Research Paper No. 08102801

Technical Supplement

California Climate Risk and Response

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November, 2008

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1. Water: Background

California's water system will change as the result of the physical impacts of climate change. The demand and supply of water in California are separated by a large distance, posing a major problem for most water strategies. Even as climate change adds pressure to California's water supply, aging water infrastructure makes California's water reliability low and adaptations costly.

Population and economic growth in California are expected to be rapid and continuous, which will put stress on the already outdated water infrastructure. California's water supply is concentrated in the north, but the majority of the demand, both agricultural and urban, is concentrated in the south. The problem has always been to move water cheaply and effectively from north to south.[1] Compounded with global warming, water-related issues worsen and critically affect the California economy. Left unchecked, Californians could face enormous economic damages. Environmental, urban, and agricultural demands will need to be reviewed and reassessed for the upcoming changes in climate.

Water Infrastructure

Currently, California's water infrastructure is a system of 1,200 reservoirs, canals, treatment plants, and levees.[2] The system's tasks include water allocation to agricultural, urban, and environmental demands, water quality management, and flood control. The distribution of the 32 million acre-feet of developed water present in California relies on this system to efficiently carry out its task.[3] The age of California's infrastructure ranges from being old to ancient. Major water projects like State Water Project (SWP) and Federal Central Valley Project (CVP) were built more than 30 years and 50 years ago, respectively. Furthermore, the oldest facilities are more than 100

[1] Howitt, Richard and Dave Sunding, Water Infrastructure and Water Allocation in California (Berkeley: 2007) 181.
[2] Department of Water Resources (DWR), California Water Plan Update (Sacramento: Department of Water Resources, 2005), 3.14.
[3] Howitt and Sunding, 2007.

years old.[4] California's water system relies on smooth operations of its individual parts. As one component of the network fails, the interdependent operations in turn decrease in their capacity. The age of current infrastructure creates an environment where the water supply is at high risk and vulnerability. The question remains: how did the system come to be in such a poor state? The main problem is lack of funding needed to maintain and rehabilitate these facilities as they age.

"Current infrastructure disrepair, outages, and failures and the degradation of local water delivery systems are in part the result of years of underinvestment in preventive maintenance, repair, and rehabilitation."[5]

Without additional funding, key adjustments necessary to accommodate the needs of a growing population and changing climate seem improbable. The California Water Plan Update 2005 details the state's maintenance backlog to be about $40 billion dollars. Even without global warming, the failing infrastructure will result in unreliable, poor-quality, and expensive water supplies for taxpayers.[6] Consider water-operating costs where the effect of only population growth increases the cost of operation by $413 million/year by the year 2050. With a warmer climate, an additional $384 million/year of operating cost would be increased.[7] Estimates from other studies such show numbers that are of magnitudes greater.

The physical manifestations of operating costs include greater pumping and treatment costs, as well as movement of water, to areas with higher-valued demands. Furthermore, infrastructure improvement is fundamentally essential if any other adaptations are to take place. If infrastructural and distribution capacity is already at its limit, an increase in water supply is useless if it cannot be moved to where the water is needed. In 2003, the Metropolitan Water District of Southern California acquired water from growers of Sacramento but was unable to move it through the Delta because conveyance was already operating at full capacity.[8] This issue is one of the major barriers facing many of the adaptations discussed in this paper. Thus, by improving California's infrastructure now, future water-operating costs can be avoided or lowered and water supplies can be made more reliable.

The SWP and CVP are two government implemented water projects that are arcane in nature and unsuited for the changing water use pattern. The approach of these two programs involves the traditional supply augmentation method. It is built on the assumption that demand for water is unchanging over time and perfectly inelastic.

[4] DWR, 2005, 3.14.
[5] DWR, 2005, 3.14.
[6] DWR, 2005, 3.14.
[7] Medellin et al., 2006,Josue, Julien Harou, Marcelo Olivares, and Jay Lund, Climate Warming and Water Supply Management in California (California Climate Change Center, 2006) 14.
[8] DWR, 2005, 23.8.

"Under this planning approach the quantity of water to be delivered by a water project is fixed, and the only question is how to minimize the costs of supplying it".[9] However, demand for water is sensitive to price changes and does fluctuate with respect to price and climate. Another factor that must be taken into account is the source of water supply that is decreasing and shifting seasonally. The SWP's projected output is 4.2 million acre-feet of water, and CVP's projected output is 4.6 million acre-feet. Of CVP's 4.6 million acre-feet of water, ten percent is allocated to urban contractors and the remaining 90 percent is distributed among the agricultural contractors. Both of these projects began in the late 1960's, but pressure from environmental interests delayed completion and operations in full capacity. The CVP was modified by the Central Valley Project Improvement Act to cut water deliveries by one million acre-feet during normal years and 804 million acre-feet during critical rainfall years.[10] Despite these structural problems, obstacles that arise from global warming have much larger and more damaging effects on the overall availability of water. Although the Improvement Act reduced water supply to the population, it only further stresses the urgency for a new water infrastructure because both the human population and nature must be taken into consideration when planning for future projects. The Improvement Act also allocated water to protect wildlife refuges and salmons runs.[11]

Physical Impacts of Climate Change

Global warming dramatically alters the historical hydrology and environment in California. Changes that will occur include loss of at least 25 percent of the Sierra Nevada snowpack, severe winter and spring flooding, longer and drier droughts, and an increase in sea level.[12] All will ultimately result in economic costs to the society as well as environmental issues.

Loss of Sierra Nevada Snowpack._One of the most significant changes associated with global warming is the loss of Sierra Nevada snowpack. Californians depend heavily on the snowpack to supply water during the dry spring and summer months.[13] With the possibility of decreasing precipitation from global warming, the reduction of snowpack can substantially increase the risk of water shortages during summer. Not only does the loss of snowpack constraint our water supply, but the loss also implies the disappearance of ecosystems that are built around the snowy landscape, and the loss of valuable species that cannot be accounted for by a figure. By 2050, the estimated

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[9] Howitt and Sunding, 182.
[10] Howitt and Sunding, 182.
[11] Howitt and Sunding, 182.
[12] Department of Water Resources, Climate Change in California (NP: Department of Water Resources, 2007) 2.
[13] Luers, Amy L, Daniel R. Cayan, Michael Hanemann, Bart Croes, and Guido France, Our Changing Climate (NP: Climate Change Center, 2006) 6.

reduction of snowpack is 4.5 million acre-feet from the historical 15 million acre-feet available[14]; moreover, other studies done by the California Climate Change Center reveals that up to 90 percent of the Sierra snowpack may disappear under high emission scenario, while 30 percent of the snowpack may still be lost in the most optimistic of low emission conditions.[15] The disappearance of snowpack implies that we need to construct more reservoirs to store the water that would have been snow. The result of global warming is an enormous cost on the water systems because we have replaced costless natural snow reservoirs with man-made ones that need constant maintenance and funding.

As less water forms into snow, winter precipitation increases and snow melts at an earlier time, creating a shift in hydrology that puts pressure on the current system of water storage. Under a study done by California Climate Change Center, stream flows of major rivers in California all follow the same trend under global warming. The overall trend projected is a lowering of summer and late-spring runoff for the rivers, including Sacramento, Merced, and Feather River.[16] Scenarios used to model conditions in the next 80 years show that during winter, the perturbation ratios are the highest. A perturbation ratio is a ratio of predicted average monthly stream flow over historical values. A value of one implies that no change has occurred relative to historical trends. Of the three major rivers studied, an increase in winter precipitation results in highest perturbation ratios in the winter months. Moreover, summer months show perturbation ratios that are far below one.[17] The overall result is that water supply that would have been available as melted snow in summer becomes rainwater runoff in winter.

Shift in River Hydrology. A decrease in water supply is expected during the summer. With the largest environmental flow reductions taking place in the upper Sacramento River and below the Kewswick Dam, the salmon populations are threatened, as their return upstream will be significantly more difficult with less water.[18] Furthermore, maintaining reservoir levels, natural or man-made, become increasingly difficult as well. For example, the water needed to maintain Mono Lake levels are predicted to be unattainable under the dry-warming change scenario. Another result projected that an average of 218.5 thousand-acre feet/year of reduced water exports through Friant-Kern Canal will be needed to keep Millerton Reservoir operational. The consequences of such reduction in export are monetary losses in the Tulare Basin by the raise of water scarcity cost by 10-15 percent.[19]

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[14] DWR 2.
[15] Luers et al., 2006, 15.
[16] Vicuña, Sebastian, Predictions of Climate Change Impacts on California Water Resources Using CALSIM II: a Technical Note (Berkeley: California Climate Change Center, 2006) 3.
[17] Vicuña 4.
[18] Medellin et al., 2006, et al., 2006, 16.
[19] Medellin et al., 2006, et al., 2006, 16.

Problems arise from not only too little water but also too much water during different times of the year. If too much water is stored in the reservoirs, there will not be enough space for the winter precipitation. However, maintaining environmental standards must also be taken into account when planning California's water plan. The California Climate Change Center predicts that water managers will have to balance the need to fill constructed reservoirs for water supply and the need to maintain reservoir space for winter flood control in the future.[20] The deviation from historical stream flows calls for actions to be taken in order to improve California's water storage system.

Flooding. As discussed earlier, the current infrastructure has not been adjusted to accept this earlier flow of water supply. Although the melting of snowpack shifts only the timing and does not necessarily decrease the overall water supply, a surge of heavier stream flow could cause flooding and damage vital levees that protect freshwater supplies. Those located in the Sacramento-San Joaquin Delta are especially vital as they protect water supplies needed for the environment, agriculture and urban uses. Two forces, rising sea level and increased stream flow, are constantly pressuring on the levees.[21] Flooding causes significant financial losses and scars fragile wetland ecosystems. One such case took place in 2004 when a levee breach caused seawater to flood into 12,000 acres of farmland and into a major drinking water source for more than 23 million Californians. The flood was out of projected range and flood season. The incident can be linked to global warming causing unforeseen and sudden climatic changes.[22] When funds are unable to keep up with the costly repairs of levees, our environment and supply of fresh water is at stake.

In a recent study, net cost estimates from levee failures ranges from $100 to $250 million dollars for California farmers with a gross loss in farm revenue of about $1.3 billion. The cost range is a reflection of the time frame that the failure takes place: before or after a drought, or during a wet period.[23] Less damage is expected if failure occurres before a drought. Other consequences of levee failure include land fallowing as the result of both reduced supply of water and land suitable for farming. Levee failure has a wide range of impact for urban users. For Southern California specifically, the cost ranges from $10 to $14 billion depending on the scenario of levee failure. An important assumption is that water supplies from non-SWP sources are affected by levee failures. If that were to change, with the supplies unaffected by levee failure, the

[20] Luers et al., 2006, 7.
[21] DWR, 2005, 3.14.
[22] DWR, 2005, 3.15.
[23] Hanemann, M., L. Dale, S. Vicuña, D. Bickett, and C. Dyckman. 2006. *The Economic Cost of Climate Change Impact On Clifornia Water: A Scenario Analysis.* (California Energy Commission, 2008).

costs are reduced greatly ranging from $1.8 to $4.1 billion.[24] These two scenarios reflect the large import dependency of urban water supply, which will be discussed later.

Another similar problem that arises from global warming also threatens fresh water supply. A drop in stream flow during summer months will allow more salt water to intrude into the delta and other water sources.[25] Major water supply affected includes water pumped from the Sacramento-San Joaquin River Delta. Additional pressure from the rising sea level significantly degrades coastal wetlands, estuaries, and groundwater aquifers.[26] In the winter of 1997-1998, damages totaling to millions of dollars were incurred by unexpectedly high storm surges in the San Francisco Bay area. More fresh water will be needed to flush out the seawater and maintain drinking standards. The resulting effect is the increased cost needed to maintain water quality. Actual amount varies depending on the type and scale of the water projects. In critical areas such as the Central Valley, urbanization and limited river channel capacity have already increased the risk of flooding. The estimated flood control projects could amount up to several billion dollars.[27]

Drought. Though winters can become wetter with global warming, summers conditions are dramatically worse off than before. In a study done by California Climate Change Center, the proportion of the year that is under critically dry conditions can increase more than 2.5 times under high emission scenario. Historical averages taken from 1922-1994 result in 18 percent of the year under critically dry condition; however, under high emission, that percentage can shoot up to 56 percent. Other emission scenarios result in similar numbers of 49 percent, 51 percent, and 36 percent.[28] Physical impacts of having half or even a third of the year under critically dry condition are significant. Coping with such conditions will require large shifts in water use pattern and management in both urban and agricultural sectors.

Agricultural Water Use

Consider the worst-case scenario in which the climate becomes drier and warmer, agricultural sector faces large and drastic changes in their water supply. In this study done by California Climate Change Center, models that resulted in more precipitation and streamflow were not used, but instead those that resulted in significant decreased in streamflow were studied to estimate the maximum damage that would occur. Predictions show that streamflows for the six major rivers studied can decrease as much as 28 percent under high emission scenario and 18 percent under low emission

[24] Hanemann, 1.
[25] DWR 1.
[26] Luers et al., 2006, 7.
[27] Luers et al., 2006, 13.
[28] Leurs 15 and Vicuña 6.

scenario.[29] The scale of streamflow change will directly affect California's water supply with California farmers losing as much as 25 percent of the water supply they need.[30]

With technological advances, crop yields, and changes from agricultural to urban land use taken into account, the projected agricultural water demand in year 2050 is 29.3 million acre-feet without climate change. An increase of 0.4 million acre-feet to 29.7 million acre-feet results from the dry climate.[31] Relatively speaking, the change in demand is small and can be attributed to the reliance on historical rainfalls for most of water requirements. All of the increase in demand is located in the Sacramento Valley, which shows that geographic location plays an important role in determining demand of water.

Varying levels of scarcity were obtained depending on the growth of population, dryness of climate, and level of reallocation allowed. Under the dry climate condition, only some areas face substantial water scarcity while other areas face mild to no water scarcity in the year 2020. For the most part, agricultural users face mild scarcity except Southern California agricultural users. Sacramento Valley experiences zero change in water scarcity. Similarly, San Joaquin and Tulare Basin experience only a small change. However, Southern Californian agricultural users face a 20 percent water scarcity.[32] The reason of such high scarcity is mainly due to the sale of water supply from the agricultural sector to urban users.

Scarcity rises considerably when the population growth by year 2050 is compounded with the effect of global warming. In just thirty years, scarcities for all areas are at least 20 percent for all agricultural users. The statewide agricultural scarcity is 24 percent, with 24 percent in Sacramento Valley, 26 percent in San Joaquin Basin, and 20 percent in Tulare Basin.[33] These numbers reflect the ability for water to be shifted between regions to optimize for economic needs. However, when water transfers are limited, water scarcities increase even more. Almost all of this increase is imposed onto agricultural water users. While limited exports decrease water scarcity for Sacramento Valley from 24 percent to 21 percent, other regions such as San Joaquin Basin and Tulare Basin face 52 percent and 25 percent water scarcity respectively. The statewide scarcity increases from 17 percent to 21 percent.[34] Scarcity is likely to be at the level of the latter case due of the age of California's water infrastructure. The importance and benefit of water infrastructure can be seen here. The scarcity of San Joaquin Basin doubled without the smooth operation of interregional water transfer. Overall, agricultural regions north of the Tehachapis experience the most water scarcity.

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[29] Medellin et al., 2006, 3.
[30] Luers et al., 2006, 7.
[31] Medellin et al., 2006, 5.
[32] Medellin et al., 2006, 8.
[33] Medellin et al., 2006, 9.
[34] Medellin et al., 2006, 9.

The economic damages done by water scarcity can be assessed by the amount of scarcity costs. "Water scarcity costs are the costs seen by local water users from receiving less water than their ideal economic water delivery."[35] When agricultural users receive their target water delivery, they see no marginal value for additional water supply nor face any water scarcity cost, because they are fully utilizing their water resource in their production to optimize their economic activity. Impacts of water scarcity in the form of scarcity cost include the reduction of agricultural production and an increased production cost. When water, a factor of production for crops, is scarce, the total output of crops will decrease as the result. The reduction of revenue from producing less is the water scarcity cost. Likewise, when the price of a factor of production increases, revenue will decrease inducing a cost on the producer. From another perspective, when water is scarce, farmers will need to upgrade their irrigation systems to efficiently utilize the water supply.[36] This is a water scarcity cost as well because it would not have been done otherwise if water were not in shortage.

In California, climate change imposes significant costs on agricultural production in the Sacramento, San Joaquin, and Tulare Basins. Large increase in scarcity costs are associated with increased scarcity. In particular, a 66 percent increase in scarcity leads to a 168 percent increase in scarcity cost in the Tulare Basin with dry climate.[37] A single percent increase in scarcity increases cost by more than 1 percent. To put some numbers on these costs, the projected statewide, urban and agricultural, scarcity cost with growing population but historical climate results in $349 million/year. If climate change is considered, the cost shoots up by $263 million/year to a total of $612 million/year.[38] Growing population and global warming put a considerable amount of pressure on the water supply system, resulting in a substantial amount of scarcity cost from high water demands. Keeping only population growth, the scarcity cost is $193 million/year. The total agricultural scarcity cost from climate change increases the cost by more than 100 percent at $447 million/year.[39] Ultimately, global warming will cause an increase of about $254 million/year, but it is possible that a lower cost can be achieved if emission levels can be controlled.

Another factor adding to the economic burden of California's agricultural system is the aging infrastructure. Poor water infrastructure results in the inability to transfer water to areas with higher-value water demand and scarcity. The projected agricultural scarcity cost from interregional inflexibility will sum up to $145 million/year with dry climate warming.[40] If optimization is allowed, the cost can be reduced by one-third to $302

[35] Medellin et al., 2006, 13.
[36] Medellin et al., 2006, 13.
[37] Medellin et al., 2006, 13.
[38] Medellin et al., 2006, 13.
[39] Medellin et al., 2006, 14
[40] Medellin et al., 2006, 13.

million/year. These factors don't just act independently, but the combined effects of population growth, climate change, and infrastructure amplify the total damage done.

Due to the geographical nature of California, this scarcity cost is not bore proportionally. Some areas actually see a decrease in scarcity cost as a consequence of interregional inflexibility with globally warming. Agricultural users of Sacramento Valley experience a reduction of $6 million/year and Southern California users a $3 million/year reduction. Despite the positive reductions in those areas, $38 million/year is added to the San Joaquin Basin, totaling an increase of $115 million.[41] Again, geography plays an important role in determining the economic damage and water demand. The effects of this imbalanced burden will make future adaptation costs difficult to allocate.

Table 1.1. 2050 Water Impacts on Agricultural Users

	Dry (regional)	Historical (regional)
Agricultural Scarcity	8,904 TAF (30%)	3,694 TAF (13%)
Agricultural Scarcity Cost	$447 million/year	$193 million/year
	Dry (statewide)	Historical (statewide)
Agricultural Scarcity	6,981 TAF (24%)	3,623 TAF (12%)
Agricultural Scarcity Cost	$302 million/year	$195 million/year

This table summarizes the effect of climate change and water transfer flexibility taken from the Medellin study. Going across, it shows the effect of climate change in different levels of water optimization. Going down, it shows the effect of varying levels of water optimization under historical and dry climates.

Table 1.2. Agricultural Demand and Agricultural Cost in Different Studies

Agricultural Demand: MAF (% scarcity)		Agricultural Cost: millions/year	
Hanemann	26 MAF (12% and 32%)	Hanemann	$279
Medellin	29 MAF (24%)	Medellin	$302
Tanaka	N/A	Tanaka	$1,774
Medellin-Azuara	29 MAF (22%)	Medellin-Azuara	$312

A summary of results from different studies is shown here. The demand and percent scarcity are about the same for all cases. However, the scarcity cost varies greatly, ranging from about $280 million/year to $1.7 billion/year. The large variation is due the method of modeling and simulation. For Hanemann, the study was based on a simulation model, while for Medellin and Tanaka, an optimization model was used. The

[41] Medellin et al., 2006, 13.

difference lies at the approach of the study; whether starting from an economic or engineering point of view.

Urban Water Use

Although urban water users experience the same physical impact from global warming, they face completely different economic effects from agricultural sectors. The estimated target demands for urban water use are 12.06 million acre-feet in year 2020 and 13.35 million acre-feet by year 2050.[42] Population growth and warmer climate increases demand by about 10 percent over the span of 30 years. However, not all of the regions in California see an increase in water demand. Specifically, Sacramento Valley actually sees a 16 thousand acre-feet reduction in urban water use from year 2020 to 2050. Other regions see an increase in urban demand with a much larger magnitude. Compared to the 16 thousand acre-feet reduction, Southern Californians will demand an additional 679 thousand acre-feet and 283 thousand acre-feet for San Joaquin Valley.[43] Compared to agricultural water use of 29.7 million acre-feet/year, urban demand is about 44 percent of agricultural water consumption. In addition to geographic location, relative size of water demands due to population density may also play an important role in policy decisions when it comes to costs distribution and adaptations.

Although urban demand is about half of agricultural water use, urban users experiences scarcity that are much smaller than their relative size in water use. The general trend observed is that urban users have almost no water scarcity despite the warmer climate. For 2020, the total water scarcity is estimated to be 123 thousand acre-feet at about 1 percent of total demand. For 2050 with drier climate, urban scarcity still remains at 1 percent with 81 thousand acre-feet shortage.[44] The result is startling; there is a decrease in the amount despite the larger demand and worse condition in 2050. Compared to urban results, agricultural scarcity is 24 times bigger than urban scarcity at 6.981 million acre-feet in 2050. Furthermore, the urban water scarcity reported above exists entirely in Southern California with zero scarcity in Sacramento Valley, San Joaquin Valley, and Tulare Basin. [45] Water market and interregional transfer are the two major factors in influencing urban water supply. Urban users don’t experience scarcity because they are able to buy water from agricultural users, which in turn shift water scarcity to the agricultural sector. In Southern California’s case as with most urban demands, a large base of imported water is usually the main source of water

[42] Medellin et al., 2006, 6.
[43] Medellin et al., 2006, 6.
[44] Medellin et al., 2006, 9.
[45] Medellin et al., 2006, 9.

supply. Even though agricultural users are losing water (incurring scarcity cost), the imported supply is made reliable by urban user's high willingness to pay.[46]

Though urban water users have almost no water scarcity, the economic impact of climate change is still substantial. Two scenarios of economic damage for 2050 were modeled in the study. The first allows statewide water transfers for optimal economic usage. In this case, urban scarcity cost is about $44 million/year from population growth; however, the cost rises by $14.6 million/year to $58.6 million/year with dryer climate. Of the $58 million/year, Southern California bears about 90 percent of the total scarcity cost at $53 million/year.[47] For the second condition, optimization is limited to only intra-regional transfers. This scenario is more realistic and representative of California's infrastructure if no major modifications have been done by 2050. Under historical conditions, the scarcity cost is at $154 million/year, a significant $110 million/year increase from those of statewide optimization. With warmer climate, the cost increases by $10 million/year at $164 million/year, which is smaller than the increase under statewide optimization.[48] Southern California pays 97 percent of the $164 million/year bill at $158.6 million/year. The results suggest that urban water users, especially densely populated Southern California, are heavily dependent on the water market. The maintenance and facilitation of water systems and transportation should be stressed, as the consequences of not having an adequate system will result in a huge scarcity cost on water users. Though climate change seems to have smaller effects than those of infrastructural impacts, it is the combined effects of climate change and water inflexibility that causes such enormous damages.

Table 1.3. 2050 Water Impacts on Urban Users

	Dry (regional)	Historical (regional)
Urban Scarcity	204 TAF (2%)	195 TAF (2%)
Urban Scarcity Cost	$164 million/year	$154 million/year
	Dry (statewide)	Historical (statewide)
Urban Scarcity	81 TAF (1%)	60 TAF (0%)
Urban Scarcity Cost	$58 million/year	$44 million/year

Like the agricultural table, the urban table summarizes the effect of climate change and water flexibility. Urban scarcity is low to begin with, but with sufficient water transfer, a substantial portion of scarcity can be eliminated. Overall, scarcity remains around 1-2 percent.

Table 1.4. Urban Demand and Urban Cost in Different Studies

[46] Medellin et al., 2006, 9.
[47] Medellin et al., 2006, 14.
[48] Medellin et al., 2006, 14.

Urban Demand: MAF (% scarcity)		Urban Cost: millions/year	
Hanemann	4.2 MAF (7%) [SoCal only]	Hanemann	$300 [SoCal only]
Medellin	12 MAF (1%)	Medellin	$58
Tanaka	N/A	Tanaka	$872
Medellin-Azuara	13.3 MAF (<1%)	Medellin-Azuara	$59

Results from other papers are presented here. Numbers vary greatly due to assumptions and climate models of each individual study. Hanemann's paper reflects a much larger scarcity and cost for the region of Southern California, which dwarfs statewide results for both the Medellin and Medellin-Azuara studies. Like the agricultural case, Tanaka's study contains the largest cost but is over a much longer timeframe.

Adaptation Options

The evidence has shown that climate change has been and will be causing substantial economic cost in California. Academic institutes and other state funded agencies have come up several potential solutions to help prevent and minimize the damage done. These potential adaptations include: secure additional and reliable water supply, improve drought preparedness, improve operational flexibility, and promote water use efficiency.[49] There are various methods to achieve these desired outcomes. Keeping the costs and benefits in mind, some methods are not practical, while others are excellent candidates for implementation. For most of these options, the cost ranges are wide; this is due to differences in each specific project including: variations in project complexity, regional differences in construction and land costs, treatment cost, availability of infrastructure, etc. The wide range of cost is another barrier to the implementation of adaptations because actual costs are hard to estimate especially when the costs are all very high. Consequently obtaining state funding is critical in the execution of these adaptations. With limited funding, the choice of implementation depends entirely on the net gain from the adaptations and policymakers in California. Even so, net benefits and savings remain uncertain without further research and data.

[49] DWR, 2005 5.3.

Table 1.5. Summary of Adaptation Strategies

Adaptation Strategy	Adaptation Potential	Cost	Average Total Cost
Water Market	~1.2 million acre-feet	$75-$185 per acre-foot	N/A
Groundwater and remediation	~2 million acre-feet	$10-$600 per acre-foot	$1.5-$5 billion
Desalination	~0.6 million acre-feet	$250-$2000 per acre-foot	$2 billion
Urban Efficiency	~2.1 million acre-feet	$227-$522 per acre-foot	$99-$236 million/year
Agricultural Efficiency	~1.6 million acre-feet	$35-$900 per acre-foot	$0.3-$2.7 billion

Adaptation: Water Market and Transfer

Without a doubt, the most practical answer to water scarcity is increasing water supply. Obtaining additional water can be easy or difficult depending on the source. These sources include stored surface water from other users, groundwater, water from crop idling, and water saved from increased efficiency.[50] As the result of an increasing need to secure additional water supply, a market for sale of water rights has emerged for both temporary and permanent needs. Water market functions as a flexible source of water that can be effective when incorporated with other forms of water management strategies.

The water market has grown substantially since the mid-1980s with the increased volume of water transferred. Compared to the 80 thousand acre-feet transferred in 1985, the amount of water transferred between districts in 2001 was 1250 thousand acre-feet. Of the current volume transferred, urban transfers account for about 20 percent while agricultural and environmental transfers have increased to 50 percent and 30 percent.[51] Large participation percentage of these two sectors suggests enormous benefits from water transfers. More water has become available that otherwise wouldn't have been. Since 1998, the State Water Project and Central Valley Project have incorporated water transfer as part of the management strategies to free up to 175 thousand acre-feet of water per year.[52] Additional water supply can also be made available by crop idling of rice and cotton. In Sacramento Valley and San Joaquin Valley, a total of 700 thousand acre-feet of water can be made available without significantly damaging the overall agricultural economy (1 percent of countywide

[50] DWR, 2005, 23.1.
[51] DWR, 2005, 23.3
[52] DWR, 2005, 23.1.

economy).[53] A developed water market essentially guarantees a new source of water supply whether temporary or long term.

Consider all the participating regions in California, 75 percent of all transfers originate within the Sacramento and San Joaquin Valleys, with the remaining transfers taking place in Southern California, the other major participating region. These three regions make up the bulk of the water transfers in California. More importantly, studies show water transfers are predominately localized (probably due to high conveyance cost). About 75 percent of all transfers take place within the same region, and 25 percent of those are traded within the same county.[54] Although interregional transfers only accounts for 25 percent, potential benefits are large. With climate change, the cost of restricting water transfers is projected to be $151 million/year. Even without warmer climate, the estimated cost of interregional inflexibility is still $108 million/year.[55]

Water Market and Transfer: Benefits

Water markets result in numerous benefits for the users. Another study, done at the University of California, Davis, suggests that as much as $1.3 billion/year statewide in economic benefit can be achieved through water transfers.[56] This is possible because water transfers acts as a safety net for forecasted future water scarcities, which allows water to be moved from areas with low demand to areas with high scarcity. With a maximum of 15 percent reduction in water use for exporters, the study suggests that only mild reduction in deliveries is needed to achieve the significant economic benefits. Up to 80 percent of economic impact from water scarcity can be reduced when water transfer is combined with effective water management strategies.[57] Thus, by expanding and encouraging interregional water transfers, there is a large potential in savings.

Simply put, water markets provide “economic incentives for those with high-priority water rights and contracts but low-valued water uses to sell water to others with more economically productive water uses”.[58] With respect to the water exporter, the sale of their excess water supply may result in revenues that can be used to fund beneficial activities. At the district level, the revenue may be used to fund public services or improve local facilities, environmental conditions or help reduce water rates. For example, Yuba County Water Agency has spent over $10 million of water revenues on flood control projects. Another benefit of water transfer is the incentive to improve water infrastructure in order to minimize cost of transfer.

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[53] DWR, 2005, 23.5.
[54] DWR, 2005, 23.3.
[55] Medellin et al., 2006, 22.
[56] DWR, 2005, 23.6.
[57] DWR, 2005, 23.6.
[58] Medellin et al., 2006, 22.

"Water markets facilitate the reallocation of water from agricultural to growing urban uses, as well as more economical operation of water resources to improve the overall technical efficiency of water management."[59]

Conveyance cost and transfer capacity plays a large role in the price of water. Enhancing these two areas will assist with the reduction of cost and scarcity. At the private level, farmers who have sold their water supplies are compensated by the revenues, which they can use to reinvest into the farming business. [60] The farmers are very likely to profit from the sale of water, because they would have otherwise incurred a scarcity cost if revenues were too low.[61] Secondary economic impacts from water transfers include the reduction of job losses incurred from water scarcity costs of farms.[62] The environment can also benefit from water transfer. By moving agricultural water for environmental use, potential habitats that were disturbed by the reduction of water can now be restored by drawing water from a different source.

Water Market and Transfer: Cost of Implementation

Water transfers, though highly beneficial, have several considerable costs and barriers. Water purchased is usually costly because the sale price only reflects the cost needed to make the water physically available. Buyers must also pay conveyance, storage, and treatment costs that are not included in the initial price of water. The cost of conveyance can be significant, summing up to as much as 100 percent of the original price. For example, in 2003, the Environmental Water Account purchased water ranging from $75 to $185 per acre-foot. The lower prices are water purchased from Northern California, while higher prices are water purchased from the groundwater bank in Kern County where conveyance cost is high.[63] Lowering theses additional costs can facilitate and increased usage of the water market.

Water Market and Transfer: Barriers

Another problem with water markets is that agricultural productivity is decreased and there are cost externalities for farmers not participating in the transfer. Reduction in demand of farm inputs, raw material, and labor is inevitable with the presence of water transfer and crop idling.[64] Consequently, those sectors will be negatively affected from an increase export of water. Since the agricultural sector often holds the largest source of water for transfers, it is crucial to balance the demand for water exports while maintaining a stable agricultural economy within the exporting region.[65] To solve this

[59] Medellin et al., 2006, 22.
[60] DWR, 2005, 23.5
[61] Medellin et al., 2006, 13.
[62] DWR, 2005, 23.7.
[63] DWR, 2005, 23.6.
[64] Howitt and Sunding, 187.
[65] DWR, 2005, 23.6.

problem, the California Department of Water Resources have already set up regulations to control the amount of water transferred. The law requires that "water transfers not unreasonably affect the overall economy of the county which the water is transferred."[66] However, concerns with over-regulation emerge as restrictions may slow down or even deter short-term transfers that may have multiple benefits. Benefits and profits of water transfer are sometimes uneven and disproportional, so it is difficult to weigh the net benefits when some gain while others lose.

Adaptation: Groundwater

Groundwater is a vital source of water that can be used with surface water to provide optimal water portfolio. The strategy, called conjunctive management, is to recharge groundwater storage when surface water is available. Substitution of groundwater by surface water is often needed to take demand off groundwater to allow it to recharge either naturally or artificially. As soon as a drought hits and surface water is scarce, the water source will be shifted to the recharged groundwater supply.[67]

Groundwater: Benefits

With proper monitoring, this strategy can be very effective and implemented both on a local and regional level. On the regional scale, Southern California has increased its average-year water deliveries by more than two million acre-feet through conjunctive management. Through artificial recharge of groundwater aquifers, the groundwater storage capacity has increased by seven million acre-feet. On the local scale, Santa Clara Valley Water District obtained 138 thousand acre-feet of storage capacity by recharging groundwater artificially via local creeks and recharge ponds. They achieved groundwater levels to those of early 1900s.[68] By preventing overexploitation of groundwater during normal years, conjunctive management has improved water supply quality and reliability. Potential statewide increase in water deliveries can be up to 500 thousand acre-feet with an additional nine million acre-feet of groundwater storage. A more aggressive estimate predicts that with a major renovation of existing surface reservoirs and groundwater, an increase of two million acre-feet for water deliveries and 20 million acre-feet of new storage can be achieved.[69] The result of conjunctive manage is highly dependant on the ability to acquire and recharge surface and groundwater of suitable water quality. Expansion of current storage and conveyance infrastructure can result in wider use and flexibility of conjunctive management projects. In addition to a direct water supply increase, beneficial secondary effects also result from conjunctive management. One such benefit is the prevention of groundwater overdraft and land subsidence. Protection of groundwater supplies also help wildlife

[66] DWR, 2005, 23.7.
[67] DWR, 2005, 4.1.
[68] DWR, 2005, 4.1.
[69] DWR, 2005, 4.2.

habitat such as wetland recover while they recharge. When shifted to groundwater use, the increase in surface instream flow can lift pressure off aquatic species.[70]

Moreover, additional groundwater supplies can be obtained through remediation of contaminated groundwater aquifers. Groundwater remediation is the process of treating groundwater and improving the water quality to a given standard depending on the use. Contamination can both occur naturally such as heavy metals or artificially from industrial, mining operations, or various runoffs. Currently, there are about 18,500 sites where active cleanup is taking place. Potential supply can meet up to 40 percent of the state's water demand.[71] Once treated, these aquifers can provide a significant amount of water, making additional water supply available that would not have been. Even if treated water do not meet high drinking standards in quality, they may still be allocated for other uses that can free up drinking water supply. One long-term benefit is that the groundwater aquifers may eventually be cleaned to the point that no further treatment is necessary, providing a reliable clean source of water.[72] Remediation also has substantial secondary effects. The avoided costs include foregone profits and taxes from businesses that decide not to locate in the area with water shortages. Moreover, controlling contaminants can prevent further spreading and cut down future remediation costs.

Groundwater: Costs of Implementation

As with the water market, groundwater usage with conjunctive management has many costs and issues associated with it. With respect to conjunctive management, the cost can range from $10 to $600 per acre-foot increase in average annual delivery. The average projected cost reported by Department of Water Resources is $110 per acre-foot.[73] The large range of cost is due to the many factors that influence the costs of increasing water deliveries. These factors include project complexity, regional differences in infrastructure, quality of recharged supply, treatment cost, and intended use. High value for water from urban demands usually results in higher willingness to pay for these water projects than agricultural users.[74]

The physical extraction process is especially costly for groundwater remediation. The costs consist of identifying all the contaminants, the capital cost of the system, and operation expenses during the length of the project. The reported cost associated with groundwater cleanup can easily exceed $300 million annually with per-site cost ranging from $100,000 to $200,000. Despite the high costs, state programs often provide reimbursement for eligible claimants. Current reimbursements distributed are about

[70] DWR, 2005, 4.2.
[71] DWR, 2005, 11.1.
[72] DWR, 2005, 11.5.
[73] DWR, 2005, 4.5.
[74] DWR, 2005, 4.4.

$180 million annually with some as high as $1.5 million per site. Finally, data from the California Department of Water Resources predicts that remediation costs could approach $20 billion over the next 25 years.[75]

With such a high price tag, some source of groundwater may be difficult to obtain due to political barriers. The determining factor in the execution of groundwater remediation is the timing of the result. Remediation can often take years to complete in which the parties who paid may not receive the benefits by the time remediation has been completed. Funding can be difficult to obtain when no apparent short-term benefits are available.[76]

Groundwater: Barriers

Water transfers tend to increase the incentive for pumping groundwater to substitute for the surface water sold. Some water right holders will want to sell surface water for profit by pumping additional groundwater for use. A raise in groundwater pumping causes a drop in groundwater levels, reduction of water quality, and increases groundwater-pumping costs for other users.[77] These actions conflict with the conjunctive management system making it harder to implement. The problem exists because groundwater is loosely regulated by the state. "Because groundwater resources are not regulated by the state, the implementation of the California water market has sparked concerns that aquifers will be subject to uncontrolled mining."[78] Because groundwater is an attractive source of water, California may risk losing a large portion of groundwater and face high water scarcity if groundwater is not properly controlled.

Nevertheless, groundwater export is not without any regulation. On the local level, counties often have their own ordinances and agencies managing a portion of groundwater being exported.[79] Since 1995, numerous ordinances have been passed to prevent and deter excessive groundwater export. By 2002, 22 of the state's 58 counties had put ordinances that require the acquisition of a permit before extraction and export of groundwater.[80] The process also includes an environmental review, which makes it even more difficult for individuals to obtain water rights. So far, results are promising. Statistics show that groundwater has decreased by 14,300 acre-feet in a county since implementation in 1990. Totally groundwater exports statewide has been reduced by 19 percent at 932 thousand acre-feet, and total water sales were reduced by 14 percent at 787 thousand acre-feet since 1996.[81] Overall, groundwater is an excellent alternate

[75] DWR, 2005, 11.5
[76] DWR, 2005, 11.6.
[77] Howitt and Sunding, 187; Vicuña et al., 19.
[78] Howitt and Sunding, 187.
[79] DWR, 2005, 4.5.
[80] Howitt and Sunding, 188.
[81] Howitt and Sunding, 188.

source of water supply; however, both political and financial barriers decrease the optimal efficient use of the resource.

Adaptation: Desalination

Desalination, a costly process in the past, has become a more common method of increasing water supply. Due to innovation in desalination technology and the rising cost of alternative water supply, desalination is becoming more practical. Though capacity is relatively small and limited, it can be incorporated into the water management portfolio to provide a more versatile water program. Currently, there are 24 desalination plants in use in California operating on both groundwater and seawater. Their annual output is about 79,000 acre-feet. Additional plants are in the process of being built or designed with estimated increase of 29,500 acre-feet of water annually.[82]

Each region in California is actively approaching desalination with numerous funding in projects and studies. In the San Francisco Bay Area, local agencies are funding the planning of a 120,000 acre-feet/year production facility. In Central and Southern California, studies of planning sustained production of 20,000 and 150,000 acre-feet/year are also being funded as well.[83] The statewide objective is to increase the water supply from desalination five-fold to 587,200 acre-feet/year. In addition to the 23 operating facilities, a total of 26 more will be constructed by 2030. This is a substantial increase in the usage of water desalination, which provides strong evidence that desalination is becoming more affordable.

