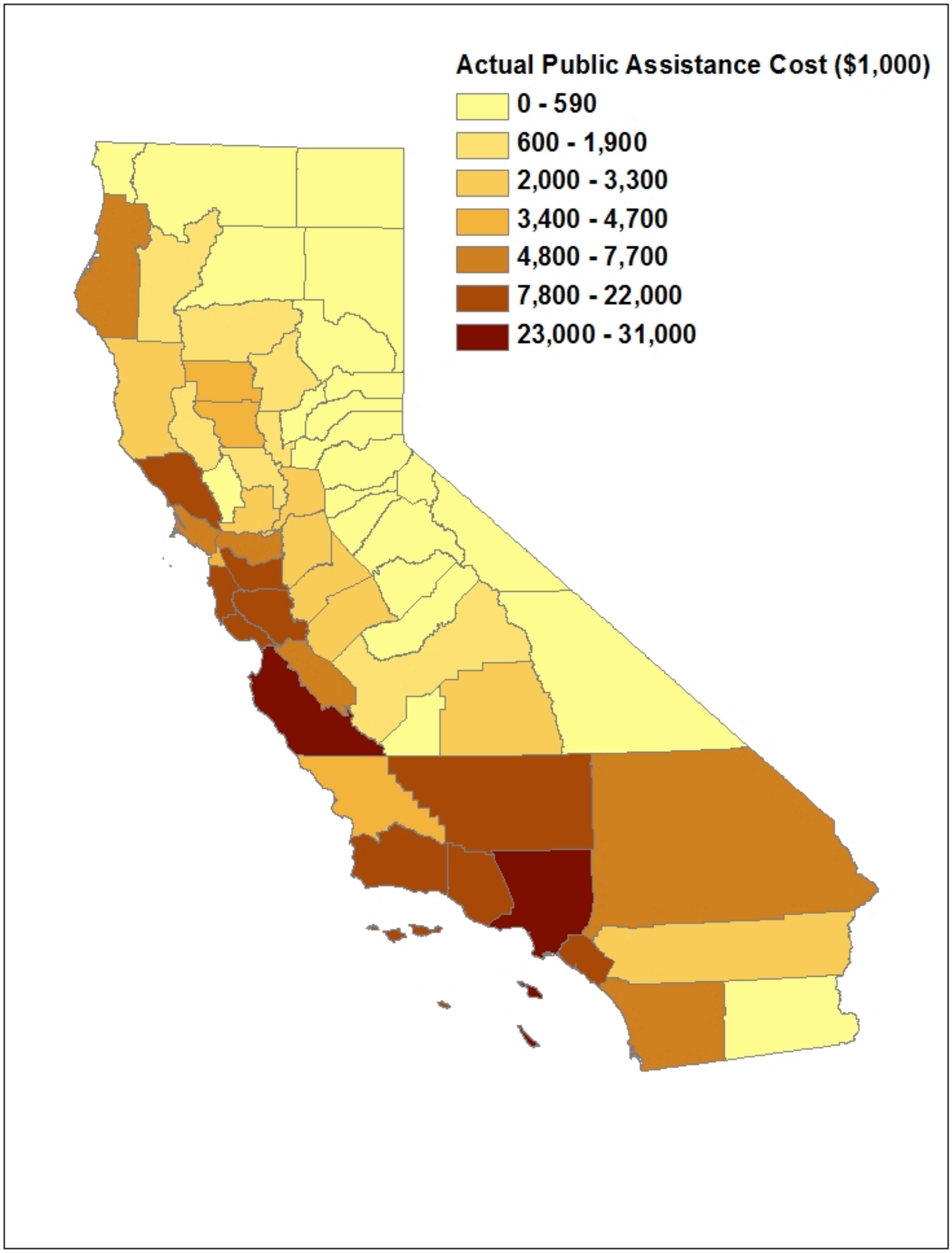
A counterbalancing perspective is that climate change may significantly increase the potential for market failures in the insurance sector. Without government intervention, insurance premiums could skyrocket in some regions, leading to public outcry and political pressure to cap rates. If the federal or state government steps in to cap premiums, it might lead to private sector withdrawal from the market and a large-scale reduction in coverage. In addition to potential market failures, the distributional consequences of structural changes in risk premiums may be significant. Poor people are generally less likely to be insured in the first place, but a rise in premium rates could further reduce coverage at the lower end of the income distribution. Lastly, increases or shifts in property risk in California are likely to be regional. By value, we estimate that more than 50 percent of California's near-shore residential real estate is concentrated in San Francisco, San Mateo, and San Diego Counties (Figure 5.9). Public assistance costs from the 1997-1998 ENSO event were concentrated in 10 counties along the coast and in the Delta region, and particularly in Los Angeles and Monterey Counties (Figure 5.10).

Figure 5.9: Estimated Value of Near Shore Housing (Millions of Dollars), 2000



Source: See Footnote 30 for a description of how these values were calculated.

Figure 5.10: Public Assistance Costs from the 1997-1998 ENSO



Source: Data are from Pielke et al., 2002

Negotiating the contentious space between public and private risk will require difficult decisions. Coastal housing provides an excellent example. Neumman et al.'s analysis of the protect versus retreat decision assumes perfect foresight; that is, that both buyers and the insurance industry can determine what property prices will be many years into the future. Based on a 30-year assessment, for instance, state and federal government agencies might decide that the least cost solution would be to protect coastal structures. Alternatively, one can imagine a situation in which expectations of sea level rise and coastal erosion cause housing prices along the coast to fall precipitously and insurance premiums to rise, leading many coastal residents to choose the retreat option. If protection was paid for with taxpayer funds, this amounts to an enormous wealth transfer to coastal residents. Both in California and in the U.S., the policy and legal frameworks to deal with these trade-offs are not yet in place.

Adaptation Options

Several adaptation strategies for the real estate sector have already been described. For wildfires, local development strategies that minimize the wildland-urban interface would reduce damages, as would more stringently enforced regulations that stipulate, for instance, the amount of defensible space around structures. For sea level rise and coastal erosion, beach nourishment, armoring, and retreat are the three primary options. Because of its role in risk management in modern economies, the insurance industry is central to all of these options. Although the insurance industry plays a key role in pooling risk and "smoothing" economic losses from natural disasters, it is important to note that insurance itself does not necessarily reduce climate-related damages.

Private insurers pay approximately three quarters of weather-related losses in the U.S., with the federal government covering the remainder (GAO, 2007).[42] Across the U.S., climate change will substantially increase the risks faced by the insurance industry. Although private insurers in the U.S. have begun to better assess their exposures, there is still substantial progress to be made in analyzing, allocating, and mitigating risk (Allianz and WWF, 2006). Federal insurance agencies have only just begun to broach the subject of climate change (GAO, 2007). Insurers have historically played a leading role in loss prevention, and are in a unique position to offer incentives that guide both climate change mitigation and adaptation efforts (Maynard, 2008; Mills, 2005).

Insurance is only possible when risks are quantifiable. One of the largest challenges facing the insurance industry is how to price a future where both the potential for climate stabilization (the emissions scenario) and local climate sensitivity to changes in average temperatures (climate modeling results) are both uncertain. For instance, how can

[42] This statistic includes all weather-related losses, including crop damage.

insurance premiums in San Diego County be priced in a way that encourages residents to internalize the changing risks of wildfire 50-100 years into the future? The insurance industry has historically looked to the past to price risk, but this approach will not be practical in evaluating climate change risk. An enormous amount of actionable knowledge could be gained from public-private partnerships that bring state agencies, the scientific community, and insurance industry together to advance climate science and better quantify the risks associated with climate change. As a leader in climate change science, California could certainly play a proactive role in forming these partnerships.

The insurance industry's exposure in California, while uncertain, is likely to be considerable. Munich Re estimates that direct insured losses account for approximately 40 percent of all economic losses in a catastrophic weather event (GAO, 2007). If near shore property is assumed to be "at risk" as a first order approximation, using this 40 percent estimate and our afore-mentioned $900 billion estimate for the value of "near shore" property the insurance industry's exposure to coastal climate impacts could be on the order of $400 billion. While much of this property is likely not at significant risk from climate change, this number does provide a high upper bound and cause to develop more nuanced estimates. Similarly, if the number of large fires in California increased to 3 per decade total damages could exceed $10 billion, which would likely require a significant change in the way that the insurance industry approaches fire damage in California.

6. Agriculture, Forestry, and Fisheries

Overview

Agriculture plays an important role in California politics, society, and economy. California is the largest farm producer in the U.S. and has been since 1948 (AIC, 2006a). Although with $15.1 billion in value added it accounted for 1.2 percent of California's $1.742 trillion GSP in 2006, the agricultural sector has extensive linkages with the rest of the state's economy, and indeed with the U.S. as a whole.[43] Including its direct, indirect, and induced linkages, agriculture accounts for an estimated 6.5 percent of California's value added (AIC, 2006b), or more than $113 billion at 2006 GSP. California produces nearly half of all U.S. fruits, nuts, and vegetables, many of which are produced only in California (CFDA, 2007).

