National Center for Ecological Analysis and Synthesis

Climate Change and Variability in California
White Paper for the California Regional Assessment

Robert Wilkinson
University of California, Santa Barbara

Teresa Rounds
Santa Barbara Museum of Natural History

Citation: Wilkinson, Robert and Teresa Rounds. 1998. Climate Change and Variability in California; White Paper for the California Regional Assessment.
National Center for Ecological Analysis and Synthesis, Santa Barbara, California
Research Paper No. 4. Available at "http://www.nceas.ucsb.edu/papers/climate.pdf".

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March 9–11, 1998
Santa Barbara, California

National Center for Ecological Analysis and Synthesis
University of California, Santa Barbara

Sponsored by the National Science Foundation

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Authors:
Robert Wilkinson
Lecturer, Environmental Studies Program
University of California, Santa Barbara

Teresa Rounds
Science Writer, Santa Barbara Museum of Natural History

Workshop Steering Committee Chair:
Jeff Dozier, Dean
Donald Bren School of Environmental Science and Management
University of California, Santa Barbara

Workshop Convenor:
National Center for Ecological Analysis and Synthesis
University of California, Santa Barbara
735 State Street, Suite 300
Santa Barbara, CA 93101-3351

Workshop Sponsor:
National Science Foundation

Contact person for this document and for the California Assessment Process:
Robert Wilkinson
Coordinator, California Regional Climate Assessment
Lecturer, UCSB Environmental Studies Program
1428 West Valerio Street
Santa Barbara, CA 93101
phone: 805 569 2590
fax: 805 569 2718
wilkinso@envst.ucsb.edu

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Forward

The writing of this White Paper has provided a wonderful opportunity to develop a snapshot of California and to consider the potential impacts of climate change and variability for the state. When we set forth on this project, I assumed that there was a basic state document that summarized the state's economy, its major sectors, and its basic features. Perhaps it exists, but it has eluded the efforts of the authors and advisors to discover it. In fact, it is surprisingly difficult to reconcile the many different figures given for key economic sectors and activities. Similarly, the precise condition of natural systems and the history of events is cloudy. The following pages seek to outline California's key economic sectors, important physical features, environmental conditions, and diverse population. It is based on official state sources, such as the California Trade and Commerce Agency's web site, and on numerous other published and electronic sources which are referenced and listed at the end of this document.

The purpose of this summary is to provide a basis for consideration of potential impacts of climate change and variability on California. The focus is therefore on California-specific information. The broader issue of global climate change has been extensively documented in the literature. Rather than restate that information here, the reader is referred to both the official published sources, such as the Intergovernmental Panel on Climate Change (IPCC) documents,[1] the scientific literature, and the numerous excellent web sites which are continuously updating information of the science and policy of climate change.[2]

There are also several good sources on the specific question of climate change impacts on California. Joseph Knox, for example, edited an excellent summary entitled *Global Climate Change and California: Potential Impacts and Responses* nearly ten years ago.[3] (Several of the authors of this volume are on the steering committee for this California Assessment Workshop. Please see Appendix.) Other reports from the California Energy Commission, the California Coastal Conservancy, the Pacific Institute for Studies in Development, Environment, and Security, and others provided extremely helpful background material, and many of the authors of those studies have assisted in the present effort.[4] We have sought to identify important new information in the present document rather than to restate

the work already undertaken. Readers are referred to these earlier reports and publications.

As a note to readers: Please consider this a *draft* document intended to inform discussion as part of the larger assessment of climate change in the United States. It is not to be intended to be a comprehensive treatment of California impacts. Rather, it is a work in progress, and edits are surely in order. I assume full responsibility for any errors or omissions, and I would be grateful for comments, corrections, and additions. Please direct them to me at *wilkinso@envst.ucsb.edu*

Robert Wilkinson, Coordinator, California Regional Climate Assessment

I. Introduction

The National and Regional Climate Assessment Process

The United States Global Change Research Program (USGCRP) and the White House Office of Science and Technology (OSTP) have organized a series of meetings to assess the possible impacts of climate change and variability on the United States and its trust territories.[5] California has been designated as a specific region for purposes of the national assessment, and the workshop held in March 1998 is intended to further the understanding of possible region-specific climate impacts. The National Center for Ecological Analysis and Synthesis (NCEAS) at the University of California, Santa Barbara (UCSB) is hosting the workshop, which is sponsored by the National Science Foundation.[6]

The workshop involves representatives from a broad cross-section of California's major economic, scientific, social, government, and environmental, and other interests. The purpose of the workshop is to engage in discussions on the possible consequences of climate change in the state. The larger objective of the workshop is to create a *process* through which scientists, decision-makers, and stakeholders in California can identify areas of concern and opportunity resulting from climate change and variability. We will explore what scientists presently understand about global warming and climate change, and we will seek to apply that knowledge to specific concerns in the region. California stakeholders will assess potential impacts on the state—such as critical water supplies to agricultural lands, coastal urban centers, and the environment—to establish adaptation strategies and research priorities.

Key Issues to be Addressed

We have been asked to address four general topics in the regional workshop:

1. Identify current stresses affecting the region, its natural resources, and economic sectors. (e.g.: issues such as water scarcity.)
2. Consider how climate variability and climate change might either amplify or mitigate these stresses, or create new ones.
3. Identify new information that would allow people and organizations to better understand the linkage between current stresses and climate change and variability.
4. Identify beneficial strategies that will help address the stresses created by climate change as well as by non-climate pressures.

Goals of the Workshop and Assessment Process

The goals of this workshop and the larger assessment process are to:

1) Convene a representative cross-section of California's stakeholder, government, and science communities to address the issue of potential climate change as outlined in the four topics above;
2) Provide information and support a process of collaborative activities which will aid decision-makers, businesses, public interest organizations, and citizens in taking climate change and variability into account in planning for the future;
3) Provide a forum and process for the identification of research needs and priorities to better serve the concerns of California stakeholders; and
4) Foster and support an on-going effort to address climate change impacts in California. We plan to establish a dialogue between stakeholders, researchers, and government institutions to discuss how we might adapt to those changes to assure that California maintains its strong economy, preserves and restores its environmental health, and continues to be a place where people live and prosper.

II. A Portrait of California

The People and the Place

California's trillion dollar economy is the largest in the nation and would rank number seven in the world if it were an independent country. Within the United States, it has the largest population, the greatest diversity of people and environments, and some of the most difficult problems. In many ways, California appears to be a series of contradictions. For example, the state has the most energy-efficient economy but the highest total energy consumption and the most automobile-dependent transportation system (and the most cars); the worst air quality problems and the largest renewable energy industry; the greatest variety of ecosystems and the largest number of threatened and endangered species in the continental U. S.

The Golden State has been called a land of superlatives. Its physical geography includes the lowest valley in the northern hemisphere, the highest mountain in the lower 48 states, the greatest climatic variation, the driest desert in North America, some of the richest agricultural lands, and the most land devoted to parks and wilderness outside Alaska.[7]

California is diverse, dynamic, and powerful, yet the state's complex natural systems and extensive human activities are highly susceptible to climate variability and change. California is subject to a number of natural stresses which can and do negatively affect the state's economy and its quality of life. From floods, mudslides, and coastal erosion to droughts, fires, and heat waves, existing climate-induced stresses are quite real. The prospect of *increased* variability in climate patterns should therefore be a major consideration for all Californians in planning the state's future.

A California Index

Economic

Gross State Product, 1997:	$ 1.037 trillion[8]
Exports, 1996:	$104.5 billion[9]

Population[10]

Population, 1997:	32,609,000
Los Angeles Metro population:	15,831,700
San Francisco Metro population:	6,798,300

Physical Factors and Variation

Total Land Area:	155,973 square miles
Total Water Area:	7,734 square miles
Total Surface Area:	163,707 square miles
Lowest Valley in Northern Hemisphere:	Death Valley, 282 ft. below sea level
Highest Mountain in Continental U. S.:	Mt. Whitney, 14,495 ft. above sea level

Climate Extremes[11]

Maximum recorded rainfall in the state:	161 inches
Santa Lucia Mountains, Coast Ranges	
Minimum recorded rainfall in the state:	no rainfall for 25 months
Bagdad, Mojave Desert	

Energy Use and Impacts

Total energy consumption:	7 quads (quadrillion BTUs)[12]
Registered vehicles:	26,580,799[13]
Air Quality, Los Angeles, 1997:	Exceeded ozone limits on 68 days[14]

Environmental Impacts

Endangered and threatened species:	132 plants, 82 animals[15]
Percentage of wetlands lost:	90 percent[16]

The Citizens of California

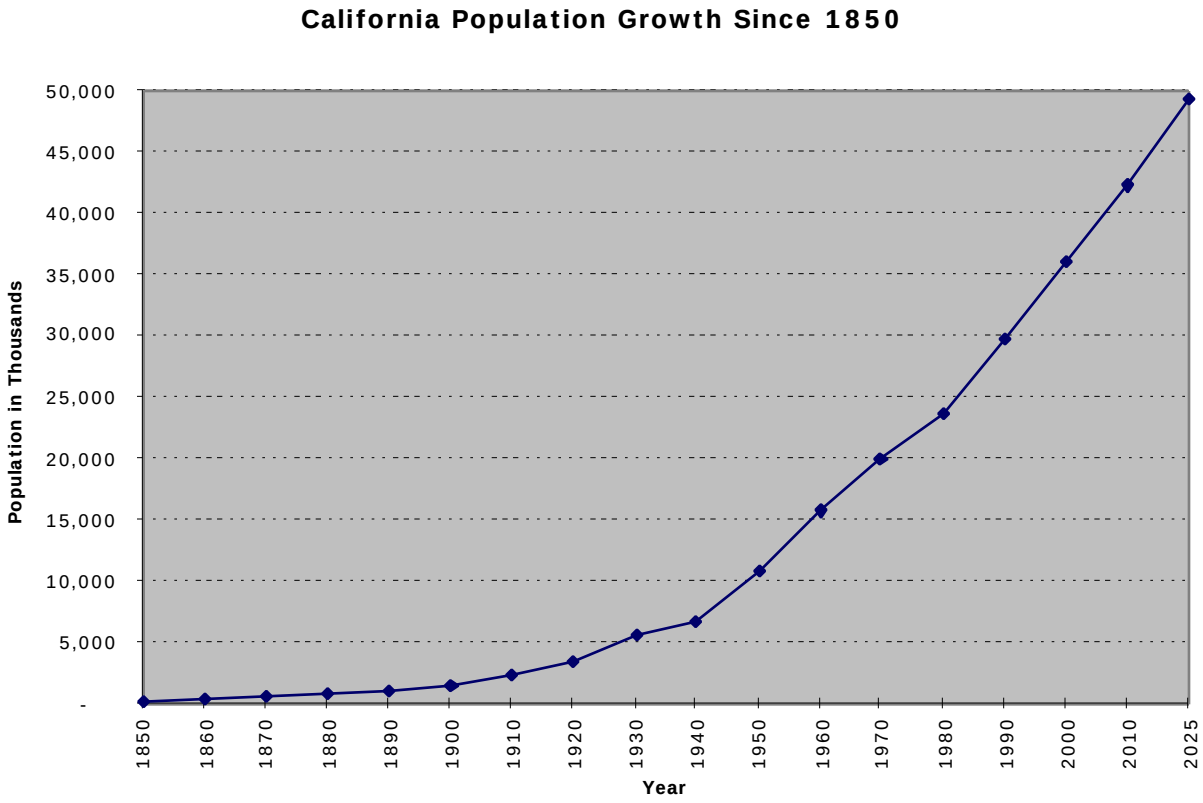
California is both the most populous and most ethnically diverse state in the union. Of the more than 32 million residents, 54 percent are white, 28 percent Hispanic, 10 percent Asian and Pacific Islander, 7 percent black, and 0.6 percent Native American.

By the year 2000 (just two years away), the non-white population is expected to exceed 50 percent, another first in the nation.[17]

California's population has more than quadrupled since World War II, mushrooming from less than 7 million in 1940 (about 5 percent of the nation) to 32,609,000 in 1997, (more than 12 percent of the U. S. population).[18] The growth rate over the past decade has fluctuated between 0.9 percent to 2.8 percent, swelling the population by 20 percent since 1986.[19] More than one-third of the increase is the result of immigration from outside the state and country. California draws the majority of its immigrants from Mexico and the Philippines, followed by Vietnam, China, Iran, and Korea.[20] Overall, growth is expected to add about 590,000 people annually,[21] and the projected California population could exceed 47 million in just 20 years.[22]

More than two-thirds of Californians live in the coastal areas of Los Angeles and San Francisco. The greater Los Angeles area—from Orange County to Ventura—is home to nearly half the entire state's population. Its 15,831,700 residents make it the second largest metropolitan area in the nation, after New York City. The 10-county San Francisco Bay Area has nearly 7 million people, and includes eight of the state's wealthiest 10 counties.[23] Much of the state's priceist real estate is located on slopes and in coastal areas which are susceptible to climate impacts.