Desalination: Benefits

In addition to the increase supply of water, desalination can provide water reliability during drought periods without pressuring groundwater or surface sources that are already in use. Increasing diversification in water sources can lighten environment impacts via alternative water sources.[84] Feedwater source for desalination are not limited to only groundwater and seawater; recycled municipal wastewater can also be treated. Overall, desalination of water is similar to groundwater remediation, which improves the water quality to a potable level from sources that would have otherwise been unavailable.

Desalination: Cost of Implementation

Though desalination has become more efficient and cheaper than in the past, it still has some significant barriers associated with it. These costs can be categorized into monetary, environmental, and time. In 2005 alone, $25 million dollars were granted to research and development of desalination projects. Aside from research cost, actual production cost of water is costly. The estimated cost of increasing desalination water

[82] DWR, 2005, 6.1.
[83] DWR, 2005, 6.2.
[84] DWR, 2005, 6.2.

supply by 415,000 acre-feet/year is about $2 billion. These water supplies cost so much in capital because the lifetime of water producing plants are only 20-30 years.[85] Per unit cost of water varies widely, ranging from $250 to $2,000 per acre-foot. The lowest costs are associated with groundwater desalination and highest with seawater.[86] In the study presented earlier, climate change still does not result in a wide usage of desalination. The average price tag is $1400/acre-foot, which is relatively high compared to other alternative sources of water. Under the model, only Southern California, with the highest marginal willing to pay, will approach this method of water supply producing 5.93 thousand acre-feet of water.[87] Due to the factors influencing production cost, the price varies from region to region depending on the type of feedwater, proximity of distribution systems, availability and cost of power, and disposal options of waste.[88] Because these projects vary case by case, environmental-specific investigation is required and often takes a long time to fully estimate the impact and issue a permit for construction. Another considerable time constraint is the relative implementation and operating lifetime of the facility. Cost and benefits must be reevaluated if it takes 20-30 years to implement plans that will only last 20-30 years.

Adaptation: Urban Water Use Efficiency

Urban water use efficiency involves lowering the water demand and per capita water use through technological or behavioral improvements. The present state of California's urban water use efficiency has benefited from much improvement over the past decade. In some parts of the state, an increase in population did not necessary result in a proportional increase. As of 2002, Los Angeles Department of Water and Power reported that water conservation helped keep the city's water use similar to levels seen 20 years ago.[89] Through the efforts of California Urban Water Conservation Council, urban water agencies cooperate to increase water use efficiency through public awareness, research and development, and policy incentives. For example, of the current 2.5 million water efficient toilets installed statewide; there remains ten million more to be installed and replaced.[90] Like the water efficient toilets, large water saving potential exists in household appliances, hardware, and irrigations. Other forms of water use efficiency are behavioral incentives. For example, rebates of $450 on purchases were awarded to people who purchased high efficiency washing machines. The CALFED Record of Decision estimated that water savings range between 0.8 million and one million acre-feet/year by 2030; furthermore, a more optimistic study

[85] DWR, 2005, 6.4.
[86] DWR, 2005, 6.5.
[87] Medellin et al., 2006, 22.
[88] DWR, 2005, 6.4.
[89] DWR, 2005, 22.1.
[90] DWR, 2005, 22.1.

done by the Pacific Institute suggests that the potential can reach up to 2.3 million acre-feet/year.[91]

Urban Water Use Efficiency: Benefits

The major benefit of improving water use efficiency is the reduction of water demand and flexibility of existing water supplies. Though additional water supply does not result from water use efficiency, the conserved water can be stored in water banks for droughts. Reduced water use will lower costs for residential and commercial parties. Operating and environmental costs can also be lessened when less water is demanded from water sources. The conservation approach is slowly being utilized as a long-term supply option rather than a short-term source of water.[92]

Urban Water Use Efficiency: Cost of Implementation

In a study done by California Bay Delta Authority, water reduction can cost between \$522 to \$233 per acre-foot depending on the level of state and local funding.[93] The actual price can vary greatly depending on the condition of the region, but the price is still lower than other urban supply options such as desalination or recycling. Obtaining the cheaper price requires a huge sum of grants. Including funds from Proposition 50, total annual investments of \$236 million were required to achieve 2.075 million acre-feet demand reduction. [94] The results are promising, but the full results cannot be expected until 2030. A constant and significant amount of funding may render water use efficiency development impractical. The problem with implementing water use efficiency projects is that funding has always been insufficient. In 2002, the expenditure was short \$4 million, and in 2003, \$235 million was short.[95] Other non-monetary impediments include lack of data, people's priority of water conservation, and communication barriers. Despite these barriers, the relative costs suggest that urban water use efficiency is likely to take a more prominent role in urban water management.[96]

Adaptation: Agricultural Water Use Efficiency

Agricultural water use efficiency involves improvement in on-farm irrigation equipment, water supplier systems, and crop water management. Farmers have a large incentive to minimize water consumption because it drives down production cost. However, they will only do so if the implementation cost is not higher than the amount saved. Like urban efficiency, the agricultural sector has made considerable technological improvement on water efficiency. For a unit of applied water, California crops have

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91 DWR, 2005, 22.3.
92 DWR, 2005, 22.2.
93 DWR, 2005, 22.5.
94 DWR, 2005, 22.6.
95 DWR, 2005, 22.6.
96 DWR, 2005, 22.5.

increased output by 38 percent and adjusted crop revenue has increased by 11 percent from 1980 to 2000.[97] The observed progress is only possible through the efforts of the agricultural industry, state, and federal agencies. Growers who are willing to risk their crops to adopt new technologies are often the ones that benefit most from the research of both commercial and academic institutes.

Hardware improvements include upgrading water delivery system, data acquisition, canal automation, and other operating components that ensure reliable and accurate water delivery. Large scale change in irrigation systems from furrow/flood to sprinkler/drip systems have been observed in the recent decade. They incorporate satellite information on crop and soil conditions to manage water delivery optimally. This system has been so effective that a change of 16 million acre-feet in water delivery has been shifted to either sprinkler or micro-irrigation system. The result is a productivity increase of up to 30 percent.[98] High benefits of advance systems also come with a high price tag. Most growers, especially smaller ones, are unwilling to make such a substantial investment in upgrading their irrigation system, which are also more power-intensive than older systems. This change will result in an increase in the production cost, which profit seeking growers are not interested.

Agricultural Water Use Efficiency: Benefits

Potential benefits from increasing agricultural water use efficiency can result in an estimated 1.6 million acre-feet/year of reduction in water. This large reduction is not only beneficial to crop production with lower cost, but also benefits the environment. At the cost of about $220 million, All American Canal and Colorado River Hydrologic Region will be able to reduce a total of 94,000 acre-feet/year of irrecoverable flow by lining the canals.[99]

Agricultural Water Use Efficiency: Cost of Implementation

Problems associated with agricultural efficiency include limited funding, willingness of the growers, and poor management. The projected per acre-foot cost ranges from $35 to $900 million, for a total net water savings of 563,000 acre-feet. At this level of savings, the annual spending can amount between $0.3 billion and $2.7 billion, which includes the canal renovation cost.[100] Like other adaptations mentioned, a large funding requirement is often the problem with carrying out these projects. Small communities who need these adaptations the most often lack political and financial means to carryout these water management practices.[101] Even when advance water saving systems are available, farmers who do not participate or poorly manage their water will not result in

[97] DWR, 2005, 3.1.
[98] DWR, 2005, 3.4.
[99] DWR, 2005, 3.5.
[100] DWR, 2005, 3.7.
[101] DWR, 2005, 3.7.

the desired outcome. Furthermore, some farmers feel that they are not necessarily using the water they save. They feel that there is no need to conserve water if they do not have the right to utilize them. However, these obstacles can be overcome. State funded grants or loans should provide incentives for farmers to adopt new technologies. On the local level, technical and planning assistance to implement better water management practices should be funded. Most importantly, public awareness and priority should be organized to help encourage and educate others in the area of water conservation. With enough help, conservation levels that surpass those observed in the past are achievable.

Financing Water Provision

Finance will play a major role in California's water adaptation efforts. As noted in its 2005 Water Plan Update, California's prevailing water policy is to "recover costs for such things as planning, operation, maintenance, capital, administrative, and some environmental costs. Secondary priorities are maintaining contributions to capital investment funds for future water projects, settling debts, and recovering external costs such as third party fees.[102] Ad valorem taxes and revenue from bonds not repaid from water rates are two other tools used to recoup costs.[103]

In some situations, agencies are not required to recover their full costs of development and maintenance. This generally occurs when an agency is advancing a social goal affecting water use. For example, the U.S. Bureau of Reclamation is not required to recover all costs of supplying water to agriculture. Similarly, because of significant federal grant funding through the Clean Water Act, urban wastewater treatment projects are often not required to recover their costs.[104]

There is variety in the structure of water rates: fixed, tiered, and uniform structures are all used. Under a fixed pricing structure, users pay the same fixed amount each month, regardless of water use; a uniform pricing structure means that a user pays a constant amount per unit of water used (requiring a metering system), and under a tiered structure the rate paid per unit increases or decreases as use exceeds certain predetermined amounts. These pricing schemes are not mutually exclusive: a fixed component might be present within uniform or tiered pricing structures and so on. If water use is unmetered in an area, fixed assessments such as connection size for urban areas or acreage irrigated for agriculture might be needed to determine rates.[105]

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[102] Department of Water Resources, 2008a, *California Water Plan Update, 2009*: *Volume 2, resource management strategies, economic incentives.*
[103] Department of Water Resources, [a]. (2005) *California Water Plan Update, 2005*: *Volume 2, resource management strategies.*
[104] DWR, 2008a.
[105] DWR, 2008a.

The general trend for California urban water agencies is toward tiered rate structures where price is based upon the amount of water used. For the tiered systems, price generally increases as consumption increases: with each additional unit of water used, the price for subsequent units increase. A problem for densely populated areas is that within an apartment building, individual tenants are not metered, and thus do not receive the benefits of conserving under volumetric pricing.[106] In some areas, seasonality is also a pricing issue. Some agricultural water providers also use tiered pricing schedules. Residential wastewater treatment is generally governed under a flat-rate pricing scheme, commercial and industrial users are more likely to be to be charged by volume, and possibly content.[107]

Decreased consumption of water is the primary motivator for the use of economic incentives such as low-interest loans, grants, or water pricing rates. However, alterations to time and amount of use, wastewater volume, and the source of supply are also common goals. Other benefits can be environmental, social, or as simple as the avoiding construction of additional supply projects. When faced with higher rates, consumers can either reduce consumption or pay the higher price. Hopefully the higher rates would prompt investment in more efficient technologies, or moderation of use (decreasing landscaping or agricultural acreage).

Setting appropriate water rates is difficult. A water shortage exacerbates this problem because incremental costs of supply can change (particularly increase) quickly, more rapidly than rates, making it difficult to recover costs. Under a system not allowing collection of revenues in excess of cost, a skewed structure might be necessary, with lower-tier prices being reduced and higher-tier prices increased; this could easily lead to an increase in average consumption by users situated in the lower-tier, an undesirable outcome for water management. Also, an increase in the price of surface water could motivate users to increase consumption of well water, decreasing groundwater volume and recharge.[108]

Equity considerations can arise when economic incentives are implemented, such as when one group of citizens incurs the cost of subsidizing another group without receiving a proportionate share of the benefit. Also, economic incentives directly affecting one group of users might have repercussions in secondary markets. An example is found when the price of water for agricultural users is increased: a decrease in water use can lead to an alteration of crop patterns and a change in farm labor required. Communities heavily dependent upon agriculture could potentially suffer, and

[106] DWR, 2008a.
[107] DWR, 2008a.
[108] DWR, 2008a.

jobs in the landscaping sector could be similarly affected by an increase in the price of water in urban areas.[109]

In 2000, approximately 8.7 million acre-feet of water was used by California cities and suburbs.[110] An immense amount of power is required to transport California's water across the state. In fact, the transportation and treatment of water (before and after it is used) in California consumes about 19 percent of all electricity, and 30 percent of non-power plant natural gas.[111] Many inter-basin transfer systems have notable hydroelectric capabilities, but the State Water Project (SWP) nonetheless remains a net energy user. However, wise use of resources, such as using baseline energy to pump water and generating hydroelectricity during on-peak hours, ensures the SWP works as efficiently as possible.[112]

Many local and regional projects which are essential to expanding water supply are funded through local taxes. An 800,000 acre-foot reservoir in Riverside County, the Metropolitan Water District's Diamond Valley Lake, is an example of a project funded for the most part by local users.[113] Other primarily locally-funded projects are planned but not yet completed, such as an upgrade to San Francisco's Hetch-Hetchy system and an expansion to water use from Lake Nacimiento in San Luis Obispo.[114]

When attempting to enlarge water supplies, an increase in local water prices might be the most equitable option, as well as potentially having the benefit of a reduction to consumption, but is often met with resistance.[115] Explicit impact fees for new water might be a good alternative. Such practices are already widely used in Colorado and Southern Nevada, and would essentially place the responsibility of supply augmentation upon utilities. In determining an impact fee for a new project such as a development, the local utility estimates each new home's approximate portion of costs to the development. Water resources are effectively packaged together with other community amenities such as schools, roads, and wastewater systems.[116]

Residential

A study by the engineering firm Black and Veatch found that from 2003 to 2006, the average monthly water bill for a single family residence in California increased from

[109] DWR, 2008a.
[110] Department of Water Resources, 2008b, *California Water Plan Update, 2009*: *Volume 2, resource management strategies, urban water use efficiency*.
[111] DWR, 2008b.
[112] DWR, 2008b.
[113] Hanak, E. (2005) *Water for Growth: California's new frontier*. Public Policy Institute of California, San Francisco.
[114] Hanak, 2005.
[115] Hanak, 2005.
[116] Hanak, 2005.

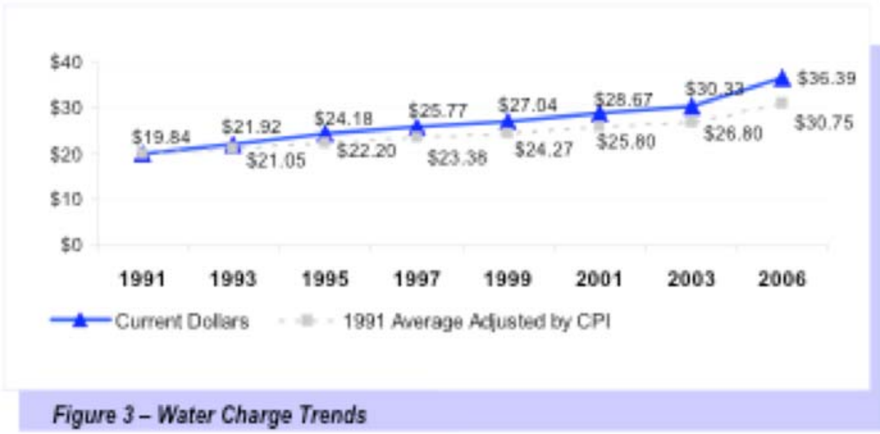
$30.33 to $36.39, a 16.7 percent total increase over three years.[117] It is important to note that Black and Veatch's study determine the water bill for residential households according to their individual pricing structure, but with a fixed volume of 11,000 gallons (1,500 cubic feet). Also, an overwhelming majority (87.6 percent) of water providers increased their rates over the three-year span, while only six percent reduced rates. Water rates are increasing at a rate exceeding inflation; the differences attributed by Black and Veatch to "increasing cost of construction materials, stringent water quality regulations, and an aging infrastructure."[118] Figure 1.1 shows the trend of prices across the three most recent incarnations of the Black and Veatch's study. Using 1991 as the base year, Figure 1.2 demonstrates the price of water in comparison to other consumer goods as a plot of residential water rates and the Bureau of Labor Statistics' Consumer Price Index.

Figure 1.1. Residential Water Rates in California

Source: Black and Veatch, 2006.

[117] Black and Veatch, 2006, *2006 California Water Rate Survey*.
[118] Black and Veatch, 2006.

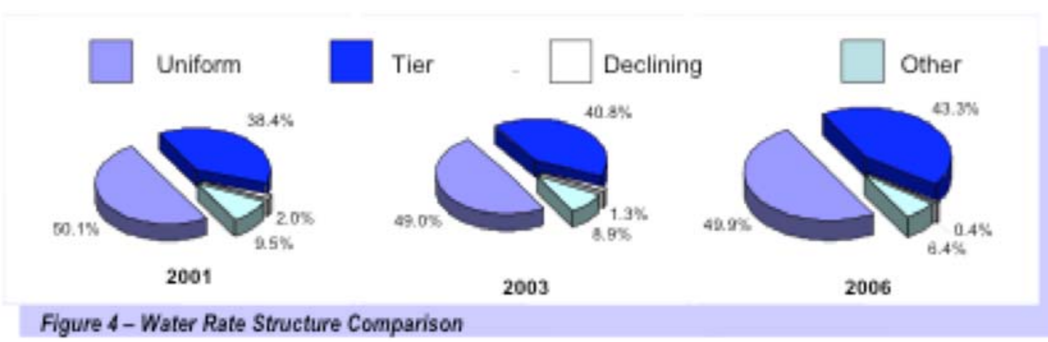
Figure 1.2. Relative Water Prices in California



Source: Black and Veatch, 2006.

Sixteen percent of the suppliers surveyed by Black and Veatch received additional financial support in the form of "grants, contributions from other funds, special assessments, general fund transfers, and property taxes."[119] As one might imagine, this supplementation can lead to lower water rates. From 2001 to 2006, there has not been a large amount of change in the structure of water rates, though some general trends, the most noteworthy being as increase in the prevalence of tiered rate structures, as Figure 1.3 demonstrates. The majority of water users interviewed by Black and Veatch (61.4 percent) are billed monthly, and most of the remainder (37.5 percent) are billed bi-monthly.[120]

Figure 1.3. Water Rate Structures in California



Source: Black and Veatch, 2006.

Geography is an important determinant of water rates. Figure 1.4 shows the remarkable differences of water rates by county. The price of water in the most expensive county is more than three times the cost of water in the cheapest county. There is also variety in

[119] Black and Veatch, 2006.
[120] Black and Veatch, 2006.

the water rate structure across the state. Figure 1.5 divides the state into four regions and examines them according to structure. In Figure 1.5, the “other” category consists primarily of flat rates, and results from a lack of installed water meters, as is often the case in the San Joaquin Valley.[121]

A resident’s water bill has three primary components: the fixed fee, variable rate, and connection fee. A fee is usually highest where capacity constrains a system. A connection fee is not universal; 29 percent of cities surveyed by Black and Veatch did not charge for connection. However, in areas such as the East Bay, 2006 connection fees were as high as $24,800.[122]

Figure 1.4. Water Rates in California by County

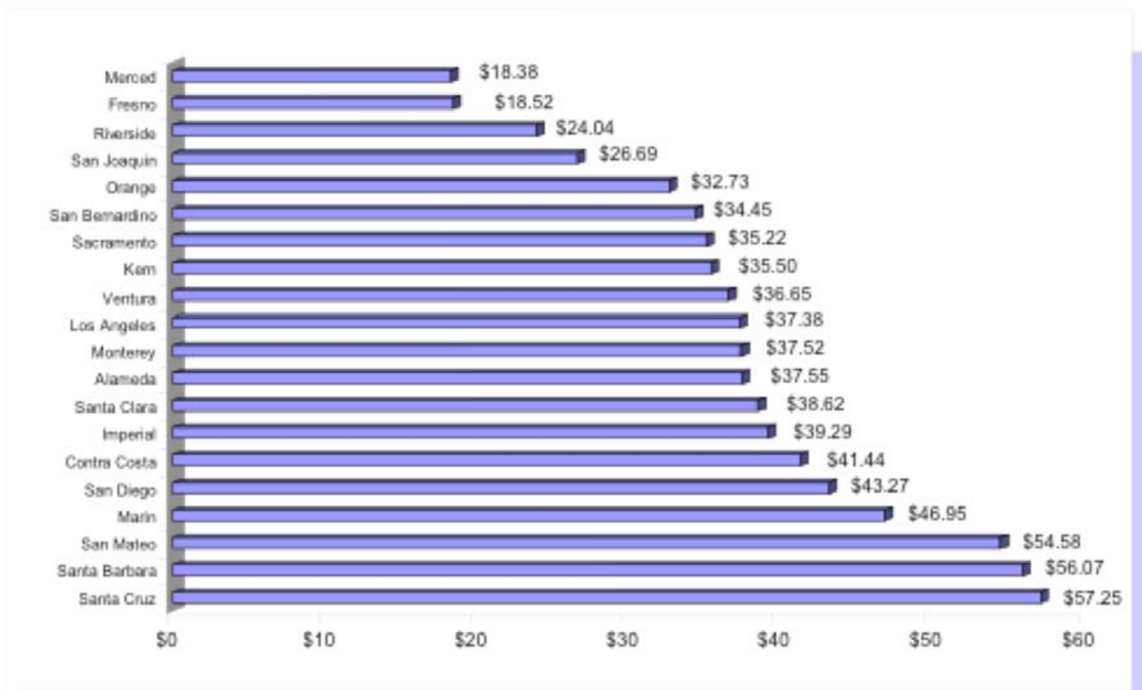


Figure 6 – Monthly Water Charge Comparison Between Selected Counties

Source: Black and Veatch, 2006.

121 Black and Veatch, 2006.
122 Black and Veatch, 2006.

Figure 1.5: Water Rates in California by Region

Region/ Rate Structure	2001 Survey	2003 Survey	2006 Survey	Change Between 01 & 03	Change Between 03 & 06
	%	%	%		
Northern					
Uniform	37.9	38.1	35.4	0.2	(2.7)
Tiered	50.2	49.0	54.3	(1.2)	5.3
Other	11.9	12.9	10.3	1.0	(2.6)
Coastal					
Uniform	34.5	34.5	39.1	0.0	4.6
Tiered	65.5	65.5	60.9	0.0	(4.6)
Other	0.0	0.0	0.0	0.0	0.0
San Joaquin Valley					
Uniform	32.1	30.2	33.3	(1.9)	3.1
Tiered	26.4	24.5	20.8	(1.9)	(3.7)
Other	41.5	45.3	45.8	3.8	0.5
Southern					
Uniform	66.7	64.4	63.6	(2.3)	(0.8)
Tiered	31.7	34.0	35.5	2.3	1.5
Other	1.6	1.6	0.9	0.0	(0.7)

Table 2 – Regional Rate Structure Comparison

Source: Black and Veatch, 2006.

Agriculture

Agriculture is an important sector of the California economy. According to the California Agricultural Statistics Service, in 2000 California used about 34.2 million acre-feet of water to irrigate an estimated 9.6 billion acres of cropland. Trends seem to be positive for efficiency of agricultural water use. For instance, agricultural production per unit of applied water (measured in tons/acre-foot) compiled for an index of 32 important California crops increased by 38 percent over the two-decade span of 1980 to 2000.[123] In the same time span California also saw an increase in inflation-adjusted gross crop revenue per unit of applied water (measured in dollars/acre-foot) of 11 percent.[124]

A recent CALFED (the California agency which coordinates the many different state and federal agencies working together on California's water issues) study generated estimates for potential water savings over the next two decades. However, because of the great yearly variance of a resource like water and the uncertainty related to applications of existing technology as well as the emergence of new technologies, the predictions are more ranges than concrete figures. CALFED predicted that if water efficiency practices continue at their current rates, by 2030 a savings of 120,000 to 563,000 acre-feet of water per year is possible. The study also predicts a reduction of

[123] Department of Water Resources, 2005a, *California Water Plan Update, 2005*: *Volume 2, resource management strategies.*
[124] DWR, 2005a.

1.6 million acre-feet per year in applied water.[125] Potential costs also vary greatly; assuming the savings due to efficiency gains is the more generous 563,000 acre-feet, per acre-foot costs could range from $35 to $900, for a total of between $0.3 billion and $2.7 billion.[126]

Central Valley annual rainfall ranges from 5 to 30 inches, depending on the region. Over three-fourths of the precipitation comes from December through April, producing seasonal droughts and floods as well as heavy runoffs in spring and winter. Water demand for agriculture is highest in fall and summer, when natural streamflow is at a minimal, so demand for water quickly outpaced available wellwater and its recharge from streams and rain.[127]

Though the Central Valley is geographically a desert, the land was found to be fertile, and by 1873, plans were formulated with the intention of transferring water from the Sacramento Valley to the San Joaquin Valley. The California Water Plan was birthed in the early 30s from fourteen reports written between 1920 and 1932 with funds appropriated by the state legislature, and examined issues such as drought, flood control, irrigation issues, and water flow in California.[128] The California Water Plan's first major venture planned for the construction of a 420 foot dam at Kennett in order to regulate water flow to Antioch and keep salt water out of Suisun Bay.[129] This dam, the first phase of the Central Valley Project (CVP), was approved by the California legislature as a state project, funded by the sale of up to $170 million in "revenue" bonds.[130] However, even with the approved bonds, California was unable to finance the project and was also unable to secure loans or grants under the National Recovery Act. Eventually, the House of Representatives' Committee on Rivers recommended $12 million in Federal on the grounds of national benefits to navigation and flood control of the Sacramento River.[131]

The federal government assumed control of the project with The Rivers and Harbors Act of 1935; first few phases were funded by The Emergency Relief Appropriation Act of 1935, and constructed by the U.S. Army Corp of Engineers.[132] The Rivers and Harbors Act was re-authorized in 1937 for $12 million, and the Bureau of Reclamation took over construction of the Central Valley Project. The first priorities were navigation, regulation, and flood control of the Sacramento and San Joaquin Rivers; supply for irrigation and

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[125] DWR, 2005a.
[126] DWR, 2005a.
[127] Bureau of Reclamation (BoR), undated. *The Central Valley Project: Overview*. Retrieved 28 August 2008. {http://www.usbr.gov/dataweb/html/cvpintro.html#Intro}
[128] Bureau of Reclamation (BoR), undated, 2. *The Central Valley Project: General overview*. Retrieved 28 August 2008. {http://www.usbr.gov/dataweb/html/cvp.html#general}.
[129] BoR, undated, 2.
[130] BoR, undated, 2.
[131] BoR, undated, 2.
[132] BoR, undated.

domestic use, the primary purposes of the Bureau of Reclamation, were lower priority. As time went on, additional duties such as recreation, fish and wildlife enhancement, and water quality improvements were conferred upon the CVP.

Each year, farms in the CVP produce $3 billion worth of crops, an impossible feat without irrigation and the conveyance of massive amounts of water across the state.[133] The Central Valley Project is the largest water storage and delivery system in California, and the largest federal water project in the nation. Seven to eight million gallons are transported per year, 90 percent of which is used for irrigation.[134] The water originates in the Sierra Nevada, and the infrastructure consists of 20 dams and reservoirs, and over 1,600 miles of canals and drains.[135] Farmers involved in the Central Valley Project receive heavily subsidized water, but it is difficult to determine exactly what the subsidy is worth. In 2002, CVP farmers paid $48 million for the water they received.[136] Because there is no decisive method of calculating the price of the water sold to CVP farmers, and consequently the value of the subsidy, it can be valued according to numerous methods. For example, in 2002, 2.72 million acre-feet of water were purchased by the CVP and sold to CVP farmers for $47.7 million.[137] When calculated at the federal "full cost" rate (which would cover operation and maintenance, reduction of accrued capital costs, and interests incurred), this water was worth an additional $59.68 million, meaning CVP farmers are at getting water at a 55 percent discount.[138] If one alternatively calculates the subsidy at the State Environmental Water Account (a state-run program which purchases water for environmental restoration from willing members within the CVP and SWP) rate, it is worth significantly more, $304.82 million.[139] But when calculated at the cost of replacing the water from proposed new reservoirs and dams along the San Joaquin River, it is worth $416.28 million, equivalent to a 90 percent subsidy.[140] Also, it is important to note that when these figures are listed, the subsidy is equal to the total cost of water provided minus what the farmers paid for it.

The water that 6,800 San Joaquin Valley farms receive through the Central Valley Project is subsidized by state taxpayers at a cost of up to $416 million per year.[141] About 20 percent of all agricultural water in California is used by CVP farmers, and in 2002, 67 percent of this water went to the largest ten percent of CVP farms by total water use.[142] The average subsidy for the top ten percent was 2,300 acre-feet, and

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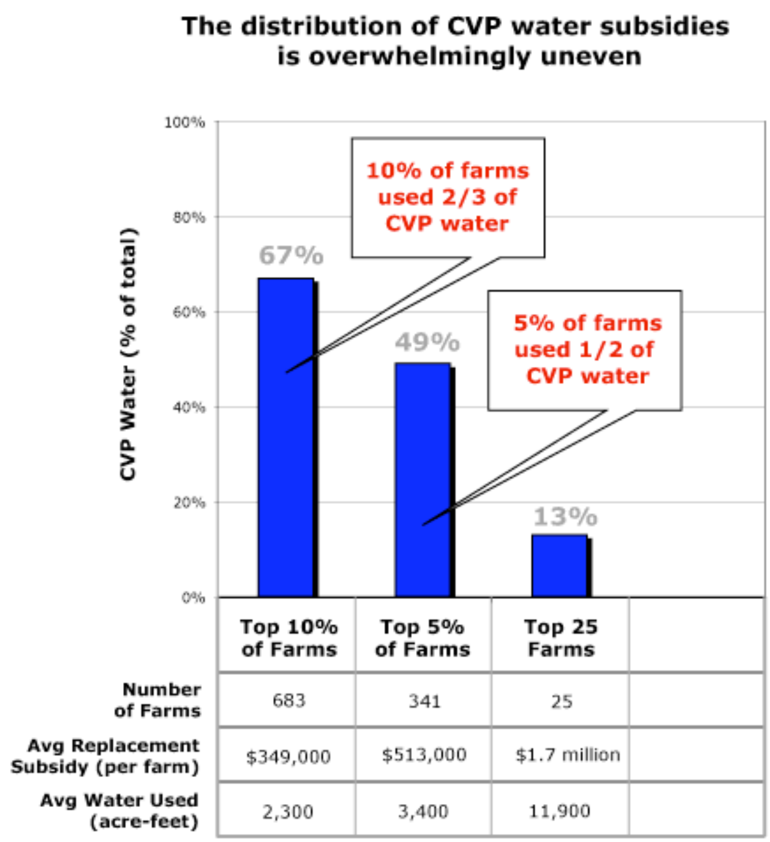
[133] Sharp, R., 2004, *California Water Subsidies*. Environmental Working Group, Washington DC.
[134] Sharp, 2004.
[135] Sharp, 2004.
[136] Sharp, 2004.
[137] Sharp, 2004.
[138] Sharp, 2004.
[139] Sharp, 2004.
[140] Sharp, 2004.
[141] Sharp, 2004.
[142] Sharp, 2004.

when calculated at market rates for replacement water, was valued at $349,000.[143] The overall average CVP farm received 350 acre-feet, at a median subsidy of $7,056.[144] For comparison, the average US household uses less than .5 of an acre-foot per year.[145] Figure 1.6 illustrates some of the disparities. The water subsidies allow farmers to receive water as rates far below market cost: the average price paid by CVP farmers is two percent of what Los Angeles residents pay for their drinking water, and ten percent of the estimated cost of replacement water from proposed dams and reservoirs. Additionally, San Francisco residents pay eight times the price of CVP water to restore the San Francisco Bay and Delta because of damage caused by diversion.

Figure 1.6: Distribution of Central Valley Project Water Subsidies



Source: Sharp, 2004.

The CVP subsidy reduces of the price of water to an artificially low level, so that although the Central Valley is a desert, local farms end up growing water-intensive

[143] Sharp, 2004.
[144] Sharp, 2004.
[145] Sharp, 2004.

crops such as alfalfa, rice and cotton. The average U.S. farm annually uses 2.48 acre-feet of water per acre per year, but California farms average 3.37 acre-feet.[146] One must bear in mind that this is a state in which water consumption exceeds natural supply by 1.6 million acre-feet in normal years and 5.1 million acre-feet in drought years.[147]

Federal taxpayers funded the CVP at a total cost of $3.6 billion.[148] The original intent was for recipients of water to repay the CVP's capital cost, with an intermediate goal of $1 billion within 50 years of the project's completion. (Sharp, 2004) However, by 2002, 60 years after water was first transferred, only 11 percent of the capital cost had been recovered.[149] This is because the 40-year contracts the farmers first signed provided the water at prices far below what was necessary to recoup the construction outlay. Considering that 17 of the CVP districts, which consumed a total of about 300,000 acre-feet of water in 2002, paid only about $2 per acre-foot for water that cost $10 to deliver, it is no wonder.[150] Unlike municipal or industrial beneficiaries of the CVP project, farmers also receive the additional subsidy of no interest on their obligations. Also, if in any given year the Bureau of Reclamation believes a CVP district will be unable to repay any of their obligation, the Bureau simply increases the rates for CVP power users, labeling this practice "capital relief."

Overall in 2002, CVP farmers paid an average of $17.14 per acre-foot for their irrigation water.[151] The Bureau of Reclamation conservatively calculates the "full-cost" of an acre-foot of this water at an average of $38.93 per acre-foot.[152] Farmers under the State Water Project, which is under the jurisdiction of the state and which is similar to the CVP, paid an average of $50.92 per acre-foot.[153] In the same time period, the Environmental Water Account bought water from willing members within the CVP and SWP for an average of $129.48.[154] Additions to the capacity of water systems coming from the construction of new or expanded dams and reservoirs along the San Joaquin River would cost at least $170.42 per acre-foot.[155] As mentioned above, residential users pay much more for water: in the same time period, San Francisco and Los Angeles residents were paying $625 and $925, respectively.[156]

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[146] Sharp, 2004.
[147] Sharp, 2004.
[148] Sharp, 2004.
[149] Sharp, 2004.
[150] Sharp, 2004.
[151] Sharp, 2004.
[152] Sharp, 2004.
[153] Sharp, 2004.
[154] Sharp, 2004.
[155] Sharp, 2004.
[156] Sharp, 2004.

The State Water Project

The California State Water Project (SWP) is the largest state-built water transportation and power conveyance system in the nation.[157] It consists of 33 storage facilities and 21 primary lakes and reservoirs comprising a total 5.8 million acre-feet.[158] The SWP provides a total of 23 million residents and 755,000 acres of farmland with water.[159] Construction began on the SWP unofficially in 1957, officially in 1960 with a $1.75 billion California bond measure, and by 2001, a total of around $5.2 billion had been spent.[160] About 78 percent of funding for infrastructure came primarily from state general obligation and revenue bonds, but also other sources include tideland oil revenues, investment earnings, recreation appropriations, and federal flood control payments.[161] Short-term funding is financed through commercial paper notes later transformed into long-term revenue bonds.

Water from the SWP is divided among SWP contractors -- 29 California urban and agricultural water suppliers. In total, the SWP provides water to two-thirds of California's population with seventy percent of the water going to agricultural users and the remainder to urban users.[162] A yearly profile (1999) of expenses for SWP contractors is as follows: bond repayment (46 percent), operations and maintenance (35 percent), power (18 percent), and replacement reserves, insurance, and miscellaneous (one percent). Ninety six percent of bond repayment by SWP contractors came from water supply and power generation; the remainder from recreation, fish and wildlife (two percent) and flood control (two percent).[163]

Based on the proportion of water they are allotted, contractors all pay the same rate per acre-foot of water used for fixed costs (operations, maintenance, and debt service), but the marginal amount paid per unit of water received depends upon the distance water must flow, energy consumed in its transport, and the amount consumed. By 2001, $9 billion in payments has been collected.[164] The SWP contractors pay all water supply related costs, totaling about 94 percent of the annual O&M costs of the project. The remaining six percent is split by the federal government (for joint operation of the San Luis facilities) and by the state under the designation of general funds for fish and

[157] Department of Water Resources, d. *The State Water Project Today* Retrieved 1 September 2008. http://www.publicaffairs.water.ca.gov/swp/swptoday.cfm?layout=print
[158] DWR, d.
[159] Department of Water Resources, [b]. *California State Water Project Overview*. Retrieved 1 September 2008. {http://www.water.ca.gov/swp/index.cfm}
[160] Department of Water Resources, [a]. *California State Water Project Overview*. Retrieved 1 September 2008. {http://www.water.ca.gov/swp/index.cfm}
[161] DWR, a.
[162] DWR, a.
[163] Department of Water Resources, [c]. *SWP Contractors Payments*. Retrieved 1 September 2008. {http://www.water.ca.gov/swp/docs/swppayments.pdf}
[164] DWR, b.

wildlife enhancement.[165] In a situation similar to the treatment of annual O&M costs, the SWP agencies repay with interest 89 percent of the capital expenditures incurred through 1995.[166] The remaining 11 percent is paid by the federal government for flood control (two percent), the state for fish and wildlife enhancement (five percent), and the remaining four percent from miscellaneous sources.[167]

Environmental/Recreational

Bonds have funded recent water projects for the restoration of California's plants and animals. California voters have passed four bond issues since 1996, and by 2003, 400 projects have been funded by the California Bay-Delta program at a total cost of $490 million.[168] CALFED has additionally pledged $150 million per year toward environmental issues.[169]

Water-dependant recreation is an important consideration when planning California water use, and comes in many forms; some such as rafting, swimming, and fishing, which occurs on lakes, reservoirs, and rivers; other activities, such as wildlife viewing, picnicking, and camping are enhanced by good health of local water resources. According to a 2002 public opinion survey by the California Department of Parks and Recreation, around 150 million adult participation-days were spent in activities directly dependent on water.[170] Many more participation-days were spent on activities such as hiking and camping that are enhanced by water, and in 2001 water-related recreation helped draw 28 million tourists to California.[171]

Between 2001 and 2002, the California Department of Fish and Game collected over $49 million in revenue from the issuance of sportfishing licenses and stamps.[172] Water-dependent recreation leads to the development of secondary economic activity; local businesses benefit from increased demand for lodging, food, and services related to travel. One example is the freshwater fishing industry in California, which is only one of the many water-dependent activities available, but which contributes $3 billion per year in revenue. A large part of this economic activity (over $2.3 billion) is from retail sales and wages and salaries.[173] Considerations for recreational activity generally account for three to six percent of the cost of a water project. For instance, three percent of all

[165] DWR, a.
[166] DWR, a.
[167] DWR, a.
[168] DWR, 2005a.
[169] DWR, 2005a.
[170] DWR, 2005a.
[171] DWR, 2005a.
[172] DWR, 2005a.
[173] DWR, 2005a.

capital expenditures in the State Water Plan are recreation-related.[174] Yearly costs for maintenance are also about three percent of the initial outlay.[175]

A common difficulty in garnering funding for the recreational segment of a given project is the disconnect between recreational and other water users. Because beneficiaries of water recreation might not benefit from the other uses of water, it can be difficult to gather funding from the different groups users in an equitable manner. From the freshwater fishing example above, one can easily see the difficulty of funneling the economic consequences of fishing into support for a water project. The Davis-Dolwig Act also specifies that recreational users may not be charged for the construction of facilities, a move that could alleviate pressure from some poorer users, but simultaneously provide an additional barrier to funding.[176]

[174] DWR, 2005a.
[175] DWR, 2005a.
[176] DWR, 2005a.

2. Energy: Background

This section focuses on the relationship between climate change and energy in California. Climate change will cause more extreme heat days in the summer and this will challenge our power supply system in California, and therefore, it is essential for us to learn more about it and enhance our system to adapt to the changes. With increasing average temperature, the demand of energy in the summertime is expected to increase, and the inflow for generating hydroelectric power is expected to come earlier. Thus, we will study the economic impacts that climate change will bring to our power plants and hydropower systems.