Forestry accounts for an even smaller part of the state's economy (around 0.1 percent of 2000 GSP),[44] with the total value of primary forest products produced in California reaching $2.3 billion in 2000 (Morgan et al., 2004). Though comparatively small as a source of income, California's forests cover 39.7 million acres, or nearly 40 percent of the state's total land area (Laaksonen-Craig et al., 2003), and play an important role in ecosystem functioning. Commercial fishing is the smallest of the three sectors examined here; its two largest components, squid and salmon fishing, are currently worth a total of about $100 million (Sweetnam, 2005; Barrow and Heisdorf, 2007).

Climate change will mean significant changes for agriculture, forestry, and fisheries in California. In lower warming scenarios, some of these changes will be beneficial for agriculture and forestry, although there is still a debate about net impact. Both higher and likely lower warming scenarios, even if they cause no net economic impacts, will lead to a gradual but substantial change in the composition and location of agricultural, forest, and fish production.

Climate Impacts

Climate change will have fundamental impacts on California's agricultural, forest, and marine ecosystems, including changes in ecosystem geography (e.g., shifts in climate zones), basic ecological processes (e.g., changes in pollination and photosynthesis), and where plants and animals live (e.g., shifting habitats for pests) (Field et al., 1999). At lower temperature increases, many of these changes will be positive, while others

[43] Data are from the Bureau of Economic Analysis (BEA) website, http://bea.gov/regional/gsp/.
[44] Forestry is not included in state or national accounts as a separate sector. We use the Morgan et al. estimate for gross revenues and assume that net revenues are approximately the same as agriculture to calculate this GSP share.

will be negative (Table 6.1). However, agriculture and forestry are generally characterized by threshold effects; once temperatures exceed a certain level the benefits of higher CO_2 levels and warmer temperatures are negated by a deterioration of basic plant functioning. For marine ecosystems, the net impacts of climate change are generally expected to be negative.

Table 6.1: Positive and Negative Effects of Climate Change on California Agriculture

	Positive Effect	Negative Effect
Higher Temperature	Earlier growing season, earlier spring flowing, expanding range of certain plants	Higher maximum temperatures means more summer heat stress on plants
	Increased rate of photosynthesis at lower temperature windows	Reduction in winter chill needed by fruit and nut crops
	Acclimation of respiration and photosynthesis	More evaporation increases plant water needs
	Reduced frost	Increased pest damage
Higher CO_2 Levels	Increased biomass production	Greater plant respiration
	Increased water use efficiency	Greater need for nitrogen or other fertilizers

Source: Baldocchi et al., 2005.

Changes in climate averages and extremes will both have important implications for agriculture, forestry and fishing. Spatial and temporal shifts in water availability may be the most important climate impact for agriculture and freshwater fishing. However, given that agricultural and environmental water use are intimately tied to urban water use, we discuss potential impacts of changes in water supplies in the *Water* section and focus here on non-water aspects of climate change impacts.

There is still considerable uncertainty in the overall, net impact of climate change on agriculture in California, as many of the average effects of climate change have both potential positive and negative dimensions. A longer growing season, for instance, would benefit perennial crops. However, earlier flowering associated with a longer growing system might have negative repercussions for pollination if flowering cycles and life cycles for pollinators become desynchronized. An increase in minimum temperatures would reduce frost, but would also reduce the annual number of chill hours. This latter trade-off is particularly important for California because fruits and nuts, which are a staple of agriculture in the state, need to be exposed to a minimum number of cold season hours below at critical threshold temperature to initiate flowering (Table 6.1). Many areas of California are already experiencing a decline in chill hours, and these regional changes in temperature extremes will have a marked impact on species ranges. Baldocchi et al. (2005) estimate that, in both a B1 (stabilization) and A2 (higher warming) scenario winter chill hours would fall below critical thresholds for many crops by 2100 (Baldocchi et al., 2005).

Table 6.2: Chill Hours per Year for Selected Tree Crops

Fruit or Nut	Number of Chill Hours Needed
Almond	400-700
Apricot*	350-1000
Fig	100-500
Grape	100-500
Kiwi*	400-800
Nectarine*	200-1200
Peach*	200-1200
Persimmon	100-500
Pistachio	800-1000
Pomegranate	100-200
Raspberry*	100-1800
Strawberry	100-200
Walnut*	400-1500

* Low-chill varieties exist that need less chilling.

Source: Baladocchi et al. 2006, Based on Australasian Tree Crops Sourcebook

Climate-induced changes in ecosystem boundaries will extend the range and increase growth rates for some pests, weeds, and pathogens, threatening both agriculture and forestry. The olive fly, Mediterranean fruit fly, pink bollworm, and yellow starthistle, for instance, are expected to increase their ranges northward (Gutierrez et al., 2006). Pierce's Disease, a bacterial disease carried by the glassy-winged sharpshooter that predominantly affects the grape industry in Southern California, has an optimal growth temperature of 82°F (28°C); vineyards in Northern California are currently sub-optimal for Pierce's Disease but may not remain so in higher warming scenarios. Already, pests and pathogens are a major problem for California; the state's Department of Forestry and Fire Protection reports that pests currently destroy 10 times more timber volume than wildfires (CDF, 2005). As they extend their ranges, interactive effects between pests and pathogens might amplify the damages from each.

Climate change will also have important implications for animal physiology. Heat-related stress leads to a decrease in feed intake in livestock, as more of their energy is used for cooling. For California's dairy cows, higher body temperatures mean lower milk yields. Hayhoe et al. (2004) estimate that, for the top 10 dairy counties in the state, rising temperatures could reduce dairy production by 7-10 percent in a B1 scenario, and by 11-22 percent in an A1fi scenario.

A final category of climate impacts on agriculture is the effects of extreme events, particularly heat waves and floods. Heat waves can lead to early flowering, reduced effectiveness of pollination, decreased ability for photosynthesis, decreased yield, and can kill plants that require long periods of growth (Cavagnaro et al., 2006). Luers et al. (2006) project that, in higher warming scenarios, the number of heat waves days in urban areas in California will increase by as many as four-fold, but a systematic study of the effects of extreme heat on the state's agricultural sector has yet to be carried out. Floods have historically been a challenge for California agriculture and, as we discuss in the section on *Water*, an increase in flood frequency or severity would be particularly taxing for the Central Valley.

Climate change will impact forests mostly through changes in CO_2 levels, temperatures, and soil moisture that affect productivity and shift the geographic distribution of tree species. Globally, these changes are anticipated to improve the productivity of managed forests and increase the world's total timber supply (Mendelsohn, 2003). For California, dynamic vegetation models predict a shift from needle-leaved to broad-leaved species, an increase in net primary productivity (NPP) in a PCM A2 model scenario, and a decrease in NPP in higher temperature GFDL model scenarios (Lenihan, 2006). Modeling these impacts is complex because shifts in temperature can lead to changes in entire ecosystems, and the effects are often site and species specific. In their case study of El Dorado County in the northern Sierra Mountains, Battles et al. (2008) predict that higher increases in temperature will have significant negative effects on some species, driven by higher summer temperatures. White fir, cedar, and Douglas fir would experience reduced growth, while impacts would be smaller for ponderosa and sugar pine. They estimate that the highest temperature scenarios decreased tree growth (i.e., mean annual increment) by 19 percent, declining gradually over the course of the century but accelerating by century's end.

Squid and salmon populations will both be affected by climate change, but potential impacts are still poorly understood. Higher seawater temperatures could increase squid growth rates, but could also lead to changes in size, population structure, and metabolism that would make squid populations more vulnerable (Pecl and Jackson, 2007). Changes in squid physiology could lead to changes in spawning regions and greater variability in spawning, with implications for both the fishing industry and natural resource managers (Pecl and Jackson, 2007). Higher frequency of major El Niño-Southern Oscillation (ENSO) events could also impact squid populations. In the 1997-1998 ENSO season, squid landings fell from their then record high of 110,000 metric tons in 1996-1997 to less than 1,000 metric tons because of the high temperatures associated with El Niño (USGCRP, 2002).

Climate change will also affect salmon by altering both their freshwater and saltwater habitats. Earlier snowmelts could push salmon into the ocean earlier, without sufficient spring phytoplankton to feed them. The balance between predators and baitfish populations at that time could affect salmon survival rates by altering the number of predators (Carter, 2007). The different phases of the Pacific Decadal Oscillation (PDO), an inter-decadal climate phenomenon in the Pacific, also appear to have an influence on salmon stocks, with dwindling salmon populations during warm phases and large populations during wet phases (Carter, 2007). The PDO was described only recently (1997), and is still poorly understood.