Growth and sprawl have become major issues in the state, as more than 100 "new towns" are planned in the Central Valley and in desert areas in the south.[24] The American Farmland Trust and the California Department of Forestry estimate that between one and two million additional acres will be urbanized in the next decade to accommodate California's population growth.[25] Demands on infrastructure and natural systems, from roads to rivers, is exceeding carrying capacity. Both the total numbers and the growth rate of the state's population place stresses on California in many ways. More than half the population lives in the driest parts of the state and relies on a drastically altered distribution of water. The highly automobile-dependent society is largely responsible for the state's air pollution. The growing population requires more space in which to live, work, and play, and this expansion into natural habitats—from coastal marshes and bluffs to inland valleys with rich soils to mountain resorts—has placed tremendous pressures on resources, ecosystems, and native plants and animals.



Source: U. S. Census Bureau

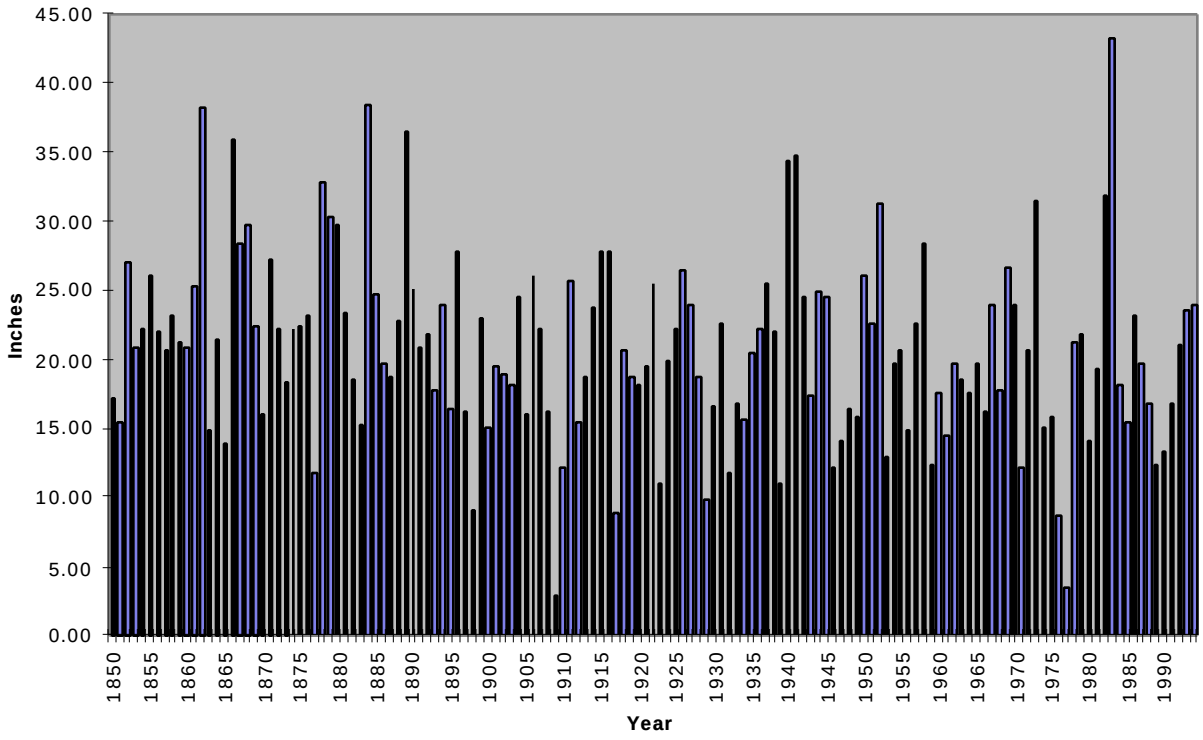
California's Environment

California stretches nearly 800 miles north to south, covering 163,707 square miles (104.7 million acres.) [26] Just over half the state's land is under private ownership. U. S. Government holdings total 46 percent: the U. S. Forest Service owns 21 percent, Bureau of Land Management 17 percent, National Park Service 4.7 percent, Department of Defense 2.8 percent, and the Bureau of Indian Affairs 0.5 percent. Just 2.5 percent is held by the state government. Some 12 million acres are in some type of protected areas—9.4 million in state and national parks—with 6.4 million set aside primarily for the protection of ecological and biodiversity values. As much as 40 percent of the state is subject to livestock grazing.[27] Farms occupy nearly 3 million acres, and of the 16.6 million acres of California's timberlands, 44 percent is held privately.[28]

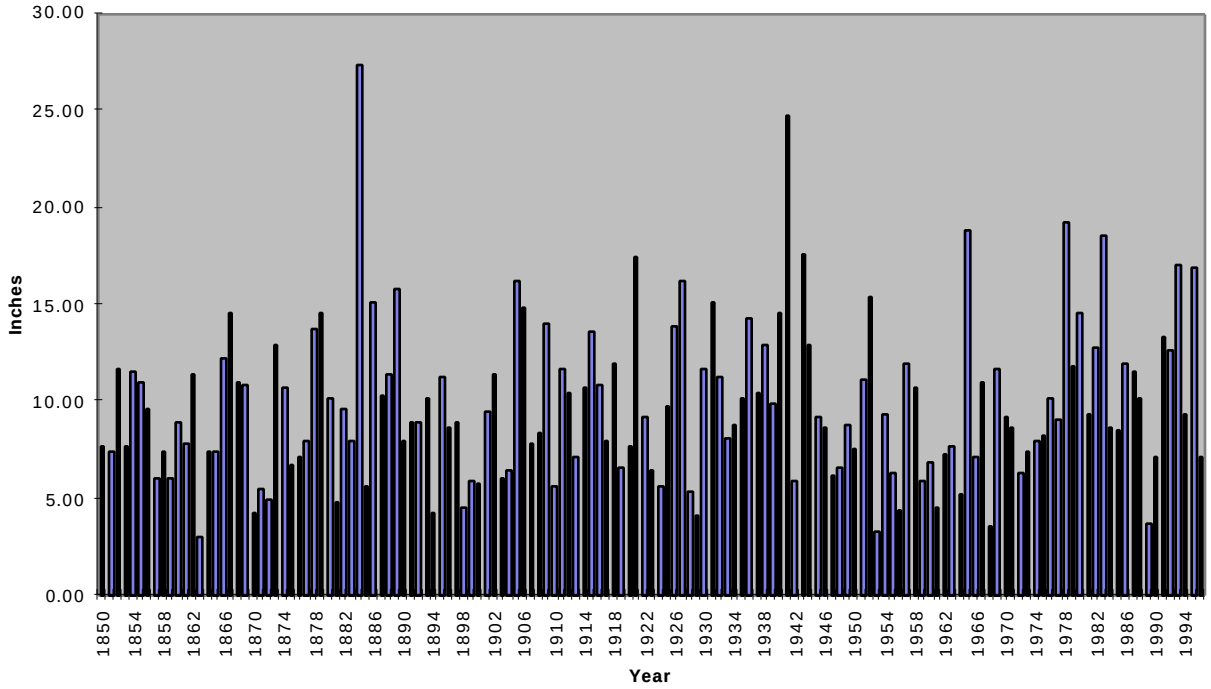
There is more diversity in the state's land forms, climate, and ecosystems and species than in any comparably-sized region in the nation, and perhaps the world. California has foggy coastal forests, hot low deserts, cold high deserts, forested mountains, alpine glaciers, vast dry valleys, rich agricultural lands, rocky shores, sandy beaches, protected harbors, inland seas, freshwater lakes, and wild rivers.

Climate conditions vary dramatically in the state. Much of California is considered to have a mild, Mediterranean climate influenced by the Pacific Ocean, with cool wet winters and warm dry summers. Precipitation fluctuates greatly from place to place and year to year, however, and floods and droughts are legendary. The highest annual rainfall recorded was 161 inches in the Santa Lucia Mountains, but Bagdad in the Mojave Desert once had no measurable rain for 25 months, a U. S. record.[29] Actual rainfall deviates significantly from the average more often than not. In 1996, for example, San Francisco had a 50 percent increase over "normal", while in the same year, Imperial County had less than 30 percent of its usual rainfall of 2.75 inches[30]. Northern California experienced a "500-year flood" in January 1997 when warm rains followed record snowfalls. This year, however, has been one of the wettest on record, bringing more devastating floods and mudslides, making the 500-year mark an ineffectual designation. In 1997, Los Angeles experienced its longest dry spell in its history—219 days—followed by the wettest February (1998) in over 100 years—nearly 12 inches.

Annual Rainfall in San Francisco Since 1850



Annual Rainfall in San Diego Since 1850



California's geography is key to both its climate and the diversity of its ecosystems. The Sierra Nevada Mountains capture the moisture of Pacific storms, resulting in large amounts of precipitation as snowfall in the mountains. Donner Summit has an 80-year average March snowpack of over 90 inches, and it reached nearly 320 inches in 1951-52, while Owens Valley, lying in the Sierra rainshadow, is a true desert, receiving less than 6 inches of rain annually[31]. In wet years, the tremendous Sierra snowpack serves as a water storage system for much of the state, gradually releasing supplies during dry summers.

California's varied climates and complex land forms create a diversity of habitats which cradles an abundance of life forms unmatched in North America. More than 5,000 native plants compose as many as 1,000 distinctive plant communities.[32] There are nearly 1,000 native vertebrate species—540 birds, 214 mammals, 77 reptiles, 47 amphibians, and 83 freshwater fishes—and countless invertebrate species inhabiting the region.[33] About one-third of California's plants are endemic, and as many as half of the animal species are found nowhere else.[34]

Throughout California, wetlands, forests, rivers, woodlands, and other natural habitats have been and continue to be altered, imperiling the state's natural diversity. By some estimates, as much as 90 percent of California's wetlands have disappeared.[35] Sixty percent of the Sacramento-San Joaquin Delta's waters are diverted for human use.[36] Almost nothing remains of the Central Valley's native grasslands, which once blanketed more than 20 million acres.[37] Native oaks are in serious decline. Nearly 90 percent of the state's riparian areas have been destroyed or seriously degraded.[38] In our increasingly stressed region, the abundance of species unique to California has led to an alarming number of threatened and endangered species, as well as some who have already become extinct. The state and federal threatened and endangered species lists include 82 mammals, birds, fish, reptiles, amphibians, and insects, and 132 plant species.[39] The state's official mammal, the Grizzly Bear, has not been seen in California since the 1920s. The state reptile, the Desert Tortoise, is endangered, as is a subspecies of the state fish, the Golden Trout. The Coast Redwood, the official tree and the tallest living thing on Earth,[40] has been reduced to about 15 percent of its original range.[41] Some salmon runs are already extinct, and others have declined by more than 98 percent.[42] Steelhead populations in parts of California were listed in 1997, and the National Marine Fisheries Service

announced in February 1998 that they plan to list 13 salmon populations in California, Oregon, and Washington.

California's environmental programs fall under the responsibility of the Resources Agency and California Environmental Protection Agency (Cal EPA). There is much overlap in the authority of the various boards, commissions, departments and agencies. For example, The Department of Conservation in the Resources Agency has authority over the "bottle bill" program, but the Integrated Waste Board has authority over solid waste reduction and recycling. The Department of Fish and Game (Resources) regulates oil spill recovery and discharge of wastes into streams, but similar programs are run by the state and regional water quality control boards (Cal EPA). This summary does not attempt to provide a full analysis of the structure of the agencies, but rather a broad overview of their structure and funding.

The Resources Agency is responsible for the stewardship, conservation, management, and enhancement of California's natural resources, including land fish, wildlife, and forests. There are 21 departments, commissions, and conservancies within the Agency:

The California Resources Agency

Department of Parks and Recreation
Department of Fish and Game
Wildlife Conservation Board
State Coastal Conservancy
California Tahoe Conservancy
Santa Monica Mountains Conservancy
Coachella Valley Mountains Conservancy
San Joaquin River Conservancy
California Coastal Commission
State Lands Commission
San Francisco BCDC
Delta Protection Commission
Department of Conservation
California Conservation Corps
Forestry & Fire Protection
Department of Water Resources
Department of Boating and Waterways
Colorado River Board of California
Energy Commission

Source:

Cal EPA is responsible for environmental protection, water and air quality and hazardous waste clean-up. There are six departments and boards within Cal EPA:

California Environmental Protection Agency

Air Resources Board
California Integrated Waste Management Board
Department of Toxic Substance Control
D Department Pesticide Regulation
State Water Resources Control Board
Office of Environmental Health Hazard Assessment

Source:

California's Economy

California as a "G-7" Country

California's Gross State Product in 1997 was $1.037 trillion.[43] Ranked as a nation, California would have the seventh largest economy in the world and would qualify for membership in the "G-7"—the group of seven largest national economies.[44]

This level of economic activity is more than a curiosity to add to the state's list of superlatives. Climate change could have significant repercussions for California's economy, and the public, private, and government sectors all have a stake in it's well-being. The assessment of potential climate impacts on an economy of this magnitude resembles the national assessment efforts of other major countries.