California has been a world leader in energy efficiency. Over the last decade, the stability of electricity demand per capita in California can be attributed to the energy efficiency incentives of the state. However, the recent extreme heat events caused by global warming has already put electricity in California under stress. The electricity supply system will be challenged by the projected increase in temperature and the increasing demand of air-conditioning due to the extreme temperature.

Through the effort of conservation, California has low average power consumption per capita. The population has grown by 80 percent since 1970, and total power consumption has grown from 148,000 gigawatt-hours (GWh) to 254,000GWh. Since 1975, California's per capita electricity sales have remained relatively stable. In 2004, each person in California used 7,100kWh, and was 41 percent lower than the national average.[177]

In order to study the impacts of climate change on the energy supply and demand in California, we need to understand the general energy background of California. Table 2.1 shows the total Electricity System Power in 2007 and the distribution of resources that are used to produce power in California. Natural gas contributes the largest share of the total system power and renewable energies (with large hydro) contribute more than 20 percent of the total system power. The energy produced by coal in-state is low; however, the total consumption of energy produced by coal in California is about 11 percent, since California has imported energy from other regions, which is made of coal.

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[177] McCann, R, Burtraw, D, Fripp, M, Moss, S, 2005. Recommendations for the design of modeling and analysis of the electricity sector to guide options for climate policy in California. The California Climate Change Center at UC Berkeley.

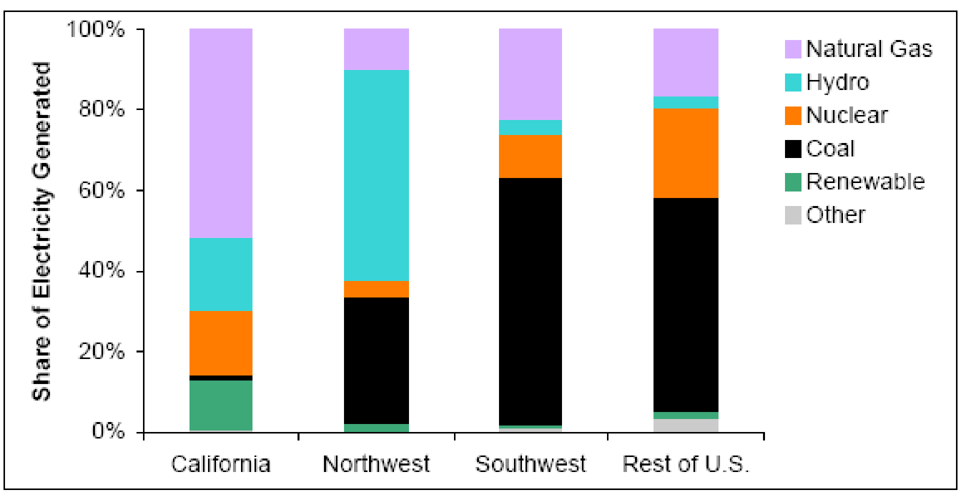
Overview of the distribution of energy source in California

Table 2.1. 2007 Total System Power in Gigawatt Hours

Fuel Type	In-State Generation	Northwest Imports	Southwest Imports	Total System Power	Percent of Total System Power
Coal*	4,190	6,546	39,275	50,012	16.6%
Large Hydro	23,283	9,263	2,686	35,232	11.7%
Natural Gas	118,228	1,838	16,363	136,063	45.2%
Nuclear	35,692	629	8,535	44,856	14.8%
Renewables	28,463	6,393	688	35,545	11.8%
Biomass	5,398	837	1	6,236	*2.1%*
Geothermal	12,999	0	440	13,439	*4.5%*
Small Hydro	3,675	4,700	18	8,393	*2.8%*
Solar	668	0	7	675	*0.2%*
Wind	5,723	857	222	6,802	*2.3%*
Total	209,856	24,669	67,547	302,072	100.0%

Source: California Energy Commission website.

Figure 2.1. Fuel used to generate electricity in California and other regions of the U.S.



Source: The California Climate Change Center at Berkeley.

Figure 2.1 shows the fuels used to generate electricity in California and how it compares to the par of the U.S. As you can see, the portion of coal used to produce electricity is relatively low when compared to other parts of the U.S. Moreover, with renewable and hydroelectric power, the sources that California uses to generate electricity are relatively clean, thus, the production of electricity will be more efficient and clean.

Climate Change Impacts on Electricity Demand

Studies done by the California Energy Commission analyzed the relationship among climate change, extreme heat, and electricity demand in California, and indicate that extreme heat events will increase rapidly. The increase in temperature is forecasted by a model based on three scenarios; A1fi, A2, and B1. A1fi is the higher emission scenario, which is usually fossil intensive and with rapid introduction of new technologic and economic growth; A2 is the mid-high emission scenario, which is a heterogeneous world, with regionally oriented development and slower growth; B1 is the lower emission scenario and is a convergent world with a rapid transitions to an information-based economy, and is a "green" scenario. We assume the population trends in these three scenarios are the same. Furthermore, e*xtreme heat* is defined here by the 90 percent exceedance probability (T90) of the warmest summer days under the current climate. JJAS is the short form of June, July, August, and September, which represents the hottest months in a year. The T90, which described as the one-in-ten JJAS high temperature day's values, also known as the threshold temperature for the top ten percent hottest summer days under the current climate. For example, the number of extreme heat days in Los Angeles, where T90 is currently 95°F, may increase from the present day value of 12 days per year up to 96 days per year by 2100.[178] So, the T90 will be the hottest ten percent summer days under current climate condition, and is threshold by 95°F. Based on this threshold, we predict that about 96 days by the 2100 summer will over 95°F, and this represented that the extreme heat days will last for the whole summer.

Since global temperature is increasing, the frequency of the temperature exceeding the T90 will expect to increase. The Intergovernmental Panel on Climate Change (IPCC) estimates that global average temperatures could increase by 1.4ºC to 5.8ºC (2.5ºF to 10.4ºF) by 2100 and that the sea level may rise from 0.09 meters to 0.88 meters (0.3 feet to 2.9 feet). According to the historical data from 1960-1990, T90 events occurred 12 times per year on average. Furthermore, extreme heat days are expected to become more intense, last longer, and occur earlier when compare to the historical reference. By the period 2005-2034, the average extreme heat days in summer are expected to double from 12 to about 23-24 days.[179]

In order to make a forecast of the future climate, different climate models are developed for the climate stimulations. The Geophysical Fluid Dynamics Laboratory (GFDL) has developed a medium-sensitivity global circulation model, and the National Center of Atmospheric Research and the U.S. Department of Energy for modeling the climate and

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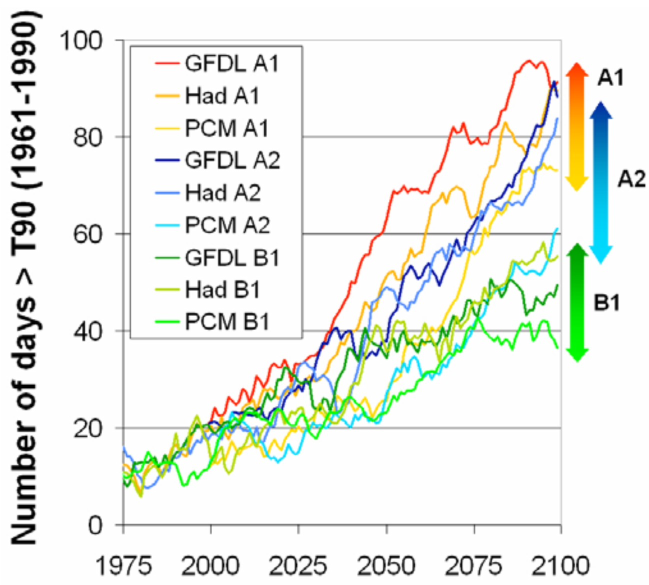
[178] Miller, N, Jin, J, Hayhoe, K, Auffhammer, M, 2007. *Climate Change, Extreme Heat, and Electricity Demand in California.* California Energy Commission, August 2007,
[179] Miller et al., 2007.

submitting the results to the Intergovernmental Panel on Climate Change (IPCC) have developed a low-sensitivity model called Parallel Climate Model (PCM).

Figure 2.2. California-wide projected average number of JJAS T90 days per year from 1975 to 2100.



Source: Franco and Sanstad, 2006.

Figure 2.2 shows the California-wide projected average number of JJAS T90 days per year from 1975-2100. According to the figure, by the end of the century, the extreme heat days are expected to increase an average of four times in B1 scenario, 5.5 times in A2, and 6.5 times in A1fi, which also mean that there are about 50 days in B1, 65 days in A2, and 80 days in A1fi that will suffer from extreme heat days in the period 2070-2099's summertime.[180]

[180] Miller et al., 2007.

Table 2.2. T90 threshold values and projected increased number of days exceed the 1961-1990 T90 threshold

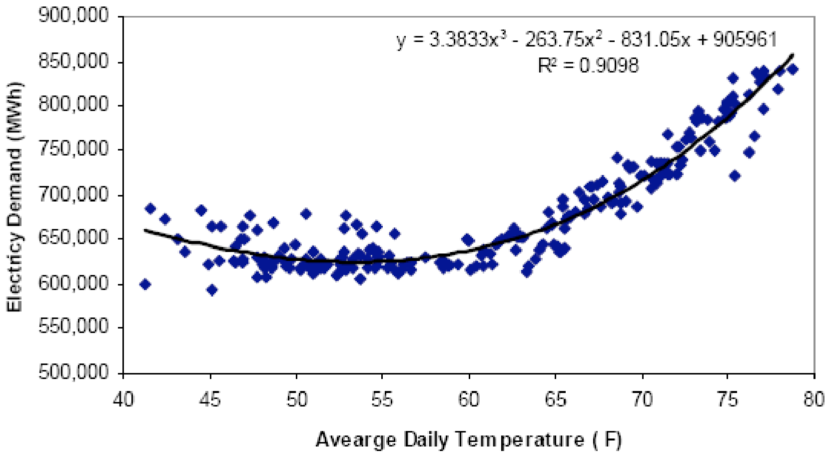
	T90 threshold (°C)	Scenario	No. of days exceeding T90 threshold		
	1961–1990		2005–2034	2035–2064	2070–2099
Statewide	35	A1fi	19–34	32-66	69-88
		A2	18–30	29-47	53-76
		B1	21–26	27–39	39–52
San Francisco	27	A1fi	20	32–46	70–94
		A2	13–28	20–48	40–91
		B1	17–23	23–35	37–49
Los Angeles	33	A1fi	24	34–50	63–93
		A2	16–24	23–48	39–98
		B1	19-24	27–36	38–45
Sacramento	38	A1fi	20	33–46	70–78
		A2	15–36	25–49	47–89
		B1	17–23	26–42	40–52
San Bernardino	40	A1fi	21–23	31–46	63–78
		A2	13–27	20–46	36–87
		B1	20–27	26–36	36–45
Fresno	40	A1fi	19–21	33–45	69–75
		A2	15–35	25–51	46–93
		B1	16–27	26–42	40–52

Source: Franco and Sanstad, 2006.

Table 2.2 gives us more specific data on how the extreme heat days will affect different cities in California. According to the table, the T90 threshold value ranged from 27 ^{o}C in San Francisco to 40 ^{o}C in Fresno. Due to the geological location, in some cities in California, like Sacramento and San Bernardino, the T90 thresholds will be over 35 ^{o}C. Thus, in scenario A1fi, these cities might have about 80 days extreme heat days, which are about 35 ^{o}C - 40 ^{o}C, in the future summertime. If this happens, people in these cities will suffer from extreme heat days for almost the entire summer. Generally, 65°F (18°C) is an average daily mean temperature threshold for human thermal comfort,[181] so more energy will be demanded for cooling as the temperature increases and the average and peak capacity of the power supply will then be challenged by the rapidly increased demand especially during the summertime.

[181] Miller et al., 2007.

Figure 2.3. Electricity demand in the Cal ISO area as function of average daily temperatures in 2004



Source: Franco and Sanstad, 2006.

Table 2.3: Estimated increases in annual electricity and peak load demands for the A1Fi, A2, and B1 scenarios, relative to the 1961–1990 base period

Climate Model	Year	Emission Scenario	Annual Electricity (%)	Peak Demand (%)
Hadley3	2005–2034	A1fI	3.4	4.8
	2035–2064	A1Fi	9.0	10.9
	2070–2099	A1Fi	20.3	19.3
PCM	2005–2034	A2	1.2	1.0
		B1	0.9	1.4
	2035–2064	A2	2.4	2.2
		B1	1.7	1.5
	2070–2099	A2	5.3	5.6
		B1	3.1	4.1
GFDL	2005–2034	A2	2.9	3.6
		B1	2.5	4.1
	2035–2064	A2	5.0	5.0
		B1	4.2	5.0
	2070–2099	A2	11.0	12.1
		B1	5.8	7.3

Source: Franco and Sanstad, 2006.

Under the worst scenario that the temperature will increase 1.9^{o}C in 2010, electricity requirements will increase by 7,500 gigawatt-hour (GWh) and the peak capacity will increased by 2,400 megawatts (MW). In this case, we are expecting an increase of energy and peak generation capacity by 2.6 and 3.7 respectively, from the 2010 base case.[182] Figure 2.3 shows the daily weekday demand of electricity for the area covered by Cal ISO services in 2004. Since weekend demand tends to be lowered, those data are excluded in this figure. The U-shaped curve indicates that temperature and electricity demand is not simply directly proportional to the temperature. At lower temperatures, demand of electricity is not demanded less as energy is used for heating. Then, the bottom point of the U-curve is the point where the temperature (approximately 55 ^{o}F) is optimum to people, so that energy is demanded less for cooling and heating. The last portion of the curve shows a direct proportion relationship between temperature and electricity demand, as when temperature increases, the electricity demand will increase correspondingly. The curve shows a high correlation between the two components, the average daily temperature and electricity demand. According to Table 2.2, the temperatures of the cities in California are expected to increase according to different scenarios. According to Table 2.2 and Figure 2.3, we can foresee the demand of electricity will be increasing rapidly, since the extreme heat days are likely to occur more often in the future, the demand of electricity will continuously remain in a high level for the use of cooling.

Transmission and Electricity Demand

According to the report “Summer 2008 Electricity Supply and Demand Outlook” issued by California Energy Commission, the four regions that they have examined are California Statewide, California ISO Control Area, California ISO North of Path 26 (NP26), and California ISO South of Path 26 (SP26). California Statewide includes major utilities in the state. The California ISO Control area is divided into Northern and Southern. Northern California includes the Pacific Gas and Electric Company (PG&E) service area. Southern California includes Southern California Edison (SCE), and San Diego Gas and Electric (SD&E). The reason why they divide the ISO Control area into two areas is because the transfer of electricity from north to south is limited by transmission constraints, which is known as Path 26.

As the temperature continues to increase, people demand more energy for cooling. This causes a huge burden on the supply of the power plant. When demand exceeds the capacity of electricity generation, then outage of power might occur and will cause a huge economic loss. Therefore, we should improve our system and capacity to meet the increasing demand, so that we can prevent outage from happening.

In summer 2008, California was still expected to have adequate electricity supplies to meet the demand. The California JJAS summer peak electricity demand was 57GW in 2004; however, it is about 65 GW in 2008.[183] In order to maintain the stability of the

[182] Franco, G, Sanstad, A, 2006. *Climate Change and Electricity Demand in California.* California Climate Change Center, February 2006, from http://www.energy.ca.gov/2005publications/CEC-500-2005-201/CEC-500-2005-201-SF.PDF.

[183] Miller et al., 2007

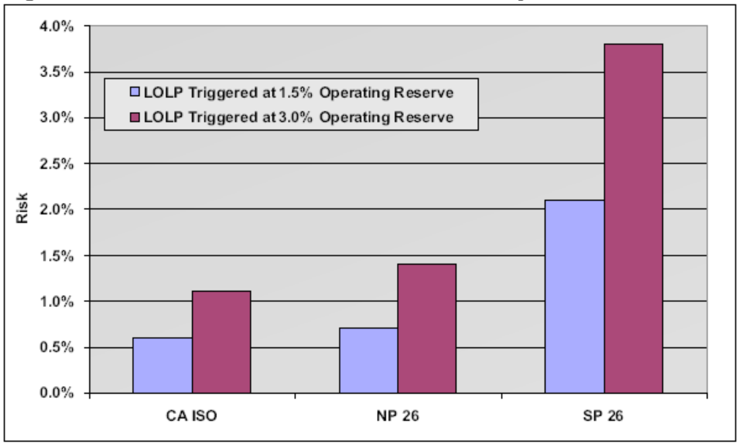
power system, we have to reserve a buffer for unplanned fluctuations when there are system errors. A reserve margin is a measure of the amount of electricity imports and in-state generation capacity available over average peak demand conditions. There are two types of reserve margin, planning reserve margin and operating margin. Planning reserve margin is a target level necessary to cover a certain range of possible system fluctuations and unexpected emergencies. A low planning reserve margin may result in a higher chance of customer curtailments. Generally, a 15-17 percent buffer of additional supplies above typical peak demand is needed to ensure the adequate supplies of electricity. Under the average summer weather conditions, the electricity reserve margins in 2008 for California is about 22 percent; even in extreme heat days, the reserve margins are still approximately 14 percent.[184] Operating margin is the target buffer that is assumed to be sufficient for control area operators to deal with immediate emergencies or fluctuations in electricity demand. It also represents the amount of imports and actual, spinning generation above current demand and represents real-time operations that fluctuate minute by minute. When it drops below a certain level, the minimum target is usually about seven percent, it will trigger additional purchase of power and calls for demand response and voluntary interruptible programs to reduce load. The California Independent Service Operator (California ISO) has divided the warning level into three stages. Stage one is when the operating reserve is at seven percent, stage two is at five percent, and stage three is when reserves fall to a level between three and 1.5 percent,[185] depending on the specific operating conditions. The southern portion of the California ISO (SP26), which includes most of Southern California, had a 3.8 percent probability of experiencing a staged emergency in 2008 summer according to Figure 2.4, however, it still remains at a comfortable level.

From the above figures and graphs, we might notice that Southern California is actually hotter than Northern California and will suffer more from climate change than Northern California. In fact, the power system in California and the other surrounding regions are interconnected, but at the same time interdependent from each other. It then provides a broad and reliable network of electricity to each connected area, moreover, the surplus energy generated in the area, which is connected to the network, can be transferred to other regions that have a higher demand during the peak demand period, therefore, the electricity cost can then be reduced. Generally, Southern California will have a higher demand of electricity than Northern California, so it will import electricity from Northern California. However, demand of electricity in California is expected to increase rapidly due to climate change, therefore, a series of problems might happen when Northern

[184] Brown, D. 2008. *Summer 2008 Electricity Supply and Demand Outlook.* California Energy Commission, May 2008, from http://www.energy.ca.gov/2008publications/CEC-200-2008-003/CEC-200-2008-003.PDF.
[185] Brown, 2008.

California experiences a deficit in electricity and will not be able to export electricity anymore to Southern California.

Figure 2.4. Loss of Load Probability



Source: Brown, 2008.

The California Independent System Operator will purchase short-term electricity if actual demand is higher than the day-ahead forecast and need to supplement the scheduled generation. Electricity can be imported from the generating plants located in other western states, such as Canada and Mexico. Tables 2.4, 2.5, and 2.6 give us an overview about California's electricity interchange. According to these tables, we can see that the import of electricity from Southern California is much larger than Northern California. This may be due to the demand of electricity for cooling is high in Southern California, since Southern California generally has an average temperature higher than Northern California. So, if climate change continues, the temperature in Southern California will expect to increase and extreme heat days are more likely to happen. Then, we can expect Southern California have to import more electricity to meet the demand, especially in hot summer season. On the other hand, Northern California imports less energy; moreover, it exports some energy to Southern California. However, if the temperature increases in the coming future, the demand for energy from Northern California will absolutely increase and might not be able to provide as much energy to Southern California. Then, Southern California may have to import even more energy from other states or western countries. The rapid increase in electricity demand might then challenge the reserve margin of the power plant, and will lead to outage of power plants.

Table 2.4: Statewide Net Interchange

Northwest Imports (COI)[6]	4,000
Southwest Imports[2]	4,100
Pacific DC Intertie (California ISO)[2]	2,000
LADWP and IID Control Areas	3,018
Total	**13,118**

Table 2.5: NP 26 Net Interchange

California ISO Share of NW Imports[2]	2,300
WAPA Central Valley Imports	950
Path 26 Exports	(3,000)
Total	**250**

Table 2.6: SP 26 Net Interchange

Path 26	3,000
California ISO Share of Pacific DC Intertie[2]	2,000
Net SW Imports[2]	4,100
Net LADWP Control Area Interchange	1,000
Total	**10,100**

Source: Brown, 2008.

Tables 2.4, 2.5, and 2.6 show the Overall Electricity Transfer in Statewide, and in Northern and Southern California. According to the graphs, we can see that Northern California is generally an electricity exporter, and exports a certain amount of energy to Southern California each year. In 2008, we predict that Northern California will export 3000 MW of electricity to Southern California through Path 26; however, it also imports surplus electricity generated from other Pacific Northwest regions where energy costs in those regions are relatively lower than in California. On the other hand, since Southern California experiences a hotter climate and thus a higher energy demand than Northern California, it is a major electricity importer and is a large portion of import electricity of the state. From the graphs, Northern California is currently having a 250 MW net import from other regions, however, when temperature continues to increase, Northern California might no longer be self-sustainable in terms of energy and need to import more energy from nearby areas. Since the energy system is interdependent, the increase in demand in Northern California will have a series effect on electricity supply in other regions. Obviously, Northern California will be unable to transfer as much as energy to Southern California if climate change worsens. Moreover, Southern California will need to import even more energy from other regions. With the surplus supply of energy reducing within the energy network, the rapid increasing demand and reducing supply will drive the price of electricity to rise. Apart from that, due to the increasing demand, we might experience a higher probability of power outage, which might increase the instability of our electricity system.

Climate Change Impacts on Hydropower

Hydroelectric power is one of the most important energy resources, which contributes about 15 percent to 20 percent of the total electricity demand in California. California has about 400 hydroelectric power plants, and produced 43,625 GW-h of electricity in 2007. The Pacific Northwest is along mountain ridges, e.g. Mount Rainer; and due to the high elevation geological advantages, it is very suitable for the hydroelectric power generation, which has contributed a significant amount of electricity to the whole region.

The water used for the generation of hydropower comes from the stream inflows generated by precipitation in winter months and snowmelt during the spring season. Thus, under the global warming scenario, the California's hydrology would experience an earlier timing of stream flows, which might greatly affect the operation of hydropower plants. According to PG&E, the runoff resources that they used to use to produce hydropower were groundwater aquifers (38 percent); snowmelt (36 percent); and rainfall (25 percent). As the temperature increases, the inflow of stream water will come much earlier as higher portions of precipitation would fall as rain instead of snow. Moreover, snow pack will also experience an earlier spring snowmelt. Since the energy demand in California's summer is much higher than other seasons, this could create a problem of timing mismatch between energy generation and energy demand, especially with reservoirs that have low storage capacity. As the summer demand of electricity is high, we have to store the spring water runoff for the power generation in summer. Thus, the size of the storage capacity of the reservoirs determines how much water inflow during springtime could be stored and used for power generation to meet the energy demand during summertime.

The California Climate Change Center conducted a study on the potential effects of climate change-induced hydrological changes on high elevation hydropower generation in California. The study is mainly focusing on a case study on the Sacramento Municipal Utility District (SMUD) hydroelectric system, which located in El Dorado County. The hydropower system was built between 1957 and 1985. The whole project includes 11 reservoirs that can store over 425,000 acre-feet (AF) of water, and eight powerhouses can generate up to 688 MW of power.[186]

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[186] Vicuna, S, Leonardson, R, Dracup, J, Hanemann, M. 2005. Climate Change Impacts on High Elevation Hydropower Generation in California's Sierra Nevada: A Case Study in the Upper American River. California Climate Change Center, March 2006, from

Figure 2.5 shows the perturbation ratios, which were based on the climate output prediction under the greenhouse gases emission scenarios A2 and B1 by using different climate models, such as NCAR, PCM, and GFDL. The unimpaired natural stream flow represents the inflow in the period 1960-1990 and was predicted by the GCM (not actual historical stream flow), and compared with stream flow prediction for 2070-2099. Therefore, if the ratio is greater than one, it means that the inflow for 2070-2099 is greater than the inflow for 1960-1990; on the other hand, if the ratio is smaller than one, it means that the inflow for 2070-2099 is smaller than the inflow for 1960-1990. According to Figure 2.5, a general pattern is shown in most of the models under scenarios A2 and B1. The perturbation ratios in between May and September are always smaller than 1, which represent that the stream flows in spring and summer are going to decline in the future, however, the spring inflows will come much earlier in wintertime (around February and March) as the ratios are higher than 1. Figure 2.6 shows monthly average stream flow conditions for Silver Creek to represent inflows into the Union Valley reservoir in between 1928 –1949. Also, according to Figure 2.7 and 2.8, the perturbation ratios have translated into simulated stream flows under climate change conditions. When compared to Figure 2.6, we can see from the graph that there is a significant change in stream flow under climate change, which could be due to early snow melt from the mountain. A shift in the stream flow period is shown, especially in model GFDLA2_39, where the high stream flow timing has shifted from May to February. Moreover, the volume of summer inflows is decreasing as well. Since the energy demand is relatively high in summer in California, the timing of inflows takes a significant role in terms of power generation and energy revenue.

http://www.energy.ca.gov/2005publications/CEC-500-2005-199/CEC-500-2005-199-SF.PDF. The remainder of this section is based on this paper.

Figure 2.5: Monthly perturbation ratios (based on 2070-2099 climate change conditions)

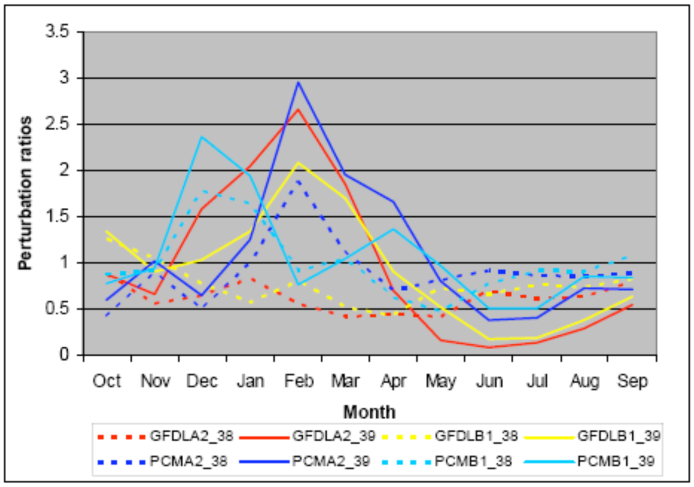
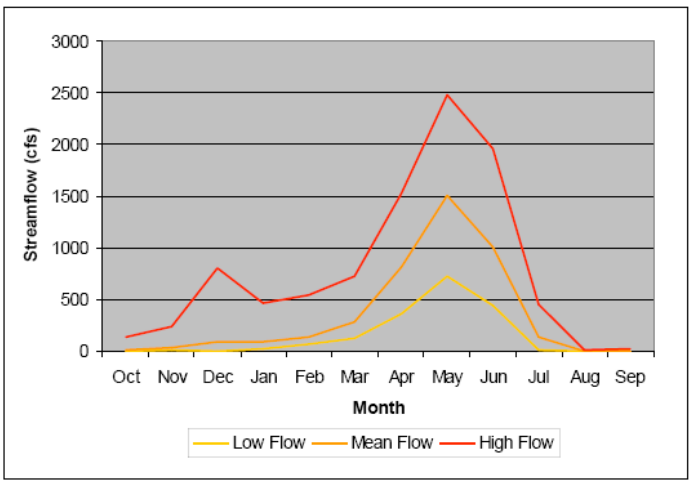
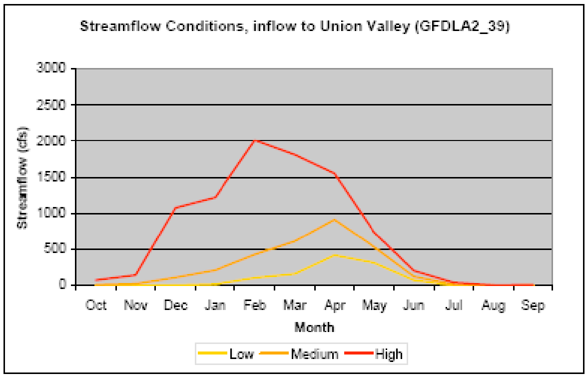


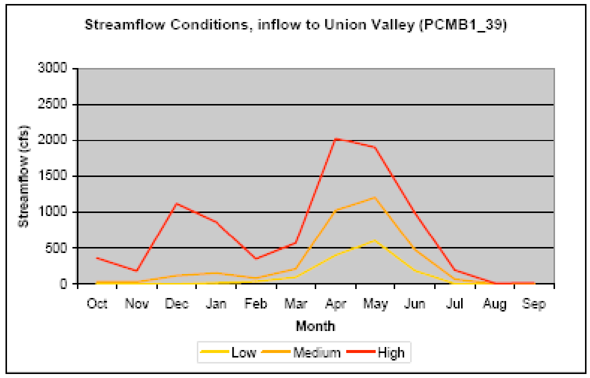
Figure 2.6: Unimpaired (pre-dam) inflows to Union Valley, 1928-1949 (Historic scenario)



Source: Vicuna et al., 2005.

Figure 2.7 & 2.8: Stream flow conditions (unimpaired inflow to Union Valley) under Climate change scenarios, 2070-2099





Source: Vicuna et al., 2005.

With the SMUD hydroelectric system set up in the Upper American River, we are interested in the system operation under different hydrological scenarios. According to Figure 2.9, the patterns show that the hydropower system will maximize its productions during summertime and minimize its productions during spring and winter, as energy value during summertime is relatively high. And referring to Table 2.7, the annual generation of electricity has dropped from 30 percent to 11 percent in different scenarios. However, when we compare the reduction in power generations with the reduction in annual inflows, we see that the change in annual inflows are similar to the annual power generation, thus, we can treat the changes in annual stream flows induced by the changes in total generation. However, the changes in annual revenue are always higher than the changes in annual inflows. The annual revenue reduced less when compared to the annual stream flows, and this shows that the system can reduce the economic effect by storing the moving water to more valuable months. For example, the annual stream flow has reduced 29 percent in model PCMB1_38, but the annual revenue has only reduced 23 percent. This shows that reservoirs and good hydropower systems can successfully reduce the impacts caused by the change in stream flow to the economy.

Figure 2.9: Energy revenues: comparison of scenarios

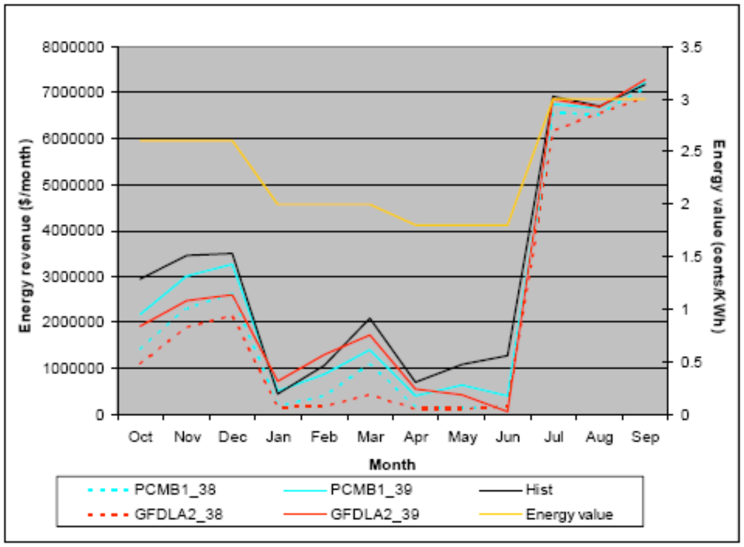


Table 2.7

	Generation Dollar/year	Percentage change	MWh/year Average	Percentage change	Change in Annual Streamflow
Historical	37319340		1422699		
PCMB1_38	28641080	77%	1025497	72%	71%
PCMB1_39	33323870	89%	1233249	87%	86%
GFDLA2_38	25973640	70%	914564	64%	62%
GFDLA2_39	32589481	87%	1208190	85%	86%

Source: Vicuna et al., 2005.

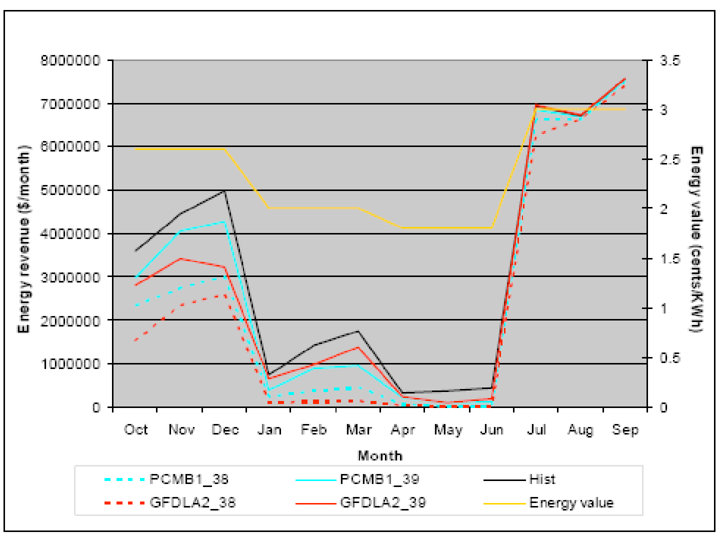
However, the operation of a hydropower generation system not only depends on the stream flows but also on infrastructure such as reservoirs, powerhouse, and conveyance capacities. We will mainly focus on how storage capacity of reservoirs can deal with changes in hydrological conditions. In the SMUD's Upper American River project, the storage capacity of more than 400,000 AF in the 11 interrelated reservoirs represent about 80 percent of average annual inflows into the system. In this study, we estimate the effect on annual revenue and generation of reservoirs with different storage capacities under the same hydrological scenario. Scenario one projects all reservoirs in the system will double in size and scenario two projects all reservoirs in the system will be reduced to a fourth of their size. The results of the two scenarios are shown on Table 2.8 and Figures 2.10 and 2.11. As shown on Table 2.8, the total annual power generated and the associated revenue in scenario one is greater than that in scenario two. Also, the generation pattern under scenario one is similar to the pattern of energy value, which indicates that the stream flow can be stored efficiently and be used at the time when energy is in high demand. However, the generation pattern under scenario two is close to the pattern of stream flow, since most of the inflows are unable to be stored in reservoirs for later use. This proves the benefits of having reservoirs to store water and move stream flow from a less valuable month to a more valuable one. Therefore, as climate change causes snow packs to melt and bringing the stream flows earlier in springtime, the storage function of reservoirs has become more important to energy generation and the revenue associated with it. However, these timing effects should not affect the generation capacity when the storage capacity of the system is sufficiently large.

Table 2.8: Changes in annual output from the system (as absolute value and as a percent compared to historical output) for a doubling and a quartering of system storage capacity

Climate scenario	Doubled Generation Dollar/year		MWh/year		Average Monthly Spills (cfs)	Quartered Generation Dollar/year		MWh/year		Average Monthly Spills (cfs)
Historical	39302000		1468197		5	28735000		1284313		226
PCMB1_38	29989220	76%	1060806	72%	0	23432000	82%	1003963	78%	31
PCMB1_39	35055000	89%	1275340	87%	0	26020000	91%	1148144	89%	127
GFDLA2_38	27176535	69%	947650	65%	0	20853100	73%	887674	69%	28
GFDLA2_39	34278000	87%	1254625	85%	18	25573100	89%	1118420	87%	172

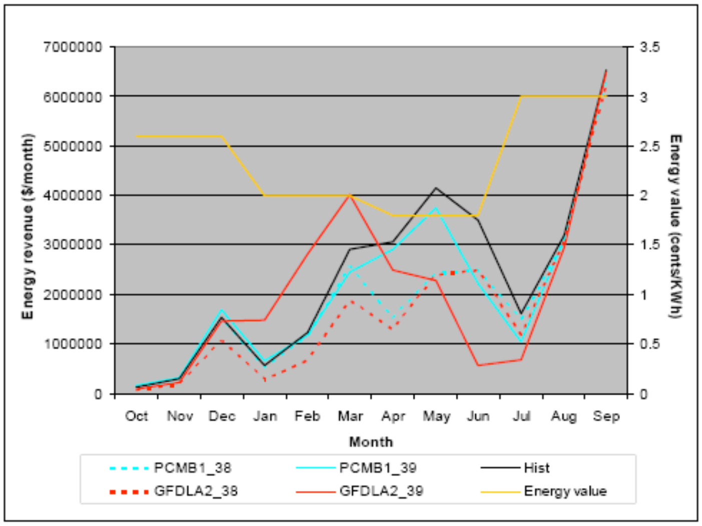
Source: Vicuna et al., 2005.

Figure 2.10: Energy revenues: doubling reservoir capacity



Source: Vicuna et al., 2005.

Figure 2.11: Energy revenues: quartering reservoir capacity



Source: Vicuna et al., 2005.

The storage capacity of reservoirs has a significant effect on the electricity generation and revenue. With sufficient storage capacity, reservoirs can hold the inflows from the months that energy value is not high and use it when energy demand and value are high. Thus, it is important for us to estimate the cost of expanding reservoir's capacity. However, construction cost of reservoirs is highly dependant on different geographical and environmental conditions for each basin and river. As a reference, the case that we are going to study is called Los Vaqueros Reservoir. This reservoir is not built for hydropower generation, however, by studying the case, we can get a rough idea about the cost of building, running, and expanding the capacity of reservoirs.

The Los Vaqueros Reservoir project was approved in 1988. Bonds were issued to gather enough money for constructing the reservoir. The reservoir is used to improve water quality and for emergency storage challenges. According to the Initial Economic Evaluation, which was based on all capital costs for construction, engineering, administration, and environmental compliance, the annual costs for operations, maintenance and power are estimated at approximately $3.55 million per year. Also, the costs to expand the reservoir to 275 thousand-acre feet would approximately cost $550 million. Based on a preliminary cost allocation, water from Los Vaqueros Reservoir will have an average cost of approximately $330 per acre-foot.

According to the figures, the average cost of expanding the reservoirs will be about $330 per acre-foot; however, the construction costs will vary according to site because the costs and methods we use to expand reservoirs are based on the location and the geography nearby. Thus, it is hard for us to generalize the construction cost of expanding the reservoirs. However, we can use the Los Vaqueros Reservoir project as a reference and assume the cost for the construction. Sufficient research and analysis, like cost-benefit analysis, is needed to analyze the site. In order to expand a "worth" expanding reservoir, we have to make sure the benefits from adapting an expanded reservoir should be able to cover the cost of adaptation.