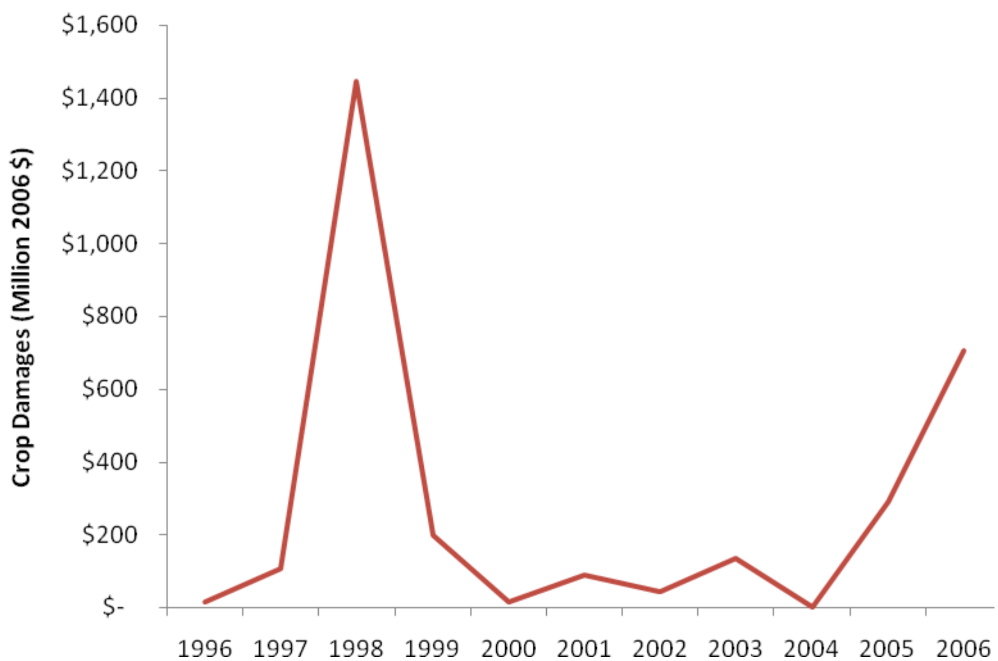
Costs Associated with Climate Change

Several studies have examined the economic impacts of climate change on California agriculture and forestry (Kolstad, 2008; Deschenes and Greenstone, 2006; Adams et al., 2003; Battles et al., 2008; Mendelsohn, 2003), though none is comprehensive. Many significant impacts, such as changes in pests, weeds, and pathogens, are exceedingly difficult to model because they involve changes in entire ecosystems, and rough extrapolation from current conditions can lead to huge over- or underestimates of damages. For others, such as changes in precipitation and extreme events, uncertainty among climate models remains an obstacle to greater consensus on potential impacts, with different models predicting radically different outcomes (Cayan et al., 2008).

In part because of these uncertainties, the potential net costs of climate impacts on agriculture and forestry in California remain a matter of debate. Based on degree-day and precipitation outputs from the Hadley model, Deschenes and Greenstone (2006) estimate that that the U.S. as a whole would stand to gain $1.3 billion annually in profits (4 percent increase) as a result of climate change, while California would lose about $750 million annually (15 percent decrease). Kolstad (2008) projects that, holding prices and water availability constant, climate change could lead to an increase in total agricultural profits in California, but the variation among crops would be substantial.

The damage and cost of controlling pests, weeds, and pathogens could be an important economic impact of climate change in California. Gutierrez et al. (2006) estimate that invasive species currently cost California $25-40 billion annually, based on a Pimentel et al. (2000) calculation that non-indigenous species cost the U.S. as a whole $137 billion per year. However, the latter's estimate includes exotic pathogens, such as AIDS and influenza, as well as other costs that are not relevant to agriculture and forestry in California. A more reasonable estimate, based on an estimate of annual damages at near or around $1 billion and state and federal outlays for pest and pathogen control totaling $449 million in 2002-2003 (Sumner, 2005), would be an order of magnitude smaller. Assuming that the damage and control costs for weeds are on the order of hundreds of millions of dollars (Schoenig, 2005), the total damages on commercial agriculture and forestry from pests, pathogens, and weeds, and the resulting control costs, in California are likely around $2-3 billion per year. This baseline is an important anchor; a 50 percent increase in costs from pests, pathogens, and weeds would be in the range of $1-2 billion, rather than $10-20 billion. We assume here that a reasonable upper bound for increases in pest, pathogen, and weed damage to agriculture and forestry would be a 100 percent increase, or $2-3 billion annually.

Figure 6.1: Damage to California Crops from Natural Disaster, 1996-2006



Source: National Weather Service website, "Natural Hazard Statistics," http://www.nws.noaa.gov/om/hazstats.shtml.

California sustained an average of $276 million (2006 $) in annual crop damages from natural disasters from 1996-2006, but as Figure 6.1 shows this average masks substantial volatility. A significant portion of these damages resulted from flooding; however, without clearer links between climate change and flooding in the state, it is unclear what the climate change "adder" to these impacts would be. California has several recent examples of the effects of extreme temperatures on the agricultural sector. For instance, unusually low temperatures in 2007 led to more than $1.3 billion in agricultural damages, roughly 60 percent of which occurred in the citrus industry (Office of the Governor, 2007). The state's record heat wave in July 2006 led to nearly $1 billion in losses for the dairy industry alone.[45] Increases in extreme heat days are particularly important for the state's dairy industry. California is the largest dairy producer in the U.S. by a wide margin, and dairy accounted for 14 percent ($4.49 billion) of the state's total agricultural production in 2006 (CFDA, 2007). At Hayhoe et al.'s (2004) estimate for potential reductions in dairy productivity as a result of temperature increases at the margin, the state could lose $0.3-0.5 billion annually under a B1 scenario, and $0.5-1.0 billion under a higher warming A1fi scenario.

Table 6.3: Range of Representative Cost Estimates for Agriculture, Forestry, and Fisheries

	B1	A2
Dairy	$0.3-0.5 billion	$0.5-1.0 billion/year
Pests, Weeds, and Pathogens	n/a	$2-3 billion/year
Forest Productivity	n/a	$0.2-0.3 billion/year

Notes: The cost estimate for pests, weeds, and pathogens is intended to be purely illustrative. There are no estimates for pest, weed, and pathogen damage increases under a business as usual climate change scenario; the number here assumes that damages double, which we argue is probably a reasonable upper bound. In a B1 scenario there will likely be some change in pest range, but this is much more difficult to bound. We use the Battles et al.-derived forestry estimates as a worst case upper bound.

Much like agriculture, the net economic impacts of climate change on California forestry are still a matter of debate. Based on the emerging consensus that climate change will likely increase the productivity of the world's of forests but reduce their range, Mendelsohn (2003) argues that the largest impact on forests would be price driven; as supply increases in the near term would cause the price of timber to fall, consumers would benefit while producers would see a fall in profits. For California, Mendelsohn (2003) estimates the magnitude of this effect as a $1 billion loss to producers and a $14 billion gain to consumers. Because decreases in the geographical range of forests are expected to occur much later in time than nearer-term increases in forest productivity, the net present value of these competing productivity-range effects is strongly positive. This argument, though perhaps controversial, is a salutary reminder that many of the most important economic impacts of climate change may be driven by the global price system, rather than by quantity-based damages in California.

[45] "California Heat Wave Costs Agriculture Industry Billions." *Environment News Service*. August 4, 2006.

Based on their case study in El Dorado County forests, Battles et al. (2006) argue, in part in response to Mendelsohn (2003), that the impacts of climate change will have a negative impact on forest growth in some parts of California. Luers et al. (2006) generalize from the Battles et al. (2006) results and assert that pine yields across will decline by 25 percent for California in an A2 scenario, but it is unclear if the Battles et al. results can be generalize in this fashion. If, hypothetically, they were, a 19 percent reduction in average forest growth across the state would lead to a roughly proportional reduction in forest output. Morgan et al. (2004) report that sawn wood sales in California were $1.5 billion in 2000. As an upper bound, then, this would imply a reduction in forestry output on the order of $200-300 million per year in a higher warming climate scenario.

Distribution of Costs

Agricultural and forestry production are regional activities in California, and the effects of changes in either sector will be felt regionally rather than state wide. For instance, while agriculture directly accounted for about 2 percent of California's total employment in 2004,[46] in 8 counties it accounted for more than 17 percent of total employment (Figure 6.2). In addition, production is highly concentrated. Most of the state's 5.2 million cattle are raised in the Central Valley (Cavagnaro et al. 2006). Most of the state's timber production, alternatively, is in the northwest (Figure 6.3). A loss in cattle or timber revenues, for instance, would have disproportionate impacts on the Central Valley and northwest, respectively.

Climate change may shift optimal growing conditions, creating winners and losers in the process. Higher temperatures could lead to a reduction in grape quality in some regions (Luers et al., 2006), but an improvement in growing conditions in areas that are currently cooler. In theory the net state-wide economic impact from these shifts would be zero provided that worsening growing conditions in some regions are balanced by enhanced growing conditions elsewhere. However, this transition will not be seamless and many of California's most valuable crops would require significant lead times to adapt to new regions because of their long productive lives (Table 6.4).