Gross Product Ranking of G-7 Countries and California

	billions of U. S. dollars
United States	$7,819.3
Japan	$4,223.4
Germany	$2,115.4
France	$1,393.8
United Kingdom	$1,278.4
Italy	$1,146.2
CALIFORNIA	**$1,037.0**
Canada	$599.0

Source: Organization of Economic Cooperation and Development.
OECD Statistics, National Accounts. February 1998.
http://www.oecd.org/std/gdp.htm

California's Major Economic Sectors

California has a broad and diverse economy with strengths in many areas. The state produces 13 percent of the nation's goods and services,[45] and is a prominent international competitor in manufacturing, agriculture, electronics, finance, entertainment, and other sectors. The state attracts more than 30 percent of the nation's total venture capital investments, mostly aimed at technology-based industries.[46]

Employment in California is spread across a diverse set of economic activities. At the end of 1997, the employment rate was the highest in more than a decade. In the early 1990s, an indication of the deep recession in California was the unemployment rate of 9.3 percent;[47] the extraordinary recovery was demonstrated in a 5.8 percent rate in November 1997.[48] In the past two years, California has gained nearly 800,000 jobs, a 6.2 percent increase that far exceeds the national rate of 4.6 percent.[49] The economic expansion has been felt throughout the state and in nearly every major industry. Foreign trade, high technology, tourism, entertainment, and professional services led the recovery. [50] The effects have reached manufacturing, agriculture, construction, and housing markets. Personal income grew 6.7 percent in 1997 over the previous year, and spending followed, rising 5.9 percent.[51]

California's Top Employment Sectors
(October 1997)

Sector	*Employees*
Government	2,257,900
Manufacturing	1,907,100
Food stores and service	1,159,900
Other retail trade	1,098,000
Business services	1,080,100
Health services	882,600
Finance, Insurance, Real estate	735,500
Construction	590,700
Transportation	437,200
Engineering and Management services	434,500
Agricultural (averaged)	349,400

Source: California Labor Market Information Division, Employment Development Department. "Labor Force and Industry Employment." December 16, 1997. (http://www.calmis.cahnewt.gov/file/indcur/cal$pr.txt)

California's economy is expected to continue building on this growth. The Center for Continuing Study of the California Economy estimates that the state will add 2.8 million jobs, 1.8 million households, and 5.1 million residents by 2005. Personal income will reach $1.13 trillion by that year, a 31 percent jump that will far outpace the 19.8 percent national average.[52]

Industry Highlights

California produces nearly every major commodity: lumber and paper, textiles and clothing, automobiles, natural gas, oil, gasoline, and other petroleum products, hardware, furniture, food and beverages, computers and software, industrial machinery, aircraft, and many other products. California employs nearly 2 million people in manufacturing durable and non-durable goods. An additional 775,000 workers are employed in wholesale trade, moving those goods from producers to retailers. Wholesalers in the state exchanged more than $475 billion in goods in 1995, more than $100 million of which were shipped to foreign markets.[53]

Selected Top Economic Sectors in California

Sector	*Revenue*	*Employees*	*Year*
Tourism	$58 billion	684,000	1996
Computers, Electronics	$56 billion	269,000	1995
Entertainment	$40 billion	262,000	2000 *
Aerospace	$31 billion	165,000	1996
Agriculture	$25 billion	349,400 (avg.)	1996
Environmental Tech	$18 billion	202,600	1997 *
Apparel	$11 billion	163,800	1997

Tourism includes: transportation, accommodations, food service, and recreation.
Computers and electronics includes software, hardware, and related services.
Entertainment includes film, music, television, and related products and services.
Agricultural employment is seasonally averaged.
Environmental technology includes pollution control, water systems, waste management, reclamation, biotechnology, pharmaceuticals, and supporting products and services.
* Estimate.

Source: California Trade and Commerce Agency. "California. An Economic Profile." September 1997.

California also leads the nation in exports. In 1996, California businesses exported more than $100 billion in products, representing 16 percent of all U. S. exports. Japan was the state's top foreign customer, receiving nearly $19 billion in California goods in 1996, followed by Canada, at $11 billion. Electronic components, telecommunication equipment, and electrical products made up 28 percent ($29.4 billion) of all exports, while another 27 percent ($27.8 billion) was industrial machinery, including computers and peripherals. California produced nearly $9 billion in processed and unprocessed food for export.[54] The aerospace industry, including search and navigation equipment, also contributes significantly to the state's exports.

Aerospace remains a strong factor in the state's economy. California accounts for 23 percent of the U. S. aerospace industry, employing 163,700 workers and producing $31 billion in products.[55] A mainstay of southern California's economy, the aerospace industry suffered a decline as a result of defense-spending cuts in the post-Cold War era. In the 1990s, an estimated 15,000 jobs were lost in the Burbank area

alone.[56] The growth of satellite telecommunications and navigation technology has added to this industry's core enterprise of producing air- and spacecraft.

Computers and electronics have become indispensable in our society, guiding and monitoring the operations of everything from spacecraft to toasters to brain surgery. California has a substantial role in computers and other electronics industries, which supply other industries as diverse as automobile manufacturing, banking, entertainment, structural design, medicine, and education. In the manufacture of computer hardware and the creation of software, California is a world leader. State sales for computer manufacturing were approximately $35 billion in 1995, more than one-third of the nation's total, and software receipts were about $21 billion. California attracts more than 30 percent of the nation's venture capital investment, primarily for electronics and other advanced technologies.[57]

California is home to some of the most successful computer technology companies in the world, including Intel, Apple, Hewlett-Packard, Packard Bell, Adobe Systems, Atari, Netscape Communications, Oracle, Sun Microsystems, and Symantec. Computer tech is one of the state's top employers, and one of the fastest-growing and highest paying industries in the state.[58] Not only is California a leader in the industry, it is also one of the top consumers of computer technology: more people in California own computers than in any other state.[59]

Environmental technology and biotechnology are terms used to define a broad spectrum of technologies that are primarily involved with air and water quality improvement and maintenance, waste and toxic materials management, development of alternative energy sources, development and production of pharmaceuticals and other health care products, biological engineering, environmental monitoring, and a broad range of research. Industries include water and waste treatment systems and facilities, interior environmental controls, a variety of measurement and control devices, and engineering and other services. Biotechnology combines engineering concepts with biological processes to produce substances and methods to create products used extensively in health care, as well as in agriculture and food processing. Its products and services encompass genetic engineering, pharmaceuticals and diagnostic systems and substances, as well as sophisticated research and testing laboratories.[60] California is the world's leader in biotechnology and has one-third of the nation's biotech companies, including

Genentech, Amgen, and Cetus Corporation.[61] Many aspects of environmental technologies have strong links with California's university systems.

1995 California Leading Agricultural Exports

Rank	Commodity	Value ($1,000)
1	Beef Products	992,930
2	Cotton Lint	799,112
3	Grapes	674,038
4	Almonds	488,439
5	Fish	440,362
6	Oranges	334,692
7	Dairy	235,661
8	Lettuce	154,088
9	Prunes	128,714
10	Walnuts	125,822
11	Lemons	125,805
12	Strawberries	120,208
13	Chickens/Eggs	119,376
14	Cherries	119,104
15	Tomatoes	112,343
16	Sudan/Alfalfa Hay	107,776
17	Onions	106,398
18	Grapefruit	103,080
19	Wheat	102,199
20	Broccoli	96,776
21	Pistachios	70,707
22	Timber	65,726
23	Asparagus	62,859
24	Peaches/Nectarines	61,675
25	Melons	59,296
26	Cauliflower	57,895
27	Vegetable Seed	54,858
28	Rice	48,665
29	Celery	46,227
30	Plums	37,746

Source: Department of Food and Agriculture, California Agricultural Statistics Service. www.dof.ca.gov/html/fs_data/stat-abs/sec_g.htm

California has produced the highest agricultural crop value in the U. S. for 50 consecutive years.[62] Nearly 30 million acres are farmed in California.[63] It is the leading dairy state, the number two cotton producer, and it grows more than half the nation's fruits, nuts, and vegetables. Total agricultural income exceeded $24 billion in 1996, nearly twice that of the second-ranked state, Texas. Exports amounted to nearly $12 billion in revenue.[64] California is the only state to produce commercial quantities of a number of important crops including almonds, walnut, pistachios, nectarines, olives, dates, and prunes.[65] Not only does the state lead the nation in growing crops and livestock, it is the largest employer in food processing—baking, canning, distilling, freezing, grinding, milling, and squeezing. California wineries produce three-quarters of the wine sold in the U. S., and they exported more than $250 million of wine in 1995.[66]

California is the nation's fourth largest producer of petroleum, and ranks third in proven petroleum reserves.[67] Extracting and refining petroleum products produced gross revenue of $8.5 billion in 1994,[68] engaging over 40,000 workers.[69]

The general category of services is the largest sector of California's economy, employing more than 30 percent of workers in the state.[70] The sector includes activities ranging from business services such as advertising, credit reporting, computer programming, data processing, to health care, to neighborhood businesses such as dry cleaning.

California's variety of cultural and scenic attractions make the state one of the most popular destinations in the world, and tourism is one of its most vital economic sectors. From Disneyland to Yosemite, it is estimated that 57 million out-of-state and foreign travelers came to see the sights in 1996, and California residents made something like 230 million trips around the state.[71] California's 11 million acres of state and national parks, recreational areas, and wilderness draw more than 35 million tourists to national parks annually, and another 65 million visit state parks.[72] California has the nation's second highest income from fishing- and hunting-related activities—more than $5 billion in 1996.[73] Nearly every county, town, and city reach out to tourists in one way or another, making tourism an important part of local economies. The Division of Tourism estimates that each county receives on average $961 million in direct travel expenditures annually, ranging from $27.4 million in Modoc County to $12.5 billion in Los Angeles.[74]

The travel industry touches many businesses directly and indirectly. Approximately 684,000 people are employed in this state in jobs related to travel. Hotels, motels, restaurants, transportation services, travel agencies, and retail stores combined received more than $58 billion in travel spending in 1996.[75]

Entertainment has become one of the state's hallmark industries, with ties to computers and electronics as well as finance, tourism, and many other sectors. Films, music, television, amusement parks, computer games, theme restaurants, and retail entertainment stores employ roughly 262,000 in the Los Angeles area, the capitol of the industry. Entertainment has rescued southern California from the economic slump resulting from the aerospace cutbacks. It is estimated that for every aerospace job lost, two have been created in the entertainment industry, and by 2000, the sector will grow to become a $40 billion annual business.[76]

Supporting the state's economy are financial industries such as banking, insurance, and real estate. Depository institutions, including commercial banks, savings and loans institutions, and credit unions, had total assets of over $417 billion in 1996.[77] The 1994 total gross product of insurance carriers, agents, brokers, and related services was nearly $18 billion.[78] Real estate is also a significant element in California's economy. Revenue exceeded $146 billion in 1994. This volatile sector experienced a 348 percent increase in just 15 years.[79] In 1996, the median home price statewide was $177,630, varying widely from around $105,000 in the Central Valley to more than $260,000 in the San Francisco area,[80] one of the most expensive housing markets in the nation.

Infrastructure

California's economy and lifestyle are supported by one of the world's most extensive infrastructure systems. From water to transportation to energy, the state relies on the reliability of a complex system of pipes, cables, wires, canals, transmitters, roads, and other investments worth hundreds of billions of dollars. During occasional disruptions to these systems, Californians are reminded of the vital services they often take for granted. Recent events in the state with the El Niño-related storms, for example, shut down major rail lines and interstate

highways, severed communication and power lines, ruptured gas and oil pipelines, overwhelmed sewage systems, and damaged water supply systems.

Water Systems

Water is critically important to both the state's economy and the ecosystems which ultimately underpin both economic productivity and the quality of life. Its scarcity or abundance—in place and time—have historically created both physical impacts and human conflicts between north and south, cities and farms, environmentalists and developers, sportsmen and hydrologic engineers. The squabbling has gone on since before statehood, and current headlines indicate that the issues have not receded. An elaborate system of reservoirs, canals, aqueducts, and other engineered facilities is matched only by the even more elaborate set of laws and policies that govern the state's most contentious resource.

The disparities between availability and demand in California spawned an unprecedented control of nature. The water diversion, conveyance, and storage systems developed in California in this century, such as the Central Valley and State Water Projects, the Colorado, and Los Angeles Aqueducts, are remarkable engineering accomplishments. These water works move millions of acre-feet of water around the state annually. The state's 1,200-plus reservoirs have a total storage capacity of 42 million acre feet (maf).[81] The state's water systems have made the Central Valley one of the nation's most productive agricultural regions. The valley is virtually a desert; Bakersfield receives about six inches a year and Fresno less than 12, while the annual average evaporation potential in the Valley exceeds 60 inches.[82] More than seven million acres are irrigated in the arid Central Valley,[83] more than 75 percent of the state's total irrigated acreage.

Three principle sources provide the state with water: surface water, which is often diverted or extracted and stored in reservoirs; groundwater; and imported supplies, principally from the Colorado River. (Conjunctive use of surface and groundwater, re-use of agricultural and urban water, inflow from Oregon, and other factors make precise accounting for water supplies a complicated task.)