3. Demographics: Background

Demographics are an important factor in determining the impacts of climate change. The issue of population growth is especially pertinent to California, with one of several current estimates predicting a growth of two percent every year in California, producing a doubling of its population to 64 million by 2035. The two percent annual growth rate is almost double that of the national average growth rate of 1.1 percent.[187] The methodology used to reach this estimate was not mentioned in the study, but other studies' estimates that used fertility and migration rates to extrapolate population levels in the future arrived at somewhat differing conclusions. However, most population forecasters agreed that by 2020 California will have a population of between 43 and 46 million.[188]

After 2020, the size of California's population is less predictable and will depend on the composition of the population, and future rates of fertility and migration, with estimates predicting a population between 50 million and around 70 million.[189] Not only do population estimates differ from one study to another, but even population estimates from the same study often can not pinpoint an exact number for the estimated population, making it extremely difficult to come up with a single figure. Although the exact rate of growth cannot be predicted, the forecasted growth rates will have a tremendous impact on the projected use of energy, water, and land availability as well as on air quality and transportation infrastructure. In turn, the projected uses of these three resources will play a fundamental role in determining the impact of climate change.

Energy

Electricity use will be affected by population growth in two separate ways – first by increasing the residential demand for electricity and second by generating more demand in the economic sector due to the creation of new jobs in the economy. Economic and population growth are the main factors linked to electricity demand

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[187] Pimentel, David, 'and' Hart, Kelsey. "Rapid Population Growth in California: A Threat to Land and Food Production." Diversity Alliance for Sustainable America 07 17 2005 May 27 2008 <http://www.diversityalliance.org/docs/Pimental-LandandFood.html >.

[188] Landis, John and Reilly, Michael. "How We Will Grow: Baseline Projections of the growth of California's Urban Footprint through the Year 2100. August 1, 2003. *Institute of Urban & Regional Development. IURD Working Paper Series*. Paper WP-2003-04. 30 August 2008. <http://repositories.cdlib.org/iurd/wps/WP-2003-04>

[189] Ibid

growth.[190] More specifically, it is both the population growth and the spatial distribution of this growth, along with economic growth that are the main drivers behind electricity demand. In the 1990's most of the increase in demand for electricity was in the building sector. In 2000, the building sector alone comprised of 2/3 of the annual electricity consumption and 3/4 of the summer peak load.[191]

Population growth is expected to be the greatest in the inland areas in California (the Inland Empire, Sacramento Metro and San Joaquin Valley).[192] These inland areas already have higher temperatures than their coastal counterparts, thereby necessitating even more energy use in the form of air conditioning. With the population growth, the inland temperatures will soar even higher due to the increase in activities that emit greenhouse gases. Air conditioner use tends to be the greatest during the day when temperatures are higher, coinciding with the 'peak time' for businesses as well, thereby increasing the demand for energy during the 'peak'. Residential air conditioning by itself makes up nearly as large a portion of the peak load as all industrial sectors combined.[193] Since power plants have to be designed to meet the demand at the peak rather than the average demand, meeting the peak demand is extremely expensive since the power plants built to provide peak demand do not operate for very long during the day.[194] In addition, these peak power plants are highly polluting as they are often inexpensive natural gas power plants.[195] Altogether, population growth has the potential to increase not only overall electricity demand but also peak demand, which would in turn increase pollution intensity and costs.

Transportation will become yet another factor to reckon with in the face of an increase in population. A rise in population will necessitate an increase in the number of miles driven and cause a higher rate of gasoline consumption as well as a higher rate of greenhouse gas emissions from cars. California has already witnessed an increase in the number of miles driven at a rate 50 percent faster than the rate of population growth in the last 20 years. Vehicles emit about 30 percent of the state's heat-trapping gases, and are the single greatest source of such emissions.[196] Since population growth is

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190 Brown, Richard, 'and' Koomey, Jonathon. "Electricity Trends in California:Past Trends and Present Usage Patterns." Energy Policy 31,9 July 2003 849-864. 25 June 2008 <http://enduse.lbl.gov/info/LBNL-47992.pdf>.

191 Ibid

192 "Growth Slows, Diversity Grows In California's Regions." Public Policy Institute of California. May 8, 2002. 02 July 2008 <http://www.ppic.org/main/pressrelease.asp?i=279>.

193 Brown, Richard, 'and' Koomey, Jonathon. "Electricity Trends in California:Past Trends and Present Usage Patterns." Energy Policy 31, 9 July 2003 849-864. 25 June 2008 <http://enduse.lbl.gov/info/LBNL-47992.pdf>.

194 "Peaker Power Plant Fact Sheet." Illinois Environmental Protection Agency. 2007. 25 June 2008 <http://www.epa.state.il.us/air/fact-sheets/peaker-power-plant.html>.

195 Ibid

196 Barringer, Felicity. "California Moves on Bill to Curb Sprawl and Emissions ." 28 08 2008. New York Times . 2 Sep 2008 <http://www.nytimes.com/2008/08/29/us/29sprawl.html?_r=1&oref=slogin

expected to be even greater in the inland areas, which have dispersed settlement patterns, vehicle miles traveled would almost certainly increase as a result of longer commute times. According to the Public Policy Institute of California, counties with the longest commute times include San Joaquin Valley and Los Angeles and San Bernardino counties. [197] These are three of the counties that are expected to experience some of the highest population growth rates in California, adding significantly to the number of miles traveled as a result of the longer commutes coupled with rapid growth rates.[198]

Other aspects of transportation such as transportation infrastructure will also be put under great stress in lieu of the expected population growth if it is not expanded to meet the increase in population. The development of this infrastructure will for the most part take place inland since that is where a significant part of the population growth is expected to take place; with the increase in infrastructure inland having a major impact on climate change by virtue of the increase in greenhouse gas emissions from the magnitude of the construction efforts. Over the last two decades, there has been a 50 percent increase in population and miles driven and yet California has increased lane capacity on its highways by seven percent. According to the census bureau, California comes in at 48th place in investment in highways and 40th overall in infrastructure investment according to personal income.[199] In addition to highways, airports and ports, which are also extremely vital to California businesses, will also need to be expanded to meet the demands of a higher population. California's airports are already working beyond capacity without much room for expansion, and will need to be improved in order to be able to cope with the population growth.[200] These improvements are especially vital to the proper functioning of California's economy.

Air Quality and Public Health

Population growth is also certain to have an effect on the air quality of California by virtue of the increased emissions. According to an article published in the journal *Demography* that addressed recorded population growth and air quality data in California in the 1980's, emissions increased as a result of population growth from

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[197] Barbour, Elisa. "*Time to Work*". Public Policy Institute of California: California Counts" February 2006. 30 August 2008. < http://www.ppic.org/content/pubs/cacounts/CC_206EBCC.pdf>

[198] Landis, John and Reilly, Michael. "How We Will Grow: Baseline Projections of the growth of California's Urban Footprint through the Year 2100. August 1, 2003. *Institute of Urban & Regional Development. IURD Working Paper Series*. Paper WP-2003-04. 30 Auguest 2008. <http://repositories.cdlib.org/iurd/wps/WP-2003-04>

[199] Infrastructure." California Business Roundtable. 2006. 02 Jul 2008 <http://www.cbrt.org/infrastructure.html>.

[200] Infrastructure." California Business Roundtable. 2006. 02 Jul 2008 <http://www.cbrt.org/infrastructure.html>.

residential and commercial sources as well as from vehicles.[201]As mentioned earlier, population growth is expected to be higher in the inland areas, where temperatures are already higher than at the coastal areas, and there the increase in pollution will also be higher in these inland areas. The increase in pollution and decrease in air quality will be accompanied by higher temperatures in areas that are hotter than average due to geographic characteristics. This poses a public health risk for the inland residents, with the increase in pollution leading to a greater number of respiratory illnesses such as asthma, and the increase in temperature leading to greater heat related hazards such as heat stroke, fainting, and dehydration. As can be seen, most of the detrimental health impacts of climate change as a result of population growth in California are a result of the spatial distribution of this population growth and the dispersed nature of pre-existing building patterns, particularly in the suburban inland empire.

Water

California is already witnessing a water crisis, and the impending population growth would further increase the complicated water supply situation. California's population is expected to reach over 47 million by 2020 and by the same year, the urban population in California is expected to use 12 million acre feet per year (mafy) of water, which is 3.2 mafy more than what was needed in 1995[202] This reality, in light of the fact that every water supply source in California is past its physical or legal capacity to be sustained, demonstrates the extent of the stress that will be placed on California's water supply as a result of population growth. Despite the 3.2 mafy increase in water usage, the per capita water use is actually expected to less in 2020 than it was in 1995].(02553 mafy per person in 2020 vs. 0.2848 mafy per person in 1995). Despite this increase in use efficiency, the amount of water used will still increase by 3.2 mafy due to the increase in population, which will more than offset the increase in use efficiency. In addition, the stress on water use will further be exacerbated by the population, especially because of the spatial distribution of this population growth.

Most of the population growth is going to be taking place in Southern California (including Imperial, San Diego, Orange, Riverside, San Bernardino, Los Angeles, and Ventura counties) where the amount of urbanized land will grow from around 800,000 hectares in 1998, to 1,000,000 hectares by 2020) and San Joaquin Valley where the amount of urbanized land will increase from 181,000 hectares in 1998 to 262,000 hectares by 2020.[203] Considering the water crisis that is already plaguing the state, this

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[201] Cramer, James. "Population Growth and Air Quality in California." Demography 35(1998): 45-56
[202] Jenkins, M. W. , J. R. Lund and R. E. Howitt. July 2002. "Impacts of Population Growth and Climate Change on California's Future Water Supplies". University of California at Davis. p. 9.
[203] Landis, John and Reilly, Michael. "How We Will Grow: Baseline Projections of the growth of California's Urban Footprint through the Year 2100. August 1, 2003. *Institute of Urban & Regional*

spatial distribution of population growth does not bode well for the shortage. Southern California already imports a little more than half of it's water from outside the region , and the expected growth in population will only further exacerbate the water shortage. [204] A significant source of water for Southern California is the San Joaquin Delta, which is experiencing a depletion in its water supply, and there is also a new restriction on when water can be pumped from the delta in order to protect an endangered species of fish. Therefore, even if Californians make a great deal of progress in their efficient use of water, California's water crisis will continue to be a major force to reckon with in the future since some of the fastest growth is expected to occur in water scarce areas. Population growth is only going to increase population driven stresses such as a water crisis in the future, and it will be especially dire due to the location of the population growth.

Agricultural water use in the future is also expected to pose a problem for the allocation of scarce water resources. Currently agriculture uses up 80 percent of California's water supply and with the expected rise in population, water will become a highly contested resource.[205] At present, the federal government provides generous subsidies to pay for water irrigation. These subsidies are estimated to be about $1.2 billion annually, and with increasing population, agriculture will have to compete even more fiercely for the water in face of growing human population and industry needs.[206] Furthermore, high quality cropland is in danger of being lost to urban sprawl and erosion and as a result poorer quality marginal land will have to be used for growing crops, thereby necessitating even more irrigation.

Land Availability

According to estimates of the population doubling to 64 million by 2035, about 32 million out of California's 100 million acres will need to be utilized for housing, employment, and transportation. [207]At present, 122,000 acres, approximately 1.5 percent of the land is lost to urban and industrial sprawl every year.[208] In addition to losing land to urban and industrial sprawl, California is losing land to agriculture, especially for biofuels as well as for carbon sequestration. The abrupt rise in oil prices spawning the rise of biofuels has also resulted in the conversion of marginal land into agricultural land strictly

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for biofuel purposes. In the next 30 years, greenhouse gases that will be emitted as a result of the conversion of land (forest or grassland) into new cropland to replace the grains that had been reassigned to biofuels are expected to increase dramatically.[209] Concurrently, there will also be an increase in population and demand for oil in these next 30 years while the price of oil will be increasing, thereby creating an even greater need for alternative fuels such as ethanol. This could result in a higher rate of land conversion, placing an even further restraint on the amount of land available for expansion for the rising population needs. A combination of losing land to urban sprawl and biofuel purposes will make it harder for citizens of California to find land to meet their residential and infrastructural needs while also meeting their agricultural and natural resource needs such as transportation fuels.

Factors discussed previously such as land availability, energy use and water are all dependent on the extent of population growth. When each of these categories is further divided, the importance of the extent of population growth is even more evident as each subcategory is dependent on the population, and therefore collectively the number of people has a large effect on the usage of a particular resource. Whether it is the consumption of water for residential as well as commercial and agricultural purposes, or the residential and commercial demand for electricity and oil, or the availability of land for expansion of residential areas and infrastructural purposes -- all of these are heavily dependent on the number of people in California. However, population growth is rather unpredictable, thereby making it difficult to come up with accurate estimates about California's population in the years to come. There have been several estimates generated, but the precise number will be unknown because it is impossible to determine how many people will be born and how many people will die; but even harder will be to determine the number of immigrants that California will be home to, both legally and illegally. Currently the projections show that most of this population growth is going to occur in Southern California, especially in the inland areas where the impact on climate change is higher as a result of the several factors as discussed earlier. In order to try to minimize the population growth effects, the California government could possibly institute policies that would encourage the new population to move into places that would be lower risk areas. California's State Assembly passed a measure on the 26th of August which would commit tens of billions of dollars in state and federal transportation subsidies to cities' and counties' fulfillments of efforts to slow down the increase in driving. The eventual goal is to encourage people to live in areas near

[209] " Biofuels, Land Conversion and Climate Change." Hill Heat:Science Policy Legislation Action. 25 April 2008. 04 July 2008 <http://www.hillheat.com/events/2008/04/25/biofuels-land-conversion-and-climate-change>.

current development and reduce commutes to work. 210 This measure would hopefully prove effective in encouraging people to settle in areas that would decrease the additional impact on climate change by driving less. Other strategies to facilitate the population growth into areas that would be lower risk in terms of the effects population growth would have on climate change would be ensure that the risks of living in the area were reflected in the prices. For example, given the water shortage in Southern California, if people wanted to settle in areas that were facing a dire water crisis, they would need to pay a price for the risk, in terms of the price of water as well as the price of housing. The government would need to get rid of subsidies that distort the true cost of living in water scarce areas and encourage residents to live in areas that have more sustainable water resources. Alternatively, in fire-prone areas, residents should have to pay for the price of the fire risk that is borne by the state through provision of fire-fighting services as well as the water used in protecting their homes during fires. Most importantly, the increase in population growth will have to be managed in such a way as to minimize the impact it would have on climate change.

This in turn, makes a significant difference to the predicted impacts of climate change because all the predictions are based on human activities. Therefore coming up with an estimate of the amount of greenhouse gases emitted and produced is highly contingent on the number of people, but since the number of people is an unknown element, the prediction could vary quite significantly depending on the population growth estimate used. Population growth is not only a factor to reckon with in terms of its impact on climate change, but it is also expected to have a tremendous effect on more imminent issues such as the water crisis, electricity consumption, and infrastructural capacities. In summary, population growth is a crucial factor not only for determining the impact on climate change, but also for shorter term issues like resource management within California.

Notes and References

[210] Barringer, Felicity. "California Moves on Bill to Curb Sprawl and Emissions ." 28 08 2008. New York Times . 2 Sep 2008 <http://www.nytimes.com/2008/08/29/us/29sprawl.html?_r=1&oref=slogin>

4. Transportation: Background

Climate change will have an impact on California's transportation infrastructure with some impacts being shorter term than others. The components of climate change that are relevant to California and were looked into were changes in temperatures, increased precipitation and rise in sea levels. The organization of this section divides California's transportation infrastructure into five sub-sections: surface transportation, aviation, railroads, ports and marine transportation, and pipelines. Within each sub-sections, first there will overview of impacts from the different components of climate change and then possible adaptations. There are two sub-sections before the sections on impacts and adaptation for specific modes of transportation. The first sub-section is for estimates of the cost of the most immediate climate change impact for California, which is increased precipitation specifically ENSO events. The second sub-section deals with the current state of California's transportation infrastructure. Besides the effects of increased precipitation, most of the impacts of climate change on transportation will be felt and have to be dealt with in a longer timeframe (Table 4.1).

Table 4.2. Expected Lifetimes and Impacts for Different Transportation Modes

Transportation Mode	Expected Infrastructure Design Life	Main Impacts on Infrastructure	Impact Timeframe
Surface Transportation			
Pavement	10-20 years	Change in temperatures, increased precipitation and rise in sea levels	Longer term, shorter term, longer term
Bridges	50-100 years	Changes in temperatures, rise in sea levels, wind loads	Longer term, longer term, shorter term
Culverts	30-45 years	Increased precipitation	Shorter term
Tunnels	50-100 years	Rise in sea levels, increased precipitation	Longer term, shorter term
Aviation			
Runway pavement	10 years	Change in temperatures, increased precipitation and rise in sea levels	Longer term, shorter term, longer term

Terminals	40-50 years	Change in temperatures, increased precipitation	Longer term, shorter term
Railroads			
Rail tracks	Up to 50 years	Change in temperatures, increased precipitation and rise in sea levels	Longer term, shorter term, longer term
Ports and Marine Transportation			
Locks and dams	50 years	Rise in sea levels, change in temperatures	Longer term, longer term
Docks and port terminals	40-50 years	Rise in sea levels, change in temperatures	Longer term, longer term
Pipelines	100 years	Increased precipitation	Shorter term

Climate change will have an important impact on California's transportation and its infrastructure, but there are very few[211] studies on the potential economic impact of climate change on transportation operations and its infrastructure. California's economy relies heavily on its transportation infrastructure, especially for trade. In 2000 trade shipments through California were $392 billion, an increase of nearly $100 billion since four years earlier[212]. As can be seen in Table 4.2, California has three of the top ten U.S foreign trade freight gateways by value of shipments in 2005. Of the few studies on the topic that have been published, there are even less that are detailed and focus specifically on California. Therefore the possible impacts can only be inferred from studies of other regions and the economical costs can only estimated.

[211] 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".
duVair, Pierre, Douglas Wickizer, and Mary Jean Burer. 2002: Climate Change and the Potential Implications for California's Transportation System. In The Potential Impacts of Climate Change on Transportation: Workshop Summary, U.S. Dept. of Transportation, Workshop, 1-2 October.
[212] duVair et al., 2002.

TABLE 3-1 Top 10 U.S. Foreign Trade Freight Gateways by Value of Shipments, 2005

Rank	Port	Mode	Shipment Value (in billions of U.S. dollars)
1	John F. Kennedy International Airport, NY	Air	$134.9
2	Los Angeles, CA	Vessel	134.3
3	Detroit, MI	Land	130.5
4	New York, NY, and New Jersey	Vessel	130.4
5	Long Beach, CA	Vessel	124.6
6	Laredo, TX	Land	93.7
7	Houston, TX	Vessel	86.1
8	Chicago, IL	Air	73.4
9	Los Angeles International Airport, CA	Air	72.9
10	Buffalo-Niagara Falls, NY	Land	70.5

Source: BTS 2007, 39.

State of California's Current Transportation Infrastructure

The current state of infrastructure in the state of California leaves much to be desired. California currently has $2 trillion of transportation infrastructure. In the last 20 years its population and miles driven has increased by 50 percent, but its lane capacity increase on highways has only been 7 percent. It currently ranks 48th in investment in highways and 40th in overall infrastructure investment[213].As of 2006, California's grade in the ASCE Infrastructure Report Card is a C-, which is only slightly better than the national one of a D. The grades for transportation infrastructure and port facilities are not much better than the grade for the overall infrastructure in the state. These grades only take into account current transportation infrastructure conditions, needs and demands, but does not take into account the additional problems and costs that can arise from the physical impacts of climate change. Even so, these grades are a good starting point to evaluate California's current transportation infrastructure.

According to the report, California receives a C- in aviation. This grade is based on forecasted consistent growth in demand for air transportation while the capacity of the aviation infrastructure in California is not ready to meet this growth due to limited capacity and restrictions on infrastructure growth. The proposed annual investment needed to achieve a B grade through the expansion of airports is $0.5 billion. The report does not stop there and provides brief overviews of the conditions of the four largest airports in the state.

The grade that California receives for overall transportation is an even lower D+. The low grade stems from concerns over capacity and lack of investment besides seismic upgrades and ongoing maintenance. The proposed investment in needed to bring the grade up to a B is $17.9 billion per year. Among the transportation related infrastructure

[213] California Infrastructure Coalition. Economic Impact of Funding California's Transportation Infrastructure.

in the report, ports received the highest grade of a C+. Current ports infrastructure is in good condition, but with projected cargo expected to double by 2010 more infrastructure upgrade is needed. The annual investment proposed for ports infrastructure is $1.2 billion[214].

These grades and estimated investments needed for improvements for the different sectors of California's infrastructure are a good starting point for the possible impacts of climate change on transportation infrastructure in general, but they are based on capacity adequacy of current transportation infrastructure while the impact of climate change will also affect and to a greater degree the quality side of infrastructure. Climate change will undoubtedly increase the estimated costs needed to maintain transportation infrastructure in the state. The importance of transportation infrastructure of course cannot be denied. The need to increase spending on transportation infrastructure should not be avoided, but there are also benefits from the increased spending in this area. Every $1 billion of transportation spending creates 18,000 new jobs in the state. As can be seen in Figures 1-3, for every construction job created with additional transportation funding in California, there would be an additional 0.76 jobs in indirect and induced sectors for a total employment multiplier of 1.76. For every dollar spent on infrastructure, there will be an additional $0.97 in indirect and induced spending in the state economy[215].

Figure 3.1. Economic Impact of Funding California's Transportation Infrastructure

[214] ASCE California Infrastructure Report Card 2006.
[215] California Infrastructure Coalition.

TOTAL ECONOMIC IMPACTS OF POTENTIAL TRANSPORTATION FUNDS

(DOLLARS IN MILLIONS UNLESS NOTED)

Impacts	*Direct*	*Indirect*	*Induced*	*Total*
		$2.5 Billion Level		
Output	$2,157	$831	$1,269	$4,257
Employment	25,384	6,560	12,668	44,611
Value Added	$1,174	$470	$750	$2,394
Employee Compensation	$955	$256	$388	$1,599
		$2.0 Billion Level		
Output	$1,726	$665	$1,015	$3,407
Employment	20,313	5,249	10,137	35,700
Value Added	$939	$376	$600	$1,916
Employee Compensation	$764	$205	$311	$1,280
		$1.5 Billion Level		
Output	$1,294	$499	$761	$2,554
Employment	15,228	3,936	7,600	26,764
Value Added	$704	$282	$450	$1,436
Employee Compensation	$573	$154	$233	$959
		$1.0 Billion Level		
Output	$864	$333	$508	$1,705
Employment	10,165	2,628	5,073	17,866
Value Added	$470	$188	$300	$959
Employee Compensation	$382	$103	$156	$640
		$0.5 Billion Level		
Output	$431	$166	$253	$851
Employment	5,071	1,311	2,531	8,912
Value Added	$235	$94	$150	$478
Employee Compensation	$191	$51	$78	$319

Sacramento Regional Research Institute, April 2004

Source: IMPLAN, 2001 Coefficients based on LAO, SAER Group, and TCRP information

Note: Differences due to rounding. Impacts do not include estimated Right of Way costs.

Figure 3.2. Sectors with Largest Greatest Total Employment Impacts

SECTORS WITH GREATEST TOTAL EMPLOYMENT IMPACTS

Sector	$2.5 Billion Level	$2.0 Billion Level	$1.5 Billion Level	$1.0 Billion Level	$0.5 Billion Level
Other new construction	14,505	11,609	8,700	5,805	2,895
Highway, street, bridge, and tunnel construction	10,609	8,489	6,369	4,250	2,120
Food services and drinking places	1,550	1,240	930	621	310
Architectural and engineering services	1,374	1,099	824	550	274
Wholesale trade	1,305	1,042	780	525	262
Offices of physicians and dentists	726	581	435	291	145
Employment services	707	566	424	283	141
Automotive repair and maintenance	528	423	317	212	106
Hospitals	517	413	310	207	103
Food and beverage stores	504	403	302	202	101
General merchandise stores	426	341	256	171	85
Real estate	424	339	254	170	85
Nursing and residential care facilities	363	291	218	146	73
Motor vehicle and parts dealers	359	287	215	144	72
Nonstore retailers	321	257	193	129	64

Sacramento Regional Research Institute, April 2004
Source: IMPLAN, 2001 Coefficients based on LAO, SAER Group, and TCRP information
Note: Differences due to rounding. Impacts do not include estimated Right of Way costs.

Figure 3.3. Sectors with Greatest Total Output Impacts

SECTORS WITH GREATEST TOTAL OUTPUT IMPACTS
(IN MILLIONS UNLESS NOTED)

Sector	$2.5 Billion Level	$2.0 Billion Level	$1.5 Billion Level	$1.0 Billion Level	$0.5 Billion Level
Highway, street, bridge, and tunnel construction	$1,086	$869	$652	$435	$217
Other new construction	$1,032	$826	$619	$413	$206
Wholesale trade	$189	$151	$113	$76	$38
Architectural and engineering services	$136	$109	$82	$54	$27
Owner-occupied dwellings	$94	$75	$56	$38	$19
Petroleum refineries	$85	$68	$51	$34	$17
Automotive repair and maintenance	$80	$64	$48	$32	$16
Food services and drinking places	$70	$56	$42	$28	$14
Real estate	$69	$55	$41	$28	$14
Offices of physicians and dentists	$62	$49	$37	$25	$12
Hospitals	$60	$48	$36	$24	$12
Monetary authorities and depository credit intermediation	$51	$41	$31	$20	$10
Insurance carriers	$49	$39	$29	$20	$10
Machinery and equipment rental and leasing	$48	$38	$29	$19	$10
Truck transportation	$39	$32	$24	$16	$8

Sacramento Regional Research Institute, April 2004
Source: IMPLAN, 2001 Coefficients based on LAO, SAER Group, and TCRP information
Note: Differences due to rounding. Impacts do not include estimated Right of Way costs.

Climate Change Impacts on Transportation

The component of climate change that will have the most immediate impact on California's infrastructure is increase in precipitation such as during ENSO events. The last one that affected California was the one from the end of 1997 through the beginning of1998. Total losses for California in this event were $1.1 billion[216]. The effects of that event hit California and specifically the Bay Area hard. The results of the increased precipitation were sink holes, landslides, flooded highways and blocked roads. In April of 1998, Caltrans had estimated the road damage for the Bay Area was $50 million and for the state's highway system it was $300 million. The hardest hit state highway was Route 1, the Pacific Coast Highway where portions were closed for 13 weeks. Most of the damage for Highway 1 and other roadways was from landslides and washouts. Another problem was in the increased number of potholes. San Francisco usually fills about 40 potholes per week, but on the week of February 16, it filled 157 potholes and statewide by early March, Caltrans had spend more than 116,000 man-hours filling thousands of potholes. Inland areas also felt the effects of ENSO such the flooding of entire towns and three underpasses of Highway 99 becoming virtual lakes due to flash flooding[217]. The damage estimates do not include the costs of preparation for ENSO, such as the more than $200 million Caltrans spent to repair storm damage from the winter of 1996-1997 and the purchase of 295,000 tons of abrasives and 12,000 tons of deicers for $3.5 million to melt snow and improve traction on mountain roads[218]. The preparation for this particular ENSO event was partly due to the $265 million in damages (approximately $2 billion in losses when adjusted to 1998 dollars) suffered during the one in 1982-1983. This suggests that the mitigation was effective in lowering losses[219].

Surface Transportation

The expected design life of surface transportation can be varied. For pavement it is 10-20 years, for bridges it is 50-100 years, for culverts, a conduit used to enclose a flowing body of water and allow the water to pass underneath a road, railway or embankment, it is 30-45 years and for tunnels it is 50-100 years. The design lives are on average, but most infrastructures operate beyond its expected design life. Climate change will have a negative impact on the expected design lives of all surface transportation.

The first major expected component of climate change is temperature variations especially increase in temperature for California. Temperature increases in the form of increases of hot days and heat waves will impact pavement and concrete construction process, cause thermal expansion on bridge expansion joints and paved surfaces. Pavement impact includes concerns regarding pavement integrity such as softening,

[216] Changnon, S.A. El Niño 1997:1998: The Climate Event of the Century. Oxford, New York: University Press, 2000.
[217] http://www.tfhrc.gov/pubrds/julaug98/planning.htm
[218] http://ceres.ca.gov/elnino/arar/bth.html
[219] Changnon, Stanley A. "Impacts of 1997-98 El Niño- Generated Weather in the United States". American Meteorological Society 80 (1999).

traffic-related rutting and migration of liquid asphalt[220]. Warmer temperatures can change the freeze/thaw cycles beneath roadways to the point where infrastructure damage in the form of heaving or buckling may occur[221]. The impact of possible decreases in cold days due to temperature is minimal. Also the benefits of reduced pavement deterioration from later onset seasonal freeze and earlier onset of seasonal thaw will be minimal for California.

The second major component of climate change is rising sea levels. Most of the impact of rising sea levels will be in coastal areas with inundation of roads. In addition underground tunnels and low lying infrastructure will be subjected more frequent or severe flooding. Bridges will be particularly affected by the component of climate change with probably erosion of road base and bridge supports, bridge scour and reduced clearance under bridges. Bridges will also be affected wind loads, which is stronger wind speeds and thus loads on bridge structures and possibly more turbulence.

The last major climate change component is change in precipitation patterns. An increase in intense precipitation events will increase the flooding of roadways and subterranean tunnels, increase road washout, landslides and mudslides that damage roadways. Increased intense precipitation will also create overloading of drainage systems that can then cause backups and street flooding. Impacts on soil moisture levels from increased intense precipitation can affect the structural integrity of roads, bridges and tunnels. There is also an adverse impact of standing water on the road base. The other side of changes in precipitation patterns is increases in drought conditions, which can increase the susceptibility to wildfires that can then be a direct threat to transportation infrastructure. In areas that are deforested by wildfires, there is increased susceptibility to mudslides. Lastly if the change in precipitation patterns is in the form of precipitation change from snow to rain in winter and spring thaws, there is an increased risk of floods from runoffs, landslides, slope failures and damage to roads. There are also impacts on surface transportation infrastructure from more frequent storms such as hurricanes, but this is not applicable to California[222]. Highway 1 already experiences frequent mudslides and high waves during mild winter storms, as well as washouts every year. Certain roadways could be closed permanently if there are significant increases in erosion, landslides or roadway undercutting. Damage from 1997-1998 El Niño event included the repeated washing out of major highways and

[220] National Research Council (NRC). Potential Impacts of Climate Change on U.S Transportation. 2008. Transportation Research Board Report 290.
[221] Pisano, Paul, Lynette Goodwin and Andrew Stern. 2002: Surface Transportation Safety and Operations: The Impacts of Weather within the Context of Climate Change. In The Potential Impacts of Climate Change on Transportation: Workshop Summary, U.S. Dept. of Transportation, Workshop, 1-2 October.
[222] NRC, 2008.

smaller roads, isolation of rural communities, destruction of 1,000 feet of the levee along the Santa Maria River resulting in the flooding of hundreds of acres of agriculture lands in Ventura County, the undermining of the Union Pacific railroad trestle by surging flows from the Ventura River and a damaged rail bridge in San Clemente. The cost of this event to the state was $550 million in total losses and damages[223].

Climate change's impact on transportation is not only limited to its impact on transportation infrastructure, but will also have economic and operational impacts. The operational impacts in terms of variations in temperatures vary depending on the sign of the temperature change. In the case of increases in very hot days and heat waves besides the obvious impact of vehicle overheating and tire deterioration there is also the impact of limitations on periods of construction activities due to health and safety concerns with restrictions typically beginning at 85°F (29.5°C) and possible heat exhaustion at 105°F (40.5°C). In the other temperature case the impact of the decrease in very cold days is usually beneficial in the form of fewer cold-related restrictions for maintenance workers and lower snow and ice removal costs, but all the impact from this case is minimal for California. In terms of the seasonal temperature change, later onset of seasonal freeze and earlier onset of seasonal thaw, its impact will be felt through changes in seasonal weight restrictions, changes in seasonal fuel restrictions, longer construction season and improved mobility and safety associated with a reduction in winter weather.

Sea level rise will only impact surface transportation operations in coastal areas where rising sea levels added to storm surges can result in more frequent interruptions in travel due to flooding. Change in precipitation patterns will have a great impact on surface transportation operations. Increase in intense precipitation events will cause increases in weather-related delays, increases in traffic disruptions, and increases in flooding of evacuation routes. Also changes in rain, snowfall and seasonal flooding that can impact safety and maintenance operations and disrupt construction activities. Increases in drought conditions will increase susceptibility to wildfires that can cause road closures due to fire threat or reduced visibility. Changes in seasonal precipitation will provide benefits for safety and reduced interruptions if it is in the form of frozen precipitation shifting into rainfall, but as mentioned earlier this can also increase risks of floods, landslides and slopes failure.

In order to deal with climate change, transportation infrastructure has to be changed and adapted to meet the new climate conditions. Temperature changes in the short term (30 to 40 years) will have minimal impact on pavement or structural design but potential significant impact on road, bridge scour and culvert design in cold regions, which is not that applicable to California. In the long term (40 to 100 years) climate change will have a significant impact on pavement and structural design, requiring new

[223] duVair et al., 2002.

materials and better maintenance strategies. Changing precipitation levels in the short term could affect pavement and drainage design. There could be a need for greater attention to foundation conditions, more probabilistic approaches to design floods (hypothetical floods used for planning and floodplain management) and more targeted maintenance. In the long term, there is going to be an impact on foundation design and the design of drainage system and culverts. Climate change will also have an impact on design of pavement sub-grade and materials. Wind loads in the short term (30-40 years) could impact change design factors for design of wind speed and wind tunnel testing will have to consider more turbulent wind conditions. In the long term, there is the need for stronger materials and there is an impact on design considerations for suspended and cable-stayed bridges. There is not much in term of short term for the effect of sea level rise. In the long term, there will be greater inundation of coastal areas. To combat this, there is a need for more stringent design standards for flooding and building in saturated soils. Also, greater protection of infrastructure of infrastructure is needed in cases when higher sea levels combine with storm surges. The impact of greater storm surges and wave heights in the short term will be felt in the need for design changes to bridge heights in vulnerable areas and the need for more probabilistic approach to predicting storm surges. In the long term, there will be a need for design changes to bridge design in both superstructure and foundation, a need for change in material specifications and more protective strategies for critical components.

Besides the adaptations described above, there are also adaptations to the previously described physical and operations impacts of climate change on surface transportation. In the case of increases in very hot days and heat waves, the adaptation options to deal with the infrastructure impact are development of new heat-resistant paving materials and greater use of heat-tolerant street and highway landscaping. In order to deal with the limitations on construction activities, there would be a need to shift construction schedules to cooler parts of the day, which is less important. The changes in operations to deal with decreases in very cold days are mainly beneficial such as reduction in snow and ice removal, extension of construction and maintenance season and shortening of season for use of ice roads, but this is less relevant for California. This last change can also be used in the case of changing seasonal temperatures in addition to the relaxation of seasonal weight restrictions. Out of all of these changes the most important one for California is the one dealing with increases in very hot days and heat waves, but climate change-infrastructure relationship for California is a topic that is just being broached by state agencies and is still a relatively unexplored area.

There are various adaptation possibilities for surface transportation infrastructure in the case of sea level rise coupled with storm surges. In term of changes in infrastructure design, the adaptation options are elevation of streets and bridges, elevation and protection of bridge, tunnel and transit entrances, additional drainage canals near coastal roads and additional pumping capacity for tunnels. Besides these adaptations, there are other possibilities that are more general and that would not only affect transportation infrastructure but also other areas. These adaptations would be along the lines of relocating sections of roads inland, protecting high value coastal real estate with levees, seawalls and dikes, strengthening these structures that are already in place, restricting development of most vulnerable coastal areas and returning some coastal areas to nature[224]. It was estimated in 1989 that the cost to elevate affected streets in Miami in order to deal with rising ground water levels due to sea level rise was $200 million in 1989 dollars. New Zealand estimated the cost of retrofitting or redesigning its bridges for climate change and found out that by doing so initial costs are increased by about 10 percent, but that over the life of the structure the incremental cost is less than 1 percent due to the decreased probability of climate related damage[225]. The most important ones in terms of transportation infrastructure are probably the changes in infrastructure design while the other adaptations are more general and not specifically dealing with transportation infrastructure.

In the case of precipitation change impact on surface transportation infrastructure and operations, most of the adaptations are to deal with increases in intense precipitation events. On the infrastructure side, the adaptation options are protection of critical evacuation routes, upgrade of road drainage systems, protection of bridge piers and abutments with riprap and addition of slope retention structures and retaining facilities for landslides. Other adaptation include increases in culvert capacity, increases in pumping capacity, increases in the standard for drainage capacity for new transportation infrastructure and major rehabilitation projects (using assumptions of a 500-year instead of a 100-year storm). On the operations side, the adaptation options are expansion of systems for monitoring scour of bridge piers and abutments, increase in monitoring of land slopes and drainage systems, increase in real-time monitoring of flood levels and integration of emergency evacuation procedures into operations. There are also other more general adaptations such as greater use of sensors for monitoring water flows and restriction of development in floodplains. In the case of increases in drought conditions, the suggested adaption option to deal with the increased probability of wildfires is vegetation management[226].

Aviation

The expected design life of aviation infrastructure varies. For runway pavements it is 10 years while for terminals it is 40-50 years[227]. Weather has a very direct impact on aviation. It is responsible for 70 percent of the delays in the National Airspace System

[224] NRC, 2008.
[225] U.S. Climate Change Science Program. Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I.
[226] NRC, 2008.
[227] NRC, 2008.

(NAS) according to FAA statistics. The estimated total national weather impact cost for accident damage and injuries, delays, and unexpected operating costs is $3 billion[228]. The economic costs from the impact of climate change on the aviation industry will undoubtedly increase these costs for the aviation industry.

The impacts of increases in temperature for aviation infrastructure are heat-related weathering and buckling of pavement and concrete facilities and heat related weathering of vehicle stock.

The impact of rising sea levels on aviation infrastructure will only affect airports in coastal areas through the inundation of airport runways in those areas[229]. Examples of coastal airports that would be affected by flooding include the San Francisco, Oakland and Santa Barbara airports that were built on wetlands back when they were called swamps and today are about 10 feet above current sea level. Extreme high tides together with flood conditions are enough to reach close to the existing levels.[230] This is really critical because airports are more expensive to deal with and moving them would be both problematic and incredibly expensive compared to the relatively easier adaptation possibilities for pavement and vehicle stock.

The impact of increased intense precipitation on aviation infrastructure is varied. The first impact is on the structural integrity of airport facilities. Another impact is the destruction or disabling of navigational aid instruments. Increased intense precipitation will also create flooding, which can damage runways and other infrastructure. In addition, pavement drainage systems can be rendered inadequate or damaged from this change in precipitation pattern and from changes in seasonal precipitation.

Temperature change will have a greater impact in terms of operations for aviation than it had in terms of infrastructure. Increases in very hot days and heat waves will have an impact on lift-off load limits at high-altitude or hot-weather climate airports with insufficient runway lengths. This will result in flight cancellations and limits on payload (i.e., weight restrictions). In addition delays due to excessive heat are possible and ground energy consumption will increase. The decrease in very cold days from temperature change will have some beneficial impacts in terms of aviation operations, but their impact for California is minimal compared to that of the increase in very hot days. Among the impacts on operations from this case in temperature change are lower snow and ice removal costs, reduction in need for deicing and fewer limitations on

[228] Kulesa, Gloria. 2002: Weather and Aviation: How does weather affect the safety and operations of airports and aviation, and how does FAA work to manage weather-related effects? In The Potential Impacts of Climate Change on Transportation: Workshop Summary, U.S. Dept. of Transportation, Workshop, 1-2 October.
[229] NRC, 2008.
[230] duVair et al., 2002.

ground crews at airports, which are typically restricted when wind chills below -20°F (-29°C). Sea levels rise will affect operations in airports in coastal zones creating the potential for closure or restrictions for airports in these areas.