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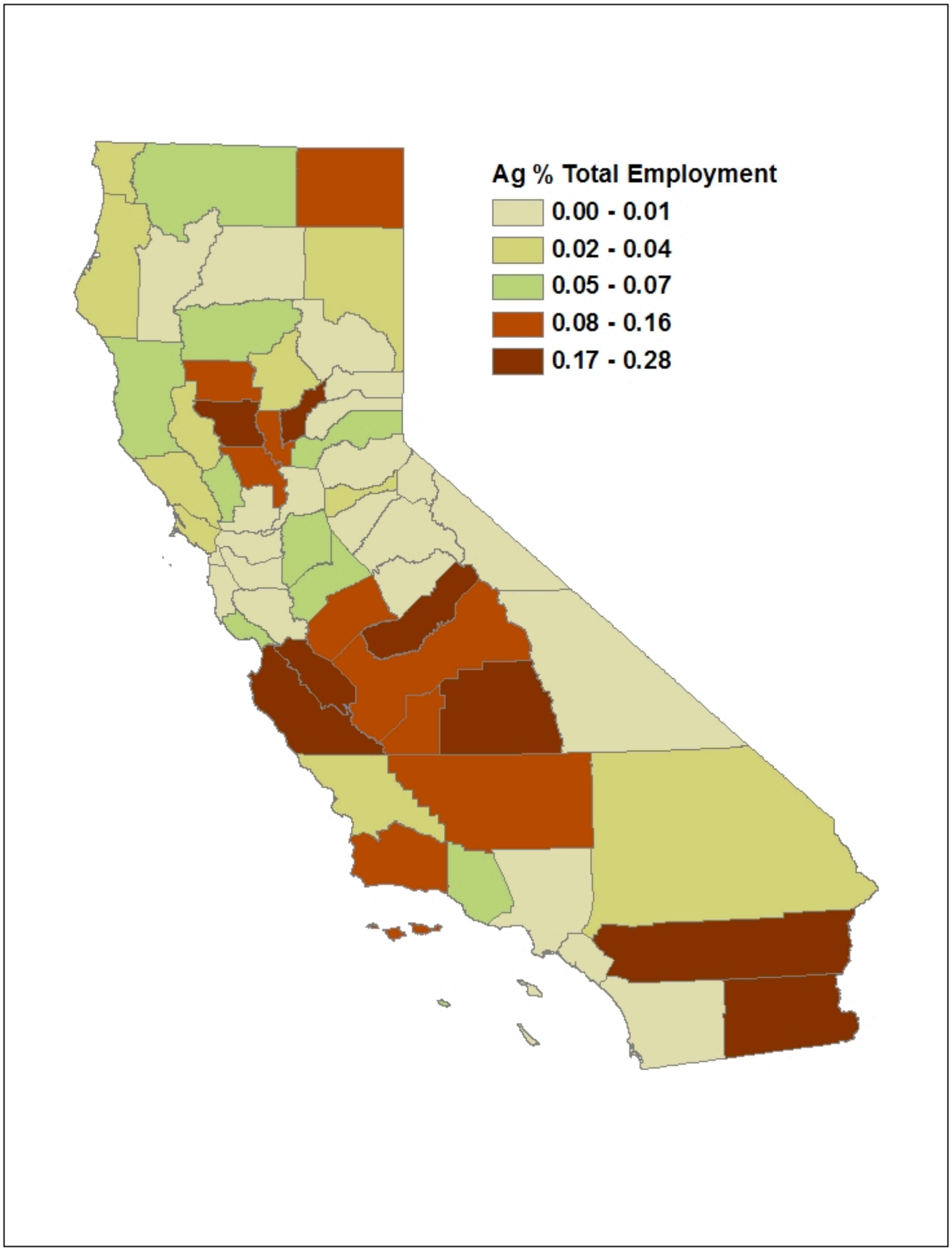
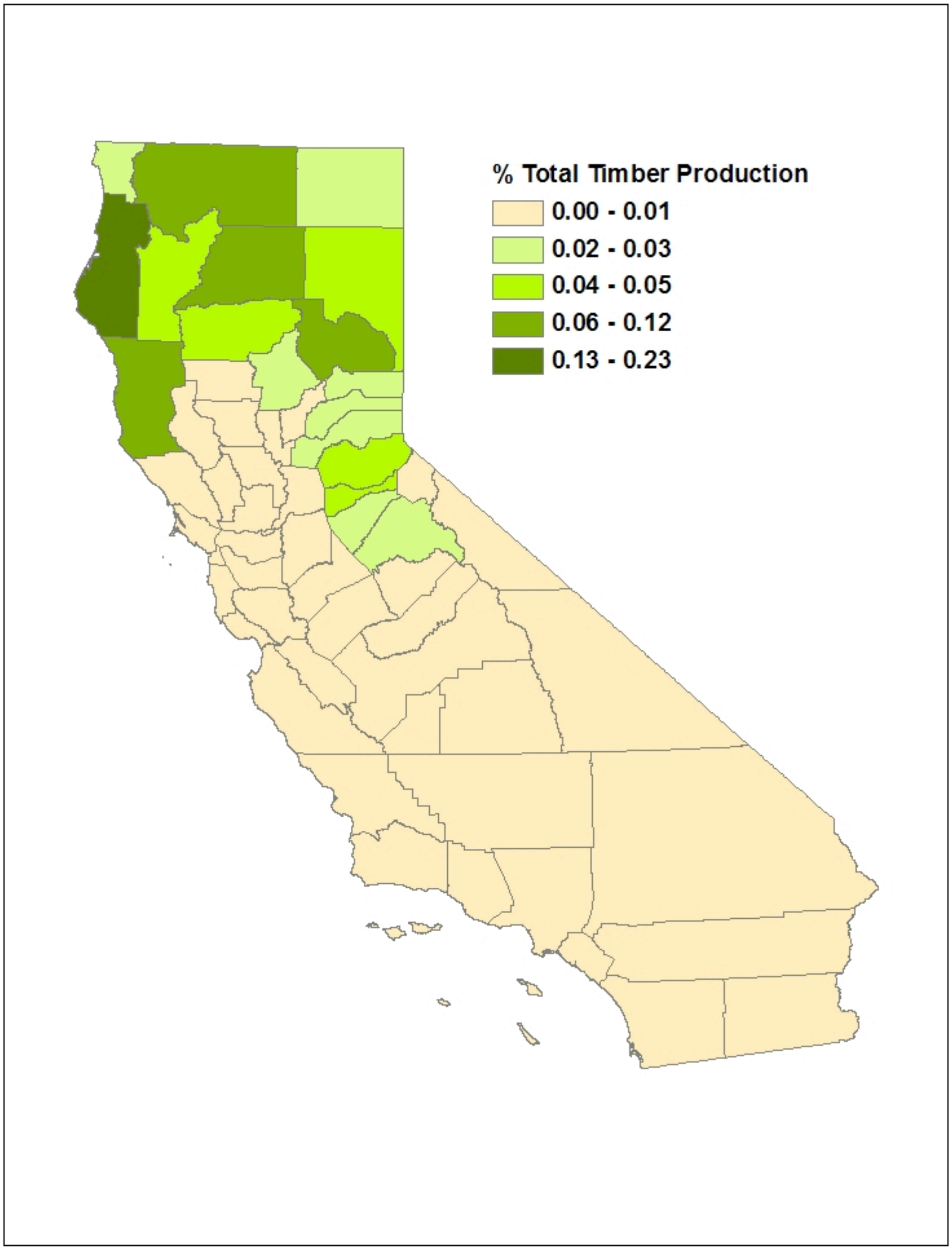
[46] California Employment Development Department (EDD), "Projections of Employment by Industry and Occupation," http://www.labormarketinfo.edd.ca.gov/?pageid=145.

Figure 6.2: Agricultural Employment as a Percent of Total Employment, California



Source: Source: California Department of Finance County Profiles

Figure 6.3: County Timber Production as a Percent of State Timber Production



Source: Source: California Department of Finance County Profiles

Table 6.4: Production Characteristics for Selected Fruits and Nuts

	Productive Life (years)	Age of First Harvest (years)	Age of Full Production (years)
Wine Grapes	25	3	5-6
Table Grapes	25	2-3	4
Almonds	22-25	3	6
Oranges	40	2-4	12-13
Walnuts	35	4	8
Avocados	30	3	7

Source: Lobell et al., 2006.

Declines in agricultural and forestry revenues could have implications beyond the private sector, particularly for forestry. Forest land in California is about evenly split between public and private ownership (Battles et al., 2006). Revenues from timber harvested on public lands are used to fund forest management; without these revenues, forest agencies might be forced to scale back activities, which would have implications for wildfire and pest management.

Adaptation Options

There are a number of adaptation options available to agriculture, forestry, and fishing sectors, all of which are predicated on the complementary duo of improved monitoring systems and a more extensive knowledge base. Improved monitoring systems could, for instance, track changes in pest and pathogen risk, while a stronger knowledge base could identify and development more pest and disease resistant crops. Longer-term planning is critical for effective adaptation. For instance, many of California's most valuable crops are perennial crops that have long production and growth timeframes (Lobell et al., 2006) and will require long lead times to adjust.

In principle, California's agricultural sector could be highly adaptive. With more reliable long-term climate forecasts, crop switching, breeding, and improved management practices could maintain farm profits as agro-ecological regions shift. New varieties of fruits and nuts that require less chill time could increase survival rates as chill hours decline. Better monitoring of pests, weeds, and diseases could lead to improved control and reduced damages. More efficient water use could reduce farmers' exposure to drought. Many of these options would have private and public benefits, in addition to acting as a hedging strategy against climate uncertainties.

A number of relatively simple adaptation strategies could be effective in reducing losses in the dairy industry. Introducing shade, "showering," and cool drinking water, changing feeding schedules, and adjusting diets to reduce heat could allow for greater heat tolerance. The effectiveness of these methods, however, may decrease at higher temperatures. Additionally, breeding for more heat resistant livestock may be a longer-term strategy; historically, heat resistance has been sacrificed for greater milk production.

Information is a major constraint to defining a more coherent climate adaptation strategy for the fishing industry. More research is needed on how squid populations are currently adapting to a changing ocean environment and what can be done to facilitate a better growth environment. For salmon, nearer-term adaptation options might include increasing stream shade and increasing summer stream flows. For squid, salmon, and other fish species, the only viable longer-term climate adaption options may be devising strategies that provide species with the time to adapt.