California Average Annual Water Supply and Extractions From All Sources

Water Source	Million Acre Feet per Year (mafy)
Precipitation	193.0
Natural recharge, percolation, and non-developed uses (a)	122.0
surface runoff (historical range: 15 mafy [1977] to 135 mafy [1983])	70.8
Average annual water supply (b)	85.0
Total groundwater resources	850.0
Economically recoverable groundwater resources	250.0
Extractions of surface water (c)	21.6
Extractions of groundwater	15.0
"Use" of groundwater (does *not* include overdraft)	7.1
Overdraft (d)	1.3
"Net" use of groundwater ("use" plus overdraft)	8.4
Surface storage capacity (reservoirs) (e)	42.8
Delta extractions (f)	10.3
Reclaimed water	0.2
Desalination	0.017
Imported Water	
Colorado River imports (g)	5.2
"Local imports"	1.0

Sources: California Department of Water Resources. California Water Plan Update, Bulletin 160-93. 1994. California Legislative Analyst's Office. Colorado River Water: Challenges for California." October 16, 1997. (http://www.lao.ca.gov/101697_colorado_river.html)

(a): "Non-developed" uses are evaporation, evapotranspiration from native plants, and percolation/

(b): Appears to include groundwater extractions including overdraft of 15 mafy and surface at 70 mafy.

(c): Based on sum of local, SWP, CVP, and other federal projects.

(d): DWR projects no overdraft from 2000 forward (Vol. 1, p. 6, Table 1-2), although it states on the same page that "...the reductions in overdraft seen in the last decade in the San Joaquin Valley will *reverse as more ground water is pumped* to make up for reductions in surface supplies from the Delta." (emphasis added)

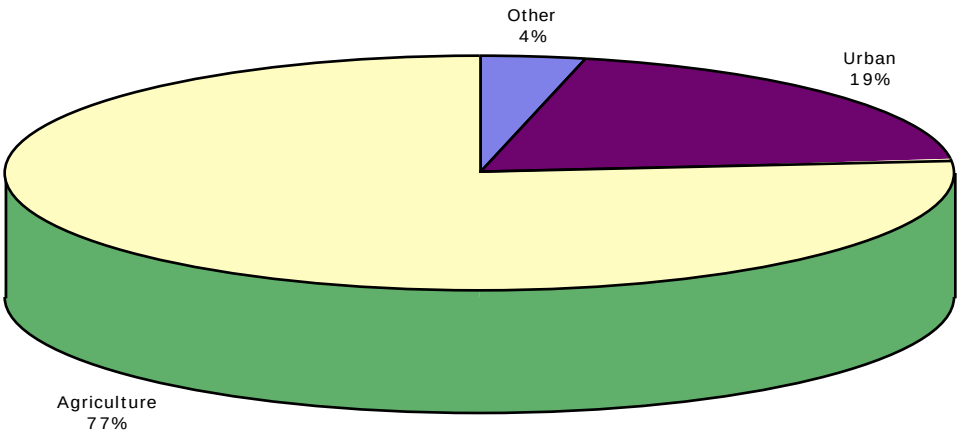
(e): California Department of Water Resources, Division of Dams. "Dams Statistical File," July 1997.

(f): Based on figures for SWP and CVP.

(g): California's entitlement is 4.4 mafy

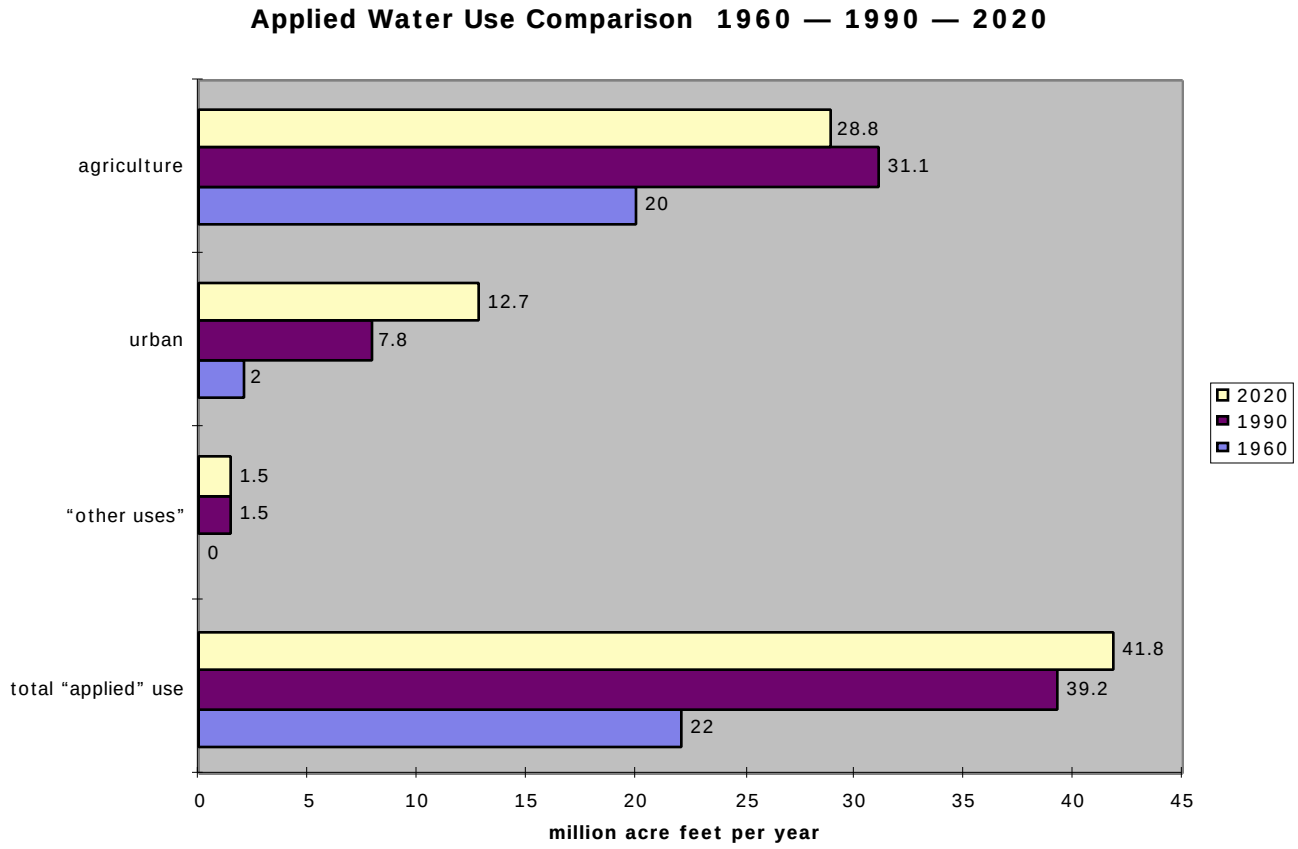
On average, about 200 million acre feet per year (mafy) falls as precipitation, two-thirds of which falls in the northern one-third of the state.[84] About 71 mafy is surface runoff, stored and redistributed for human use.[85] Water from the Colorado River Basin supplements in-state supplies and provides for about 14 percent of the state's total water; it provides more than 60 percent of the 8.4 million acre-feet used in southern California.[86] Groundwater supplies an average of about 7 mafy, but in drought years, this may increase drastically. Overdraft and contamination has reduced the availability of groundwater supplies throughout the state, and salt water intrusion in coastal aquifers is already a problem in some coastal areas.

Total Water Use—1990



Water in California is used primarily for urban, agricultural, and environmental purposes. The urban water use sector includes residential, commercial, industrial, and institutional uses, as well as municipal uses such landscaping and fire fighting. As the state's population continues to grow, urban uses of water are steadily increasing. Agricultural demand, however, peaked at the end of the 1980s and is declining.[87] In the early 1970s, agriculture used about 85 percent of the state's developed water supply.[88] By the end of the 1980s, the percentage of the state's water used by agriculture had fallen to 80 percent. Irrigated land area increased from about 4 million acres in 1930 to a high in 1981 of 9.7 million acres.[89] In place of the continuing increase in water used for irrigation projected in earlier forecasts, the

state now projects a continued decline in water use for agriculture.[90] Land retirement, crop shifting, water transfers, and improved efficiencies in irrigation as well as conveyance and management will all contribute to a reduction in water used for irrigation.[91] Despite this decline, however, total extractions from the state's water systems has increased through the years, with flows for the environment decreasing as a result.



* Total of "other outflow" and "environmental", a category which is not disaggregated for 1960. Assumes total water resources of 85 mafy for 2020, consistent with 1960 and 1990 data.
Source: California Department of Water Resources. California Water Plan Update, Bulletin 160-93. 1994.

With very real limits to the state's water system, and every major supply source being reduced, the state's water systems may be fairly said to be stressed. Every

major water supply source in California is currently beyond the physical or legal capacity to be sustained.

California's entitlement to Colorado River water is 4.4 mafy, but it has been taking 5.2 mafy.[92] An average of 1.3 mafy of groundwater extractions is overdraft;[93] that is extractions exceed recharge by more than 18 percent. In severe drought years, this overdraft may be as high as four to 10 mafy,[94] which drastically depletes economically recoverable groundwater resources.

Water Policy

Henry Vaux concludes his analysis in *Global Climate Change and California: Potential Impacts and Responses*, with the statement that: "Today California's water economy is not in good shape. Even in average years, water supplies are balanced with water use only because of groundwater mining, a practice that cannot be sustained indefinitely."[95]

As a consequence of past management practices, the state is now working to restore some of the devastation of aquatic, riparian, and wetland ecosystems. The stresses already in place are causing list of threatened and endangered species to continue to grow. As much as 90 percent of the state's riparian habitat has been ruined, 95 percent of the state's wetlands have been destroyed,[96] and 95 percent of the salmon and steelhead habitat for spawning in the state's Central Valley have been lost.[97]

In order to restore environmental damage, court decisions on Mono Lake water and pending restrictions on water from the Owens River and Owens Lake are limiting diversion of Sierra water sources to Los Angeles. In the past, Los Angeles has relied on this water for an important share of its annual consumption.

Pressures on water supplied to the San Francisco Bay–San Joaquin Delta also have environmental consequences, and is the subject of a major water-use controversy. The largest remaining wetland in the western U. S., the Bay-Delta supplies water to more than half the state's population, irrigates nearly half the nation's crops, and provides habitat for more than 120 species of fish and other wildlife.[98] For years, urban, agricultural, and environmental interests have made demands on a system

with insufficient flows to meet everyone's desires. Legal mandates for restoration of the system from Congress, such as the Central Valley Project Improvement Act, and requirements to comply with various laws including the Endangered Species Act (ESA) are driving an extensive evaluation of water management. A joint effort by state and federal agencies, known as CALFED, is currently seeking to develop a process to manage the Delta's water supplies and demands.

The CALFED Bay-Delta Program, initiated in 1995 by Governor Pete Wilson and the Clinton Administration, is an unprecedented collaboration among state and federal agencies and the state's leading urban, agricultural and environmental interests to address and resolve the environmental and water management problems associated with the Bay-Delta bioregion. The Bay-Delta is the largest estuary on the west coasts of North and South America. More than 22 million Californians rely on the Bay-Delta system for all or some of their drinking water. The Bay-Delta system is a key component of the state's $24 billion agricultural industry, supplying irrigation water to millions of acres of the world's most productive farmland. A federally chartered advisory group consists of leaders of stakeholder groups throughout the state. The mission of the CALFED Bay-Delta Program is to develop a long-term comprehensive plan that will restore ecological health and improve water management for beneficial uses of the Bay-Delta system. To date, the state and federal governments have committed $820 million to this program.[99]

Fundamental and historic change is occurring in California water policy. The values and logic that are emerging to guide policy, along with physical and economic constraints, portend a new basis for water policy and management in the future. In response to environmental damage, both the courts and Congress have established requirements for *restoration* of ecosystems and species, and they have required mitigation of environmental damage. To achieve these policy goals, water rights have been altered and new priorities are being established which fundamentally change water allocation in California. In particular, environmental values and policies that reflect society's growing demand for environmental preservation and restoration are increasingly driving policy. Commenting on the "dramatic changes" occurring in water law to address these problems, water law expert Arthur Littleworth observes:

> Venerable court decisions that *historically defined the rules* governing riparian, appropriative and overlying water rights are now less relevant to California water issues than the Federal Endangered Species Act, the Clean Water Act, the public trust doctrine, "fixing" the Delta, the thicket of state and local regulations affecting water transfers, and the newly developing programs to manage local supplies.[100]

Environmental considerations, long neglected in water policy, are now a determining factor. Littleworth and Janice Weis comment further:

> In the early 1990's, the listing and proposed listing of water-dependent species in the Bay-Delta *has essentially taken control* over the operation of the State Water Project and the Federal Central Valley Project.[101]

The challenges posed by climate change and variability will add to the already difficult water problems facing the state. As Henry Vaux notes: "It is not unreasonable to speculate that water-related losses in California due to global climate warming could amount to as much as a billion dollars annually."[102] Billions of dollars of facilities have been proposed to add to the state's prodigious plumbing system. Widely divergent perspectives exist regarding response strategies to climate change. Some view the prospect as an opportunity to build more dams. Others see a need for improvements in efficiency and greater use of market signals, including price signals that more closely reflect true costs. One certain prediction is that the debates will continue and intensify with climate-induced stresses layered onto a serious existing problem.