Changes in precipitation patterns will have a great impact on aviation operations. Increase in intense precipitation events will increase delays due to convective weather, increase the probability delays and closing of airports from flooding due to storm water runoff that exceeds the capacity of collections systems. There are also implications for emergency evacuation planning, facility maintenance and safety management. Increases in drought conditions will decrease visibility for airports located in drought areas with potential increases in wildfires. Changes in seasonal precipitation will have similar effect on air transportation as it did on land transportation with the benefits of safety and reduced interruptions if frozen precipitation shifts to rainfall.

As expected from the greater impact of changes in temperatures on aviation operations compared to infrastructure, there are more adaptation options for aviation in that area. The adaptation options for aviation infrastructure in the case of increases in very hot days and heat waves are development of heat-resistant runway paving materials and extension of runway lengths at high-altitude or hot-weathered airports if it is feasible to deal with conditions such as high density altitude and payload restrictions that hamper takeoffs. On the operations side, the adaptations are increase in payload restrictions on aircraft at high-altitude or hot-weathered airports and increase in flight cancellations. In the case of decreases in cold days, the adaptations are on the operations side and beneficial such as reduction in snow and ice removal, and reduction in airplanes deicing. This last aspect is not that relevant for California since most of the major airports are not at a relatively high altitude, but there are still some airports that are.

The adaptation options for aviation in the case of sea levels rise only apply to those airports that are located in coastal areas and are on the infrastructure side. One adaptation possibility is the elevation of some runways. Other adaptations are construction or raise of protective dikes and levees, and relocation of runways if feasible, but this is a regional thing depending on the airport.

The main infrastructure adaptation for aviation to deal with the change in precipitation patterns of climate change is through increases in drainage capacity and improvement of drainage systems supporting runways and other paved surfaces. On the operations side, the adaptations are to be ready for more disruption and delays in air service and more airport closures in the case of increases in intense precipitation events[231]. Overall, weather will have a significant impact on the operations side, however on the cost

[231] NRC, 2008.

perspective there is not much in terms of infrastructure adaptations besides the improvements to runways that are similar to the pavement adaptations.

Railroads

The expected design life of rail tracks is up to 50 years. In terms of railroads, floods produce some of the largest economic damages[232]. The Midwestern river floods of 1993 flooded or idled over 4000 miles of track and estimated losses were over $200 million. In 1997 in Kingman, Arizona, a flash flood weakened an existing wooden trestle and led to the derailment of an Amtrak passenger train with damages of $7.2 million[233].

The impacts of increases in temperature for railroads are rail track deformities and equipment failure is possible when air temperature is above 110°F (43°C)[234]. Track misalignments caused by heat kinks are often the reason for train derailments that can lead to injuries, fatalities, property damage and toxic release of hazardous material. Another consequence of temperatures extremes is that railroad tracks may be exposed to uneven thermal expansion when shade is covering nearby sections, which can create the risk of warp and misalignment to freight traffic[235].

The impact of rising sea levels for railroads is only limited to inundation of rail lines in coastal areas.

The impact of increased intense precipitation on railroads is increased flooding of rail lines, possible damages to rail-bed support structures and landslides and mudslides that can damage tracks[236]. Coastal railroads have had similar problems such as landslides and mudslides during heavy storms with the results of shutting down of passenger and freight traffic for days[237].

Changes in precipitation patterns will have a similar impact on railroads as it did on surface transportation. Increases in intense precipitation events will cause increases in weather-related delays and disruptions of construction activities. Also changes in rain, snowfall and seasonal flooding that can impact safety. Increases in drought conditions will increase susceptibility to wildfires. Last, changes in seasonal precipitation will not have as great of an impact on railroads as it did on other surface transportation.

[232] NRC, 2008.
[233] Rossetti, Michael A. 2002: Potential Impacts of Climate Change on Railroads. In The Potential Impacts of Climate Change on Transportation: Workshop Summary, U.S. Dept. of Transportation, Workshop, 1-2 October.
[234] NRC, 2008.
[235] Rossetti
[236] NRC, 2008.
[237] duVair et al., 2002.

The adaptation option for railroad infrastructure to deal with increases in very hot days and heat waves is to have a greater use of continuous welded rail lines[238]. Continuous welded rail lines are more expensive and have been common in main lines since 1950s in the U.S and they are usually installed at 90 °F to cope with extremes of up to 120 °F. The cost to replace track range is from $0.5 million to $3 million per mile excluding any additional right of way expenses[239].

The adaptation option for railroad infrastructure to deal with sea level rise coupled with storm surges is elevated rail lines. In addition there are other more general adaptations options along the lines of relocating of sections of rail lines inland that affect other areas besides transportation and that have been already mentioned earlier in the surface transportation section. In the case of railroad transportation adaptations for the changes in precipitation patterns aspect of climate change, the adaptation options to deal with increased frequency of landslides, mudslides and wildfires are similar to those in the surface transportation section[240].

Ports and Marine Transportation

The expected design life for ports and marine transportation varies a little. For locks and dams it is 50 years while for docks and port terminals it is a little less, 40-50 years. Ports and marine transportation as expected will be the sub-sector of transportation most affected by rising sea levels. Rising sea levels will cause higher tides and storm surges that will necessitate changes in harbor and port facilities to accommodate for them. There will also be reduced clearance under waterway bridges and mentioned previously in the surface transportation. Rising sea levels will also create changes in the navigability of channels with some being more accessible and further inland due to deeper waters while others will be restricted due to changes in sedimentation rates and shoal locations[241]. Harbors may be subjected to wave damage, additional siltation from storm runoff and other navigation and safety problems[242].

The impact of increased intense precipitation on ports and marine transportation will impact harbor infrastructure through wave damage and storm surges. It will cause changes in underwater surface and silt and debris buildup, which can affect channel depth. Changes in seasonal precipitation will cause changes in silt deposition leading to reduced depth of some inland waterways and impact the long-term viability of some inland navigation routes.

[238] NRC, 2008.
[239] U.S. Climate Change Science Program
[240] NRC, 2008.
[241] NRC, 2008.
[242] duVair et al., 2002.

Temperature change's impact on ports and marine transportation infrastructure is minimal, however it will have an impact on its operation. Increases in very hot days and heat waves will have an impact on shipping due to warmer water in rivers and lakes. Decreases in very cold days will a positive impact in shipping through less ice accumulation on vessels, decks, rigging and docks, less ice fog and fewer ice jams in ports. The impact from seasonal temperature change is extended shipping season for inland waterways[243]. The other side of this is the effect of droughts on the inland river transportation system. California can learn from the experiences of mid-western states on the subject such the 1988 drought that affected the Mississippi River that reduced traffic by one fifth. California's rivers have similar control mechanisms in place to those of the Mississippi navigation system to maintain water levels and safeguard navigation during much of the year, but that may not even be enough as was the case in 1988 where low water levels in the Mississippi River left nearly 4000 barges stranded in Memphis, Tennessee[244].

Sea level rise will not have much impact on the actual operation of ports and marine transportation, which is in direct contrast with the huge impact this aspect of climate change has on infrastructure. Combined with more severe storm surges it can lead to required evacuation and interruption of operations.

Changes in precipitation patterns have an impact on marine transportation. Increases in intense precipitation events will cause increases in weather-related delays while increases in drought conditions will have an impact on river transportation routes and systems. Changes in seasonal precipitation and flow patterns will cause periodic channel closings or restrictions in the case of flooding increases.

The adaptation options for ports and marine transportation to deal with changes in temperature are not that many and mainly on the operations side. The only adaptation on the infrastructure side is in the case later onset of seasonal freeze and earlier onset of seasonal thaw, where the infrastructure adaptation is to design shallower bottom vessels for seaway travel. To continue with this aspect of temperature change, the adaptation in the operations side is through increases in summer load restrictions. There are also other more general adaptations such as shifts more dredging that come with environmental and institutional issues. In the case of decreases in cold days, the operational adaptation will be improvement in operating conditions from less ice accumulation, fog and jams.

Sea level rise is the aspect of climate change that will have the most direct impact on ports and marine transportation, therefore it is the area where the implementation of adaptation options is more critical. On the infrastructure side, the adaptations are the

[243] NRC, 2008.
[244] duVair et al., 2002.

raising of dock and wharf levels and retrofitting of other facilities to provide adequate clearance, the protection of terminal and warehouse entrances and the elevation of bridges and other structures. On the operations side, the adaption is in the form of more frequent bridge openings to handle shipping. There are also other adaptations such as more dredging of some channels and raising or constructing new jetties and seawalls to protect harbors.

The impact of changes in precipitation patterns on ports and marine transportation requires a few adaptations. In the case of increases in intense precipitation events, the adaptation options are all on the infrastructure side and include the strengthening of harbor infrastructure to protect it from storm surges and wave damage, and the protection of terminal and warehouse entrances from flooding. Another possible adaptation is more dredging on some shipping channels. In contrast, the adaptation options in the case of increases in drought conditions are on the operations or other category. The change in operation is through restrictions on shipping due to channel depth along inland waterways and in other river travel. Other possible adaptations to deal with this aspect of change in precipitation is release of water from upstream sources, shifts to other transportation modes and again the option of more dredging on some shipping channels and harbors. The adaptation options in the case of changes in seasonal precipitation are similar to those in the previous case of increases in drought conditions[245].

Pipelines

The expected design life of pipelines is 100 years. Temperature shifts resulting from climate change scenarios are not expected to have much direct or indirect impact on pipelines because pipelines protected from the effects of temperature change by the moderating and insulating effects of water and soil[246]. The main component of climate change that will have an impact on pipelines is increase in intense precipitation, which can cause increase scouring of pipelines roadbeds and damages to pipelines themselves. The adaptation for this impact is in the form of increases in monitoring of pipelines for exposure, shifting, and scour in shallow waters[247].

Financing Transportation Infrastructure

Finance will be an important part of climate change adaptation in the transportation sector, and we provide a quick synopsis of current financing mechanisms here. The funding for California's transportation system primarily comes from a combination of

245 NRC, 2008.
246 U.S. Climate Change Science Program
247 NRC, 2008.

federal, state, and local taxes. Other funding sources include fees, assessments, and private investment. These revenues from these sources go into a number of funding accounts. California then has a number of programs that guide the use of these funds.

Federal Funds. The IRS collects the Federal fuel excise tax. The revenues are deposited into the Highway Trust Fund (HTF). 85 percent of the HTF revenues go to the Highway Account of the HTF while the other 15 percent go to the Transit Account.[248] The funds in the Highway Account are distributed among the states as federal funds for projects on the state highway systems by the Federal Highway Administration (FHWA). This federal agency has an annual budget of over $30 billion. For the fiscal year of 2007, the FHWA had a total budget of approx. $39.1 billion. In addition, the FHWA is requesting a budget of $40.1 billion for 2009.[249] The funds in this account are mainly divided into two different programs. The first program is the Federal-aid Highway Program which provides resources and technical assistance to State and local governments for constructing, preserving, and improving the National Highway System. The program also provides resources for urban and rural roads that are eligible for Federal aid. The second program under the FHWA is the Federal Lands Highway Program. This program funds public roads and highways that are on federal and tribal lands that are not a State or local government responsibility. In addition to upkeeping the highway systems, funds are also put toward promoting safety, congestion mitigation, and environment issues. The FHWA uses funds toward new technologies research and outreach projects that promote safety standards. Funds are also given to traffic control centers in metropolitan areas to help remove congestion on their system. Funds are also given to projects to support and restore the environment.

The funds in the Transit Account are distributed to regional agencies and local transit providers in each state by the Federal Transit Administration. This federal agency distributes federal funds to locally planned, constructed, and operated public transportation systems throughout the United States. These systems include buses, subways, light rail, commuter. The FTA is requesting a budget of $10.1 billion for the fiscal year of 2009. $8.4 billion of the budget is to go for transit services, including security, planning, bus and railcar purchases and maintenance, facility repair and construction, and operating expenses. The grants in this budget also goes toward special transportation needs of he elderly, people with low incomes, and persons with disabilities. It also hopes to improve the accessibility of over-the-road buses, alternatives analysis for projects, and to fund the National Transit Database. $59.6 million of the proposed budget is to go toward transit research programs. These programs include grants to help develop solutions to improve public transportation and

[248] Transportation Funding in California, pg. iii-iv.
[249] "U.S. Department of Transportation Fiscal Year 2009 Budget in Brief - Federal Highway Administration", <http://www.dot.gov/bib2009/htm/FHA.html>

develop clean fuels and hybrid-electric buses. $1.6 billion of the proposed budget goes toward capital investment grants. These grants sponsor the construction of new guideway corridors, and extensions of existing systems. In addition, $48.3 million of the budget is requested to support transit security. Through its assistance and other programs, the FTA will use its money toward security training for transit system employees, emergency preparedness and response, and public awareness efforts. The rest of the proposed budget is to go toward the salaries of the people overseeing all the programs involved.[250]

State Funds. The state of California has four main sources of funding for their transportation system:

> State Fuel Tax California collects an excise tax on gasoline and diesel fuels. 65 percent of this revenue is distributed to California Department of Transportation (Caltrans). The other 35 percent is given to cities and counties.[251]
> Truck Weight Fees California collects a fee on commercial vehicles based on their weight. This represents a compensation for the wear and tear on the roadways.
> State Sales Tax California collects a 7.25 percent sales tax. Certain portions of this tax are put aside for transportation. In 1971, the Transportation Development Act set aside ¼ percent of this state sales tax for transit purposes only. In order to do so, a *Local Transportation Fund (LTF)* was set up in each county to receive the money. The act also extended the state sales tax to gasoline sales to compensate the state general fund for the loss of the ¼ percent sales tax. Any excess revenues are deposited into the *Public Transportation Account (PTA)*.[252]
> Proposition 1B Bonds This 2006 bond act provides $19.9 billion to fund projects that will improve the transportation system.[253] For more information on the Prop 1B bonds, please refer to the Prob 1B Bond program below.

California's highways, local roads, transit and rail, and aviation are funded through a variety of mechanisms. However, many of these mechanisms are outdated and can no longer support operations. For instance, many of California's highways have already surpassed their intended life. As a result, maintenance costs have continued to grow. Proposition 1B does provide a one-time additional funding for rehabilitation projects, but it does not address the problem that maintenance costs are rising faster than current revenue streams. A proposed solution to increase revenues is to index the gas tax for

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[250] "U.S. Department of Transportation Fiscal Year 2009 Budget in Brief – Federal Transit Administration, <http://www.dot.gov/bib2009/htm/FTA.html>
[251] Transportation Funding in California, pg. iv.
[252] Transportation Funding in California, pg. iv.
[253] Transportation Funding in California, pg. iv.

inflation. This will lead to an increase in the gas tax and will increase the revenues received. Another proposed approach is to create mileage based fees. An overview of current funding mechanisms is as follows.

Highways. The main funding account in use for highways is the State Highway Account. The funds in the State Highway Account get distributed into many different programs to improve the highway system. Some of the funds are put into maintaining and operating the current highway systems. Funds are also put into the SHOPP and Local Assistance programs. The rest of the funds are put into the STIP. In addition to the state highway account, the STIP also receives funds from the TIF. 25 percent of the funds in the STIP are given to Caltrans for the Interregional Transportation Improvement Program (ITIP) which works to improve intercity highways. The other 75 percent of the funds in the STIP go to Regional Transportation Planning Agencies that run the Regional Transportation Improvement Program (RTIP) that work to improve regional highways.[254]

Local Street and Roads. Local funding comes from a variety of sources. First off, some of California's fuel excise tax is given to cities and counties. Local areas also get some federal and state aid and some funds from the TIF. Local streets and roads also receive funding from their own local sources.

Transit and Rail. California's transit and rail system receives funding from a large variety of sources. One of the sources is the STIP rail funds which consist of funds from both the SHA and PTA. Like state highway funding, the ITIP funds in STIP are put toward intercity rail systems while the RTIP funds in STIP are put toward urban and commuter railway systems. The other sources of funding are the TCRF, Prop 116 Rail Bond Account, and Federal Transit Aid. These funds are distributed between intercity rail agencies, commuter rail agencies, and urban agencies by the California Transportation Commission (CTC). Intercity rail agencies include Pacific Surfliner, San Joaquin, and Capitol. Commuter rail agencies include Caltrain, ACE, Metrolink, and Coaster. Urban rail agencies include BART, Muni Metro/Cable Car, LA Metro Rail lines, Sacramento RT Light Rail, Santa Clara VTA Light Rail, and San Diego Trolley. The CTC also distributes some of the funds to other transit services like buses and ferries.

Aviation. Currently, the State Aeronautics Account is the only state source of funding for California's division of aeronautics. This account receives its revenues from the 18cents/gallon General Aviation Gas Tax and the 2cents/gallon Generation Aviation Jet Fuel Tax.[255] The other source of funds for California's aviation system is from federal aid. Unfortunately, the State Aeronautics Account has been decreasing since the fiscal year 1999-2000. It is estimated that the account will continue to decline until another

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[254] Transportation Funding in California, Chart 4.
[255] Transportation Funding in California, Chart 13

funding source is found. The Technical Advisory Committee on Aeronautics (TACA) has made a couple of recommendations to the CTC to add additional sources of funds to the Aeronautics Account. One recommendation is to add the revenue received from the aviation jet fuel sales tax to the Aeronautics Account. Currently, this revenue stream goes directly into the state and local general funds. By redirecting this revenue into the Aeronautics account, the State of California will have a dramatic increase of funds to improve their aviation systems. The TACA also recommends increasing funding for Caltrans to help smaller airports secure state and federal grants.

5. Tourism and Recreation: Background

As the tourism capital of the United States, California depends on its unique array of natural features to attract visitors from different counties, states, and countries. In 2007, 352.3 million tourists were drawn in by everything from the snowy slopes of Tahoe to the wide beaches of San Diego. Tourism brings in more money than any other industry in the state.[256] That year tourism brought in around $96.7 billion, showing how these visitors, and the recreation activities that drew them in, represent the economic success of the state as a whole.[257] These 352.3 million tourists make up an 11.5 percent share of the annual domestic travelers and a 21.7 percent share of the travelers from abroad who come to visit the country, showing that Californian tourism is not only good for the state itself, but the whole nation depends on it as well.[258]

With the inevitability of some degree of climate change, the tourism sector of the Californian economy is at risk. This is because so much of California's tourism depends on the conditions of the environment and unfortunately the changes in climate are beginning to affect the conditions of popular recreation areas. Certain outdoor recreation activities require specific conditions which can be affected by the change in climate (Table 5.1).

Table 5.1. Recreational Activities Vulnerable to Climate Change[259]

Table 2. Features of leisure and recreation types affected by climate change. General leisure: urban outdoor activities, e.g. tennis, golf, jogging, biking, park visits

Activity	Feature
General leisure	Daily temperature Precipitation/humidity Sunshine Extreme events (hurricanes, tornadoes)
Site-specific outdoor recreation	
Hiking, biking	Forest composition, vegetation cover, density
Fishing, boating	Water quality, quantity, fish habitat and catchability
Hunting	Animal habitat, availability
Bird/animal watching	Animal, species availability
Beach-going	Sea level, loss of beach/coastal areas
Skiing/winter sports	Snow loss
Rock climbing	Storm intensity, frequency

[256] California Travel and Tourism Commission, 2008. California Travel Fast Facts and Highlights
[257] California Travel and Tourism Commission, 2008. California Travel Fast Facts and Highlights
[258] California Travel and Tourism Commission, 2008. California Travel Fast Facts and Highlights
[259] Shaw WD, and JB Loomis. 2008. Frameworks for analyzing the economic effects of climate change on outdoor recreation p. 264

These effects are both directly and indirectly linked to climate change as shown in Figure 5.1 below. The changes in the environment that are caused by climate change can and most likely will affect the economics of tourism and recreation in California, therefore it is important to have an idea of what we are risking by continuing to allow the environment to deteriorate.

Table 5.2. Links between Climate Change and Outdoor Recreation[260]

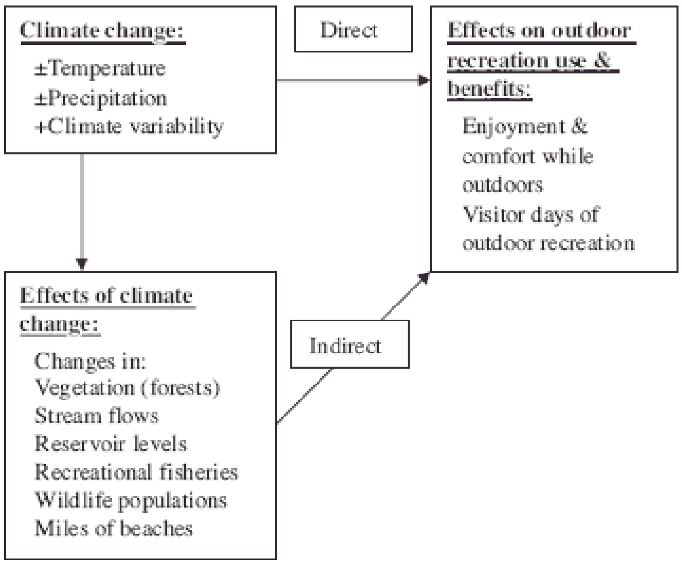

Fig. 1. Direct and indirect effects of climate change on recreation

In order to better understand California's current situation, this report will focus on two of the state's biggest tourist draws: the powdery slopes of California's ski industry and the sandy beaches that have made this state the epitome of vacation leisure. Studying these two recreation areas will provide us with an estimate of the potential environmental and economic damages of climate change.

One of the major issues with climate change in California is that the western states are heating nearly twice as quickly as the rest of the country, even heating up at a faster rate than the world average. This makes it safe to assume that California will feel the effects of climate change as much if not more than any other region of the world. According to Rocky Mountain Climate Organization in association with the Natural Resources Defense Council:

"The American West has heated up even more than the world as a whole. For the last five years (2003 through 2007), the global climate has averaged 1.0 degree Fahrenheit warmer than its 20th century average. For this report, RMCO found that during the 2003 through 2007 period, the 11 western states averaged 1.7 degrees Fahrenheit warmer

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[260] Shaw WD, and JB Loomis. 2008. Frameworks for analyzing the economic effects of climate change on outdoor recreation p. 264

than the region's 20th century average. That is 0.7 degrees, or 70 percent, more warming than for the world as a whole. And scientists have confirmed that most of the recent warming in the West has been caused by human emissions of heat-trapping gases.[261]"

This extra warming will have numerous effects on the environment, one of which will be earlier snowmelts and less snow overall. Clearly this is of huge concern to the ski industry which depends on consistent levels of snowpack year after year in order to run above operating costs. Because the ski industry's profit is directly linked to the climate (more snow = more money), it is easy to see the potential economic effects of climate change, or more specifically less snow and poorer ski conditions, on the economy.

Every year there are 7.2 million skier visits to the slopes in California.[262] Each of the skiers arrives at the slopes and consumes multiple goods and services including lift tickets, food, and lodging. On average each of these tourists brings in $68.18 of revenue to the ski industry, making the total estimated annual revenue of the California ski industry $490,896,000.[263] However the economic effects of the ski industry may trickle down even more, to the point where whole towns rely on a good ski season for their livelihood. For instance at Snowbowl ski resort in Flagstaff Arizona, each skier is estimated to bring in $240 of revenue for the town as a whole (with around 125,000 skiers a year that is about $30 million), losing the snow would mean many lost jobs and might even mean losing the town.[264]

Because the west is getting warmer at such an alarming rate, many popular ski areas on the western side of the country have been subjected to drastic drops in snow levels, and because of this, slopes in many western states (and even slopes in Switzerland and France) have seen huge decreases in participation and revenue, sometimes even shutting down permanently. During the 2006-2007 ski season, due to poor ski climate, pacific ski slopes lost 16.5 percent of their skier visits and though this is only representative of a loss of about $80,997,840 to the California economy, it is an ominous sign of the economic disaster that might be lingering in our future.[265] States like New Mexico and Arizona have already felt the negative effects of the warming west, as ski visits in New Mexico have dropped 50 percent recently and Arizona has had nearly 80 percent fewer ski visits over the past few years.[266] If California were to follow suit, it could mean an economic loss of $245,448,000 (50 percent total revenue) or even $392,716,800 (80 percent). Unfortunately things are only looking worse and worse for

[261] Saunders S, and others. 2008. Hotter and Drier: The West's Changed Climate p. iv
[262] California Ski & Snowboard Safety Organization: Ski and Snowboard General Facts (2008)
[263] National Ski Areas Association. 2006. 2005/06 Ski Resort Industry Research Compendium: A Summary of Major Research Projects Conducted for National Ski Areas Association
[264] Saunders S, and others. 2008. Hotter and Drier: The West's Changed Climate p. 34
[265] Saunders S, and others. 2008. Hotter and Drier: The West's Changed Climate p. 33
[266] Saunders S, and others. 2008. Hotter and Drier: The West's Changed Climate p. 33

the ski industry as resorts struggle to stay afloat, so desperate that some are even considering the logistics of running ski slopes comprised merely of man-made snow.

The situation with the California ski industry is an example of lost revenue directly linked to climate change; however there are many instances where the effects of climate change can have an indirect impact on the state's economy. The most important example of this concerns the disappearing of California's legendary beaches due to climate change. The difference between analyzing the ski economy and the beach economy, is that beaches are free; no one pays for the cool water or warm sand. The beaches in California have a priceless cultural value, however even without any direct revenue it is possible estimate the value of the economic losses due to beach erosion and poor climate. Economists look at spending patterns from beach goers and have developed a few estimates which are applicable here. We will take a look at these estimates after getting a better understanding of the environmental effects of climate change on coastal regions.

Climate change poses a few threats to California's beaches. Experts predict increasing sea levels which will lead to the inundation of beaches and erosion due to changing wave patterns, ultimately reducing the total beach area of the state.[267] However the sandy beaches aren't the only thing at risk; the infrastructure that supports these beaches is also under threat from climate change:

By the year 2100 experts have estimated that the sea level in California would rise by about one meter in a worst case scenario, leading to an average loss of 10 meters of width for all of the state's beaches; this would be a 26 percent loss of total beach area, with some beaches disappearing entirely.[268] As the sea level rises, more and more of California's coast will be vulnerable to the powers of erosion and harsh storms. This includes many of California's most popular attractions that involve the beach and are located right on the coast. Top attractions such as the Santa Cruz Beach Boardwalk and the Monterey Bay Aquarium (drawing in around 3 million and 2 million annual guests respectively), depend on the beach and the coastal infrastructure, meaning that any damage to the shore could put many of these attractions out of business, depriving the state of some of its most appealing tourist destinations.[269]

Currently California's beaches attract around 238 million beach visits a year. These visitors don't spend money to get into the beach, but they do bring in money though other purchases, such as parking, food, lodging, and of course surfboards; all of this

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[267] Linwood P, and others. 2008. The Economic Impacts of Sea Level Rise on Southern California Beaches

[268] Linwood P, and others. 2008. The Economic Impacts of Sea Level Rise on Southern California Beaches

[269] California Travel and Tourism Commission, 2006. Statewide and Regional Tourism Facts and Figures: California Fast Facts 2006.

amounting to $5.5 billion in Gross State Product (GSP) and $2.4 billion in Gross National Product (GNP).[270] The overall economic impact of these beaches is even more significant, as economists predict that the total annual economic value of the beaches is $8.3 billion to the state and $6 billion to the whole nation.[271] If the 26 percent loss in beaches causes an equal drop in annual beach visits, in the year 2100 there could be only 176 million beach visits representing a loss of GSP of about $1.43 billion and a loss of $624 million in GNP. The effects on the overall economy would be even more drastic, as 26 percent fewer visits would mean around a $2.158 billion drop in the state economy and a $1.56 billion drop in the economy of the nation. These are large chunks of money that both the state of California and the entire United States rely on.

The economic effects of climate change are not all negative. In fact, many experts believe that changes in the Californian climate are having an overall positive effect on tourism and recreation revenues. Table 5.1 below, highlights the estimated change in visitor days for different outdoor recreation activities, based on an estimated 2.5 degree Celsius increase in temperature by year 2050. The estimates are compiled by two different duos who have written countless studies on the economics of tourism and climate change, the first is Loomis and Crespi the second Mendelsohn and Markowski.

[270] King, P. 2002. The Potential Loss in Gross National Product and Gross State Product from a Failure to Maintain California's Beaches. p. 3
[271] King, P. 2002. The Potential Loss in Gross National Product and Gross State Product from a Failure to Maintain California's Beaches. p. 3

Table 5.3. Changes in Visitor Days with Climate Change Impacts[272]

Table 1. Examples of changes in visitor days with climate change impacts (2.5°C increase by 2050). L&C: Loomis & Crespi (1999); M&M: Mendelsohn & Markowski (1999). Note: M&M estimates are averaged over states analyzed across the USA

Activity	L&C (%)	M&M (%)
Boating	9.2	36.1
Camping	−2.0	−12.7
Fishing	3.5	39.0
Golf	13.6	4.0
Hunting	−1.2	No change
Snow skiing	−52.0	−39.0
Wildlife viewing	−0.1	−38.4
Beach recreation	14.1	Not estimated
Watercourse recreation	3.4	Included in boating
Gain in visitor benefits (in billion $US)	2.74	2.80

Based on this chart, the industries expecting a decrease in activity due to the warming climate are camping, hunting, snow skiing, and wildlife viewing, while the industries that should expect to gain from climate change are boating, fishing, golf, beach recreation, and watercourse recreation. State and national parks also expect higher attendance rates due to climate change and even the famous California wine industry that attracts millions of tourists to places like Sonoma and Napa Valley expects to have longer growing seasons, less frost damage, and better vintages with an overall positive economic effect on the industry.[273] California state parks have had increasing attendance recently bringing in additional revenue from various sources:

> Visitor Attendance – Total - This Figure 5.reached 79,828,629 an increase of 4.20 percent over the previous fiscal year report. It should be noted that the State Park System's unit-level attendance figures, with few exceptions, are based on estimates rather than actual counts. In addition, the total attendance for the State Park System as a whole is believed to be substantially underestimated. Revenue - User Fees - The total of $73,270,885 reflects a 5.98 percent increase over the previous fiscal year. Visitor fees did not change during the 2006/07 fiscal year.

[272] Shaw WD, and JB Loomis. 2008. Frameworks for analyzing the economic effects of climate change on outdoor recreation p. 261

[273] Wilkinson, R. 2002. Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change. P. 291.

Revenue – Concessions - The total of $11,991,649 reflects an increase of 5.25 percent over the previous year.

Revenue – Miscellaneous - The total of $476,850 reflects an increase of 98.49 percent over the previous year. This seemingly large increase actually reflects the additional reporting of parking violations fees revenue which includes $165,359 within the OHMVR Division.
Total Revenue - The System's total revenue of $85,739,516, the sum of the above three categories, reflects an increase of 6.15 percent from the prior fiscal year. The three revenue categories listed above, based on the Department's "earnings", constitute an important part of the State Park and Recreation Fund (SPRF).[274]

Surprisingly all of these increases in outdoor recreation participation outweigh the decreases, leading to an overall boost in the Californian tourism industry. Not surprisingly, the data from Table 5.1 shows some patterns as far as which industries have increasing participation and which are decreasing; all of the recreation activities having to do with water will have increased participation with increased temperatures, as people flock to the beaches and lakes to beat the heat. On the other hand almost all of the activities that depend upon a well balanced and maintained ecosystem (hunting, wildlife viewing, etc.) are predicted to see drops in participation, due to decreasing biological diversity caused by damages to the environment and disturbances of the ecosystem's delicate balance.

Unfortunately it is extremely difficult to gauge climate change and predict its effects on the environment, and it is even more difficult to Figure 5.out its effect on the tourism and recreation economy. Though there are many studies in circulation that attempt to estimate these effects and make predictions of how the economy will react, much more time, money, and research must be put into this project. The major issues with current data and research are listed below.

Table 5.4. Weaknesses in Predicting Travel Flows[275]

[274] Planning Division, California Department of Parks and Recreation. 2007. *The California State Park System Statistical Report: 2006/07 Fiscal Year.* P.7.
[275] Gossling, S and M Hall. 2006. UNCERTAINTIES IN PREDICTING TOURIST FLOWS UNDER SCENARIOS OF CLIMATE CHANGE. P. 165

Major weaknesses of current models in predicting travel flows

- Validity and structure of statistical databases
- Temperature assumed to be the most important weather parameter
- Importance of other weather parameters largely unknown (rain, storms, humidity, hours of sunshine, air pollution)
- Role of weather extremes unknown
- Role of information in decision-making unclear
- Role of non-climatic parameters unclear (e.g., social unrest, political instability, risk perceptions)
- Existence of fuzzy-variables problematic (terrorism, war, epidemics, natural disasters)
- Assumed linearity of change in behaviour unrealistic
- Future costs of transport uncertain
- Future levels of personal disposable income (economic budget) and availability of leisure time (time budget) that are allocated to travel uncertain

Notes and References

6. Real Estate: Background

Real estate under climate change will be impacted primarily by property damage from extreme events – wildfires along the wildland-urban interface and coastal flooding as rising sea levels lead to coastal levees and beach protections being breached. Wildfire risk will vary by vegetation type, but is expected to increase 11-55 percent depending on scenario.[276] Coastal flooding damages will come primarily from decreases in the storm return intervals as events that are now considered extreme become more frequent.

Wildfire Impacts

Many effects of global warming can influence the incidence and severity of California wildfires. Even in the mildest of climate change scenarios that include a concerted effort globally to reduce emissions and lower climate sensitivity, California temperatures are expected to rise 3 to 5.4 ° F. For higher emissions scenarios, the temperature increase could reach up to 10.4 ° F by the end of the century[277]. Rising temperatures can lead to a number of deleterious effects that impact wildfire risk in California. These effects include increased spring and summer temperatures, reduced precipitation, increased evapotranspiration, and an earlier snow-pack melt that can in turn lead to longer and drier fire seasons in many mid to high elevation forests.[278]

Westerling and Bryant classify two types of plant-life regimes in California with respect to wildfire behavior. Energy limited regimes are more characteristic of forested areas where wildfires are associated strongly with dry conditions and warm temperatures the year of the fire, giving the forest enough energy to dry out the abundant fuels that are already present. Moisture limited regimes are more characteristic of grassland and shrub areas where wildfires are strongly associated with a moisture anomaly the year before, allowing plentiful vegetation growth which serves as needed fuel to facilitate wildfire spread in these normally hotter, dryer areas. While actual vegetation regimes are usually somewhere between the two extremes, they serve as a useful framework for modeling wildfire behavior under climate change.

Predictions for wildfire risk are more or less certain depending on the cause of that risk. The primary mechanism by which climate change will affect wildfire in California is through changes in moisture. The certainty of these predictions varies by regime type.

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[276] California Climate Change Center. "Our Changing Climate: Assessing the Risks to California." 2006

[277] California Climate Change Center, 2006

[278] A. L. Westerling and B. P. Bryant, "Climate Change and Wildfire in California". Climatic Change 87 (Suppl 1): S231–S249, 2008.

In energy-limited regimes where fire risk is associated with higher temperatures drying out the available fuel, these predictions are relatively more certain. However, due to the uncertainty regarding precipitation predictions over the next century, the outlook for moisture-limited regimes is relatively less certain as they are more associated with precipitation forecasts than energy-limited regimes.

An early report by Fried et al. on wildfire severity in California under a doubled carbon scenario suggested that the number of fires escaping their initial containment area would double and that the total area burned by contained fires would increase 50 percent. They estimated that the fire return interval on grass and brush would be cut in half[279]. A more recent study revisits these predictions while correcting many of the weaknesses of the original methods and considering multiple warming scenarios.[280]

Table 6.1. Yearly Predictions for the Amador El-Dorado Unit 2070-2099[281]

	Base	GFDL A2	GFDL B1	PCM A2	PCM B1
Overall Area Burned (acres)	475	538	513	516	489
Percent Increase from Base	n/a	13.2%	8%	8.63%	**2.95%**

Notes: The Base number of escapes is a model-output simulation of historical values which closely resemble actual values obtained from the historical record of wildland fire incidents.[282] GFDL and PCM are different climate change models that are similar in many respects, but GFDL is generally considered a higher-sensitivity model while PCM is a lower sensitivity model. A2 is a climate change scenario which represents continued reliance on fossil fuels and little action toward climate change; the effects of this scenario worsen after the twenty-first century with expected temperature increases of 3.4 ° C (by 2100. B1 represents the lowest warming scenario offered by the IPCC and includes a rapid shifting toward more environmentally friendly technologies with expected temperature increases of 1.8 ° C by 2100.[283]

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[279]. Fried, Jeremy S, Margaret Torn, and Evan Mills. "The Impact of Climate Change on Wildfire Severity: A Regional Forecast for Northern California" Climatic Change 64: 169–191, 2004.
[280] Fried, Jeremy S, J. Keith Gilless, William J. Riley, Tadashi J. Moody, Clara Simon de Blas, Katharine Hayhoe, Max Moritz, Scott Stephens, and Margaret Torn. "Predicting the Effect of Climate Change on Wildfire Severity and Outcomes in California: Preliminary Analysis" Energy Commission: Publication No. CEC-500-2005-196-SF.
[281] Fried et al. 2005. 44-45.
[282] Fried et al. 2005. 32.
[283] IPCC, 2007: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor

Table 6.2. Number of Escaped Fires (ESL's) By Administrative Unit and Scenario[284]

Administrative Unit	B1: Change BASE to MIDCEN	A2: Change BASE to MIDCEN	B1: Change BASE to ENDCEN	A2: Change BASE to ENDCEN
Santa Clara (SCU)	1.74*	1.95*	1.56*	5.31*
Amadaor El Dorado (AEU)	4.27*	7.44*	3.2*	
San Bernardino (BDU)	2.56*	2.37*	-0.2	**2.38***

Note: Base ESL refers to a modeled output simulation of historical values. Fried et al suggest that these results are best interpreted in relative terms based on scenario as many things can change their absolute values including changes in firefighting methods and technology among other possibilities. All estimates in this chart are predicted using a GFDL model.

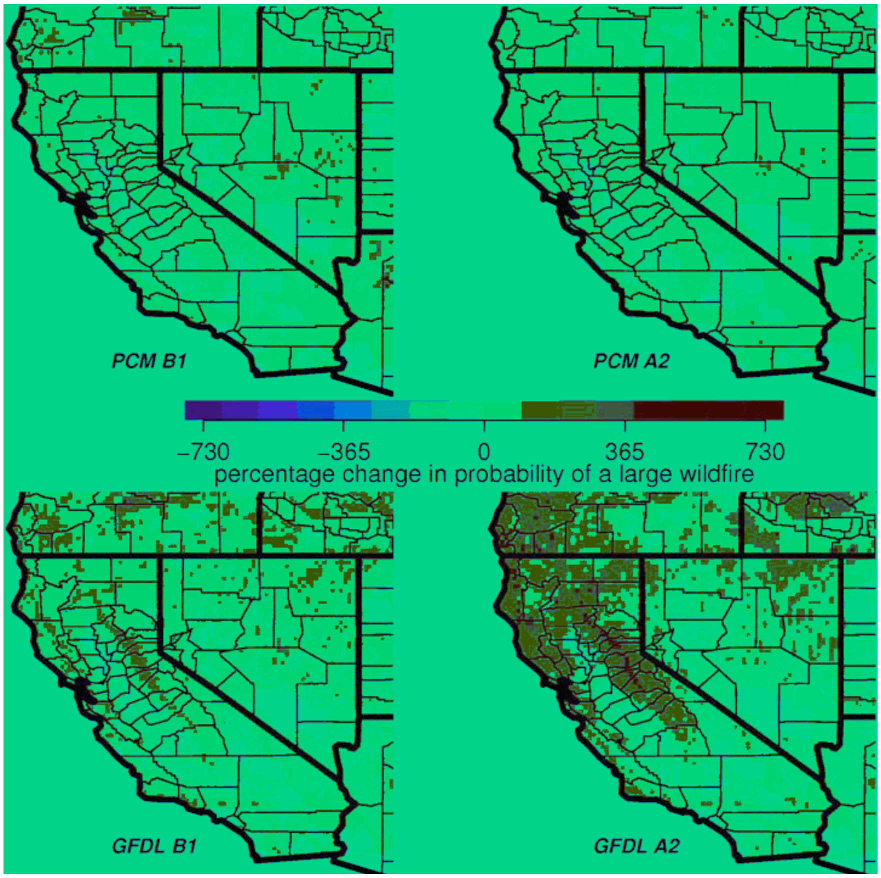
These estimates are more conservative than the estimates of the former report primarily due to differences in wind speed predictions. The predicted values of wind speed were generally not significant or the changes were minor. A study focusing on the Santa Ana winds indicated that Santa Ana wind occurrences are likely to increase during the California fire season, but indicated that overall wind occurrences were unlikely to change dramatically. However, further research in this area is needed in order to better understand the changes in intensity and duration of Santa Ana occurrences as well as the multiple complex factors which could affect them.[285]

and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
Fried et al. 2005. 11.