7. Public Health

Overview

Californians have the worst air quality in the U.S. (Luers et al., 2006). Air pollution leads to respiratory and cardiovascular disease that cause thousands of premature deaths every year in California, with the number of deaths from air pollution in the state on par with those from traffic fatalities and second-hand smoke (ARB, 2004). In addition to air quality, heat-related mortality is becoming an area of increasing concern for California policymakers.

Climate change has already begun to create new public health risks across the world, and the negative human health effects of higher temperatures will likely strike areas of the world that are least able to adapt (IPCC, 2007b). For California, most of these will be tied to air quality and temperature rather than the spread of malnutrition and diseases like malaria. Effective government intervention could significantly reduce health-related impacts from climate change. As with other sectors described in this report, developing the capacity to deal with current problems will be the first step in an adaptation strategy.

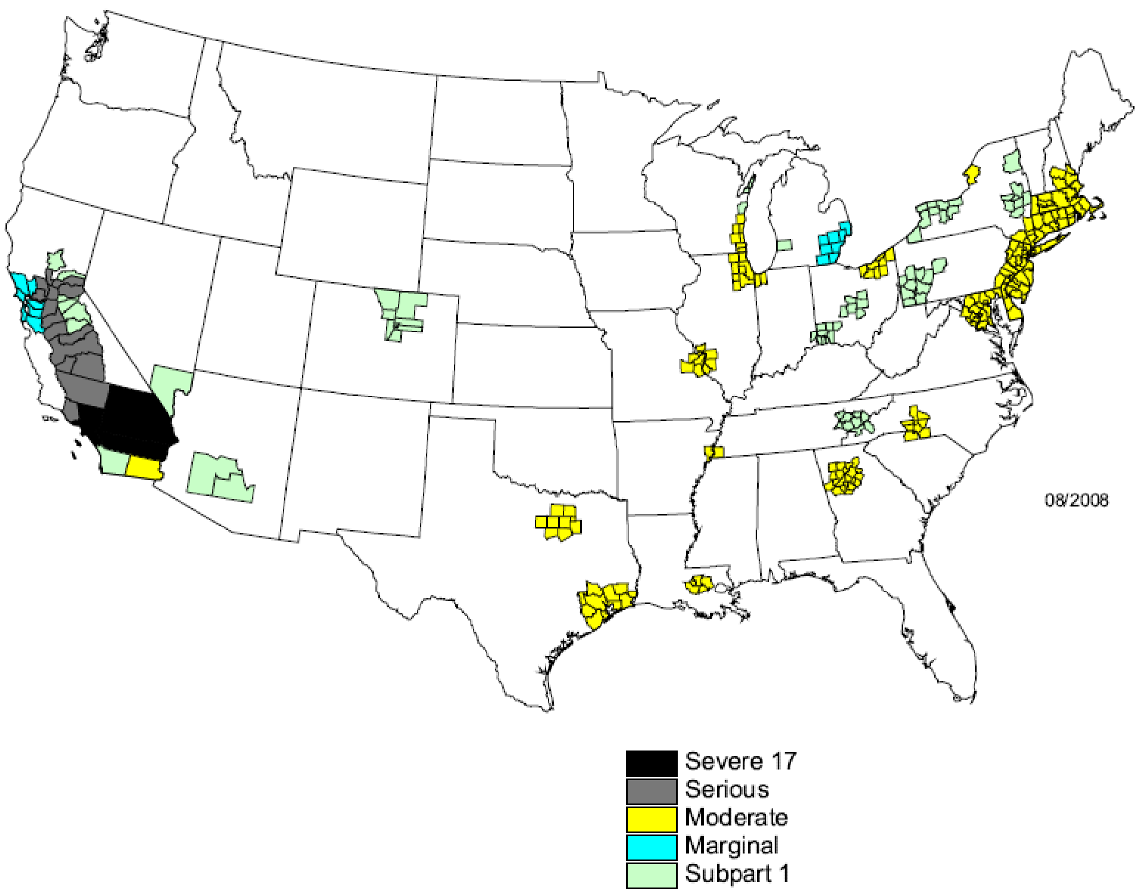
Climate Impacts

For California, two public health impacts of climate change stand out as significant and relatively certain: increases in ozone concentrations and a rise in the frequency, intensity, and length of heat waves. Changes in other air pollutants may also have important implications for human health. For instance, particulate matter (PM) pollution would be expected to increase with a rise in the number of wildfires, but the health impacts are difficult to assess, even at a rough scale. A potential increase in vector-borne and water-borne diseases resulting from changes in climate, while critical in other areas of the world, would be less of an issue in California because of its strong surveillance and control programs and the capacity of its health care system to effectively respond (Dreschler et al., 2006; Wilkinson, 2002). For these reasons we focus here on ozone and heat waves.

Ozone is one of six criteria pollutants regulated by the Environmental Protection Agency (EPA), and is a “secondary pollutant” — ozone forms from atmospheric precursors and is not emitted from a smokestack or tailpipe. Oxides of nitrogen (NO_x) and volatile organic chemicals (VOCs), the two primary precursors for ozone, are primarily emitted from anthropogenic sources, but the non-linear relationship among NO_x, VOCs, and ozone concentrations has historically made ozone difficult to control. Ozone is primarily a respiratory irritant, and can aggravate existing lung diseases such as asthma

(McConnell et al., 2002). Active children are typically the most at risk group to higher ozone levels because they are frequently outdoors during the ozone season, which extends from May to October in California. Ozone also has a deleterious impact on vegetation and ecosystems, reducing crop and forest yields and increasing the susceptibility of plants to pest and disease.

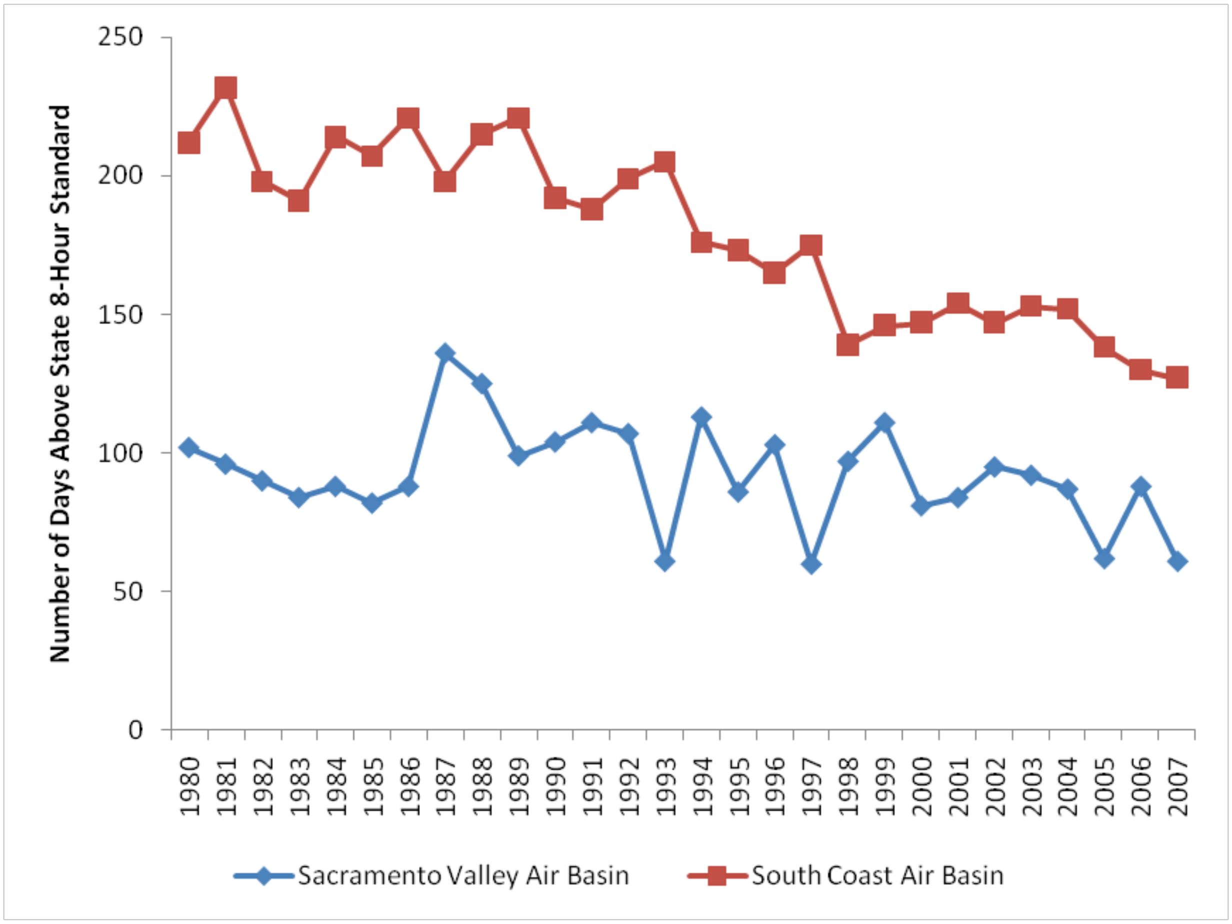
Figure 7.1: Counties Designated Non-Attainment for 8-hour Ozone



Source: Environmental Protection Agency (EPA) website, http://www.epa.gov/oar/oaqps/greenbk/map8hr.pdf.