Transportation Systems

Californians have long been defined by their mobility, made possible largely by the automobile. There are more than 20 million licensed drivers in the state,[103] and more than 26.5 million cars, trucks, and motorcycles,[104] traveling over an intricate maze of 170,500 miles of streets, roads, and highways. Los Angeles County alone has nearly 21,000 miles of roads.[105]

About 80 percent of total petroleum consumed in the state is used for transportation,[106] which is by far the largest producer of CO_2 emissions.[107] Fewer

than 20,000 of the 26.5 million vehicles in California are fueled by "alternative" energy sources, mostly ethanol-gasoline blends or natural gas.[108] This dependence on gasoline-powered transportation in the state has resulted in some of the nation's worst air quality.

Transport of goods is a critical element of California's foreign and domestic trade. The state's important position in the world's economy make the state a major center for handling foreign trade. In 1996, shipments by land, sea, and air through California ports totaled $294 billion. Nearly 65 percent was destined for Pacific Rim nations, particularly Japan, China, Taiwan, and South Korea. California produced 84 percent of the $124.1 in exports, and its ports handled more than 21 percent of all U. S. exports. Almost 40 percent of imports and nearly 50 percent of exports through California were made via air transportation. The Los Angeles/Long Beach harbor complex is the busiest container port in the nation.[109]

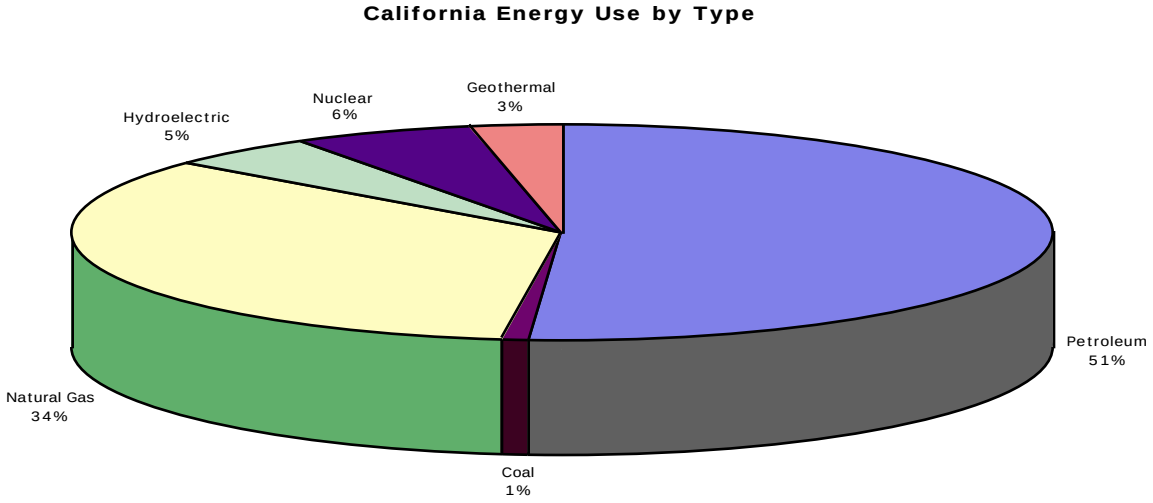
Energy Systems

Energy systems are both the principle cause of climate change and a sector vulnerable to the impacts of change. While the focus of this White Paper and assessment is on the latter, we include some basic information on California's energy system structure and greenhouse gas emissions. This information is provided both to develop a baseline for consideration of physical impacts and because future policy responses to climate change will in themselves constitute important impacts for the state. Given the state's experience and leadership in many aspects of energy systems—from renewable energy technologies, advanced transportation systems, and other technology, to deregulation and other policies implemented in the state—it is important to assess the potential impacts at both the energy systems and the policy world. It is also probable that key sectors of California business and could benefit from increased demand for certain products and services as part of future climate change mitigation strategies.

California uses more energy than most nations, with a total consumption of more than seven quads (quadrillion BTUs).[110] The state has the country's second-highest total energy consumption, trailing Texas. On a per capita consumption basis, however, California ranks 48th in the nation,[111] and on the basis of energy used per

dollar of gross product, California ranks 46th.[112] Residents have become significantly more efficient in energy use over the last two decades, decreasing individual consumption by about 14 percent. California per capita primary energy consumption fell from over 80 percent of the U. S. average in 1975 to 69 percent in 1995. Californians used about seven fewer barrels of oil equivalent in energy per person in 1995 than in 1975. Despite the improvements in energy efficiency, California's net use is increasing.

California is not energy self-sufficient. California relies on imports for 65 percent of its total energy use. Half of the petroleum, 83 percent of the natural gas, and nearly 18 percent of the electricity used are imported from out-of-state.[113]



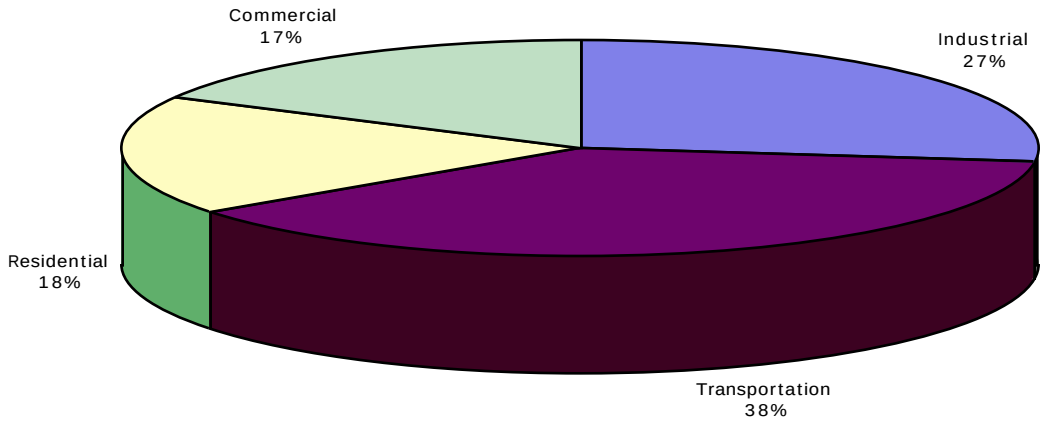
Source: California Energy Commission. (http://www.energy.ca.gov)

According to the California Energy Commission, California's electricity use has increased an average of 2.3 percent per year since 1977. The greatest share of electricity consumption is in the commercial sector, using 34 percent of the total and growing at an average annual rate of 3.3 percent. Residential electricity consumption has increased 2.3 percent per year on average, and industrial demand has grown at 1.4 percent per year.[114] By some projections, the state's population

could increase 50 percent by 2020,[115] and energy requirements will continue to rise with it.

California has achieved one of the world's most diverse electric generation systems in terms of primary energy sources used to produce electricity. More than 1,300 power plants generate electricity in California.[116] Natural gas, oil, nuclear, hydro, coal, geothermal, wind, solar, and biomass all contribute to the generation mix. Natural gas and electricity imports are used more during periods of drought, which reduces hydroelectric generation. Natural gas contributed heavily to California's electric generation over the last 10 years because of the growth in co-generation, the continued low price of gas, the drought, and the shift from use of oil to natural gas to reduce air pollution.

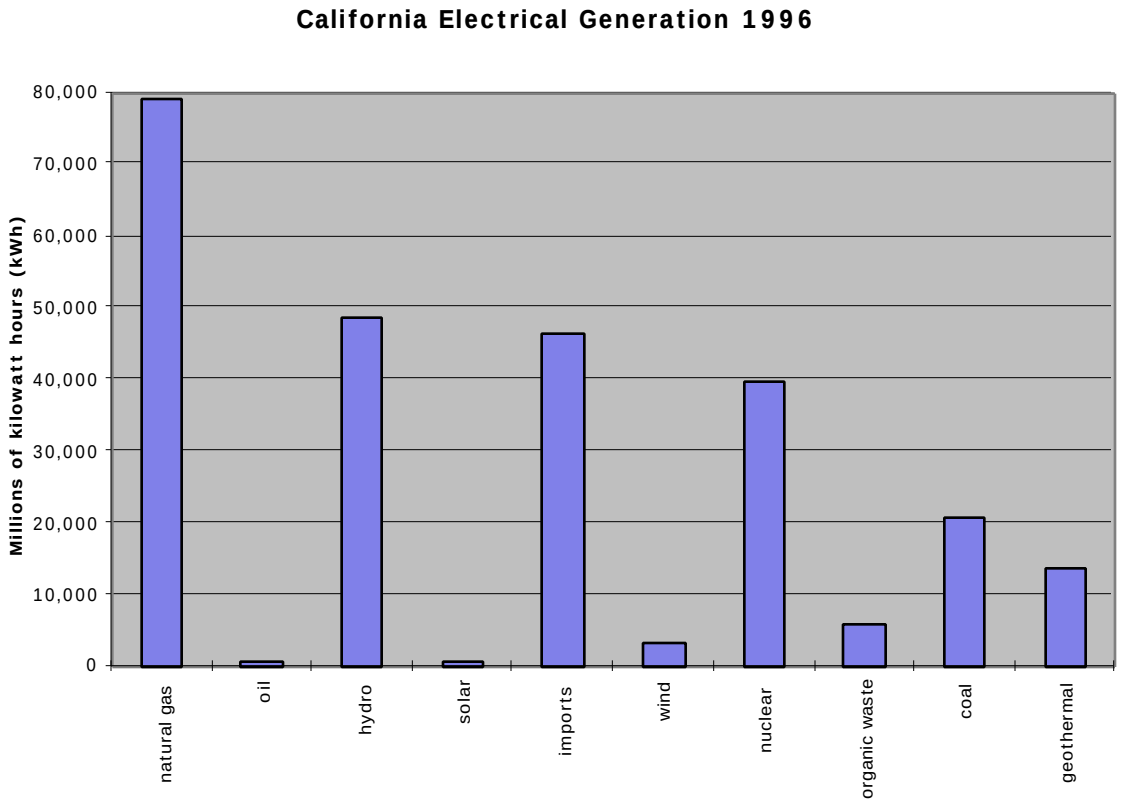
California Energy Consumption by Sector—1993



Source: California Energy Commission. (http://www.energy.ca.gov)

Though still a small fraction of the total generation mix, renewable energy sources including hydro, geothermal, wind, biomass, and solar, have been developed and commercialized in California and show considerable promise for the future. California was the world leader in the development and installation of wind energy technology until recently. Advanced technologies for transportation and energy

conversion, such as fuel cells and solar photovoltaic cells, are also important aspects of California's energy sector. Both for in-state use and for export, the potential for expansion of production and use of these technologies is potentially a major economic opportunity for the state.

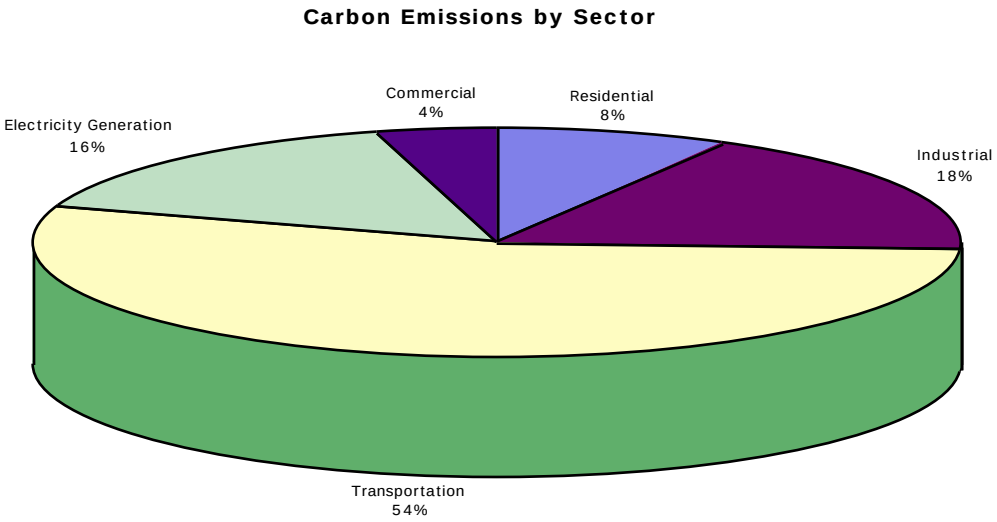


Source: California Department of Finance. California Statistical Abstract. Table J-11 "California Electrical Energy Generation." December 17, 1997. (http://www.dof.ca.gov/html/fs_data/stat-abs/toc.htm)

California Greenhouse Gas Emissions

Carbon dioxide, methane, and nitrous oxide are the three most important greenhouse gases produced by human activity. The U. S. produces by far the largest amount of greenhouse gases, both in terms of per capita and total emissions.