[284] Fried, Jeremy S., J. Keith Gilless, William J. Riley Tadashi J. Moody, Clara Simon de Blas, Katharine Hayhoe, Max Moritz, Scott Stephens, Margaret Torn. "Predicting the effect of climate change on wildfire behavior and initial attack success". Climatic Change (2008) 87 (Suppl 1):S251–S264. DOI 10.1007/s10584-007-9360-2

[285] Miller & Schlegel. "Climate Change Projected Santa Ana Fire Weather Occurrence" Energy Commission: Publication No. CEC-500-2005-204-SF

Figure 6.4: Percentage change in large wildfire probability by scenario and geographic area.[286]



[286] Westerling and Bryant. 2008.

Figure 6.2. Change in California Burned Property Value, Structures and Threatened Structures between 1961-1990 and 2070-2099[287]

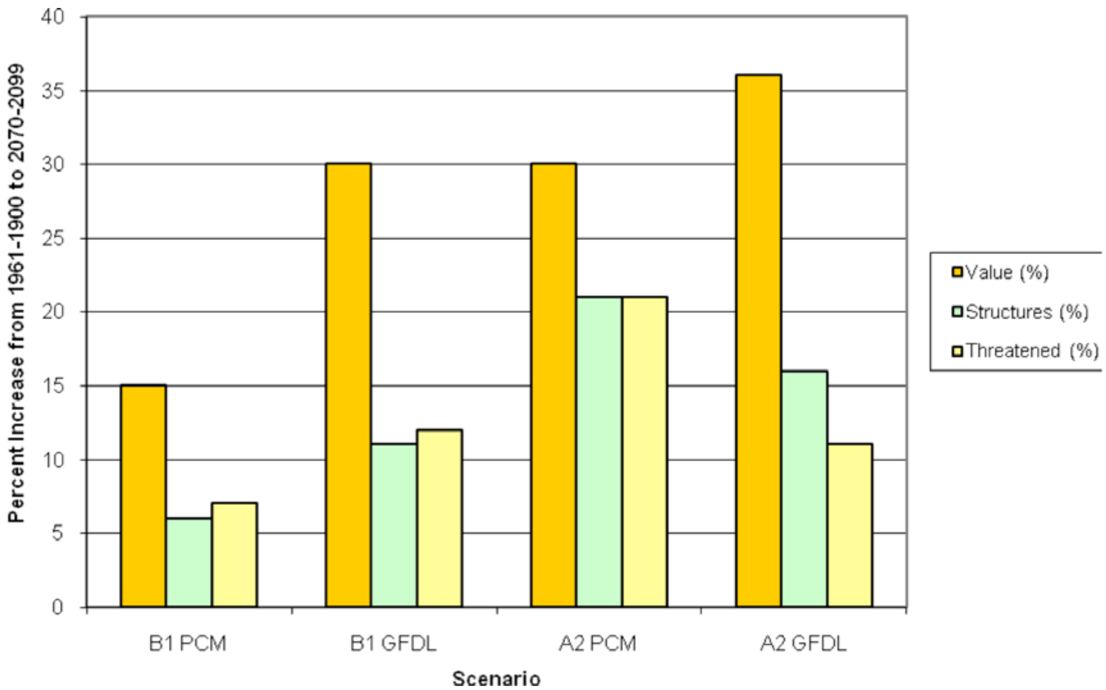


Table 6.2. Relative Impacts on Northern California

	B1 PCM	B1 GFDL	A2 PCM	A2 GFDL
Total Value Increase (millions)[288]	730	1,470	1,470	1,760
CA Large Fires (%)	12	23	34	
NC Burned Value (%)	21	48	37	96
NC Burned Structures (%)	12	31	26	
NC Threatened Structures (%)	12	30	25	71
NC Large Fires (%)	15	38	37	**90**

Note: Total Value is the dollar amount difference between the thirty year period of 1961-1990 and 2070-2099. Large Fires refer to fires >200 ha.

The numbers for Total Value Increase are approximate and represent a change from one thirty year period to the next. These estimates were obtained by taking the estimates for average yearly wildfire damage from the California fire plan, converting to a thirty year period, and applying the Westerling and Bryant damage ratios and then rounding to the nearest ten-million. While this measure is far from exact, it provides an

[287] Westerling and Bryant, 2008.
[288] California Board of Foresty. "California Fire Plan". 1996.

order-of-magnitude estimate that can inform policymakers as to the scope of this problem.

Increases in the percentage of threatened structures were highest for the A2 PCM scenario, and ranged from 7-21 percent. The total value of property burned increased 15-36 percent, and was highest for the A2 GFDL scenario. The number of large fires was expected to increase regardless of scenario, but was most severe for A2 GFDL.

Wildfire damages in this analysis are dominated by the proximity of wildfire risk to major urban centers, primarily the coastal areas of Southern California, the outlying portions of the Bay Area, and Northeast of Sacramento.[289] For example, in the A2 GFDL scenario, very dramatic changes in wildfire risk for the Sierra Nevada Mountains and Cascades were predicted but those areas are relatively sparsely populated and thus cause a small increase in predicted burned property value and structures.

Most of the increased fire risk is expected to occur in energy-limited regimes, so the bulk of the increased risk will occur in Northern California. These increases compensate for what were sometimes net improvements in predicted fire risk for Southern California. As precipitation estimates are uncertain, fire risks for Southern California are expected to increase slightly or even decrease depending on model sensitivity and the scenario. The estimated changes in burned property values below do not take into account any potential feedback from changes in vegetation distribution. In addition, development levels are held fixed at the 2000 census, so these estimates do not take into account any changes in housing and development patterns over the next century.

Wildfires: Adaptation

The majority of damages from wildfires occur in cities with extensive wildland-urban interfaces, such as the outlying areas of the San Francisco Bay Area, the coastal counties of Southern California, and northeast Sacramento.[290] The most important adaptation for avoiding additional damages beyond those listed above is to implement a development strategy which includes minimizing the wildland-urban interface so as to limit vulnerability to changes in wildfire behavior. Many mid-level elevation forests in California including the Sierra Nevada foothills are expected to have above average fire risks and redirecting development or reducing uninsured private exposure in these areas could avoid a great deal of future damages.

For example, in the Lake Tahoe area the Tahoe Regional Planning Agency (TRPA) and other governing organizations closely monitor wildfire risk and necessary preventative

[289] Westerling and Bryant 2008.
[290] Westerling and Bryant 2008.

measures. Property owners in the Lake Tahoe area are required to receive approval both from the TRPA and their district fire protection authority before most construction projects, residential, commercial or public. Ordinances also exist to regulate the amount of defensible space around existing structures and the types and organization of vegetation around the home to help prevent fire spread.[291] This type of regional regulation and supervision of fire risk may be a viable solution if localized to other California communities along the wildland-urban interface.

In addition, firefighting will obviously play an important role. Fire suppression efforts currently cost California over $1 billion annually in 1994-1995. The additional cost of emergency fire suppression is over one thousand dollars per acre and has been increasing historically.[292] As escaped fires are expected to burn an extra 14 to 63 acres per year in the Amador El Dorado unit, this could translate to up to $15,862 - 71,379 in additional firefighting costs per year for the Amador El Dorado unit only.[293] If these ratios of increased firefighting need per existing acre of forestland in California were to hold, then, based on the estimates of total forestland in Brown et al, these costs could be $420,000 – 1,870,000 per year.[294]

Flooding and Storm Impacts

In the low warming scenario B1 sea levels are expected to rise 11-54 cm by the end of the century with 6-31 cm of that taking place by mid century. In the medium scenario A2, sea levels are expected to rise 14-60 cm by the end of the century with 6-28 cm of that taking place by mid-century. Finally, in the high warming scenario A1fi, temperatures are expected to rise 17-71 cm by the end of the century and 7-32 cm by

[291] C. G. Celio & Sons Co., Steve Holl Consulting, and Wildland Rx. “Community Wildfire Protection Plan for the California Portion of the Lake Tahoe Basin”. Tahoe Basin Fire Safe Council, Fallen Leaf Fire Department, Lake Valley Fire Protection District, Meeks Bay Fire Protection District, North Tahoe Fire Protection District: 2004.

[292] Matthias, Ruth, Dana Coelho, and Daria Karetnikov. “The US Economic Impacts of Climate Change and the Costs of Inaction”. Center for Integrative Environmental Research, University of Maryland. 2007.

[293] This estimate was obtained by multiplying the emergency firefighting cost found in Ruth et al. by the additional acres expected to burn in escapes in the Amador El Dorado unit.

[294] Brown, S., A. Dushku, T. Pearson, D. Shoch, J. Winsten, S. Sweet, and J. Kadyszewski. 2004. Carbon Supply from Changes in Management of Forest, Range, and Agricultural Lands of California. Winrock International, for the California Energy Commission, PIER Energy-Related Environmental Research. 500-04-068F.

California Department of Forestry and Fire Protection . “Amador El Dorado Fire Management Plan”. 2005.

These estimates were derived by taking the total Direct Protection Area (DPA) for the Amador El Dorado Unit (AEU) from the Amador El Dorado Fire Management plan of 903,803 acres, dividing by the total estimated amount of forestland in California in Brown et al to create a ratio and dividing the firefighting cost estimates for the AEU by that ratio to upscale it for all of California and rounding to the nearest ten thousand These estimates are intended as order of magnitude figures only.

mid-century. In addition, the incidence of high sea level events which exceed the current capacity of most California levees and flood protections is expected to increase dramatically as higher sea levels interact with storm events. This will reduce the storm return interval for levees, making stresses that they are designed to bear infrequently happen much more often.[295] The following figures show the Coastal Vulnerability Index (CVI) for the California Coast and the San Francisco Bay.[296]

Figure 6.3: Map of the Coastal Vulnerability Index (CVI) for different areas along the California Coast.

[295] Cayan. D., P. Bromirski, K. Hayhoe, M. Tyree, M. Dettinger, and R. Flick. 2006b. Projecting future sea level.

[296] Thieler, Robert E. and Erika S. Hammar-Klose. "National Assessment of Coastal Vulnerability to Sea-Level Rise: Preliminary Results for the U.S. Pacific Coast". U.S. Geological Survey Open-File Report 00-178: Woods Hole, Massachusetts

Shoreline homes account for 16.12 percent of all California homes in 2000[297]. In addition, the shoreline areas are home to 4.8 million people, or 14.25 percent of California's population. Given the large number of people and high value of property along the coast, it is generally more efficient to protect California's coastal homes and property.[298]

Coastal Flooding: Adaptation

Coastal adaptation options generally fall into one of two categories: beach nourishment and hard structure armoring. The cost of protection for a doubling in sea level rise is more than double of the previous cost. Consequently, differences in adaptation costs between scenarios can be dramatic. However, the most severe costs associated with coastal flooding and sea level rise will not be incurred until the latter third of the century when, depending on scenario, costs will reach 36-257 billion per decade by 2080 and 57-303 billion per decade by 2100.[299]

Table 6.3. Sea Level Rise and Present Adaptation Investment[300]

Sea Level Rise	33 cm	50 cm	67 cm
Approximate Present Investment Required (2000 dollars)[301]	47 million	117 million	224 million
Plausible Scenarios[302]	All	All	**A1fi**

297 National Ocean Economics Program: http://noep.mbari.org/. Accessed July 11, 2008.
298 Neumann, Hudgens, Herr, Kassakian. "Appendix XIII: Market Impacts of Sea Level Rise on California Coasts". CEC 500-03-058CF. 2003.
299 Neumann et al. 2003.
300 Neumann et al. 2003.
301 Neuman et al. 2003. These estimates reflect a model using a 3 percent discount rate.
302 Of the three mentioned above, B1 (low), A2 (medium), A1fi (medium-high), those whose predicted sea level rise range contains the relevant estimate.

These estimates do not include any potential value lost to wetland inundation, for which Neumann et al. were unable to estimate economic cost. Present investment range indicates the amount of money that would need to be invested now to account for the risk if discounting is included. More research is needed for careful, site-specific estimates as well as the specific effects on the San Francisco bay area. The model used by Neumann et al. may also be useful in making site-specific coastal adaptation decisions when combined with localized research into dynamic land-use patterns. Finally, as with wildfire adaptation, the best option may come in changing land-use patterns and land development of the coastal areas to insure that most of the future coastal development in California occurs in areas that are not flood prone.

Notes and References

7. Insurance: Background

The insurance sector contributes $28 billion per year to California's GSP and employed 300,777 people in 2006.[303] Private insurers pay approximately three quarters of weather-related losses in the US with federal flood and crop insurance covering the remainder.[304] Insurers have historically played a leading role in loss prevention and are in a unique position to offer behavior incentives for helping with climate change mitigation and adaptation.[305] One of the biggest challenges facing the industry is the prevalence of using the past as a model for the future – under climate change the foundations underlying the success of this strategy for risk modeling start to break down. Many insurers now use catastrophe models in addition to historically based models, but much could be gained by both sides from an active private-public discussion focused on localized weather-related risks making use of both catastrophe and climate science models to estimate risks and climate change impacts for all concerned.

Regulating the insurance industry under climate change poses several difficulties for policy makers. Limiting premiums charged, market withdrawal and circumstances of coverage denial are all imperfect solutions that may aid rising premiums or low policy-holding rates in the short-term but may compound the risk of market failures and lack of coverage in the long-term.

Climate Change Impacts

The insurance industry is in a position to be effected by many of the impacts discussed in this report. Virtually all branches of insurance will be impacted in some way. Health, life, property, business interruption, crop, flood, marine and vehicle insurance will all be impacted with a high degree of certainty.[306] Health and life insurance will be impacted by more heat wave days, electricity interruption, and poor air quality, to name a few possibilities. Property and flood insurance will be impacted by the increased frequency of extreme events, many of which have been mentioned in this report. Crop insurance may suffer not only from expanded pest ranges but also changing crop ranges, increased drought frequency, and other malaise.

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[303] Insurance Information Institute. "A Firm Foundation: How Insurance Supports the Economy". 2008

[304] United States Government Accountability Office. "Financial Risks to Federal and Private Insurers in Coming Decades are Potentially Significant." 2007.

[305] Mills, Evan. "Climate Change and the Insurance Industry". Environmental Energy Technologies Division Newsletter: Vol. 6, No. 3

[306] Vellinga, Pier and Evan Mills. "Insurance and Other Financial Services" in Climate Change 2001: Impacts, Adaptation, and Vulnerability. IPCC: 2001.

Figure 7.4: Risks to the insurance industry as a result of climate change.[307]

Changes in Extreme Climate Phenomena	Observed Changes (*Likelihood*)	Projected Changes (*Likelihood*)	Type of Event Relevant to Insurance Sector	Time Scale	Sensitive Sectors/Activities	Sensitive Insurance Branches[b]
Temperature Extremes						
Higher maximum temperatures, more hot days and heat waves[c] over nearly all land areas	Likely[a] (mixed trends for heatwaves in several regions)	Very likely[a]	Heat wave	Daily-weekly maximum	Electric reliability, human settlements	Health, life, property, business interruption
			Heat wave, droughts	Monthly-seasonal maximum	Forests (tree health), natural resources, agriculture, water resources, electricity demand and reliability, industry, health, tourism	Health, crop, business interruption
Higher (increasing) minimum temperatures, fewer cold days, frost days, and cold waves[c] over nearly all land areas	Very likely[a] (cold waves not treated by WGI)	Very likely[a]	Frost, frost heave	Daily-monthly minimum	Agriculture, energy demand, health, transport, human settlements	Health, crop, property, business interruption, vehicle
Rainfall/Precipitation Extremes						
More intense precipitation events	Likely[a] over many Northern Hemisphere mid- to high-latitude land areas	Very likely[a] over many areas	Flash flood	Hourly-daily maximum	Human settlements	Property, flood, vehicle, business interruption, life, health
			Flood, inundation, mudslide	Weekly-monthly maximum	Agriculture, forests, transport, water quality, human settlements, tourism	Property, flood, crop, marine, business interruption
Increased summer drying and associated risk of drought	Likely[a] in a few areas	Likely[a] over most mid-latitude continental interiors (lack of consistent projections in other areas)	Summer drought, land subsidence, wildfire	Monthly-seasonal minimum	Forests (tree health), natural resources, agriculture, water resources, (hydro) energy supply, human settlements	Crop, property, health

Within the lower warming range, temperatures are expected to rise 3-5.5 ° F. Sea levels are expected to rise 6-14 inches. There will be twice as many urban heat wave days, and 10-35 percent more risk of wildfire, with the forested areas of Northern

[307] Velling and Mills. 2001.

California being most at risk. In the medium warming range, temperatures are expected to increase up to 8 ° F. Sea levels are expected to rise up to 22 inches. There will be up to four times as many urban heat wave days and 55 percent more risk of wildfire. In the worst scenarios, average temperatures could increase as much as 10.5 ° F and sea levels could rise by up to 40 inches.[308]

In all scenarios, air quality is expected to decline. Ozone concentrations will rise by 25-80 percent, depending on the scenario. Changing temperatures and precipitation seasons could also expand or alter the ranges of many infectious diseases. Coastal flooding from extreme precipitation events could lead to water supply contamination and the spread of water-borne disease. The worst increases in extreme heat in California will occur in Los Angeles. In addition, days conducive to high ozone formation will increase 25-35 percent for a lower warming scenario and 75-85 percent for a higher warming scenario. The extent that these predictions will come true depends on how California meets air quality regulations in the future in addition to climate change.[309]

The impacts on public health could be widespread and compounding. Ross, Mills and Hect summarize the anticipated risks:

> Infectious disease vector expansion
> Heat stress
> Respitory and coronary disease linked with increased allergens, pollution and temperatures
> Waterborne diseases and water-treatment contamination
> Physical injury and disease clustering from extreme events
> Toxic materials released and distributed by extreme events
> Food poisoning, e.g. the strong correlation between salmonella outbreaks and heat.[310]

Many of these impacts can combine and interact to cause more severe impacts on public health, even in the absence of extreme weather events.

Adaptation for the Insurance Industry

There are many risks facing the insurance industry and as the cost of risk of losses increase, so will the cost of insuring those losses. Insurance is possible when the risks it insures are quantifiable, diversifiable, fortuitous and economically priced. As

[308] California Climate Change Center. 2006.
[309] Dreschler et al. 2005
[310] Ross, C. E. Mills, S. Hecht. 2007. "Limiting Liability in the Greenhouse: Insurance Risk Management Strategies in the Context of Global Climate Change." Stanford Environmental Law Journal and the Stanford Journal of International Law, Symposium on Climate Change Risk, Vol 26A/43A:251-334.

conditions change in new and potentially unknown ways, insurers may be unable to quantify the risk. As many areas are affected at the same time across the globe, it may affect insurers' ability to diversify. As losses due to climate change become a regular occurrence, premiums will have to rise to meet them which may increase premiums to a point where many are unprepared to pay. All of these factors create potential conditions for market failure.[311]

To reduce the impact of climate change on the insurance sector, reducing underlying vulnerability by limiting the capacity for property and health damage is an excellent place to start. Ensuring that beachfront property is adequately protected will reduce insured losses and investing in adequate fire prevention will do much the same. However, there are many other measures that need to be taken in addition to those already mentioned and public intervention may create more problems than it solves. For example, the National Flood Insurance Program, while providing a valuable service and helping keep residents in their homes, also distorts market signals by keeping insurance premiums artificially low in high risk areas, effectively encouraging development in areas that might otherwise be considered too risky.[312]

One of the most important things that can be done to minimize the impacts of climate change on the insurance industry in California is collaboration between the private and public sectors on a variety of issues. Information sharing and disclosure is vital. Scientific data and models produced by public agencies have much to offer the insurance industry, both public and private. Working to combine the economically-oriented perspective of insurance loss and catastrophe models with California state researchers scientific approach may prove mutually beneficial., increasing the predictive power for both policy makers and private insurers.[313]

Improved information, analysis and research on a company-to-company, localized basis so that insurance companies are aware of the full extent of their vulnerability. Disclosing these risks can prevent capital flight amid concerns of climate change woes. Developing a standardized reporting format for disclosure of material risks will help spot problems early, pointing the way for research and technological innovation.[314]

There are many ways to go about loss prevention to reduce insurers' exposure. Prevention can afford huge savings, as was seen with Hurricane Katrina where insurance customers that instituted engineering recommendations before the hurricane

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[311] Maynard, Trevor. "Climate Change: Impacts on Insurers and How They Can Help With Adaptation and Mitigation". The Geneva Papers, 2008, 33, (140–146)
[312] Allianz Group and WWF. "Climate Change and Insurance: An Agenda for Action in the United States". 2006.
[313] Mills, Evan. "From Risk to Opportunity: 2007, Insurer Responses to Climate Change". Ceres: 2007.
[314] Ross et al. 2007.

hit sustained an eighth of the damages of their less prepared peers.[315] While individual preventative measures would vary in their effectiveness, there are many possibilities which could reduce losses significantly. Improved building codes and building code enforcement, especially for homes at risk of high winds, wildfire exposure, coastal storms or flooding, or any other appreciable climate change related risk would help to minimize losses should the worst happen.[316]

As has been mentioned in previous sections, land and development planning is extremely important. Growing communities in at-risk areas present some of the most significant possibilities for loss.[317] Rebuilding or retrofitting structures to reduce risk can provide opportunities to increase energy efficiency and help make homes “greener” as well.

The insurance sector has an opportunity for growth in adaptation. Providing discounts on insurance for “green” buildings which tend to be more disaster resistant and improve residential air quality will not just help provide financial incentives to live in those buildings, but will also help reduce future exposure as those buildings are less susceptible to future losses. For example, the Fireman’s Fund Insurance Company is implementing a 5 percent rate credit for the owner’s of “green” buildings since they both help with mitigation and are more resistant to weather-related damages than traditional building materials and types.[318] Building awareness of these programs will also help improve insurer’s reputation while increasing their implementation and effectiveness.[319]

The single largest factor in prevention of heat-related illness is the presence of an air conditioner in the home, especially central cooling systems. However, the elderly are less likely to use an air conditioner even if one is available, perhaps due in part to a decreased ability to perceive heat risks. The poor may be unable to afford the energy costs of operating one. In addition, air conditioners use fossil fuels which in turn worsen carbon emissions and increase energy costs. Air conditioners provide more benefits than temperature relief – cooled, indoor areas provide protection from increased air pollution levels as well as relief from heat-related environmental stress. Therefore, ensuring the universality of air conditioner use and helping to subsidize their use for the most at-risk segments of the population is crucial. Additional research is needed to

[315] Dankwa, D. 2006. “FM Global Touts Underwriting by Engineering as Superior.” *Best’s Review*, p. 93, June.
[316] Mills. 2007.
[317] Placer paper
[318] Allianz and WWF. 2006.
[319] Mills. 2007.

determine the costs of any such programs and their potential to increase greenhouse gas emissions.[320]

Another critical adaptation is the implementation of a public heat warning system, similar to those used in many other major American cities. Dreschler et al. estimate that the initial cost of these systems will be $50,000 for each of ten National Weather Service regions in California and $500,000 per year, based on 5-7 annual extreme heat events for each major city. Adaptations to air pollution vary widely by how well California will meet air quality standards in the future. Current compliance costs total to approximately $10 billion annually, but the outlook for air quality improvements is uncertain.

Another problem facing California is the expansion of vector-borne diseases. For example, current mosquito control programs cost California $200 million per year, but the prediction of the future impact of pest habitat expansion on California's public health and insurance costs will require further research.

Notes and References

[320] Dreschler, Deborah, Nehzat Motallebi,Michael Kleeman, Dan Cayan, Scripps, Katharine Hayhoe1, Laurence S. Kalkstein, Norman Miller, Scott Sheridan, and Jiming Jin . "Public Health-Related Impacts of Climate Change" CEC-500-2005-197. 2005

8. Agriculture: Background

This section highlights the economic impact of climate change on Californian agriculture by looking at the changes in factors influencing agriculture and at expectations in the changes in yields and economic values of crops and livestock products. The information will be divided between how gradual increases in temperature and sudden, extreme weather conditions will impact agriculture. Suggestions for adaption will be described though estimates of their cost and success are unavailable.

Agriculture plays an important role in California's economy so we'll first look at its economic value in the state. In 2006, California's gross state product exceeded $1.6 trillion[321] with agriculture grossing $31.4 billion in cash receipts[322], or 1.9625 percent of the GSP. Comparatively, 2005 produced an all-time high of $32.8 billion in receipts and 2004 produced $30.9 billion in receipts, surpassing $30 billion for the first time[323]. The 2006 output was produced on 26.1 million acres of land for farming and ranching, with 76,000 farms, though acreage has been decreasing[324]. The $31.4 billion in cash receipts for 2006 were derived from different goods. Table 8.1 shows the values of the top five commodities in 2006.

Table 8.1. Value of Top Five Commodities in Cash Receipts in 2006[325]

Goods	Value in billions
Milk and Cream	$4.49
Grapes	$3.03
Nursery and Greenhouse	$2.77 (up from 4th in 2005)
Almonds	$2.04 (down from 3rd in 2005)
Cattle and Calves	$1.67

These products are consistently among the top 5 contributors in value to California's agriculture and the impact of climate change on their yield will be discussed later. Agriculture directly and indirectly provides employment for about 1.1 million people, about 7.4 percent of total employment in California, with concentrations in certain areas such as parts of the Central Valley where 25 percent of employment comes from agriculture[326].

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321 California Legislative Analyst's Office (LAO), Cal Facts 2006, 6 Aug. 2007. 30 June 2008 <http://www.lao.ca.gov/2006/cal_facts/2006_calfacts_econ.htm#economy>.
322 California Department of Food and Agriculture (CDFA), California Agricultural Overview/ Summary -'07. 15 Feb. 2008. 11 June 2008.
323 CDFA, 2008
324 CDFA, 2008
325 CDFA, 2008
326 Cavagnaro, Timothy, Louise Jackson, and Kate Scow, 2006, "Climate Change: Challenges and Solutions for California Agricultural Landscapes," California Climate Change Center White Paper.

California also contributes greatly to US and international agricultural output and consumption, valued economically and productively. Since 1948, it has placed number one in state agricultural cash receipts with approximately 13 percent of total US receipts in current years[327] while Texas at number two was worth $16.0 billion in 2006[328]. Not only is agriculture valued economically, it is also the majority producer of many varieties of fruits and crops in the US. Almost 80 percent of the California's agricultural output was consumed in the US, showing a high domestic demand as it produces about half of all US grown fruits, nuts and vegetables[329]. The 24 percent of production that was exported in 2006 was worth nearly $9.8 billion, down from $10.9 billion in 2005[330,331].

Gradual Changes in Temperature

Different emissions scenarios result in varied changes in temperature but the general consensus shows a gradual increase in mean temperature. While the mean temperature of the planet is expected to increase between 1.7° to 4.9°C (3.1°F to 8.8°F) by 2100[332], expectations for California's temperature are higher. The California Climate Change Center used PCM and HadCM3 models with scenarios of high and low emissions to model changes in temperature. The high emissions scenario used factors of low population growth, very high economic growth, low to medium changes in land-use, high resource availability and rapid technological change involving coal, oil and gas, balanced of non-fossil fuels. The low emissions scenario had different conditions, with low population growth, high economic growth, low energy use, high land-use change, low resource availability and medium to rapid increases in efficiency and dematerialization in technology involving coal, oil and gas, balanced of non-fossil fuels. These conditions led to predictions of summer temperatures increasing between 2.15°C (3.87°F) and 8.3°C (14.9°F) and winter temperatures increasing between 2.15°C (3.87°F) and 4.0°C (7.2°F) [333].

Changes may be more significant in the north and northeast regions than the southwest coastal areas and increases in minimum temperatures may be the most noticeable though another model suggests that they might decline[334]. From 2020-2049, in the Western US, temperatures may increase 1.35°C (2.43°F) and 1.5°C (2.7°F) under the low and high scenarios of the PCM model and 1.6°C (2.9°F) to 2.0°C (3.6°F) under the

[327] Cavagnaro et al., 2006.
[328] CDFA, 2008
[329] Cavagnaro et al., 2006.
[330] LAO, 2007
[331] CDFA, 2008
[332] Cavagnaro et al., 2006.
[333] Cavagnaro et al., 2006.
[334] Cavagnaro et al., 2006.

low and high scenarios of the HadCM3 model[335]. During the period of 2070-2099, California's temperatures may increase 2.3°C (4.1°F) and 3.8°C (6.8°F) with the low and high scenarios of the PCM model and 3.3°C (5.9°F) to 5.8°C (10.4°F) with the low and high scenarios of the HadCM3 model[336]. However, HadCM2 and Canadian Climate Center Models with the IS92 emissions scenarios of the Western United States, used in the national assessment of climate change impacts on the United States, suggested increases of 2°C (3.6°F) by 2030 and 4.5°C–6°C (8.1°F–10.8°F) by 2090[337]. Different models are showing different levels of changes in temperature over time but they show only small differences in degree. Looking at different emissions scenarios shows a slow but steady increase of mean temperature for California from the present to 2100. These slow changes will have impacts on California's agriculture but the slow rate also allows farmers to adjust and adapt with these increases in mind.

The gradual increases of temperature can impact various factors that in turn influence crop production. Factors taken into consideration in this paper are the changes in CO_2 levels, pest effect, decrease in chill time, supply of water, changes in photosynthesis and the length and timing of growing seasons. Increases in temperature combined with different levels of CO_2 can create positive and negative changes in agriculture. Higher levels of CO_2 give plants a high initial growth rate that declines but allows plants a greater collective growth[338]. The following table will show impacts of elevated CO_2 levels and warmer temperatures.

335 Cavagnaro et al., 2006.
336 Cavagnaro et al., 2006.
337 Cavagnaro et al., 2006.
338 Baldocchi, Dennis, Simon Wong, and Andrew Gutierrez, 2005, "An Assessment of Impacts of Future CO2 and Climate on Agriculture," Public Interest Energy Research (PIER) White Paper.

Table 8.2. Summary of positive and negative effects on California agriculture by associated elevated CO2 and regional warming[339]

	Positive (+) effects	Citations	Negative (-) effects	Citations
CO_2				
	Increase biomass production	(Ainsworth and Long, 2005; Centritto et al., 1999; Long et al., 2004)	Greater plant respiration, which scales with increased biomass	(Gifford, 2003)
	Reduced stomatal conductance, increasing water use efficiency	(Ainsworth and Long, 2005; Long et al., 2004)	Increase the need for fertilizer or nitrogen	(Zavaleta et al., 2003)
	Marginal increase in the rate of evaporation for irrigated and closed canopies and C_3 crops	This report	Increase the absolute need for water	(Izaurralde et al., 2003)
			Enhanced insect herbivory	(Lincoln et al., 1993)
			Down-regulation of photosynthesis	(Wolfe et al., 1999)
			Weeds are benefited more that crops	(Ziska, 2003)

Changes in temperature affect the environment of pests, which determines their ranges and rates of growth. Pests include weeds, insects, large and small animals, and viruses. Weeds currently infest over 20 million acres in California with costs of control and lost productivity estimated at over hundreds of millions of dollars each year[340]. Many invasive plants and weeds are expected to increase their range as warmer climates create more hospitable habitats. Weeds can also adapt quickly to climate change because they reproduce at an early age at a high level, allowing them to evolve as the climate changes[341]. Warmer climates can also allow for quicker reproduction of insect pests and can expand their range[342] as they already reproduce at a faster rate than their host plants and weeds and so can evolve more easily[343]. For example, the

[339] Baldocchi et al., 2005.
[340] Cavagnaro et al., 2006.
[341] Cavagnaro et al., 2006.
[342] Baldocchi et al., 2005.
[343] Cavagnaro et al., 2006.

olive fly, Mediterranean fruit fly, pink bollworm and others are predicted to increase their range into the San Joaquin Valley and increase their damage in their current locations[344]. The impact of climate change on large and small animals that damage crops and transmit insects and diseases are unknown but how they react depends on changes in their habitats and how temperature influences them physically. Pathogens might grow faster and for longer with warmer temperatures and their range can increase as crops, insects and animals shift to adapt and new regions grow more hospitable[345]. For example, Pierce's Disease prefers a temperature of 28°C (82°F) and causes damage to grapes, costing millions in damages and control efforts in Southern California[346]. But if temperatures increase in Northern California to the point where Pierce's Disease can survive, it can create large economic losses as it affects over 100 species of plants, many of which are important to the agricultural economy, such as almonds and oranges[347]. More information is needed on how and where these pests will develop to effectively minimize their damage. Warming of California's climates will benefit weeds, insects and pathogens, increasing growth rates and ranges of survival to allow for greater damage and economic losses.

Many fruit trees need to experience a number of cold season hours below a critical temperature (7°C or 45°F), typically referred to as chill time, or their yield and quality will reduce[348]. They generally need from 200 to 1200 hours to flower but with climate change, chill time will likely continue to decrease as warming will lower the number of days of frost[349]. Different regions of California are currently losing from 50 to 500 chill degree hours per year with the greatest changes in the Bay Delta region and the mid-Sacramento Valley[350]. Winter chill hours are expected to fall to about 500 hours by 2100, the critical threshold for many fruit trees so farmers may need to replace them or develop versions that require fewer chill hours[351].

Problems of water supply will be covered more extensively in another section but as climate change affects precipitation and snow levels, agriculture will need to change according to availability. Increased rainfall and decreased snowpack will lead to less surface water availability and greater reliance on groundwater[352]. Depending on the dry/wetness of the year and water demand, agricultural water supply will shift so farmers need to prepare for low levels of water availability.

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[344] Gutierrez, Andrew Paul, Luigi Ponti, C. K. Ellis, and Thibaud d'Oultremont, 2006, "Analysis of Climate Effects on Agricultural Systems," California Climate Change Center White Paper.
[345] Cavagnaro et al., 2006.
[346] Cavagnaro et al., 2006.
[347] Cavagnaro et al., 2006.
[348] Baldocchi et al., 2005.
[349] Baldocchi et al., 2005.
[350] Baldocchi et al., 2005.
[351] Baldocchi et al., 2005.
[352] Cavagnaro et al., 2006.

Growing season length and times will change as warming decreases days of frost, changing the development of crops. The last springtime frost and first day of autumn sum up the growing season so as frost decreases, the growing season lengthens, which has been happening at about a day per decade in California[353]. Data on early blooms indicate an earlier spring leading to a longer growing season which can benefit and harm crops[354]. Perennial crops, such as grapes and fruit trees, can benefit from a longer and warmer growth period but it also leaves fruit trees with less chill time and a shorter dormancy period[355]. A longer growing season would mean greater evaporation and usage of the water supply and a shift in the times of flowering could disrupt pollination while warming could reduce the viability of pollen[356].

Changes in temperature could affect plants ability for photosynthesis as extreme temperatures cause many plants to cease photosynthesis. While plants cease photosynthesis at temperatures over 50°C (122°F) and below 10°C (50°F), the ranges are beyond those estimated in the climate models[357]. At most, one of the previously mentioned models suggested an increase in summer temperature of up to 8.3°C (14.9°F) but as California's highs are generally in the 90s and low 100s, total cessation of photosynthesis for long periods seems unlikely. However, higher temperatures can affect the rate of photosynthesis with higher temperatures leading to decreasing rates.

As temperature changes can affect plants through the previously mentioned effects, it can lead to changes in yield and quality of crops which in turn changes the economic value of the crops. However, information regarding models of yield and value were limited and depended on specific circumstances, such as a doubling of CO_2. The next few tables show expectations of changes in crops with the conditions of their models that led to these results.

[353] Baldocchi et al., 2005.
[354] Baldocchi et al., 2005.
[355] Baldocchi et al., 2005.
[356] Baldocchi et al., 2005.
[357] Baldocchi et al., 2005.

Table 8.3. Responses of economically important California crop commodities to increased temperature[358]

Crop	Response	Reference
Tomato	Reduced fruit number	(Peet et al. 1998; Sato et al. 2000)
Lettuce	Shortened growing season	(Wheeler et al. 1993)
	Increased incidence of tipburn	(Saure 1998)
	Early bolting (flowering onset)	(Waycott 1995)
Rice	Reduced yields	(Moya et al. 1998; Peng et al. 2004; Ziska et al. 1997)
	Increased spikelet sterility	(Matsui et al. 1997)
Stone fruits	Decreased fruit size and quality	(Ben Mimoun and DeJong 1999; DeJong 2005)
Citrus	Reduced frost losses and increased yields	(Reilly and Graham 2001; Rosenzweig et al. 1996)
Grapes	Premature ripening and possible quality reduction	(Hayhoe et al. 2004)
	Increased yield variability	(Bindi et al. 1996)

Table 8.4. Changes in Crop Yield with Double CO_2 [359]

Wheat	Barley	Rice	Corn	Soybean	Cotton	Potato
+35%	+70%	+15%	+29%	+29%	+209%	+83%

[358] Cavagnaro et al., 2006.
[359] Baldocchi et al., 2005.