Ozone was "discovered" in Los Angeles and is in some ways a unique problem for California because of the state's distinctive meteorological conditions. As Figure 7.1 shows, all of the counties with EPA-designated serious or severe levels of 8-hour ozone concentrations in the U.S. are in California, mostly concentrated in the Central Valley and Southern California. Though the number of days above the state's 8-hour ozone standard has fallen substantially in areas of Southern and to a lesser extent Northern California over the past three decades with greater NO_x and VOC emissions control (Figure 7.2), climate change is expected to put upward pressure on ozone concentrations and prolong the ozone season (Dreschler et al., 2006).

Figure 7.2: Number of Days Above California 8-Hour Ozone Standard, Sacramento Valley Air Basin and South Coast Air Basin

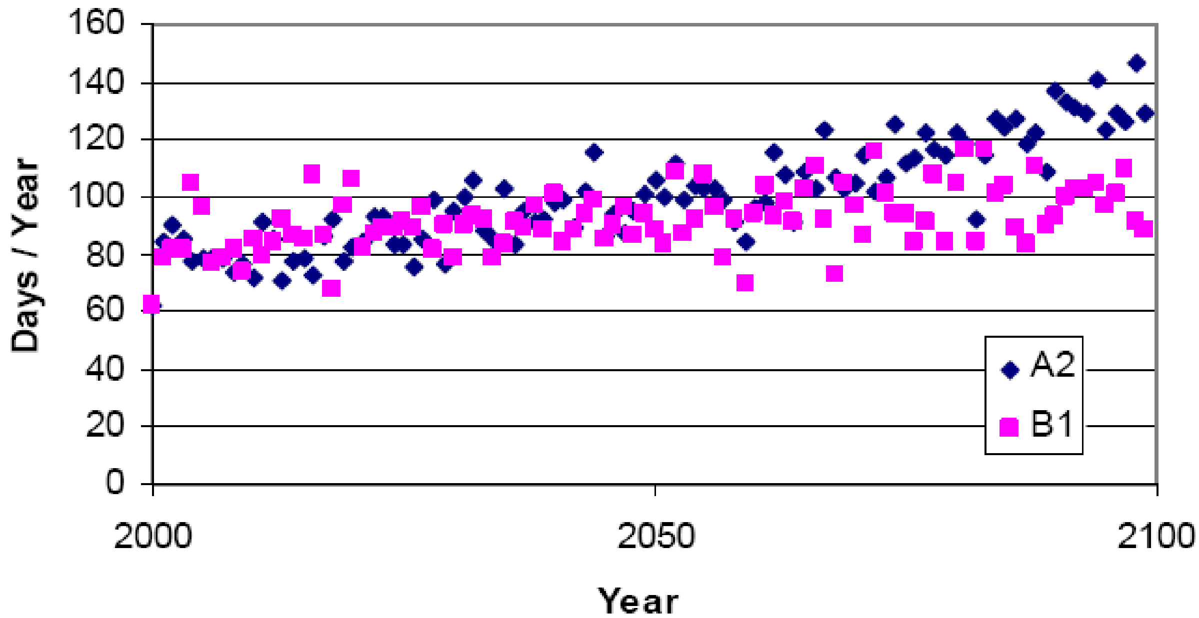


Source: Data are from the California Air Resources Board's Air Quality Data Statistics database, online at: http://www.arb.ca.gov/adam.

Ozone formation in the atmosphere is dependent on meteorological conditions, including temperature, and higher temperatures in the troposphere increase the frequency of meteorological conditions conducive to ozone formation. Higher temperatures also increase biogenic emissions of VOCs, which leads to significantly higher ozone concentrations in some parts of California (Harley, 2008). Additional factors, such as the positive relationship between higher temperatures and the amount of NO_x emitted by power plants, could amplify these effects. A final concern is that the "background" rate of ozone in the troposphere, which is directly influenced by methane emissions, has rapidly increased over the past three decades, and background ozone levels may soon exceed state standards (Dreschler et al., 2006).

Based on an analysis of traditionally high ozone areas of Los Angeles (Riverside) and the San Joaquin Valley (Visalia), Dreschler et al. (2006) project that the number of days with conditions conducive to ozone formation could increase by 25-80 percent by 2100, depending on warming scenarios. Differences between warming scenarios are marked, as illustrated by Figure 7.3: In Riverside, for example, the number of days with ozone concentrations greater than 90 parts per billion (ppb) follows a significantly steeper trend in the GFDL A2 scenario (higher emissions and warming, the blue dots) than in the GFDL B1 scenario (lower emissions and warming, the pink dots).

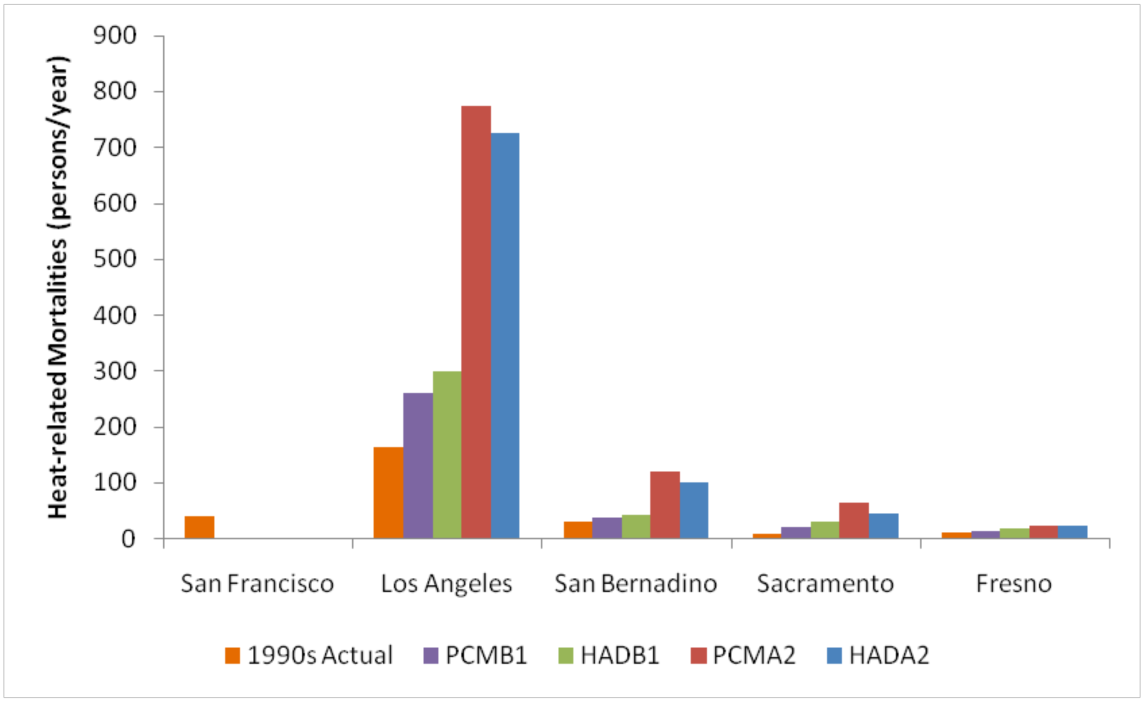
Figure 7.3: Predicted Number of Days with Ozone Concentrations Greater than 90 ppb



Source: Dreschler et al., 2006

Unchecked, rising average surface temperatures could lead to a substantial increase in the number, length, and severity of heat waves. Extreme heat increases the risk of heat stroke, heart attack, and severe dehydration, particularly among the elderly, children, ethnic minority groups, and farm workers. A series of recent epidemiological studies found that a 10 degree Fahrenheit (6°C) increase in temperatures corresponded to a 2.3 percent increase in heat-related mortality, and that those most at risk were persons over 65, infants 1 year old or younger, and African Americans (Basu and English, 2008). Historically, there has been debate on whether it is possible to distinguish the health effects of heat waves from air pollution, given that air pollution levels are also higher on extremely hot days. More recent studies suggest that these effects are in fact distinguishable, and that the direct effects of extreme heat on human health are significant (Ostro, 2008).

Figure 7.4: Average Annual Heat-Related Mortalities in Five Major Metropolitan Areas of California, 1990s Actual and by 2100



Source: Dreschler et al., 2006.

Dreschler et al. (2006) examined changes in extreme heat events and heat-related mortality over the course of the century using a range of climate models and scenarios (Figure 7.4). Again, B1 is a lower emissions scenario, while A2 is a higher emissions scenario; HAD is the wetter and warmer Hadley model, where PCM is the drier Parallel Climate Model. The key difference in Figure 7.4 is between scenarios rather than between models. Heat-related mortality increases by a factor of 2-4 in scenario A2 vis-à-vis both scenario B1 and estimated average heat-related deaths during the 1990s. For all five cities, heat-related deaths increase by 746-755 per year over a 1990s baseline. Los Angeles County accounts for the bulk of population and premature deaths among these give metropolitan areas; Dreschler et al. estimate that a higher warming scenario would cause 595-635 additional premature heat-related deaths per year in Los Angeles County alone by 2100.