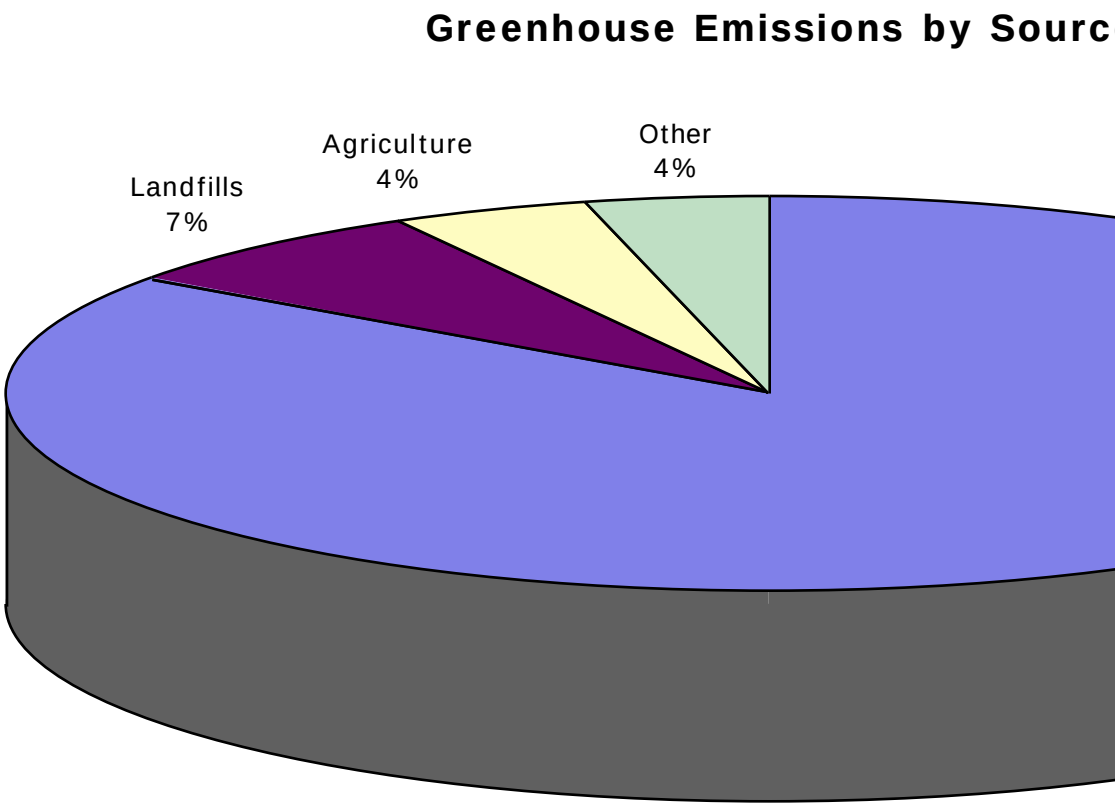
Overall carbon emissions are attributed to four major sources: transportation, industrial and commercial activities, electric utilities, , and residential uses.



Source: California Energy Commission. "Historical and Forecasted Greenhouse Emissions Inventories for California." September 30, 1997.

The California Energy Commission has inventoried California's greenhouse gas emissions. In 1994, the state produced more than 458 million tons of CO_2 equivalents. Carbon dioxide accounts for 87 percent, methane 11 percent, and nitrous oxide 2 percent. (Methane and nitrous oxide emissions are converted to carbon dioxide equivalents by determining their respective global warming potentials in order to allow the comparisons of the relative contribution of different greenhouse gases.)[117]

Carbon emissions due to electricity generation are considerably greater for out-of-state sources than from electricity generated within California. In-state sources produce nearly 170,000 gigawatt hours (GWhr), while emitting a little over 50,000 thousand tons of CO_2 (.29 tons per GWhr). Out-of-state electrical generation plants provide California with about 100,000 GWhr, while producing 60,000 thousand tons of CO_2 (.60 tons per GWhr), more than twice as much. This is due to the coal-based power that is imported into the state.



Source: California Energy Commission. "Historical and Forecasted Greenhouse Emissions Inventories for California." September 30, 1997.

The California Energy Commission estimates that by 2010, total greenhouse gas emissions will increase about 15 percent, with fossil fuel combustion still producing about 85 percent of the total.[118]

III. Global Climate Change Scenarios and Impacts on California

Climate Projections

The Intergovernmental Panel on Climate Change (IPCC) was formed by the World Meteorological Organization and the United Nations Environment Programme in 1988 to assess the scientific and technical literature on climate change, the potential impacts of change, and options for adaptation to and mitigation of climate change.[119] The IPCC has established several scenarios which take into account low, medium, and high levels of human population growth, greenhouse gas emissions, and environmental sensitivities to atmospheric carbon dioxide concentrations. The scenarios project that in the next century, global temperatures will increase by 1° to 3.5° C (1.8° to 6.5° F). This warming is expected to cause thermal expansion of the oceans (warmer water expands in volume) which, along with melting glaciers, will cause sea level to rise by 15 to 95 cm (6 inches to 3 feet). The timing, amount, and distribution of precipitation is also expected to change.[120] Global air and ocean currents may shift significantly, altering present patterns of heat distribution worldwide. Local predictions are much less certain, and regional variations are likely to be considerable.

The IPCC report, "The Regional Impacts of Climate Change: An Assessment of Vulnerability" does not specify impacts on California, but states that "Many systems in North America are moderately to highly sensitive to climate change, and the range of estimated effects often includes the potential for substantial damages."[121]

The United States Environmental Protection Agency (EPA) cites the same figures for global warming (1.6° to 6.3° F),[122] but adds that the United States is projected to warm more than the global average. In the next century, the average temperature in California could increase by about 5° F, and annual precipitation could increase from 20 percent to 50 percent.[123] In a region as diverse as California, averages are still difficult to extrapolate to local conditions. In general, EPA agrees that California is currently experiencing stresses from population growth, land-use changes, and pollution which will be exacerbated by climate change. Agriculture, water resources, ecosystems, sea level, and public health may be significantly affected by climate change and variability.

Assessments of Climate Change in California

The specific impacts of climate change in California are by no means certain. That changes will occur, however, seems indisputable, and many aspects of California's economy and environment could be affected. Two specific aspects are important: sea level rise and increased climate variability, including so-called "low-frequency, high-intensity" events.

Several studies conducted in the past decade have specifically examined the potential consequences of climate change in California. A 1989 report by the California Energy Commission, *The Impacts of Global Warming on California*, surveyed the current understanding of global climate change and applied that knowledge to California.

The Energy Commission assessed natural habitats, water resources, energy systems, economy, and agriculture, and determined potential risks to each sector. The Commission concluded that there would be significant risks to California's water resources, agriculture, forestry, natural habitats, and sea level; moderate risks to energy supply and the overall economy; and possible risk to air quality and human health.[124] In the last decade, scientific understanding about the potential for global warming has been refined, and while the report is nearly 10 years old, the overall findings of climate change impacts remain applicable.

Global Climate Change and California: Potential Impacts and Responses is a report stemming from three workshops held in 1989, sponsored by the University of California and the U. S. Department of Energy.[125] The workshops used climate scenarios, based on the scientific understanding at the time, as tools for analysis and discussion. The scenarios posed predictions that by 2070 temperatures would increase 2° C to 4° C, precipitation could increase or decrease 20 percent, and sea level would rise up to 1 meter. Winter and spring would be wetter and warmer, resulting in diminished snowpack and increased winter stream flows, while autumn and summer would be dry. The report also projected a 10 percent to 20 percent increase in ozone concentrations downwind of urban areas.[126]

Impacts on California

Climate change and variability will potentially affect the state's diverse economic sectors in important and different ways. Some activities and enterprises will be impacted directly through changes in natural resource and ecosystem services. Water shortages and disruption of pollination of crops due to impacts on insects, for example, will have direct impacts on the state's highly profitable agricultural sector. Precipitation falling as rain instead of snow could cost the state's world-class winter sports sector to suffer serious losses and will pose major problems for water managers. Sea level increases of up to three feet over the next century, with consequent implications for coastal erosion, inundation of wetlands, salt water intrusion of coastal and delta aquifers, and impacts on developed areas would clearly be extremely expensive (in economic terms) and devastating to some ecosystems and human settlements.

Other impacts to the economy will be indirect but just as important if climate change and variability increase. For example, rising costs for infrastructure maintenance, resources, and insurance will reduce California's economic competitiveness. Not all impacts will necessarily be negative, however. It is possible that the hydrological conditions will increase flows in some water systems, reducing stresses on certain species and ecosystems and providing more opportunities for water use. Some businesses may prosper by manufacturing products and selling services which increase in demand due to climate change, such as renewable energy technologies (e.g.: wind machines, biomass, and solar energy systems), fuel cells, and other technologies which reduce greenhouse gas emissions.

It is important to bear in mind that one critical determinant of whether a specific change brought about by climate change is detrimental is the rate of change in the system. Rapid changes and greater variability are generally more difficult and expensive to adapt to than slower changes and lower variability. Electric utilities, water managers, and transportation system managers are all subjected to very large expenditures to manage sophisticated infrastructure systems in both the private and public sectors in response to climate variability. Both storms and droughts cause hundreds of millions of dollars in preventive costs and in damages. Pacific Gas and Electric, for example, allocated $250 million in a single year (1997) for tree trimming to reduce the incidence of power outages in its service area. Farmers are also

impacted heavily. While field crops may be switched by the season, perennial crops including vineyards and orchards are long-term investments. The reported damages from the El Niño storms in 1997-98 for agricultural losses was approaching $100 million in February. From dairy farmers losing cows to exhaustion as they try to escape the mud and are attacked by diseases, to strawberry growers losing crops to the rain, farmers have experienced significant losses due to strong variability.

Sea Level Rise

Sea level rise may have widespread impacts on California. The cumulative effects of glacial melting and thermal expansion of the oceans could cause the global average sea level to rise as much as three feet. This would inundate hundreds of square miles of low-lying land.[127] Coastal structures from harbors to houses will succumb to the ocean, as numerous California beachfront homes did in February. Beaches and wetlands will be flooded. Agricultural lands in the Sacramento-San Joaquin Delta, some already as much as 25 feet below sea level, may be permanently lost. As the ocean encroaches, some aquifers near the coast could become contaminated by saltwater intrusion. As Henry Vaux noted in 1989, "Seawater intrusion already threatens water quality in several coastal aquifers."[128] Today, sewage systems in coastal communities are frequently overwhelmed by storm runoff and high tides, and the problems could become much more serious as sea level rises.

Storms and Floods

The recent storm patterns causing widespread destruction in California and resulting in some of the highest rainfall totals on record are attributed to the El Niño Southern Oscillation (ENSO). ENSO is a warming of tropical Pacific waters which alters normal jet streams and affects weather globally, from Australia to Peru to the Caribbean to Canada. Some scientists believe that these conditions could become far more common, if not 'normal', in the next century if global warming continues.[129] In the not-too-distant future, the notions of one-hundred- and five-hundred-year floods may completely lose their meaning and usefulness as planning tools. Some suggest they already have. Floods now gauged to have a one-in-500 or one-in-100 chance of occurring every year are likely to occur more frequently.

El Niño storms during February brought as much as three times the average rainfall for the month, causing numerous deaths in addition to damage to homes, businesses, roads, utilities, and crops that could top $1 billion.[130] Saturated soils caused mudslides. Rivers and streams overflowed. Heavy storm surf eroded coastlines. Underground pipelines ruptured. Roads washed away or were obliterated by mudslides. Agricultural fields were inundated, resulting in millions

dollars of lost crops. Utility lines were downed, causing widespread power outages. Telephone and other communication services were interrupted when transmission lines and transmitters were damaged by rain, wind, and mud.

California has had wet years in the past: this El Niño year saw some long-standing records broken, while others were untouched. Santa Barbara had just under 47 inches of rain this year, breaking its 1940-41 rainfall record of 45 inches; average is about 18 inches. Los Angeles' wettest year on record was in the last century, and remains unbroken; 40.29 inches of rain fell in 1884; 1982-83 had 34 inches; this year had almost 31 inches; and average is about 15 inches.[131]

The ramifications of the increase in severe storms associated with climate change on the insurance industry and its customers could be vast. Taxpayers, homeowners, businesses, farmers, and utility companies will bear the brunt of the costs of weather disasters. Most insurance policies do not cover flood damage, and California insurance companies haven't provided homeowner coverage against mudslides since the 1950s because of the high risk of huge losses. (Lloyds of London is the single exception, and they have reportedly not written a single policy in California due to the high cost of the coverage.)[132]

State and federal government agencies, particularly the California Office of Emergency Services and the Federal Emergency Management Agency (FEMA), are stepping in this year to aid Californians. At the same time, demands are being made for federal assistance in other regions such as Florida, where dozens have died in the ENSO-related weather events. These resources are being increasingly called upon, and may not be able to bear the additional burdens placed on them by widespread climate change and disruption. In the wake of the recent storms, government may feel the need to extend landslide insurance to homeowners, as it does for flood and earthquake damages in high-risk regions, or attempt to persuade insurance companies to provide coverage.[133] The results are likely to be higher premiums and taxes to cover the potentially tremendous costs of storm damage.