Table 8.5. Percent Change in yield relative to current production in San Joaquin Valley for eight possible changes in precipitation and temperature (Adams et al., 2001)[360]

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Temperature change (C)	3.00	3.00	5.0	1.8	0.6	1.5	5.0	1.5
Temperature change (F)	5.40	5.40	9	3.24	1.08	2.7	9	2.7
Precipitation change (%)	0	18	0	11	4	9	30	0
Year forecasted	2100	2100	2100	2060	2020	2020	2020	2020
Crop								
Corn grain	-.0634	-.0714	-.1647	-.0283	-.0021	-.0201	-.1813	-.0167
Corn Silage	.0329	.0492	.0411	.0324	.0121	.0274	.0701	.0196
Barley	-.1386	-.1817	-.2579	-.1027	-.0363	-.0843	-.3431	-.0657
Sorghum	-.0535	-.0594	-.0774	-.0423	-.0245	-.0378	-.0865	-.0347
Cotton(pima)	-.0612	-.0830	-.1714	-.0396	-.0357	-.0346	-.2453	-0.0321
Cotton	-.1072	-.1307	-.2359	-.0764	-.0475	-.0664	-.2782	-.0554
Dry Beans	-.0914	-.1359	-.1563	-.0751	-.0266	-.0612	-.2668	-.0472
Oats	-.3346	-.3308	-.7937	-.1525	-.0427	-.1187	-.7799	-.1189
Rice	-.0756	-.1001	-.1764	-.0426	-.0003	-.0302	-.2309	-.0211
Sugar Beets	-.0753	-.0579	-.1096	-.0461	-.031	-.0429	-.0694	-.0491
Winter wheat	-.0326	-.0635	-.1009	-.0326	-.0176	-.0269	-.1507	-.0111
Durum Wheat	.029	.0467	.0293	.0256	-.0051	.0186	.0609	.0102
Valencia orange	-.1452	-.2475	-.1530	-.1837	-.1601	-.1726	-.4493	-.1498

360 Baldocchi et al., 2005.

Table 8.5 (continued)

Hay alfalfa	.0871	.0928	.1432	.0540	.016	.0443	.1595	.0430
Grapes (table, raisin)	-.3819	-.5247	-.7539	-.2747	-.085	-.2196	-1.0812	-.1684
Grapes (wine)	.1647	.1523	.2127	.1199	.0814	.111	.1928	.1174
Tomatoes (fresh)	-.3742	-.3566	-.7157	-.2170	-.1115	-.1877	-.6641	-.1915
Tomatoes (processed)	.0211	-.0103	.0448	-.0071	-.0111	-.0070	-.033	.0030
Almonds	.5384	.5478	.9664	.3121	.1082	.258	1.0131	.2603
English Walnuts	.076	.0407	.085	.0429	.0358	.0425	.0153	.0578
Prunes (dried)	.434	.4509	.7967	.2568	.0911	.2125	.8384	.2071
Olives	-.3995	-.3989	-.8092	-.2088	-.0547	-.1669	-.7952	-.1643
Avocados	.0099	-.1612	0.0022	-.0659	-.0151	-.0466	-.4277	.0063
Potatoes	-.149	-.1527	-.2543	-.0936	-.0388	-.0794	-.261	-.0776

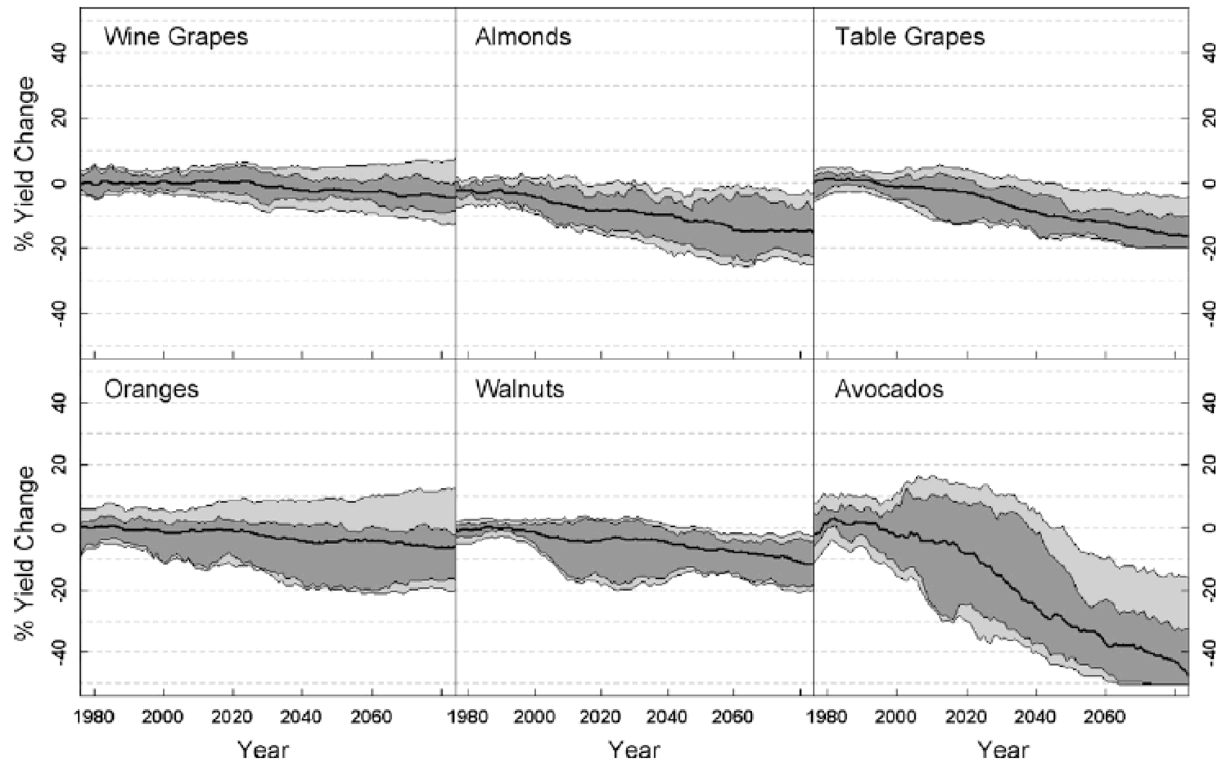
Table 8.4 shows how yield is expected to increase due to a doubling of CO_2 levels because it increases photosynthesis, though a long period of exposure decreases the percent increase in photosynthesis. These estimates contrast with the overall decreases in yield seen in Table 8.5, where changes temperature, precipitation and technology were taken into consideration but not changes in CO_2 levels. The information also assumes that there will be adequate water supplies for agriculture. These two tables show the varied results that different models and considerations have on forecasting changes in yield.

Special notice should be given to perennial crops because of their limited adaptability and long periods of development and growth. They require long term investments but climate change would make some regions currently growing these crops unfavorable while cooler regions that would warm would become more ideal for them[361]. More information is needed on where the greatest decreases and increases of yield of these

[361] Lobell, David B., Christopher B. Field, Kimberley N. Cahill, and Celine Bonfils. "Impacts of future climate change on California perennial crop yields: Model projections with climate and crop uncertainties." Agricultural and Forest Meteorology 141 (2006): 208-18.

crops would be so farmers can make plans to continue, begin or change their development since any action with perennial crops would require time. Figure 8.1 shows projected changes in perennial yield with the black line representing median projections and the shaded areas showing confidence after accounting for climate uncertainty (dark grey) and confidence after accounting for both climate and crop uncertainty.

Figure 8.1. Changes in Yield of Perennial Crops[362]



There is also little information regarding changes in qualities of crops though fruits in particular are very sensitive. Their rate of development could increase and size decrease because rising temperatures would increase their heat accumulation, the number of hours between 45 and 95°F, and decrease their chill hours[363]. Grapes could also ripen early and see a reduction in quality due to high temperatures though the change will be moderate until toward the end of the century where they could ripen one or two months early[364].

Farmers might choose to switch crops and establish in more favorable regions due to high levels of water usage, inability to produce profitable yields, etc. While annual crops can be easily moved or replaced, long-lived species such as grapes would require much

[362] Lobell et al., 2006.
[363] Luers, Amy L., Daniel R. Cayan, Guido Franco, Michael Hanemann, and Bart Croes, comps. Our Changing Climate. California Climate Change Center. 2006. 18 June 2008.
[364] Our Changing Climate. et al. 2008

time and money to move[365]. But climates may force certain crops out of production in current regions. For example, the loss of chilling hours in southern California and the low temperatures in the north would force olives to grow in central California, the region currently favorable for olives[366]. The sensitivity of some of California's specialty crops to the effects of climate change, such as fruits and nuts, might lead to decreases in quality and market value so farmers might choose to replace them for more profitable crops. However, little information was found on alternatives in crop production and expectations of switching as climate changes the environment of a region.

Studies show little estimates of changes in economic value of crops as yields and quality of crops change in California. In the United States, agricultural production is expected to increase overall so prices will fall and producers will lose while consumers gain[367]. Depending on the models used leading to different climate situations, climate change could lead to agricultural economic losses of $5 billion to $8.1 billion for the US, not including water-related impacts and in 1990 dollars[368]. However, California's outlook could be vastly different as it will have a water supply problem and currently have many specialty crops whose demand could fall as costs increase for production[369]. Information is scattered on the expected change in economic value of the agricultural industry in California, with only tidbits on one crop or one region under specific conditions. For example, the Central Valley is estimated to lose around $278.5 to $803[370] million, reductions of 9 to 26.3 percent of current net revenue[371], due to annual water shortages and $6 billion per year during extremely dry years[372]. One study using the Hadley 2 Long Run 2070-2099 model of climate change, based on growing season degree-days and total precipitation, estimated that California could lose about $750 million annually, estimated in 2002 constant dollars and nearly 15 percent of current profits[373].

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[365] Gutierrez et al., 2006.
[366] Gutierrez et al., 2006.
[367] Cavagnaro et al., 2006.
[368] Schlenker, Wolfram, W. Michael Hanemann, and Anthony C. Fisher. The Impact of Global Warming on US Agriculture: an Econometric Analysis. Department of Agricultural and Resource Economics and Policy. University of California Berkeley. 2002. 18 June 2008.
[369] Cavagnaro et al., 2006.
[370] Correction of information from source in footnote 52.
[371] Hanemann, M., L. Dale, S. Vicuna, D. Bickett and C. Dyckman. 2006. The Economic Cost of Climate Change Impact on California Water: A Scenario Analysis. California Energy Commission, PIER Energy-Related Environmental Research. <http://www.energy.ca.gov/2006publications/CEC-500-2006-003/CEC-500-2006-003.PDF>
[372] The US Economic Impacts of Climate Change and the Costs of Inaction. Center for Integrative Environmental Research, University of Maryland. 2007. 18 June 2008 <http://www.cier.umd.edu/climateadaptation/>.
[373] Deschenes, Olivier, and Michael Greenstone. The Economic Impacts of Climate Change: Evidence From Agricultural Profits and Random Fluctuations in Weather. Dept. of Economics, MIT. 2006. 30 June 2008.

Gradual changes in temperature also influence dairy production, consistently the top commodity in California. There are about 5.2 million cattle in California, concentrated mostly in the Central Valley[374]. Due to limited water supplies and heat stress, cattle will have difficulty dealing with higher temperatures[375]. Cows eat less due to heat stress because at high temperatures of over 35°C or 95°F, metabolism contributes to a third of their heat load and they give up feed for reduced heat[376]. With higher body temperatures, dairy cows are less efficient and produce a lower milk yield[377]. The ideal temperature for cows is between 41 and 77°F because they need to expend energy to cool themselves when over that range[378]. This can lead to lower production so when temperatures increase, towards the end of the century, milk production can decrease by up to 20 percent[379]. But if temperatures stay within or below the lower range of warming, milk production can decrease by 10 percent or less[380]. This means a loss of $287-902 million every year[381] to the industry currently worth $4.49 billion in California[382].

Extreme Weather Conditions

With climate change, models have shown that California will have more occurrences of extreme weather, such as heat wave, floods, etc[383]. At best these would only create delays in planting but they could also heavily damage crops, costing billions as in the flood damages of the 1990s[384]. Heat waves can cause early bolting, reduce effectiveness of pollination, decrease plants ability for photosynthesis, etc leading to decreased yield and quality as in the gradual weather changes. But extreme events can also kill plants that require long periods of growth, such as fruit trees and grapes, leading to a loss of production for years until they recover or can be replaces. Information on extreme weather leading to changes in yield and economic value of crops and dairy is lacking as models show only an increase and intensity of occurrences.

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374 Cavagnaro et al., 2006.
375 Cavagnaro et al., 2006.
376 Cavagnaro et al., 2006.
377 Cavagnaro et al., 2006.
378 Jones, Gerald M., and Charles C. Stallings. "Reducing Heat Stress for Dairy Cattle." Virginia Cooperative Extension 404 (1999). 4 Nov. 1999. 7 Aug. 2008 <http://www.ext.vt.edu/pubs/dairy/404-200/404-200.pdf>.
379 Luers et al., 2008.
380 Luers et al., 2008.
381 The US Economic Impacts of Climate Change and the Costs of Inaction. et al. 2008
382 California Agricultural Overview/ Summary -'07 et al. 2008
383 The US Economic Impacts of Climate Change and the Costs of Inaction. et al. 2008
384 Wilkinson, Robert. California. California Regional Assessment Group. Preparing for a Changing Climate. 23 Apr. 2002. 18 June 2008.

To give an idea of the economic impact of extreme weather on California's agriculture and dairy, here are some estimates of previous events. Unusually low temperatures in 2007 damaged many crops, such as citrus, strawberries, cabbage, etc. and cost the agricultural industry more than $1 billion[385]. The record heat wave in July of 2006 created losses of over $1 billion for the dairy industry alone[386]; figures for other sectors of agriculture are unknown. Over half a billion was lost due to damages to citrus crops because of the four days worth of freezing temperatures in 1998[387].

Adaptation

Suggestions for adaption covered here include choosing crops more suited to new environmental and economic climates, alleviating heat stress in livestock and changing management. Using agricultural land as sinks for GHGs and improving water use efficiency are strategies for mitigating the effects of climate change. Increasing the capability of agricultural lands to serve as sinks for GHGs could improve soils though it would only benefit crops for a short period of time as vegetation and soils have a limited ability to sequester CO_2[388]. Permanently setting aside surplus agricultural land as sinks also serves to conserve natural resources[389]. Mitigation strategies will be further discussed in another section.

With problems in water supply, increasing water use efficiency would create more resources for agriculture rather than forcing farmers to rely heavily on precipitation and snow levels. Looking into wastewater reclamation and reuse, seawater desalination and water conservation, while expensive, could be cheaper than alternatives depending on the region, especially in Southern California[390]. Water use efficiency at the farm level depends on the type of crops grown and irrigation systems used and improvements at that level are still possible[391]. Flood irrigation produces a WUE of 60 percent or less while micro-irrigation produces a WUE of up to 95 percent[392]. More efficient sprinkler systems that apply water just above the soil reduces losses from evaporation and precision irrigation through laser fielding of fields can decrease water

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[385] "Californians Urged to Support Local Farmers, Economy Following Winter Weather Crop Disaster." Business Wire 31 Jan. 2007. 30 June 2008 <http://findarticles.com/p/articles/mi_m0EIN/is_2007_Jan_31/ai_n27132219>.

[386] "California Heat Wave Costs Agriculture Industry Billions." Environment News Service 4 Aug. 2006. 30 Aug. 2008 <http://www.ens-newswire.com/ens/aug2006/2006-08-04-09.asp#anchor4>.

[387] Purdum, Todd S. "4-DAY COLD SPELL SLAMS CALIFORNIA; CROPS DEVASTATED." New York Times 25 Dec. 1998. 30 June 2008 <http://query.nytimes.com/gst/fullpage.html?res=9D00E3DC1F3CF936A15751C1A96E958260>.

[388] Cavagnaro et al., 2006.

[389] Cavagnaro et al., 2006.

[390] Cavagnaro et al., 2006.

[391] Cavagnaro et al., 2006.

[392] Cavagnaro et al., 2006.

use and improve distribution of water though it is expensive and probably more appropriate for high value crops[393]. Drip irrigation can be profitable depending on the crop, for example, it led to higher yields and greater returns in a study of peppers in two locations in California, but it would also be more appropriate for higher value crops[394]. Water can also be saved by allowing agricultural lands to grow fallow during dry years, decreasing demand and allowing water to be diverted for other uses[395].

Breeding based on climate change could produce crops and animals of higher yields and farmers who could more easily switch crops should look into ones better adapted for their region. Breeding crops and livestock suited for new climates would take time and knowledge of varied information, such as reactions to CO_2 levels and temperature, but could lead to benefits of higher yield and greater resistance to problems of heat stress, pests, etc. With warming across the state, production would be more possible in the north for crops that need higher temperatures and longer growing seasons, such as olives and citrus[396]. As pests will increase, planting crops that are more resistant or choosing varying crops over time to discourage pests would minimize damages[397]. Farmers could also choose crops that are more water efficient while also providing greater value for increased economic returns. Table 8.6 shows information on the volume of water needed to produce one kilogram of a crop while Table 8.7 shows the applied water usage in acre feet per acre. More information is needed on GMOs and their value in situations of climate change.

393 Cavagnaro et al., 2006.
394 Cavagnaro et al., 2006.
395 Cavagnaro et al., 2006.
396 Cavagnaro et al., 2006.
397 Cavagnaro et al., 2006.

Table 8.6 Volume of Water Needed to Produce One Kilogram of a Crop[398]

Crop	Volume of Water
Alfalfa	1100 liters per kilogram
Wheat	900 liters per kilogram
Corn	650 liters per kilogram
California Rice*	1080 liters per kilogram

* Rice generally needs 1600 liters per kilogram but California's rice is more water efficient

Table 8.7 Applied Water Use in Acre Feet Per Acre in California, 2001[399]

Crop	Water in Acre Feet Per Acre
Grain	1.51
Rice	5.88
Cotton	3.23
Sugar Beet	4.11
Corn	3.09
Dry Bean	2.47
Alfalfa	5.30
Cucumber	4.53
Potato	2.71
Vine	2.12

As mentioned before, heat stress can lead to lower production in dairy cows but choosing animals based on tolerance to heat could lead to lower yield. Breeding for greater milk production over the past 50 years has led to increases in heat energy as energy for milk production increases so they have become more intolerant while producing more[400]. Simple methods of introducing shade and cool drinking water, changing the feeding schedule and adjusting the diet to reduce heat can lead to greater tolerance for heat[401] , though their effectiveness may decrease in higher temperatures and farmer may need to employ a variety of methods.

With longer growing seasons, increased CO_2, decreased water supplies, etc. changing management practices could increase production of crops. Planting dates and timing of thinning could be used to improve yield because of changes in the development of

398 Cavagnaro et al., 2006.
399 California. Department of Water Resources. Irrigated Crop Area 2001. 11 July 2008 <http://www.landwateruse.water.ca.gov/annualdata/landuse/years.cfm>.
400 Cavagnaro et al., 2006.
401 Cavagnaro et al., 2006.

crops due to new environments and changes in resources[402]. Many farmers also plan which crops to plant based on estimates of surface and groundwater water supplies at the beginning of the growing season[403]. They can use the information to decide how to distribute their crops, what they can plan during the season and what lands they can allow to go fallow. Fallowing land during dry years greatly decreases demand for surface water and can reduce irrigation requirements by 20 to 30 percent in some districts[404]. In pest control, management decisions on which crops, when to plant, fertilization, irrigation and pest control are all strategies that farmers can implement now (since they're being used for dealing with weeds)[405]. Greater monitoring and more information that includes consideration on climate change are needed to effectively manage future changes in pests, weeds and diseases.

Notes and References

[402] Cavagnaro et al., 2006.
[403] PIER White Paper For The. Climate Change Impacts on Water for Agriculture in California: a Case Study in the Sacramento Valley. California Climate Change Center. 2006. 6 June 2008.
[404] Climate Change Impacts on Water for Agriculture in California: a Case Study in the Sacramento Valley. et al. 2008
[405] Cavagnaro et al., 2006.

9. Forestry: Background

Forestry is an important California industry. The total value of all primary forest products created in California was 2.3 billion in the year 2000. Of that, 65 percent was lumber sales and 62 percent were sold in California.[406] This industry faces many risks as a result of climate change, including increased temperatures and changing soil moisture that may impact timber productivity, growth, and health. As trees become more stressed, they may become more susceptible to a variety of pest and pathogen risks. The implications for timber management in California are varied and complicated, potentially leading to changes in the way forest stands are maintained.

Physical Impacts

Climate change influences California's forests primarily through changes in temperatures and moisture availability. While warmer temperatures generally increase plant productivity, they can also lead to decreased soil moisture. Additional complications arise from the fact that survivable conditions for seeds, seedlings and adult trees may vary. Generally, we can expect forests to change in terms of forest composition, location and productivity as a result of climate change.[407]

Battles et al[408] recently published an extensive paper on the impact of climate change on California's forests. This report relies on a case study approach looking specifically at Amador and El Dorado forests. While it is not possible to generalize from their work and more research is needed to determine the extent that their results reflect results for California's forests as a whole, their work constitutes the most exhaustive survey of detailed climate change projections for forests in California to date.

In this paper, they described the effect of climate change on tree growth, yield and non-catastrophic mortality, for both pine plantations and mixed conifer reserve stands. The most adversely effected tree types were white fir, incense cedar and Douglas fir while ponderosa and sugar pine were relatively less affected. Changes in forest productivity were uniformly negative and decreased with time, with one exception – in the less sensitive version of the reduced emissions scenario (PCM B1), a slight increase in

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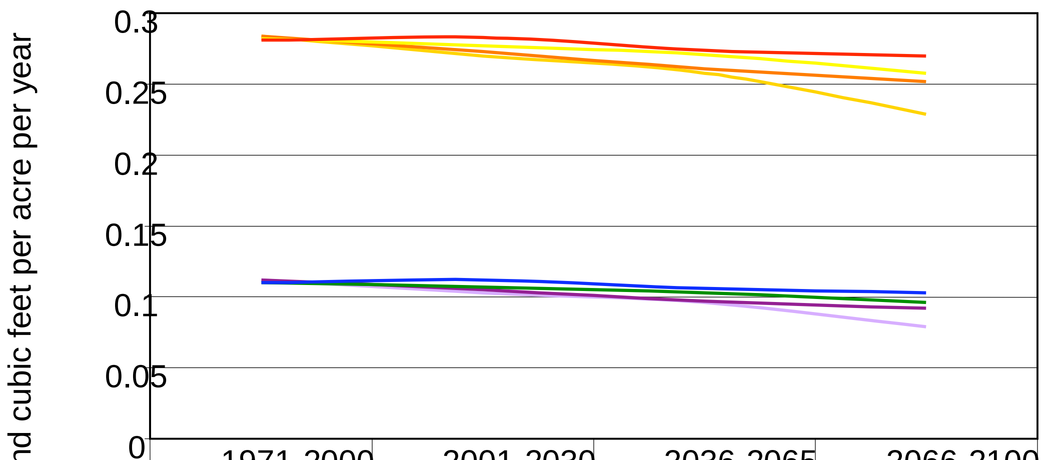
[406] Morgan, Todd A.; Keegan, Charles E., III; Dillon, Thale; Chase, Alfred L.; Fried, Jeremy S.; Weber, Marc N. 2004. "California's forest products industry: a descriptive analysis". Gen. Tech. Rep. PNW-GTR-615. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station

[407] Shugart, Herman, Roger Sedjo and Brent Sohngen. "Forests and Global Climate Change: Potential Impacts on US Forest Resources". Pew Center on Global Climate Change: 2003.

[408] John J. Battles, Timothy Robards, Adrian Das, Kristen Waring, J. Keith Gilless, Frieder Schurr, John LeBlanc, Gregory Biging, and Clara Simon. "Climate Change Impact on Forest Resources".

productivity was predicted for the first part of the century but with significant declines thereafter.

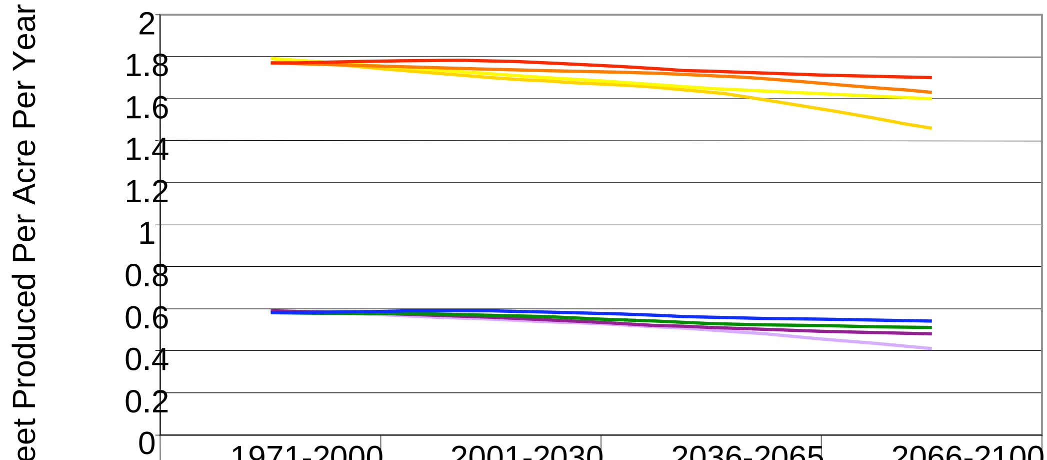


	1971-2000	2001-2030	2036-2065	2066-2100
	0.284	0.27	0.258	0.229
Reserve GFDL B1	0.284	0.273	0.261	0.252
Reserve PCM	0.282	0.277	0.271	0.258
Reserve PCM	0.281	0.283	0.274	0.27
Plantation GFDL A2	0.112	0.103	0.096	0.079
Plantation GFDL B1	0.112	0.105	0.097	0.092
Plantation PCM A2	0.11	0.107	0.103	0.096
Plantation PCM B1	0.11	0.112	0.106	0.103

Figure 9.5: Growth Changes for Pine and Conifer Forests by Scenario[409]

Decreases in forest growth by the end of the century ranged for mixed conifer reserve stands from 3.9 percent in the mildest climate change scenario to 19.4 percent under the business-as-usual higher-sensitivity model. Growth reductions for pine plantations ranged from 6.3 percent to 29.4 percent. In most cases, growth decreased gradually over the course of the century, but in the higher emissions and sensitivity scenarios, conditions worsened rapidly near the end of the century.

[409] Battles et al. 2003. 16.



	1971-2000	2001-2030	2036-2065	2066-2100
Reserve GFDL A2	1.79	1.7	1.63	1.46
Reserve GFDL B1	1.79	1.72	1.65	1.6
Reserve PCM A2	1.77	1.74	1.71	1.63
Reserve PCM B1	1.77	1.78	1.73	1.7
Plantation GFDL A2	0.59	0.55	0.5	0.41
Plantation GFDL B1	0.59	0.56	0.51	0.48
Plantation PCM A2	0.58	0.57	0.53	0.51
Plantation PCM B1	0.58	0.59	0.56	0.54

Figure 9.6: Yield Changes for Pine and Conifer Forests by Scenario[410]

Forest yields are expected to follow much the same pattern as forest growth. For reserve stands, yield decreases will range from 3.9 percent to 18.4 percent. Pine plantation yields will decrease between 6.9 percent and 30.5 percent. For both reserve stands and plantations under the B1 (reduced emissions) scenario, yields are expected to increase slightly during the first third of the century.

As noted above, yield and growth are not the only way that forests will be impacted. Non-catastrophic mortality is the mortality that can be expected only from changes in normal weather factors – it does not include wildfires, changes in pest ranges, etc. Changes were in non-catastrophic mortality are expected to be modest for all scenarios. Distribution of mortality is expected to change, however, with the weakest trees becoming weaker over time. Whereas a tree at the 50th percentile of distribution is expected to have a .983 survival probability in the GFDL A2 scenario, a tree at the 25th percentile is expected to have a .956 survival probability.

410 Battles et al. 2003. 16

Table 9.1: 50th Percentile Tree Survival Probability by Scenario[411]

	2002	2030	2065	2100
GFDL A2	.998	.997	.993	.983
GFDL B1	.998	.997	.994	.994
PCM A2	.998	.998	.997	.992
PCM B1	.998	.997	.997	.998

In addition to weather-related mortality, California's forests are in danger from a variety of pests whose range may be expanded by milder winter temperatures and increased tree vulnerability. Modeling the variety of complex ecological factors which influence pest habitat and ecosystem changes is very difficult and more research is needed to predict the effect that expanded pest ranges may have on forest health. Pests annually destroy ten times more timber volume than wildland fires.[412] However, as the number of stressed trees increase, the prevalence of these organisms is likely to increase. Climate change can affect pest organism's rates of reproduction, development, and survival. Models exist to predict these effects nationally but need to be adapted regionally to California. In addition, insects and forest pathogens could have interactive effects on forest health which may severely impact the timber base. More research in this area is needed to determine the potential effects of timberland management on pest habitat ranges and spread.[413]

Economic Impacts

Among the economic impacts that can be expected from changes in forest growth and yield are decreasing budgetary revenue for California, and decreased revenue for any forest harvesters. Lower forest harvests will mean lower payments from the Timber Yield Tax Law. One of the main challenges for California is to preserve the sustainability of California's forestry programs while continuing to produce an adequate amount of revenue despite declining harvests.[414]

Table 9.2: Change in Annual Revenue Per Acre[415]

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[411] Battles et al. 2003. 18.
[412] California Department of Forestry. "Resource Management". 2005
[413] Battles et al. 2003. 21.
[414] Battles et al. 2003. 22.
[415] These estimates are derived by multiplying the MBF yield changes predicted by Battles et al. by the expected mixed conifer value found in the California State Board of Equalization Timber Harvest Schedule, adopted December 12, 2007. They apply only to the Amador & El Dorado units focused on in the original study.

	GFDL A2 Reserve	GFDL B1 Reserve	PCM A2 Reserve	PCM B1 Reserve	GFDL A2 Plantation	GFDL B1 Plantation	PCM A2 Plantation	PCM B1 Plantation
2030	-10.8	-8.4	-3.6	1.2	-4.8	-3.6	-1.2	1.2
2065	-19.2	-16.8	-7.2	-4.8	-10.8	-9.6	-6	-2.4
2100	-28.8	-14.4	-13.2	-9.6	-16.8	-9.6	-7.2	-6

Changes in revenue will be most severe for reserve stands under the business-as-usual scenario and least severe for plantation revenue under a less-sensitive reduced emissions scenario. For reserve stands, the decrease in revenue per acre by the end of the century in forest unit studied by Battles et al ranged from $9.6 to $28.8. For plantations, the decreases ranged from $6 to $16.8. More research is needed to generalize these results and discover how other forests in California may be affected. These estimates do not include the potential effects of carbon fertilization.

Adaptation

Adaptation options generally fall into one of three categories: investment reduction, harvesting increases, or changes in silvicultural management. In addition, there may be a need for increased pest control and fire management. More research is needed to determine the cost to California of all these measures given the changes in future expectations under climate change.

Public agencies may be forced to abandon some of their maintenance of tree stands due to decreased revenue. Reducing management could have many implications for forest health and wildfire risk. If thinning intervals were to decrease or shrub management to grow less intensive, wildfire risk could increase.[416] Harvesting increases could help to ameliorate temporary budget short-falls, but would threaten the sustainability of California's forest management. The third option, silvicultural changes, could help with these trade-offs. Stands with a single dominant species are most at risk for many of the problems threatening forest health. Increasing the diversity of tree stands in tree age and species will help to limit the spread of tree pathogens and pests, as will reducing tree density and increasing strategic pruning measures. While this report has treated each impact as separate and distinct, there are many potentially disastrous interactions that could take place which could drastically increase the yield and revenue effects listed here.[417]

[416] Battles et al. 2005. 22-23.
[417] Battles et al. 2003. 22-23.

Notes and References

10. Fisheries: Background

This section describes the impacts of climate change on the fishing industry in California, focusing on squid and salmon. It will provide information on the various factors influenced by climate change that will in turn affect the populations of the squid and salmon. Adaptation strategies will be discussed though it should be noted that estimates for the economic costs of the impact of climate change and proposed adaptation methods are unavailable. The following Table 10.summarizes the paper with climate change impacts that influence squid and salmon and the adaptation and mitigation options open to each.

Table 10.1. Climate Change Impacts and Adaptation Options for the Squid and Salmon Industries

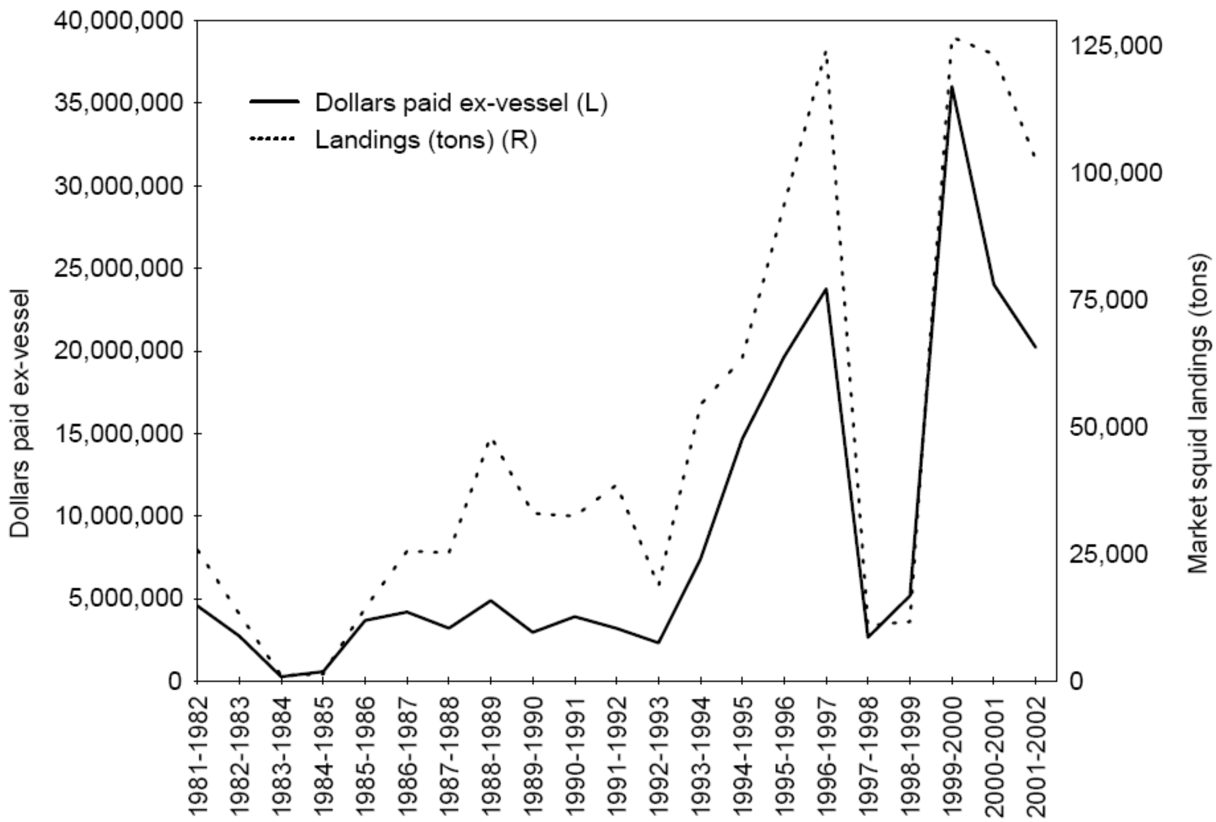
	Climate Change Impacts	Adaptation Options
Squid	-Increased Water temperatures -increase growth rates -shorter life spans -smaller hatchlings emerging earlier -need more food per unit body size and oxygen -decrease in ability to handle food shortages -greater impact on surrounding ecosystems -population might shift to other regions -predictability of spawning could fall -Increases in more extreme events and their conditions such as El Niño	-Need more information on the various types of squid and their different environments -Learn how to best preserve the squid, allowing them enough time to adapt themselves because of the fast growth rates
Salmon	-Warmer freshwater habitats -Increased winter flooding, reduced summer streamflow -Change in timing of migration influencing the availability of food and presence of predators -increase in ocean temperature influencing their food supply -Pacific Decadal Oscillation- potential impact, causes and predictability unknown	-Increase stream shade -Changing dam operations to increase summer flows -Removing dams -Increase monitoring -Learn how to best preserve their diversity to allow them to adapt

California's Fishing Industry

Before discussing squid and salmon in particular, let's first look at the role of the fishing industry in California. The most specific information available regarding the value of the fishing industry provided by the U.S. Bureau of Economic Analysis combined it with "forestry and related activities". In this category, California had the highest GDP of the states in 2006 with $7,490 million while the second highest was $2,478 million for Washington[418].

Market squid produces the most volume and revenue among California's commercial fishing, worth more than $35 million at its peak in 1999-2000[419]. The majority of the squid is frozen and exported to China, Japan and Europe, ranking first in volume and revenue for California's fishery exports[420]. The bulk of the market squid revenues have gone to the Santa Barbara and Los Angeles port areas, with landings in the Southern fisheries above those in the Northern since the 1980s[421]. For a better idea of its value domestically and abroad, the first following Table 10.shows the dollars paid ex-vessel and the landings in tons for the period of 1981-2002 while the second shows information on squid exports from 1989-2000.

Figure 10.1. Market Squid: Dollars Paid Ex-vessel and Landings in Tons 1989-2002[422]



418 "Gross Domestic Product by State- Forestry, fishing, and related activities for All States." Bureau of Economic Analysis Regional Economic Accounts. 5 June 2008. U.S. Department of Commerce. 6 Sept. 2008 <http://www.bea.gov/regional/gsp/>.

419 Sweetnam, Dale, comp. Market Squid Fishery Management Plan Ch. 2. USA. California Department of Fish and Game. 1 Apr. 2005. 29 Aug. 2008 <http://www.dfg.ca.gov/marine/msfmp/index.asp>.

420 Sweetnam, 2008

421 Sweetnam, 2008

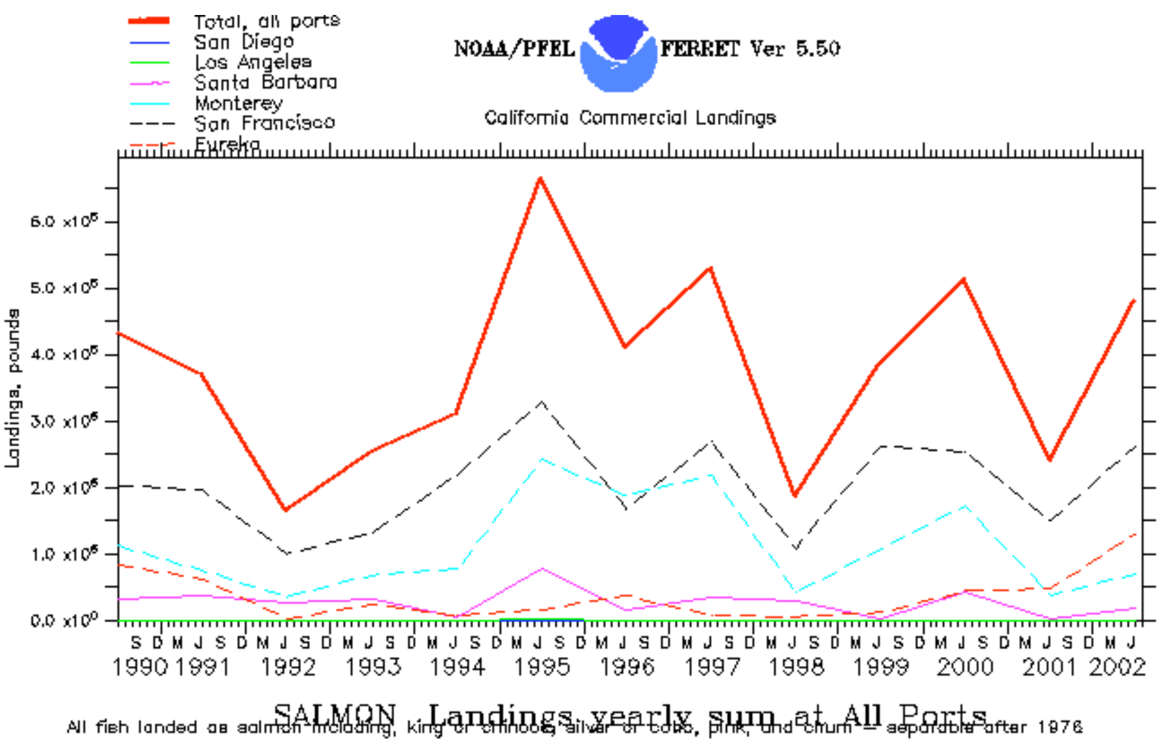
422 Sweetnam, 2008

Table 10.2. Market Squid Volume and Value Exported 1989-2000[423]

Year	Squid exported (tons)	Export value*	Rank by volume	Rank by value	Percent catch exported
1989	5,267	$5,667,283	1	7	11.7
1990	4,571	$4,110,021	2	10	14.6
1991	2,619	$2,637,344	12	20	6.4
1992	4,187	$3,938,031	2	8	29.0
1993	4,569	$5,448,155	1	6	9.7
1994	15,801	$15,817,174	1	3	25.8
1995	24,107	$21,196,325	1	1	30.2
1996	36,377	$32,802,620	1	2	41.1
1997	49,745	$45,989,317	1	1	64.2
1998	1,554	$2,109,087	8	20	48.7
1999	37,411	$36,355,586	1	1	29.8
2000	92,701	$71,637,625	1	1	75.2

*Note: export value not adjusted for inflation.