In their statistical analysis for the U.S. as a whole, Deschênes and Greenstone (2007) find that a business as usual climate change scenario would lead to much smaller percentage increase in mortality (less than 2 percent) by 2100 than that predicted by Dreschler et al. (2006), suggesting that either heat-related impacts will be regional or that there is a more fundamental disagreement over the potential scope of heat-related mortality resulting from climate change.

As noted elsewhere in this report, in more severe climate scenarios the occurrence of large fires in California increases significantly. An increase in the frequency of fires also has public health implications, as summer fires are a significant source of $PM_{2.5}$ in the western United States (Jaffe et al., 2008). Additionally, $PM_{2.5}$ accounts for most of the pollution-related mortality in California (Croes, 2007) and has a potential link to increased risk of lung cancer (ARB, 2004). Although an increase in wildfires would in theory lead to higher $PM_{2.5}$ concentrations and health impacts, the extent of these impacts is difficult to estimate because the health impacts of wildfires are influenced by both fire-specific characteristics and proximity to population, both of which are highly uncertain (Dreschler et al., 2006).

Generally speaking, climate change will slow progress toward meeting air quality goals. Thus, for instance, continued reductions in NO_x and VOC emissions could still lead to an absolute increase in ozone concentrations under a higher warming scenario. Achieving absolute reductions in emissions in a higher warming scenario would prove much more challenging than under a lower warming scenario. In the former case, continued growth in methane emissions could increase background ozone to levels that exceed California's current ozone standards, which would effectively render them impossible to attain (Dreschler et al., 2006).

Costs Associated with Climate Change

The California Air Resources Board (ARB) estimates that air pollution — primarily ozone and fine particulate matter pollution — currently costs the state $71 billion/year. The vast majority ($69 billion) of these costs is associated with the estimated 8,800 premature deaths caused by air pollution in California each year. An estimated 2.2 billion/year is associated with hospital visits for major and minor illnesses associated with air pollution (ARB, 2005). Not included in the costs of pollution are the lost productivity associated with 4.7 million school absences and 2.8 million lost work days. When valued at an estimated $70/day[47] caregiver cost and the May 2007 California average wage of $135/day[48] these would amount to approximately $0.8 billion.[49]

Estimates for current statewide heat-related mortality are not available in the literature. Coroners reported 142 deaths from California's 2006 heat wave; however, heat-related deaths are likely to be underreported because of confounding factors and actual heat-related deaths in 2006 may have been 2-3 times higher than reported deaths (Rasu and English, 2008). Based on higher statistically-derived estimates from Chestnut et al. (1998), Drescher et al. (2006) report that total actual heat-related mortality in the five

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[47] Based on a rounded average from Hall et al. (2006).
[48] Bureau of Labor Statistics website, "May 2007 State Occupational Employment and Wage Estimates California." Online at: http://www.bls.gov/OES/current/oes_ca.htm#b00-0000.
[49] ARB premature mortality and hospital costs are median values based on a probable range of 3,000-15,000 premature deaths and 4,600-14,000 hospitalizations. School absences and lost work days are similarly ranges, with 1.2-8.6 million school absences and 2.4-3.2 lost work days.

metropolitan areas of Fresno, Los Angeles, Sacramento, San Bernadino, and San Francisco averaged 261/year during the 1990s. Using the EPA's current value of a statistical life (VSL) of around $7 million/person,[50] this leads to a cost to society of $1.8 billion/year for excess heat-related mortality in these five metro areas. These five areas accounted for more than 40 percent of California's population according to the 2000 census.[51]

The incremental cost of climate change on public health has not yet been estimated. Our goal here is not to provide a robust estimate of this cost, but simply to give it boundaries. In doing so we assemble impact estimates from a variety of different sources and, in some cases, extend these linearly. As with many of the other cost estimates in this report, the damages reported here are partial, based primarily on a cost of illness (COI) approach that includes premature death, hospitalizations, and lost productivity. Improving these estimates would require both more comprehensive and higher resolution projections for impacts.

For ozone, we assume that climate-induced health effects increase linearly with increased concentrations. While exposure-response for ozone is not linear, the assumption is rather that rises in ozone concentrations that result directly from climate change represent a return to previous ozone levels rather than exceeding them. Thus, for instance, climate change might increase the number of days above standard in Figure 7.1 back to 1980 levels, but would not lead to an increase in days above standard in excess of 1980 levels. This approach is consistent with the notion that, in any emissions scenario, gradually increasing temperatures will not stop efforts reduce ozone, but will certainly frustrate those efforts. We use the Dreschler et al. (2006) estimate of a 25-80 percent increase in days conducive to ozone in B1 and A2 scenarios, respectively, and assume that the health impacts of ozone scale linearly with increases in the number of days conducive to ozone formation and thus proportional to current health impacts.

Using the ARB estimate of 800 ozone deaths per year and its reported "at least a factor of two" uncertainty (Croes, 2007), a 25-80 percent increase in ozone-related mortality would amount to a $0.5-$2.2 billion per year increase in costs under a B1 scenario, and a $2.2-$8.7 billion per year increase in costs under an A2 scenario. Hospitalization costs include both ozone- and particulate matter-induced costs, and it is not immediately obvious how to distinguish the contribution of each given that estimated

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[50] The EPA uses a range of VSLs. Historically, the EPA's most frequently used VSL was around $7.8 million per person, which is similar to the implicit value used by the California Air Resources Board in their $69 billion pollution cost estimate. The EPA has been downwardly revising these numbers to reflect greater consistency with the economic literature. For our purposes, the difference between $7 billion and $7.8 billion is not significant. We do not adjust this value for age, under the assumption that the health impacts described here affect both extremes of the population distribution.

[51] U.S. Census Bureau, county population dataset.

hospitalization costs are point estimates and that ARB does not yet have air basin-wide data on $PM_{2.5}$. We take a more heuristic approach here, rounding up to the nearest $500 million dollars. If $PM_{2.5}$ and PM_{10} are responsible for most (> 50%) of the pollution-related hospitalizations in California, increases in peak ozone concentrations would lead to at most a $0.5 billion increase in ozone-related hospitalization costs under a B1 scenario, and a $0.5-$1.0 billion increase under an A2 scenario. These numbers would hold if ozone's contribution to hospitalizations was within approximately 30 percent of a total contribution of just under half (i.e., 49 percent). Using the same approach to account for lost productivity, costs would range from less than significant (i.e., less than $250 million) under a B1 scenario and $0-$0.5 billion under an A2 scenario. Summing up these three categories would give a damage of $0.5-$2.7 billion under a B1 scenario and a $2.7-$10.2 billion damage under an A2 scenario.

Table 7.1: Representative Cost of Ozone and Heat Waves under Different Emissions Scenarios

	Estimated Cost (B1)	Estimated Cost (A2)
Ozone	$0.5-$2.7 billion/year	$2.7-$10.2 billion/year
Heat Waves	$3.3-$4.5 billion/year	$12.8-13.9 billion/year

For the five metropolitan areas analyzed by Dreschler et al. (2006), heat-related mortalities are projected to increase by 183-249 persons in a B1 scenario and 746-755 persons in an A2 scenario, which, using the same VSL as above, translates into a social cost of $1.3-1.7 billion and $5.2-5.3 billion, respectively. These costs only cover Fresno, Los Angeles, Sacramento, San Bernadino, and San Francisco metropolitan areas. To extend these estimates to California as a whole, we assume that these five counties are approximately representative of conditions in the state and calculate a statewide annual heat-related mortality rate of 6-7 (B1) and 20-22 (A2) per million persons by taking an average of projected deaths per 2100 projected population over the five counties. Multiplying by an estimated 2100 population of 92 million people leads to a total increase of 476-657 premature heat-related deaths under a B1 scenario and 1,858-2,019 deaths under an A2 scenario against the 1990s baseline; as Dreschler et al.'s approach intended, these results do not depend significantly on population.[52] The costs associated with these deaths range from $3.3-4.5 billion to $12.8-13.9 billion, depending on the emissions scenario. We did not find a sufficient entry point to estimate the hospitalization or lost productivity costs of climate-induced heat waves.

All of these estimates are highly uncertain and should only be seen as illustrative. Both with air pollution and extreme heat, the statistical value of life dominates other costs. It

[52] Population projections are based on Landis and Reilly, 2000.

is useful to put the values in Table 7.1 in context. The climate-induced costs of ozone would amount to an increase of roughly 2-8 percent (B1 and A2 scenarios, respectively) over current costs, or, equivalently, a 2-8 percent reduction in the benefits of controlling ozone. Heat-related mortality would increase by roughly 3-fold over the 1990s baseline. However, even in tandem the climate induced-costs of ozone and heat waves are at most less than half of the current cost of pollution in California.[53] Scaled up efforts to reduce the impacts of ozone and heat waves could better prepare the state to deal with the committed effects of climate change.

Distribution of Costs

As noted previously, the health-related impacts of climate change will be concentrated along the two tails of the population age distribution and within poorer communities. Among older and poorer groups, adaptive capacity is also significantly lower than in the population at large. Air conditioning provides an illustrative example of limitations in the ability to adapt. The elderly, for instance, may be less likely to use an air conditioner even if one is available, perhaps due in part to a decreased ability to perceive heat risks. The poor may be unable to afford the energy costs of buying or using an air conditioner. Given the potentially high rates of risk and relatively low costs of intervention there is an obvious role for state agencies in reducing heat-related mortalities, but programs to do so must be well targeted to be effective.