Air Quality Impacts

California's population, postwar industrial boom, agricultural success, and dependence on the automobile have resulted in troubling problems with air and water pollution. Cars and trucks are California's primary sources for air pollution, emitting carbon dioxide, carbon monoxide, nitrogen oxides, particulate matter, and other harmful substances. In a 1986 study, transportation accounted for 57 percent of the state's carbon emissions, substantially above the national average of 32 percent.[134]

California has had tremendous success in cleaning its air over the past two decades, but still fails to meet U. S. standards. In the Los Angeles area, population density, cars, climate, and geography combine to create the nation's worst air quality. In 1997, Los Angeles had its cleanest year in 50 years, even though federal ozone limits were exceeded on 68 days. [135]

California's stringent auto emission control regulations and reformulated gasolines have made today's automobiles and trucks as much as 95 percent cleaner than cars running 30 years ago.[136] However, we have some 26 million vehicles on California roads, all emitting some pollutants. The increasing popularity of trucks and sport utility vehicles is also contributing to the state's problems—these vehicles produce 1.5 to 2.5 times the emissions of passenger cars.[137] At the beginning of 1998, however, GM and Ford motor companies made public commitments to reduce emissions by producing more electric hybrid cars and fuel-cell vehicles, as well as improving fuel efficiency in popular trucks and sport-utility vehicles.[138] California already has some of the most stringent emissions standards in the nation, but as concern grows for both human health and global climate stability, auto manufacturers selling in this state may face greater restrictions in the near future.

California's air quality also suffers from ozone pollution. Again, the transportation sector is the greatest contributor to these pollutants. Ozone (O_3) in the lower atmosphere (as opposed to stratospheric ozone) is produced when sunlight initiates a photochemical reaction between oxides of nitrogen (NO_X) and hydrocarbons, both products of fossil fuel combustion.

Exposure to ozone for several hours can create respiratory distress in as many as 20 percent of healthy adults and children, while prolonged chronic exposure can cause irreparable lung damage.[139] Ozone also causes tissue damage to plants, decreasing productivity in agricultural crops, landscaping, and natural vegetation. Los Angeles exceeded federal ozone limits on 68 days last year, down from 90 the previous year,[140] while the Bay Area never did—for the first time since 1969.[141]

Another significant air pollutant is particulate matter less than 10 microns in diameter, known as PM_{10}. Health problems can result from prolonged exposure to PM_{10}, particularly the particles less than 2.5 microns which can easily penetrate deep into the lungs. Ash, soot, and dust are the primary constituents of particulate matter pollution, but any solid or liquid particle smaller than 10 microns can contribute to this type of pollution. A major source of particulate matter is incomplete combustion of organic substances—from gasoline to wood. Various industrial activities—processing metal, wood, fiber, and many other materials—can also produce aerosols. In farming regions, agriculture contributes to particulate matter. Heavy equipment disking the soil and aerial application of pesticides and fertilizers can send huge amounts of dust and droplets into the air. An additional health concern from agricultural dust is the potential for soil pathogens to become airborne, such as that which causes Valley Fever.

Water Quality Impacts

Climate change will likely exacerbate serious water quality problems in California. Agriculture, a sector particularly vulnerable to climate change, is also a major contributor to California's water pollution problems. Climate change could in fact worsen the problem. Substances found in agricultural waste water discharges include toxic metals and pesticides such as mercury, arsenic, lead, selenium, cadmium, Chlordane, PCBs, and many other dangerous compounds.[142] These substances pose significant threats to urban water supplies as well as fish and wildlife. The infamous Kesterson Reservoir and Wildlife Refuge received agricultural runoff containing excessive amounts of selenium, resulting in high mortality and grotesque deformities in birds and fish.

In arid farming regions, particularly the southern Central Valley, irrigation can cause soil pollution. Salts, naturally found in California's soils and water, build up in irrigated soils when seasonal rainfall does not flush the salts away. In closed drainage basins such as the Tulare Basin, heavy irrigation can also raise the groundwater table, resulting in saturated soils as well as contaminated groundwater.[143] With increased rates of evapotranspiration, additional irrigation water will be demanded. Additional water brings more salt and requires more water for leaching. As Vaux notes, "These leaching requirements would be imposed on a water-supply system that may already be unable to meet the various demands for consumptive and in-stream uses. In addition, the use of minimum leaching fractions will tend to concentrate salts in the drain water. Given that the diluting capacity of receiving waters will be reduced, the problem of managing agricultural drain waters will become even more serious than it already is."[144]

Henry Vaux, in assessing the impacts of climate change on California's waters, makes the following powerful statement:

> The quality of California's surface waters and groundwater is deteriorating inexorably. Toxic wastes, residues from irrigated agriculture, and shortsighted watershed management practices all threaten to reduce water quality even further. Efforts to control existing threats of water contamination have not been fully successful, and effective strategies for dealing with future problems have not been developed. The continuing degradation of California's waters threatens to widen even farther the disparity between available supplies of adequate quality and projected water demands. By permitting the degradation of water quality to continue, Californians contribute to a worsening of the future water-supply situation as surely as if they destroyed existing water-supply facilities.[145]

The concern expresses above is shared by Lowell Lewis, William Rains, and Lynne Kennedy. In "Global Climate Change and California Agriculture", they state that "irrigation waters in some areas of the state are presently causing an accumulation of salts in qualities detrimental to crop yields and survival. Unless irrigation practices improve and leaching and proper drainage occur, many of these areas will loose their productive capacity in a matter of decades, with or without global warming."[146]

Climate Change and the Economy

The state's economy could be affected by climate change in both positive and negative ways. Agriculture and outdoor recreation enterprises may be directly influenced by the weather and climate variability. Floods or even unseasonable rain can ruin crops. Drought will stress plants and place extraordinary demands on water resources. Rain falling instead of snow could limit the ski industry. Lingering coastal fog will deter tourists from spending vacations on southern California beaches. Other interests will be affected indirectly. Requirements for goods and services may shift as the climate imposes different demands on individuals, businesses, and infrastructures. Some businesses may find their particular product or service no longer sought after, and their trade will decline. However, many businesses and entrepreneurs are likely to find new opportunities to meet changing needs, and new ventures will multiply. On the negative side, energy, water, and transportation costs could rise if California's climate changes drastically, and these increases will translate into higher consumer prices.

Agriculture will perhaps be the sector most highly susceptible to climate changes. California will hopefully be able to maintain its productivity and contribution to the nation's economy, but farmers may have to alter their practices. As Lowell Lewis, William Rains, and Lynne Kennedy note in "Global Climate Change and California Agriculture", "A consensus of many scientists is that agriculture is on a collision course with itself; without significant change there may be no agriculture left in some parts of California for climate change to affect."[147] The serious problems they report include soil and water quality deterioration noted above in the discussion on water, air pollution and increased levels of ozone, increased pest damage due to various stresses, and other factors which are all exacerbated by climate change. It is also possible that climate changes will benefit agriculture in certain ways.

Agriculture might be beneficially affected by increased CO_2 and a longer growing season in some areas. An effect known as CO_2 fertilization could cause some crops to grow faster and use water more efficiently. In a CO_2-rich atmosphere, water loss is decreased during photosynthesis, and water efficiency can increase in some plants by as much as 10 percent.[148] Higher CO_2, however, may not be as beneficial as this would appear to indicate: the increase in water efficiency could be more than offset by an increase in evapotranspiration created by the hotter summers. Increased crop

production also appears to be dependent on heavy applications of fertilizers, pesticides, and water, and there is some evidence that the nutritional value of plants may decrease as a result of CO_2 fertilization.[149]

Milder winter temperatures could lengthen the growing season and result in a northward shift of some crop ranges, assuming the land and infrastructure is available for such shifts. This could allow some crops to be grown in previously unfavorable areas. Frost-sensitive plants once grown primarily in areas such as the Imperial Valley may be grown in the Central Valley. Conversely, crops that prefer cold winters could experience ranges limited to more northern areas.

In California, water is often the limiting factor for plant growth. Water-demanding crops such as cotton, rice, alfalfa, and irrigated pasture may have to be replaced by thriftier plants. Overall, changes in crop yields are predicted to have mixed results: wheat could decline by 48-66 percent, and cotton by 9-17 percent, while crops like tomatoes could increase by 50 percent and oranges by almost 100 percent.[150]

Higher evapotranspiration rates may contribute to increases in soil salinity in heavily irrigated areas of the southern Central Valley, as noted in discussions above. In agricultural areas on the coast, however, evapotranspiration could decline because of foggier conditions in spring and summer. (Rising air in hot inland regions draws in more ocean moisture, cooling the coast.) California's seasonal patterns of precipitation may shift, forcing agriculture to adjust planting and harvesting schedules. Vineyards, for example, could experience losses if rains increase nearing harvest time—unseasonable rain can cause molds to bloom, ruining the grapes. Cotton crops can also be decimated by rain at critical stages of growth.

In the heavily farmed San Joaquin-Sacramento Delta, levees have long held back the waters. Delta land has been sinking as much as three inches every year over the past century, due primarily to erosion and peat oxidation. Many areas are as much as 25 feet below sea level, and 35 feet below high tide.[151] Maintaining the fragile levees against the rising waters may become impractical. As California's human population expands, existing land uses could prevent growers from simply moving their farms. Along with the potential for water shortages and soil degradation, this

could ultimately reduce the total acreage devoted to food production and decrease agricultural revenues.

Variations in climate could affect the cattle industry. During hotter, drier summers, irrigated pasture will be more expensive to maintain, and free range cattle will find less forage. If winters become wetter, as this season has, dairy cattle may suffer as well. In the Chino area, which produces 25 percent of the state's milk, some 6,500 head of cattle died in February. Cows and calves became mired in mud, weakened by the cold, succumbing to bacterial infections that breed in the muck, literally exhausting themselves to death. Under these stresses, even healthy dairy cows are producing as much as 20 percent less milk. Dairy cows often develop mastitis under these conditions, requiring antibiotic treatment and rendering the milk unusable. In the Chino area alone, dairies suffered as much as $6 million in direct losses in February.[152]

Air quality could also affect agriculture. Higher temperatures degrade air quality by accelerating photochemical reactions of auto exhaust and sunlight. Ozone in the upper atmosphere forms a critical blanket of protection against ultraviolet radiation, but at ground level it is a highly reactive molecule that can damage cells in all living organisms—from peas to people. A major component of smog, ozone damages crops, and concentrations of the gas increase with temperature. In the 1980s, ozone pollution caused losses of sensitive crops of up to 20 percent; [153] losses could be much greater in a warmer California climate.

In sum, while agriculture may benefit in some ways from climate change, it will be susceptible to increased ozone, higher evapotranspiration rates, degraded soil and water quality, intense and erratic storms, unseasonable rains, increasingly costly or unreliable water deliveries, and more frequent occurrences of pest infestations and livestock diseases will adversely affect agricultural yields and practices.

The demands global warming could place on natural resources may have consequences on nearly every industrial sector. Costs for water, electricity, natural gas, and transportation could rise, resulting in an increase in the cost of doing business, and therefore boosting the prices of nearly all products. Consequently, the competitiveness and profitability of California's businesses and economy could be

reduced.[154] Impacts of warming on other regions of the world, particularly the Pacific Rim, could also affect California, which is highly involved in global markets.

However, many new technologies may arise to confront the challenge of our changing world. California will need to address reductions in greenhouse gases, develop more efficient use of energy by everything from refrigerators to tractor-trailers, cope with severe weather events, assure adequate water supply, and deal with many as yet unforeseen complications of climate change and variability. California is in an excellent position to take the lead in using technology to help us mitigate—or adapt to—climate change.

The impacts of climate change on environmental technology industries—from construction to research—are potentially enormous. The increased needs for air and water quality control and improvement could require more heavy construction and repair of dams and levees; reconstruction or relocation of sewage treatment facilities, particularly those near sea level; greater demands for efficient interior environmental controls; and many other technological innovations. The need for cleaner energy sources to reduce carbon emissions could trigger enormous growth in 'alternative' energy production, such as wind, biomass, and solar power generation plants.

Conceivably, climate change has large implications for biotechnology as well. The possibility of health complications from heat and air pollution has the potential to expand the need for biologically-engineered treatments. Crops and livestock may benefit from genetic engineering and other biotechnological aid in adapting to stresses imposed by climate change, including increased evapotranspiration rates, pest infestations, and disease.

Tourism in California is strongly tied to the state's climate. Whether people come to bask on a legendary California beach or to ski a world-class mountain slope, weather plays a role. If our coasts become foggier in summer, sunbathers and sailors will not travel to the coast. If Sierra snowfall diminishes and the San Bernardino Mountains get only rain in winter, snowboarders and skiers will seek pure powder elsewhere. Tourism will not end in California, but its patterns will change, and the industries and businesses that rely on tourism will have to change the ways they do business and market the state to tourists.

The energy sector may be heavily impacted by climate change. Both physical changes and threats posed by climate change and vulnerability and policy changes will have important effects on the sector. Demand for electricity will rise along with the temperatures. California uses considerably more energy to cool buildings than to heat them.[155] The use of air conditioning to cool our buildings and refrigerate our foods will jump. Estimates from the California Energy Commission indicate that a three-degree C increase in average temperature would increase peak demand by 3 to 7 percent. Overall demand would increase by 1.5 to 2.5 percent. [156]

Crops will require substantial irrigation as evapotranspiration increases, and electricity will be needed to pump groundwater. Again, the Energy Commission estimates that for each degree of warming, electricity demand for pumping will increase by one percent.[157]

Power production will also be affected by climate change. Hydropower production will be impacted, particularly in terms of timing. High water flows in winter and spring may be followed by below normal flows in the summer, when peaking power is in demand. The efficiency of thermal power plant cooling systems also decline with increases in temperature.

Some energy systems may actually be enhanced by climate change. Increases in temperatures could increase the thermal gradient and increase the wind potential in some of California's windy passes where wind farms have been developed.

Petroleum products may become more expensive. Refining operations will be faced with stricter regulations on emissions production, which will also be more expensive. And the products themselves will be required to be burn cleaner, which may entail more elaborate processing. The trickle-down effects of higher fuel costs could be far reaching. Anything requiring transportation, from manufactured goods to newspapers to people, will cost more. Cars and trucks will have to be more efficient. Automobiles sold in California have had the most stringent emissions standards for two decades. In light of the increased need to reduce emissions, pressure is being placed on manufacturers to double fuel economy.[158]

Energy distribution systems could face problems as well. More extreme winter storms could knock down power lines, while erosion undermines them. The unstable air in warmer storms could increase the incidence of thunderstorms, which tend to be destructive to above-ground power lines and transfer stations. Underground systems such as pipelines are also vulnerable to storms, primarily from mudslides and erosion. Companies responsible for maintaining electrical facilities and pipelines will have to pass the added costs on to consumers, quite possibly driving up energy prices. In addition, interruption of service will itself constitute a major economic impact due to lost revenues, damages to equipment, and spoilage. Nearly everything Californians do requires energy, and therefore nearly everything we do could become more expensive.

There are many possible responses to these changing needs, nearly all with their advocates and opponents. Technological advances in energy efficiency of products we use every day could reduce our per capita consumption as well as reduce our emissions. Expansion of the state's alternative energy sources—primarily sun, wind, organic waste, and geothermal heat—is a promising avenue for many reasons. These sources are renewable and vastly cleaner, and reducing reliance on fossil-fueled power plants will also reduce greenhouse gas emissions.

California's transportation infrastructure—highways, railroads, airports, and harbors—could all be affected by our changing climate. This season's storms have given the state a taste of the destruction that increased precipitation can wreak. Sections of Highway 101, Highway 99, Interstate 5, the San Francisco-Los Angeles rail link along the coast, and many other major transportation arteries all experienced closures and damages during February's storms. Sadly, some of the problems have led to the loss of life, including two California Highway Patrol officers whose car dropped into a river on a collapsed roadway.

On the coast, stormy, turbulent seas can cause extreme erosion. Coupled with sea level rise, roads, railroads, homes, and other structures will be threatened. Pacific Coast Highway in southern California is besieged by mudslides and high waves even during mild winter storms. Legendary Highway 1 from Cambria to Carmel suffers washouts nearly every year, some closing the road for months. Future erosion occurring more frequently could close it permanently if it becomes too costly to maintain. Roads throughout California deal with mud and rock slides each

winter. Coastal rail routes experience the same problems during heavy storms, sometimes shutting down passenger and freight traffic for days.

Many coastal airports are vulnerable to flooding. Built on wetlands back when they were called swamps, many of these facilities, such as San Francisco, Oakland, and Santa Barbara airports, are about 10 feet above current average sea level.[159] Extreme high tides, coupled with flood conditions, can reach close to the existing levels. A recent tidal flux in the San Francisco Bay area closed Highway 101 north of the city due to eight-foot tides, two feet above what had been expected. With an additional meter of sea level, a number of critical facilities would be highly vulnerable. In the future, sea level rise, storm surges, and high tides could conspire to inundate runways. Harbors may suffer wave damage, additional siltation from storm runoff, and other navigation and safety problems. Jetties and seawalls may have to be raised and strengthened to protect harbors, which support commercial shipping, recreation, tourism, and many other economic sectors.

Climate Change and the Environment

All natural habitats, whether pristine or altered, will be affected by climate changes. Shifting rainfall patterns will alter plant communities. Floods, droughts, and wildfires all may be more frequent and intense. Wildlife will have to adapt to changing habitats; some species will move, others may alter their behavior. Plants and animals pressured by human encroachment will be further stressed by climate changes. Some may not be able to adapt, and the number of threatened and endangered species in the state could rise significantly.

IPCC scenarios call for a more vigorous hydrologic cycle,[160] resulting both in more rain and more evaporation. In California, rainfall patterns could be altered considerably, fundamentally affecting water storage and delivery systems. A warmer climate will cause more precipitation to fall as rain rather than snow at higher elevations. The resulting decrease in the snowpack will affect the state's reliance on it as a vital water storage and metering system. More intense rainfall events mean runoff will be higher in winter and lower in summer, further reducing water availability in summer. Two-thirds of the state's water comes from drainage systems in the north.[161] Water is distributed widely to meet demands in

more arid regions—primarily the agricultural Central Valley and densely populated southern coastal counties. If winter runoff increases, large amounts of water will be 'lost' for urban and agricultural purposes. Existing water storage systems in the north could quickly reach safe capacity during heavy winter rains, and much water will be allowed to continue downstream rather than be stored for use in drier areas and seasons. Without gradual snowmelt replenishing the water storage systems, and with current pricing practices and use patterns in the agricultural and urban sectors, the thirsty south and central regions will quickly draw down reservoirs following the rainy season.

Ironically, drought may also increase in some areas. While the total rainfall may rise 20 percent in some areas, it may not be distributed evenly.[162] It is possible that some regions will receive below-normal levels. The northern portions of the state are currently much wetter than the southern and inland regions. Climate change may result only in intensifying these conditions rather than increasing rainfall equally.

The stress on cultivated and natural vegetation could be enormous. In the arid Central Valley, evaporation already exceeds precipitation by as much as 50 inches annually.[163] If summers become hotter there, evaporation will increase and place even greater demands on over-subscribed surface waters as well as already overdrafted groundwater supplies. By some estimations, runoff in the Colorado River basin could decline by as much as 20 percent,[164] seriously affecting southern California's supplies.

Water use, pricing policies, and transfers are a subject of intense discussions and debate in California. Transfers of water are being proposed for Colorado River water currently used for agriculture in the Imperial Valley to be used by San Diego and for other supplies elsewhere in the state. Water use efficiency is also being scrutinized by water managers, users, and environmental interests.[165]

Potential responses to both severe winter flooding and summer drought could include structural approaches, such as raising existing dams as well as building more dams. However, because of the high cost of such projects, the unavailability of 'easy' dam sites, and growing concern regarding environmental impacts of dams, large-scale dam building is unlikely in the future. More cost-effective options include

non-structural solutions such as pricing structures, incentives for efficiency improvement, and transfers.

Many of these conjectural impacts assume little change in current water use patterns. A growing number of water experts foresee a future of wiser water use when the unsustainable practices of the past will be replaced. Some recommendations include moving away from crops with high water demand such as irrigated pasture, alfalfa, cotton, and rice, and toward more water-thrifty plants; an increase in use of reclaimed water; and improved urban and industrial water efficiency. Such shifts could significantly reduce the impact of climate change and variability on California by building greater resilience in the state's water systems.[166]

Water quality may also suffer from climate warming if stronger pollution control measures are not undertaken. Pollutants concentrate when stream flows drop in summer. Saltwater creeps farther and farther upstream in estuaries, and can intrude into coastal aquifers. Algae blooms prodigiously in warm, stagnant waters, depleting oxygen levels, sometimes resulting in large die-offs.

California's wetlands have long been under siege. It has been estimated that more than 90 percent of the state's original coastal wetlands have vanished,[167] and climate change could add to the battles for preserving these integral ecosystems. Rising sea level could inundate many coastal wetlands, and development in areas such as San Francisco, Los Angeles, San Diego, and other coastal communities may prevent wetlands from migrating inland with the sea. Countless species dependent on estuaries at one time or another in their life cycles and which already suffer from environmental pressures could decline further.

Forests may retreat up-slope as well as north, but may not be able to naturally migrate rapidly enough to survive climate change. Pest species will probably adapt to new conditions more quickly, and trees stressed by heat and erratic precipitation will be more vulnerable to infestations. In dying forests, the threat of fire becomes much greater, and intense wildfires may become more frequent, widespread, and destructive. Forests managed for production might be able to shift to new species better adapted to the changed climate. Grasslands might take over thinning forest area, which could be a benefit to grazing livestock, but water availability problems

could diminish this benefit. Erosion could accelerate if the intensity and frequency of storms increases while fire removes ground cover and root structures.

These possible changes in habitat will have a variety of impacts on wildlife. Animals have generally been able to adjust to climate changes that have taken place periodically as long as there has been life on the planet. Today, however, climate change seems to be occurring at a rate far faster than any we know of. Mobile and highly adaptable species such as birds will be able to move to other habitats, if suitable ones can be found. Wildlife already restricted to marginal habitats may not be able to make the changes or moves necessary for survival.

Warmer waters will alter the distribution of coastal fishes, requiring commercial fishing to travel farther or change to different fisheries. Rapid changes to coastal wetlands, including fluctuations in salinity levels, could threaten critical life stages for many marine species, further altering current species distribution. Inland fisheries might also decline as cold-water species do not adapt to warmer waters. California supports the southern-most populations of some salmon and steelhead species that require cold water. As waters warm and stream flows fluctuate, these species could decline drastically or become extinct.[168] Rivers and lakes are likely to have lower levels of dissolved oxygen as waters warm, stressing ecosystems and fish. Freshwater pollution, which could increase as streamflows decrease, will further endanger fish.

Climate Change and Human Health

Several potential effects of climate change on human health have been identified. Temperature rise itself is likely to increase the incidence of heat-related stress and mortality. Highly susceptible people include the elderly and those with heart and respiratory problems, but anyone can be affected. The summer of 1995 provided an extreme example of a lethal heat wave in the Midwest, when more than 700 people died in Chicago alone.[169] Heat waves have occurred in California in recent years and are of particular concern to both firefighters and public health officials.

Air quality is also closely related to temperatures, especially in cities. Ozone production increases with heat, and ozone-related health problems could follow.

Prolonged exposure to ozone causes reduced lung function and aggravates asthma and other respiratory conditions. In agricultural areas, drier summers could increase dust, which will increase particulate matter pollution and possibly transmit soil-borne pathogens such as that causing Valley Fever.

In the tropics and sub-tropics, vector-borne diseases are likely to increase. For example, the IPCC projects that with global warming, the proportion of the world's population subjected to malaria could rise by nearly 50 percent.[170] Mosquitoes and other insects could expand their ranges farther north, bringing more people into contact with vector-borne diseases. Warmer surface waters can also be more hospitable to bacteria, increasing the potential for outbreaks of disease associated with water pollution such as cholera. Both natural vectors (e.g. insects) and human-induced pathways are of concern. In our increasingly mobile society, such diseases could be spread much more readily.

IV. Building Resilience in Systems

If the majority of scientists are roughly right, climate change is real and it is already occurring. There is a need to consider coping and adaptation strategies. The IPCC identifies three terms and concepts which need to be considered: sensitivity, adaptability, and vulnerability.[171] Each term and concept is important to both private and public sector investment and planning. Quoting from the IPCC definitions:

> **Sensitivity** is the degree to which a system will respond to a change in conditions.
>
> **Adaptability** refers to the degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes. (Adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of changes in conditions.)

Vulnerability defines the extent to which change may damage or harm a system. (It depends not only on a system's *sensitivity* but also on its ability to *adapt* to new conditions.)

Note that the focus is on systems. As this assessment has outlined, the economic activities, physical infrastructure, and natural systems in California are inextricably linked. A good understanding of the dynamics of these systems is essential, as is a clear sense of their interrelationships. These concepts apply as much to business enterprises as they do to ecosystems. In considering appropriate strategies, whether they are labeled "response" or "coping" or "adaptation", we must consider the nexus between sensitivity to changes, capacity to change or adapt, and vulnerability to change. These factors will inform the cost/benefit estimates and the social and political assessment of acceptability. Ultimate action on responses will also be driven by a sense of ethical and moral duty. As recent environmental policy decisions in both the courts and the legislative bodies of the state and federal government indicate, people do seem to care about the rights of future generations and other species.

The goal of California stakeholders and decision-makers should therefore be to craft investment and policy decisions which reflect appropriate levels of resilience to maintain ecosystem health, productive capacity, and quality of life. These decisions will in turn be based in large measure on a scientific understanding of important aspects of the issue.

A priority for on-going research and collaborative efforts in the region will be to better understand and define the degree of sensitivity of key systems (natural and human) to climate change and variability, the potential for adaptability, and the vulnerability of these systems. We can then plan for change and preserve the values we cherish in this unique region of the world.

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