Adaptation Options

Air pollution and extreme heat require different, and in some ways conflicting, adaptation strategies. In addition, while we do not focus on these here, preparing for any shifts in vector- and water-borne diseases will be an important part of adapting to a changing climate in California.

Controlling criteria pollutant emissions is the most powerful option for reducing the pollution-related impacts of climate change. Winer (2004) argues that, although conventional point of source control technologies have been remarkably successful in reducing air pollution in Southern California over the 1990s, continued population growth will likely test the limits of traditional approaches to pollution control. Longer-term solutions for air quality may instead require a host of other considerations, from transportation and land use planning to fuel choices to greater attention to environmental justice issues.

[53] The largest share of current costs would be if ARB's estimate for current mortality and hospitalization is low ($35.5 million), in which case a high emissions scenario heat-related mortality and lower ozone estimate ($16.6 million) would be nearly half of current costs.

AB 32 will undoubtedly play a role in pollution control efforts in California. Importantly, greenhouse gas abatement efforts through AB 32 may be a sufficient but not necessary condition for reducing air pollution. Carbon capture and storage (CCS), for instance, would actually lead to a small increase in criteria pollutant emissions because of the energy required to isolate and capture carbon in the flue gas. Increased substitution of diesel with biodiesel could lead to an increase in NO_x and subsequently ozone emissions without appropriate control technology (McCormick, 2005). More aggressive emissions reduction strategies, in parallel with but not replaced by AB 32, will be an important part of climate change adaptation in California.

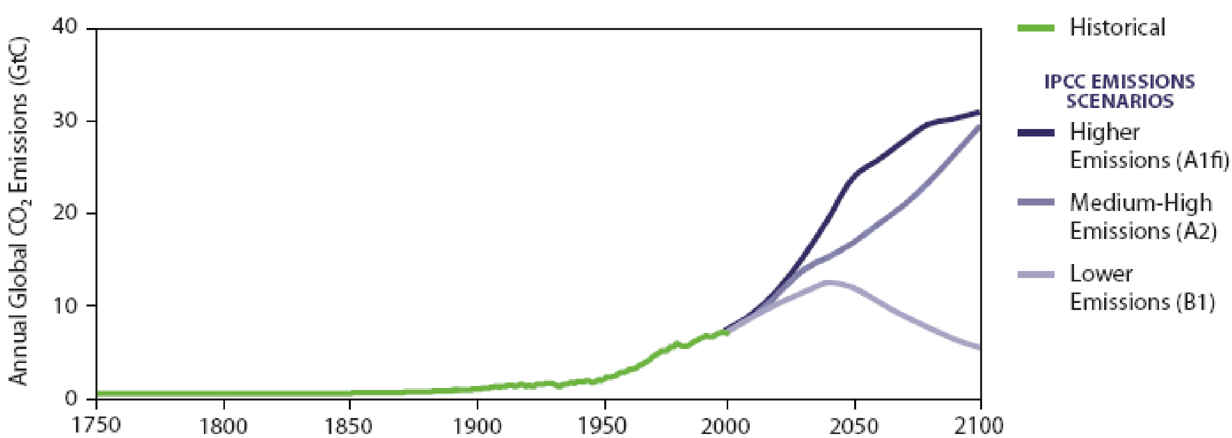
Relatively simple strategies could significantly reduce mortality during heat waves in California. These include early warning systems, public education, cooling centers, and air conditioning. Dreschler et al. (2006) estimate the cost of regional heat emergency warming systems and intervention plans would total $500,000, which is less than one-tenth of one percent of the VSL-based losses from the official estimate of premature deaths during the 2006 heat wave. However, the most effective way to prevent heat-related illness and death is likely through the use of air conditioning. Air conditioning use during heat waves presents a dilemma for policymakers, as electricity demand during high peak periods is met by the most inefficient, highest polluting power plants in the system, and the increased emissions from these plants could offset the benefits of air conditioner use. Breaking this link between air conditioner use and the dispatch of “peaker” plants will be an important adaptation strategy for California.

Annex 1 – Emissions Scenarios and Climate Models Referred to in this Report

Changes in the earth's climate over the next century will be determined by the amount of greenhouse gases (GHG) emitted to the atmosphere, the timing of these emissions, and how sensitive the earth's climate is to an increase in GHG emissions. All of these three variables are highly uncertain. The amount and timing of GHG emissions depends on factors that range from the rate of global economic and population growth, to the energy intensity of economic growth, to the success of climate change mitigation efforts. Climate sensitivity depends on the nature and magnitude of complex feedback effects in the earth's climate system, and may ultimately be impossible to determine precisely.

Climate models account for these uncertainties in different ways. To deal with uncertainty in the amount and timing of GHG emissions, most climate models typically rely on a family of four scenarios (A1, A2, B1, B2) defined by the Intergovernmental Panel on Climate Change (IPCC). Climate modeling work in California has generally focused on three of these scenarios: a fossil fuel-intensive, high emissions scenario where emissions rise rapidly and slow over time (A1fi); a medium-high scenario where emissions grow steadily over time (A2); and a lower emissions scenario where emissions rise until almost mid-century and then begin to fall (B1) (Figure A1.1). A1fi and A2 represent a tripling, and B1 a doubling, of atmospheric CO_2 concentrations relative to pre-industrial levels by 2100. The IPCC predicts that the A1fi and A2 scenarios will lead to substantial warming. Although the B2 scenario might be a climate stabilizing scenario, it is still accompanied with a significant amount of warming and sea level rise (Table A1.1.

Figure A1.1: Global Emissions to 2100 under Af1i, A2, and B1 Scenarios



Source: Luers et al., 2006

Table A1.1: Projected Temperature Change and Sea Level Rise under A1fi, A2, and B2 Scenarios

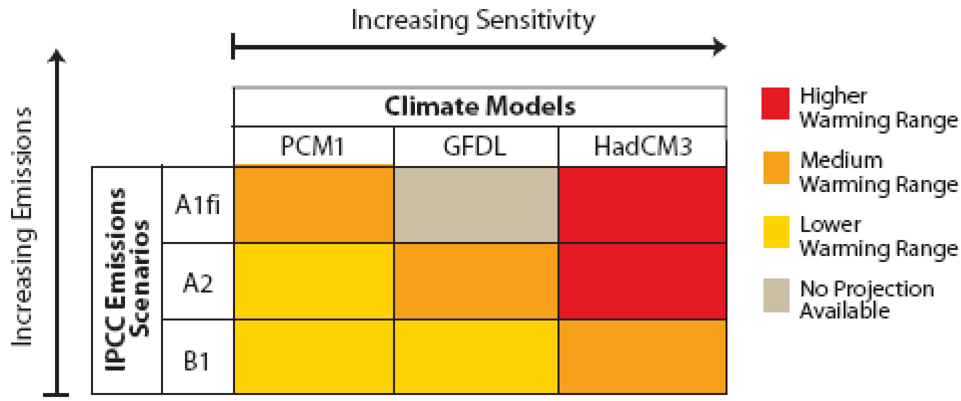
Scenario	Global Average Surface Temperature Change (2090-2099 relative to 1980-1999, °C)	Sea Level Rise (2090-2099 relative to 1980-1999, meters)
A1fi	2.4-6.4	0.26-0.59
A2	2.0-5.4	0.23-0.51
B2	1.4-3.8	0.20-0.43

Notes and Source: Temperature change estimates are the likely range, which indicates that the IPCC assesses their likelihood at greater than 66 percent. Sea level rise estimates are based on model results and are not probabilistic. All reported estimates are from IPCC (2007a).

Different climate models have different climate sensitivities, depending on how different features of the earth's climate system (e.g., aerosol-cloud interactions) are represented in the model. Much of the climate modeling work in California has relied on three models: the National Center for Atmospheric Research's Parallel Climate Model (PCM), the Geophysical Fluid Dynamics Laboratory's (GFDL's) CM2.1 model, and the Hadley Centre's Climate Model, version 3 (HadCM3). CM2.1 is often referred to as the GFDL model, and in this report we tend to use GFDL rather than CM2.1 to refer to the model.

Because of their different climate sensitivities and other modeling choices, these models often produce predictably different results. PCM1 has a lower climate sensitivity, and generally tends to be a "wetter" climate model, meaning that it projects that climate change will lead to more precipitation vis-à-vis that projected by other models. GFDL has a somewhat higher climate sensitivity, and tends to be a drier model. HadCM3 is the most climate sensitive of the three models, and tends to be drier as well. Figure A1.2 provides a typology of scenarios and models, ranging from the higher warming, more sensitive HadCM3 A1fi scenario to the lower warming, less sensitive PCM1 B1 scenario.

Figure A1.2: A Typology of Emissions Scenarios and Global Climate Models



Source: Luers et al., 2006.

Two messages are important to take away from this overview of greenhouse climatology. The first is that, even in a lower emission B1 scenario, humanity has already committed itself to some level of climate change, and adaptation will be important. Second, climate models typically do not account for the possibility of abrupt climate change. There is a risk, albeit small, that a major, unknown feedback in the earth's climate system, such as major changes in ocean circulation patterns, could lead to changes in climate and impacts much larger than those projected by climate models.

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