Figure 10.2. Landings of Salmon in Pounds, in Total and for Various Ports 1990-2002[424]



Based on the economic values for California's commercial salmon fishery, recreational ocean salmon fishery and steelhead fishing in the Sacramento River and tributaries, it is

423 Sweetnam, 2008

424 "California Fish Landings: Live Access Server." Datasets > 1. Simplified list of the 57 most common market categories, for longer time series > 1. Fish, Marine and Anadromous Variable(s): SALMON. Southwest Fisheries Science Center. 1 Sept. 2008 <http://las.pfeg.noaa.gov:8080/las_fish1/servlets/data>.

estimated that all salmon fisheries combined contributes approximately 28.8 to 50.6 million dollars annually to the economy[425]. More specific information on yearly values of salmon fisheries is unavailable for California alone though the fisheries of California and Oregon combined average an economic impact of $133 million[426]. The following Figure 10.shows the landings of salmons in pounds, in total and for each port in California.

Climate Change Impacts on Squid and Adaptation Options

Climate change increases water temperatures, which would affect the development of the squid, and leads to greater possibilities of extreme ocean events and their conditions. Higher temperatures increase the squids' growth rates while shortening their life-spans, which accelerates turnover of the population[427]. But it also leads to hatchlings emerging earlier and at a smaller size, possibly forcing them to mature into adults faster, which would impact their population structure[428]. They would also need more food per unit body size, more oxygen to metabolize faster and a decreased ability to deal with food shortages[429]. Their dietary needs would have a greater impact on their ecosystems with increased temperature and depending on the size of the stock[430]. The population themselves might shift to more hospiTable 10.regions for spawning, into deeper waters unavailable to fishermen[431]. The predictability of spawning might also change, making it more difficult for management practices of protecting spawning adults within enclosures to encourage more eggs[432].

Some predictions of climate change include increases in more extreme events, such as El Niño, as well as its conditions, which could have a devastating impact on the squid population. In the 1997-1998 season, squid landings fell from their then record high of 110,000 metric tons in 1996-1997 to less than 1,000 metric tons because of the high temperatures associated with the El Niño event at that time[433]. At this time, squid also had slower growth rates and were smaller because of the scarcity of food, with the

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[425] Barrow, Scott, and Marc Heisdorf. California's Living Marine Resources: A Status Report, Salmonids: Overview. USA. California Department of Fish and Game. 27 June 2007. California Department of Fish and Game. 1 Sept. 2008.
[426] Pacific Fishery Management Council Votes To Allow Lowest Ever 2006 Salmon Fisheries Off California And Oregon. USA. Pacific Fishery Management Council. 10 Apr. 2006. 1 Sept. 2008 <http://www.pcouncil.org/newsreleases/pr040706_sal.pdf>.
[427] Pecl, Gretta T., and George D. Jackson. "The potential impacts of climate change on inshore squid: biology, ecology and fisheries." Reviews in Fish Biology and Fisheries (2007). 21 Nov. 2007. SpringerLink. 29 Aug. 2008 <http://www.springerlink.com/content/c06170q14113g33t/>.
[428] Pecl and Jackson, 2008.
[429] Pecl and Jackson, 2008.
[430] Pecl and Jackson, 2008.
[431] Pecl and Jackson, 2008.
[432] Pecl and Jackson, 2008.
[433] Climate Action Report 2002. USA. US Global Change Research Program. 28 May 2002. 29 Aug. 2008 <http://www.usgcrp.gov/usgcrp/library/thirdnatcom/chapter6.htm>.

pause in upwelling causing a fall in productivity[434]. Figure 10.1, seen previously, shows the sharp fall in landings due to El Niño conditions.

Little information is available on possibilities of mitigation and adaptation to support squid populations. More information is need on the various types of squid, suited to their different environments, and their survival needs to understand what can be done to allow them the best possible chance to grow and adapt themselves. Their initial fast growth rates and the increase in that rate that will be caused by elevated temperatures will help them adapt quickly to changes in their environments so it seems best to understand how to help preserve them and allow them the time to adapt[435].

Climate Change Impacts on Salmon and Adaptation Options

Climate change will affect the freshwater and saltwater environments of salmon and decrease their chances of survival by changing their food supply and the presence of predators. Increases in winter flooding could hurt the eggs while decreased summer flooding would raise the temperature of the water, with warm water harmful to salmon[436]. Juvenile salmon could be pushed to the ocean earlier, with earlier snow melts and peak spring streamflows, before there is enough spring phytoplankton to feed them because they bloom with the summer northerly winds[437]. The timing of their arrival could also influence their chances of survival because the balance between predators and baitfish populations at that time would determine their number of predators[438]. The different phases of the Pacific Decadal Oscillation also seem to have an influence on salmon stocks, with fewer stocks during warm phases and more during wet phases[439]. While causes and predictability for the PDO are unknown, some climate simulations have included them for various reasons so climate change could influence the duration of the two phases[440].

Most adaptation and mitigation plans apply only to the short term and would eventually become ineffective so it seems best to learn more about how to protect the salmon so that they can adapt themselves, as with the squid. Several short term options include increasing stream shade and changing dam operations to increase summer flows to

434 Pecl and Jackson, 2008.
435 Pecl and Jackson, 2008.
436 Carter, Lynne M. US National Assessment of the Potential Consequences of Climate Variability and Change Educational Resources Regional Paper: Pacific Northwest. USA. U.S. Global Change Research Program. 23 May 2007. 29 Aug. 2008 <http://www.usgcrp.gov/usgcrp/nacc/education/pnw/pnw-edu-4.htm>.
437 Carter, 2007.
438 Carter, 2007.
439 Carter, 2007.
440 Mantua, Nate. "The Pacific Decadal Oscillation (PDO." 21 Feb. 2008. Joint Institute for the Study of the Atmosphere and Ocean. 6 Sept. 2008.

mitigate warming water temperatures[441]. Removing dams would also decrease water temperatures but it would also decrease control over summer flows and water shortages[442]. More information and monitoring would help to understand more about how climate change could affect them and could help set fishing guidelines based on population levels, such as limiting fishing during warm PDO years[443]. The diversity of salmon and ability to survive in various environments helps them adapt so learning how to and working to protect that diversity would increase their chances of survival[444].

Notes and References

[441] Carter, 2007.
[442] Carter, 2007.
[443] Carter, 2007.
[444] Carter, 2007.

11. Public Health: Background

California is also home to some of the most polluted air in the nation. Californians are already facing increased rates of health problems associated with high levels of air pollution which include premature death, respiratory illnesses, and asthma.[445] Over 90 percent of people living in California currently breathe unhealthy air.[446] However, this threat, already acting upon the public, will become even more harmful to the public in the future as a result of climate change. Climate change will become a factor when calculating air pollution levels and for determining health related effects of pollution. Increasing temperatures facilitate the creation of ground-level ozone and smog which is already proven to be a threat to human health.[447] Increasing temperatures and more intense heat waves in California induced by the greenhouse effect also result in a different set of public health problems such as heat-related death and illness and an increased risk and rate of wildfires.[448] Other public health issues of concern are an increased prevalence of vector-borne diseases and water-borne pathogens; problems associated with increased rainfall and flooding in California.[449] Along with increased rates of public health problems due to climate change comes increased spending on health care and loss of valued life, which translates as an economic burden to Californians.

Climate Change and Air Pollution

Though often subtle and acclimated over time, Californians are already burdened with the effects of high levels of pollution in the air. Many types of air particles created through a variety of human activities are harmful to human health. Air quality standards are set by the Air Resources Board to limit the amount of air pollution released into the air, and thus, to limit the adverse health effects associated with exposure to air pollutants. In California, the California Ambient Air Quality Standards (CAAQS) define "the maximum amount of a pollutant that can be present in outdoor

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[445] "Recent Research Findings: Health Effects of Particulate Matter and Ozone Pollution." California Environmental Protection Agency, Air Resources Board. January 2004. <http://www.arb.ca.gov/research/health/fs/PM-03fs.pdf>

[446] Croes, Bart. "California's Air Pollution and Climate Change Policies." California Air Resources Board. Powerpoint. 2007. <http://www.healtheffects.org/Slides/AnnConf2007/Croes.pdf>

[447] Parry, Martin L., Canziani, Osvaldo F., Palutikof, Jean P., van der Linden, Paul J., and Hanson, Clair E.,eds. "Climate Change 2007: Impacts, Adaptation, and Vulnerability." Intergovernental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom. 2007.

[448] Wilkinson, Robert. "Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change." California Regional Assessment Group. September 2002.

[449] Wilkinson, 2002.

air without threatening the public's health."[450] These standards set limits on the concentrations of pollutants in the air. For the sake of analyzing air quality and public health we are mainly concerned with the pollutants PM2.5, PM10, and ozone. However, only ozone has a proven connection to climate change patterns and will be the air pollutant of concern in this analysis.[451] Ozone causes health problems ranging in severity from irritating coughs to chronic respiratory problems, increased susceptibility to other diseases, decreased lung function and development, and premature death.[452] Illnesses associated with ozone pollution also correlate with increased spending on health care and economic losses as a result of missed workdays and schooldays and general limitation of daily activities.[453]

Climate change contributes to increased levels of the air pollutant ozone through rising temperatures. A study conducted by the Intergovernmental Panel on Climate Change found that higher temperatures do result in greater concentrations of ozone in the air.[454] Higher temperatures and increased carbon dioxide emissions in the air facilitate the creation of ground-level ozone, or smog.[455] Smog is inhaled by California's population on a daily basis which is why ozone is so harmful to the health of those who live under ozone-polluted air. Ozone pollution and exposure over time is considered the culprit for increased rates of respiratory problems in the long and short run.

Ozone is a gaseous air pollutant that is formed in the atmosphere through reactions of chemicals which are emitted from automobiles, industrial plants, and consumer products.[456] Ozone, an oxidant, can damage the respiratory tract. It can cause inflammation and irritation which leads to respiratory symptoms such as coughing, chest pains, shortness of breath, and the aggravation of asthma symptoms.[457] Long-term exposure to high ozone levels can eventually damage the lung tissue, decrease lung capacity and function, and make a person more susceptible to long and short

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[450] "Ambient Air Quality Standards." California Environmental Protection Agency. Air Resources Board. 27 June 2008. < http://www.arb.ca.gov/research/aaqs/aaqs.htm>

[451] Parry et al., 2007.

[452] "Review of the California Ambient Air Quality Standard for Ozone." California Environmental Protection Agency. Air Resources Board. Powerpoint. 28 April 2005. <ftp://ftp.arb.ca.gov/carbis/board/books/2005/042805/05-4-1pres.pdf>

[453] Hall, Jane V., Victor Brajer, and Frederick W. Lurmann. "The Health and Related Economic Benefits of Attaining Healthful Air in the San Joaquin Valley." Cal State Fullerton. Institute for Economic and Environmental Studies. March 2006.

[454] Parry et al., 2007.

[455] "Climate Change – Health and Environmental Effects." U.S. Environmental Protection Agency. 24 June 2008. <http://www.epa.gov/climatechange/effects/health.html>

[456] "Ozone and Ambient Air Quality Standards." California Environmental Protection Agency. Air Resources Board. 11 June 2008. < http://www.arb.ca.gov/research/aaqs/caaqs/ozone/ozone.htm>

[457] "Ozone and Ambient Air Quality Standards." California Environmental Protection Agency. Air Resources Board. 11 June 2008. < http://www.arb.ca.gov/research/aaqs/caaqs/ozone/ozone.htm>

term respiratory illnesses.[458] The current CAAQS for ozone in an 8 hour period is 0.07ppm.[459]

According to data taken from various counties' air monitoring stations, since 2001, average 8 hour ozone concentrations have decreased about 7 percent. 2007 levels were also about 4 percent lower than 2006 levels. Ozone levels seem to be declining slowly throughout California on average over the past few years. However, data still shows that on average, 8 hour ozone levels are still higher than the CAAQS, 0.07ppm. In 2007, the average 8 hour ozone level throughout California at its highest was roughly 0.084ppm. This number is the upper bound for ozone levels in California in 2007, but still shows that many counties in California are still exceeding the standard for ozone at given times in the year.[460]

Though data shows that ozone levels have declined over the past few years, we cannot assume that ozone levels are steadily decreasing and will continue to in the future. Climate change becomes an issue when discussing ozone levels since higher temperatures induced by increased greenhouse gas levels facilitate ozone formation. Population increases are expected to factor into future levels of ozone pollution as well since population growth will entail more production and more vehicles on the road, meaning more ozone in the air.[461] Rising costs of health care in general are also expected to factor into higher total economic costs of public health.[462] It is expected that ozone levels will increase by 0.04-0.08ppm, or a 50-100 percent increase over 2006 levels, by the end of the century as temperatures are expected to increase 3.6-12.6 degrees Fahrenheit.[463] The Air Resources Board also estimates that an increase in temperature by 3.6 degrees Fahrenheit will result in a 0.03ppm increase in ozone concentration.[464] The California Climate Change Center also conducted a report on projected temperature increases in California by the end

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[458] "Recent Research Findings: Health Effects of Particulate Matter and Ozone Pollution." California Environmental Protection Agency, Air Resources Board. January 2004. <http://www.arb.ca.gov/research/health/fs/PM-03fs.pdf>

[459] "Ozone and Ambient Air Quality Standards." California Environmental Protection Agency. Air Resources Board. 11 June 2008. < http://www.arb.ca.gov/research/aaqs/caaqs/ozone/ozone.htm>

[460] "Air Quality Data Statistics." Air Resources Board. <http://www.arb.ca.gov/adam>

[461] Harley, Robert. "Guiding Future Air Quality Management in Central California: Sensitivity to Changing Climate." University of California Berkeley. Powerpoint. 20 February 2007. < http://es.epa.gov/ncer/events/calendar/2007/feb20_2/harley_presentation.pdf>

[462] Kuehl, Sheila. "Rising Costs and Universal Health Care in California." Senate Health Committee. 18 July 2008.

[463] Drechsler, D. M., N. Motallebi, M. Kleeman, D. Cayan, K. Hayhoe, L. Kalkstein, N. Miller, S. Sheridan, J. Jin. "Public Health-Related Impacts of Climate Change in California." California Climate Change Center. March 2006.

[464] Kleeman, Michael J., and Linda Smith. "Public Health-related Impacts of Climate Change for California. California Environmental Protection Agency. Air Resources Board. 13 December 2005.

of the century. They expect temperatures to increase by 3-10.5 degrees Fahrenheit.[465]

There are also California Ambient Air Quality Standards set for PM2.5, PM10, nitrogen dioxide, carbon monoxide, sulfates, hydrogen sulfide, and visibility reducing particles. PM2.5 is a prominent public health threat in both the long and short term, and PM10 poses short term health threats.[466] However these two pollutants have no demonstrated relation to fluctuations in temperature or environmental conditions caused by climate change. Other pollutants for which CAAQS are set mainly cause public annoyances such as limiting visibility and bad odors, rather than short or long term health problems and also are not affected by climate change.[467]

Since California does not attain the standards for ozone and since ozone's concentration trends do relate to climate change trends, we will focus on the health problems caused by this pollutant, the effect that climate change has and will have on ozone concentrations, and the adverse health effects attributed to increased temperatures and climate change in relation to air pollution. Ozone pollution is often grouped together with particulate matter pollution, which is also detrimental to human health. Many of the estimates of ozone impacts also contain the effects of particulate matter pollution as well and the impacts of the two can be difficult to differentiate.

The California Air Resources Board estimates that currently per year, ozone and particulate air pollution lead to 9,000 hospitalizations and 1,700,000 cases of respiratory illness including asthma and bronchitis.[468] High levels of air pollution can lead to up to 480,000 cases of lung cancer, 1,300,000 missed school days, and 2,800,000 missed workdays per year.[469] ARB also estimates that ozone pollution is the cause of 800 premature deaths per year.[470] The number of cases for each of these health effects and the costs associated will increase as a result of climate change if mitigation measures are not implemented and if ozone and temperature trends are as predicted.

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465 "Our Changing Climate: Assessing the Risks to California." California Climate Change Center. 2006. <http://www.energy.ca.gov/2006publications/CEC-500-2006-077/CEC-500-2006-077.PDF>

466 "Particulate Matter –Overview." California Environmental Protection Agency. Air Resources Board. 25 April 2005. <http://www.arb.ca.gov/research/aaqs/caaqs/pm/pm.htm>

467 "Ambient Air Quality Standards." California Environmental Protection Agency. Air Resources Board. 27 June 2008. <http://www.arb.ca.gov/research/aaqs/aaqs.htm>

468 "Recent Research Findings: Health Effects of Particulate Matter and Ozone Pollution." California Environmental Protection Agency, Air Resources Board. January 2004. <http://www.arb.ca.gov/research/health/fs/PM-03fs.pdf>

469 "Recent Research Findings: Health Effects of Particulate Matter and Ozone Pollution." California Environmental Protection Agency, Air Resources Board. January 2004. <http://www.arb.ca.gov/research/health/fs/PM-03fs.pdf>

470 Croes, 2007.

Health Effects of Ozone Pollution

Long term effects of high levels of ozone exposure may include decreased lung function, respiratory illness and premature death.[471] Short term effects include asthma attacks and increased risk of attacks, upper and lower respiratory problems, hospitalizations and emergency room visits for various illnesses, and bronchitis.[472] These health problems translate into economic costs. In this section we will discuss these health effects in greater detail.

Premature Death. Air pollution has shown to be a prominent cause of increased incidents of premature death in California. It was estimated in 2003 that annual health and economic costs associated with inadequate air quality, due to particulate matter and ozone pollution, ranged $36-$136 billion per year and caused 3,000 to 15,000 deaths annually.[473] ARB has more recently estimated premature deaths in California due to all air pollution up to 23,800 per year. Their lower bound estimate for premature deaths due to all air pollution is 14,800.[474] The South Coast Air Quality Management District (SCAQMD) concluded its 2007 Air Quality Management Plan that "A considerable number of population-based and laboratory studies have established a link between increased morbidity and in some instances, earlier mortality and air pollution," emphasizing that this correlation between air pollution and premature death has been proven.[475]

When only taking only ozone into account, ARB notes that current ozone levels are hazardous to health, and if current levels persist, 800 ozone-related premature deaths will ensue each year.[476] Particulate matter pollution accounts for 14,000-23,000 premature deaths per year, indicating that PM pollution is considerably more detrimental to human health. However, PM pollution is not demonstrably exacerbated by climate change as ozone is. Economic costs associated with 3,000-15,000 premature deaths due to air pollution totaled $36-$136 billion in 2003, accounting for deaths attributable to both particulate matter and ozone pollution.

The Environmental Protection Agency has commented on the criteria for assessing the costs of premature deaths. The EPA uses the "value of statistical life", or VSL, to ascertain the value of premature deaths prevented. *Science Daily* has summarized

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471 Balmes, John R. "Climate Change and Respiratory Health." University of California Berkeley. Powerpoint. 2003.
472 Hall et al., 2006.
473 Drechsler, D. M., N. Motallebi, M. Kleeman, D. Cayan, K. Hayhoe, L. Kalkstein, N. Miller, S. Sheridan, J. Jin. "Public Health-Related Impacts of Climate Change in California." California Climate Change Center. March 2006.
474 Croes, 2007.
475 South Coast Air Quality Management District. "2007 Air Quality Management Plan: Appendix I – Health Effects of Air Pollution." 2007.
476 Croes, 2007.

the EPA's description of a VSL as "the price [adults] would be willing to pay - - i.e., what benefits or conveniences someone would be willing to forgo - - in order to change their risk of death in a given period by a small amount", or "the value of extending life."[477] People of all ages have the same VSL. Ozone is likely to cause 1000-1800 premature deaths per year by 2100. The EPA's most current VSL as of 2006 is estimated at $6.8 million.[478] This number is not certain to be steady over time due to changes in the US economy, and is hard to predict for the future due to fluctuations in the economy and the public's reaction to these changes.

Respiratory Disease. Lower respiratory symptoms are classified as coughs, chest pains, and wheezing. Upper respiratory symptoms include runny nose and eye irritations.[479] Together, these symptoms limit a person's daily activities whether it is a child's absence from school or an adult's missed workday. These limitations translate to economic costs when school or work is missed.[480] There are also costs associated with respiratory symptoms for basic medications and other amenities to care for a sickness. If California were to attain the particulate matter and ozone standards, this would annually prevent 600,000 cases of lower respiratory symptoms, and 600,000 cases of upper respiratory symptoms. This would also prevent 800,000 cases of respiratory illnesses like colds and flus per year.[481] Currently, air pollution is the cause of 2,000,000 cases of respiratory illness per year, which include upper and lower respiratory problems. These "respiratory illnesses", upper and lower, do not include long term, chronic illnesses. These illnesses can generally be treated with over-the-counter or prescription medication. An afflicted person can also buy amenities to alleviate respiratory irritations. In addition to these costs, economic costs are incurred even further and to a greater extent when these respiratory illnesses limit a person's daily activity, often for multiple days, preventing him or her from performing daily activities.

Limitation of Daily Activities. Those affected by high levels of air pollution are not only burdened with monetary costs of treatments and hospital visits, but also incur economic losses when daily activity is limited. This includes missed school days for children and missed workdays for adults. According to a report by the Air Resources Board, air pollution related illness accounted for 1,300,000 school absences per year

[477] The National Academies. "Link Between Ozone Air Pollution And Premature Death Confirmed." *ScienceDaily* 23 April 2008. <http://www.sciencedaily.com /releases/2008/04/080422135728.htm>.
[478] Deck, Leland and Lauraine Chestnut. "Recommended Health Benefit Assessments Methods for 2007 AQMP." Stratus Consulting. South Coast Air Quality Management District. 13 December 2006.
[479] Hall et al., 2006.
[480] Hall et al., 2006
[481] "Recent Research Findings: Health Effects of Particulate Matter and Ozone Pollution." California Environmental Protection Agency, Air Resources Board. January 2004. <http://www.arb.ca.gov/research/health/fs/PM-03fs.pdf>

and 2,800,000 missed workdays per year.[482] It has also been estimated that for every 0.05ppm increase in ozone level, school absences increase by 13.01 percent.[483] Each missed work day ranges in value from about $150-$250 (money a person would be paid for being at work) and each school day missed accounts for a loss of $70-$90 which includes possible caretaking and the value of time to care for a child who is sick.[484]

Hospitalizations and Emergency Room Visits*.* As illnesses are more prominent with high air pollution levels, so is the number of hospitalizations for those who become ill. The estimated value per hospitalization is currently $32,000.[485] The current estimate for the number of hospitalizations each year for various illnesses associated with high levels of air pollution is 9,000.[486] Assuming that the cost of a hospitalization as a result of air pollution is on the same scale as the cost of a hospitalization for a general illness, this totals $300 million per year that Californians must pay currently for hospitalizations that are the result of particulate matter and ozone levels higher than California's standards.

Emergency room visits have also been attributed to air pollution. According to the Air Resources Board if CAAQS are not attained, 4,000 emergency room visits will occur per year, which are mostly for asthma attacks.[487] Each emergency room visit is estimated to cost a patient up to $400 which means that the total cost of emergency room visits per year will total $1,600,000.[488] Emergency room visits are not considered long term hospital stays which is why hospitalizations and emergency room visits are considered separate costs. Hospitalizations include the cost of time that caretakers must give up to care for a sick person as well.[489]

Asthma*.* Asthma is another effect of exposure to high levels of ozone pollution. Increased exposure to ozone increases the risk of asthma attacks and also increases the rate of asthma attacks.[490] This means there will be an increase in

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[482] "Recent Research Findings: Health Effects of Particulate Matter and Ozone Pollution." California Environmental Protection Agency, Air Resources Board. January 2004. <http://www.arb.ca.gov/research/health/fs/PM-03fs.pdf>

[483] Hall et al., 2006.

[484] Hall et al., 2006.

[485] Hall et al., 2006.

[486] "Recent Research Findings: Health Effects of Particulate Matter and Ozone Pollution." California Environmental Protection Agency, Air Resources Board. January 2004. <http://www.arb.ca.gov/research/health/fs/PM-03fs.pdf>

[487] "Recent Research Findings: Health Effects of Particulate Matter and Ozone Pollution." California Environmental Protection Agency, Air Resources Board. January 2004. <http://www.arb.ca.gov/research/health/fs/PM-03fs.pdf>

[488] Hall et al., 2006.

[489] Hall et al., 2006.

[490] Balmes, John R. "Climate Change and Respiratory Health." University of California Berkeley. Powerpoint. 2003.

emergency room admissions and hospitalizations for asthma attacks when ozone levels increase due to climate change. Asthma is also a very costly illness to treat. California's attainment of particulate matter and ozone standards would prevent 2,000 asthma- related emergency room visits. 350,000 asthma attacks would also be prevented each year.[491] On average, asthma attacks account for 38,000 hospitalizations and about 400 deaths per year.[492] Economic costs are also associated with these impacts. $1.3 billion was estimated as the total for asthma related expenditures including hospitalizations, medication, and missed days from work in California due to the effects of high PM and ozone levels. This total comes out to be roughly $5000 per asthma patient annually.[493]

Climate Change and Extreme Temperatures

Increased average temperatures can lead to increased incidents of heat stress, heat stroke, hospitalizations, and heat-related deaths.[494] Heat waves are expected to be much more intense and last longer, especially in the month of July when the heat-related death rate is the highest.[495] Public health issues induced by climate change also result in economic losses to the public in the form of health care spending and loss of productivity and life.

In Los Angeles, it is predicted that by 2020 the number of days exceeding 90 degrees Fahrenheit will double, and by 2080 that number will be five times what it is today. Consequently, heat-related mortality is expected to increase by 62-88 percent for the general population by 2080 in California.[496] The California Climate Change Center estimates that deaths associated with extreme temperatures will increase 2-3 times the number of incidents in 2006 by 2050.[497] The Environmental Protection Agency estimates that in a city like Los Angeles with dry, hot summers, an increase in average temperature by 3 degrees Fahrenheit can double the rate of heat-related

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[491] "Recent Research Findings: Health Effects of Particulate Matter and Ozone Pollution." California Environmental Protection Agency, Air Resources Board. January 2004. <http://www.arb.ca.gov/research/health/fs/PM03fs.pdf>

[492] Milet, M., S. Tran, M. Eatherton, J. Flatterly, R. Kreutzer, L. Wohl-Sanchez. "The Burden of Asthma in California: A Surveillance Report." California Department of Health Services. June 2007.

[493] "Recent Research Findings: Health Effects of Particulate Matter and Ozone Pollution." California Environmental Protection Agency, Air Resources Board. January 2004. <http://www.arb.ca.gov/research/health/fs/PM-03fs.pdf>

[494] Fielding, Jonathan E. "Beating the Heat: Public Health and Climate Change." Southern California Public Health Association. Annnual Conference Powerpoint. 18 April 2008.

[495] "Our Changing Climate: Assessing the Risks to California." California Climate Change Center. 2006. <http://www.energy.ca.gov/2006publications/CEC-500-2006-077/CEC-500-2006-077.PDF>

[496] Fielding, Jonathan E. "Beating the Heat: Public Health and Climate Change." Southern California Public Health Association. Annnual Conference Powerpoint. 18 April 2008.

[497] "Our Changing Climate: Assessing the Risks to California." California Climate Change Center. 2006. <http://www.energy.ca.gov/2006publications/CEC-500-2006-077/CEC-500-2006-077.PDF>

deaths.[498] The California Office for Environmental Health Hazard has estimated that for every 10 degree Fahrenheit increase in temperature, deaths increased by 3 percent on any given day.[499] Since average temperatures are expected to increase by 3-12.6 degrees Fahrenheit by the end of the century, this means the number of heat-related deaths will increase significantly by that time. Elderly people over 65 years old, people with existing heart disease, and infants younger than 1 year old were groups found to be most susceptible to heat-related death according to previous “temperature and mortality” studies conducted in counties throughout California.[500]

Increased greenhouse gas emissions and increasing temperatures due to global warming contribute to total premature death cases in California. Heat-related deaths over the past years have been increasing in California.[501] In 2006 the number of heat-related deaths totaled 140.[502] According to the California Climate Change Center, with climate change trends as expected, total heat-related deaths will total 280-420 in 2050, or 2-3 times the 2006 level.[503] By the end of the century the number of heat-related deaths should total 300-600 each year. Concurrently, temperature-related deaths rates are expected to increase each year along with economic costs.

When average temperatures and air pollution levels are both increasing and also affecting one another, mitigation measures must take all these effects into consideration to effectively improve air quality and environmental conditions.[504] Air conditioning is a good way to protect against heat waves and is able to alter one’s environment to prevent heat-induced health problems. However, air conditioning also comes at a cost to the public.

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[498] Wilkinson, 2002.

[499] Basu, Rupe, and Bart D. Ostro. “Epidemiological Study of Temperature and Mortality in California: Implications for Climate Change.” Air Pollution Epidemiology Section/OEHHA California Environmental Protection Agency. Powerpoint. 15 September 2006.

[500] Basu, Rupa, and Paul English. “Public Health Impacts from Climate Change.” California Energy Commission. 21 August 2008.

[501] Fielding, Jonathan E. “Beating the Heat: Public Health and Climate Change.” Southern California Public Health Association. Annnual Conference Powerpoint. 18 April 2008.

[502] Becerra, Hector, Tami Abdollah, and Carla Hall. “For heat’s victims, a quiet death.” *Los Angeles Times*. A-1. 6 September 2007.

[503] “Our Changing Climate: Assessing the Risks to California.” California Climate Change Center. 2006. <http://www.energy.ca.gov/2006publications/CEC-500-2006-077/CEC-500-2006-077.PDF>

[504] Drechsler, D. M., N. Motallebi, M. Kleeman, D. Cayan, K. Hayhoe, L. Kalkstein, N. Miller, S. Sheridan, J. Jin. “Public Health-Related Impacts of Climate Change in California.” California Climate Change Center. March 2006.

Climate Change and Increased Wildfire Rates

Increased temperatures also increase the risk of wildfires occurring which puts human lives at risk and also exposes the public to extremely polluted air. Wildfires pose a threat to public health, causing both immediate physical harm and respiratory problems when extremely polluted air is inhaled.[505] One effect of climate change is changing rainfall patterns. This may mean periods of heavy rain or periods of very little rain. These dry periods leave land susceptible to wildfires.[506] Since many parts of California, especially Southern California, historically have had high rates of wildfires, higher temperatures in the summer predicted for California only increases the risk of wildfires occurring. Dry vegetation in the summer puts the public at risk for being in the path of a wildfire.[507] California also has an arid climate and low levels of moisture in soil which increases the risk of wildfire even more when temperatures rise.[508] More intense storms due to "El Nino" weather also increase the rate of lightning strike incidents which are sometimes catalysts for fires. A study conducted by Anthony L. Westerling modeling fire response to climate change in the Sierra Nevada has shown that there is an increased rate of fires concurrent with increases in temperature and decreases in soil moisture in the summer months.[509]

Wildfires pose a threat to public health as immediate physical threats. However, wildfires also result in extremely polluted air which can lead to another set of health problems. Wildfires have shown to contribute to "bad air days" in California, days with high levels of air pollutant concentrations in the air.[510] People with existing diseases such as heart disease, asthma, and lung disease are especially affected by wildfire smoke and soot that is inhaled daily when a wildfire is taking place in the region.[511] Children, whose lungs are not fully developed, are also adversely affected by the inhalation of fire smoke which inhibits lung development.[512]

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[505] Lipsett, Michael, and Barbara Materna. "Wildfire Smoke – A Guide for Public Health Officials." U.S. Environmental Protection Agency. July 2008.
[506] Fielding, Jonathan E. "Beating the Heat: Public Health and Climate Change." Southern California Public Health Association. Annnual Conference Powerpoint. 18 April 2008.
[507] Fielding, Jonathan E. "Beating the Heat: Public Health and Climate Change." Southern California Public Health Association. Annnual Conference Powerpoint. 18 April 2008.
[508] Wilkinson, 2002.
[509] Wilkinson, 2002.
[510] Wu, J., A. Winer, and R. Delfino. "Exposure Assessment of Particulate Matter Air Pollution Before, During, and After the 2003 Southern California Wildfires." *Atmospheric Environment*. January 2006.
[511] "Health Threat from Wildfire Smoke." Depatrtment of Health and Human Services. Centers for Disease Control and Prevention. 19 April 2007. < http://www.bt.cdc.gov/disasters/wildfires/facts.asp>
[512] "Health Threat from Wildfire Smoke." Depatrtment of Health and Human Services. Centers for Disease Control and Prevention. 19 April 2007. < http://www.bt.cdc.gov/disasters/wildfires/facts.asp>

According to the Union of Concerned Scientists, if average summer temperatures increase by 5.5-8 degrees Fahrenheit by the 2050, the risk of wildfires increases by 20 percent by that time. They also predict that wildfires will increase in incidence by 50 percent by the end of the century. In very dry areas this risk could increase by up to 90 percent by 2100.[513] According to a study conducted by scientists at the University of Washington in five regions in the Western United States, it was found that wildfires accounted for a 1.11ug/m³ increase in PM2.5 levels over the summer, when the rate of wildfires is the highest, indicating that the presence of wildfires definitely contributes to PM2.5 air pollution.[514] PM2.5 is an air pollutant that is proven to be harmful to human health when inhaled, which is why climate change and in increased risk of wildfires will likely result in increased economic costs for public health.[515]

Particulate matter causes numerous adverse health effects in both the short run and long run if people are continually exposed to concentrations of PM that exceed air quality standards. For PM2.5, the current CAAQS is 35ug/m³ for a 24 hour exposure time.[516] ARB discerned that the risk of death (from all causes) increases by 10 percent for every 10ug/m³ increase in PM2.5 in an annual period.[517] Studies conducted at the University of Washington by Kristin A. Miller and Joel D. Kaufman, also found that for each 10ug/m³ increase in PM2.5 concentrations, the risk of a cardiovascular event increased by 24 percent in women.[518] The risk of cardiovascular death for older women also increases by 76 percent for the same 10ug/m³ PM2.5 increment.[519] According to the American Cancer Society's Prevention II study which tracked the health of over 1.2 million people from 1982 to

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[513] Westerling, A., and B. Bryant. "*Change and wildfires around California: Fire modeling and loss modeling."* Sacramento, CA: California Climate Change Center. 2006. <www.energy.ca.gov/2005publications/CEC-500-2005-190/CEC-500-2005-190-SF.PDF>

[514] Jaffe, Dan, Hafner, William, Chand, Duli, Westerling, Anthony, and Dominick Spracklan. "Interannual Variations in PM2.5 due to Wildfires in the Western United States." *Enrivonmental Science and Technology*. Vol 42, No 8. 28 January 2008. 2812-2818.

[515] "Recent Research Findings: Health Effects of Particulate Matter and Ozone Pollution." California Environmental Protection Agency, Air Resources Board. January 2004. <http://www.arb.ca.gov/research/health/fs/PM-03fs.pdf>

[516] "Particulate Matter –Overview." California Environmental Protection Agency. Air Resources Board. 25 April 2005. < http://www.arb.ca.gov/research/aaqs/caaqs/pm/pm.htm>

[517] Croes, Bart. "California's Air Pollution and Climate Change Policies." California Air Resources Board. Powerpoint. 2007. <http://www.healtheffects.org/Slides/AnnConf2007/Croes.pdf>

[518] Miller, Kristin A., David S. Siscovick, Lianne Sheppard, Kristen Shepherd, Jeffrey H. Sullivan, Garnet L. Anderson, and Joel D. Kaufman. "Long-Term Exposure to Air Pollution and Incidence of Cardiovascular Events in Women." *NEJM* . Volume 356:447-458, Number 5, 1 February 2007

[519] "Revised Proposed 2008 PM2.5 Plan." San Joaquin Air Pollution Control District. Powerpoint. 30 April 2008. <http://www.valleyair.org/Air_quality_Plans/docs/AQ_Final_adopted_PM2.5/PM25_presentation.pdf>

1998, an increased risk of lung cancer and increased risk of dying from existing lung cancer did, in fact, correlate with increased exposure to air pollution. This study concluded that "the risk of lung cancer death went up by 8 percent for every 10 micrograms of fine particles per cubic meter of air." Total deaths from all causes combined increased by 4 percent for every 10ug/m³ PM2.5 increment.[520]

Climate Change and Increased Risk of Vector-Borne Illness

Another concern for public health taking into account climate change is the concern for increased cases of vector-borne illnesses. Unpredictable rainfall patterns are expected, varying from long, intense rainy seasons to very dry seasons. Some areas may experience abnormally high rainfall patterns and more intense storms or "El Nino" type weather.[521] These incidents result greater areas of stagnant water, breeding grounds for insects that carry vector-borne illnesses. Rising sea levels may also result in flooding, which would create a greater area of still water.[522] This puts public health at risk of contracting vector-borne diseases when more blood-feeding insects are present that may carry diseases. Breeding areas for these insects may also shift to unfavorable locations when climate changes.[523] However, according to Robert Wilkinson, Coordinator of the California Regional Climate Impacts Assessment in 2002, this concern is not expected to be an economic burden to Californians.[524] There are relatively inexpensive means of treating vector-borne illnesses and ways to significantly lower the risk of contracting these diseases. Wilkinson states in his report, "While there is some indication that changing climactic conditions may increase the risk of vector- and water-borne diseases, sanitation and public health system infrastructures in the United States should prevent these diseases from becoming widespread."[525]

Climate Change and Water Contamination

Another concern for public health in the face of climate change is water contamination. With higher rainfall expected in wet seasons, California may see increased levels of flooding which threatens California's water supply. This may also

[520] "Air Pollution Linked to Deaths from Lung Cancer." American Cancer Society. 6 March 2002. <http://www.cancer.org/docroot/NWS/content/NWS_1_1x_Air_Pollution_Linked_to_Deaths_From_Lun_Cancer.asp>
[521] Wilkinson, 2002.
[522] Fielding, Jonathan E. "Beating the Heat: Public Health and Climate Change." Southern California Public Health Association. Annnual Conference Powerpoint. 18 April 2008.
[523] Fielding, Jonathan E. "Beating the Heat: Public Health and Climate Change." Southern California Public Health Association. Annnual Conference Powerpoint. 18 April 2008.
[524] Wilkinson, 2002.
[525] Wilkinson, 2002.

affect food production if water is contaminated with bacteria or pathogens. When contaminated water is ingested or contaminated food is eaten, many Californians will become sick.[526] Water-borne infections, like vector-borne illnesses are not seen as a big economic concern for the future in California because we have the infrastructure and sanitation systems to deal with water contamination problems.[527]

Adaptation Strategies

Currently, mitigation measures are being devised, some already imposed, in order to monitor and regulate air pollutants. One such measure is AB 32 along with Executive Order S-01-07 which was put into effect in September 2006. For air basins that exceed air pollution levels set by the CAAQS, State Implementation Plans are required, outlining means to attain standards and by how much.[528] Since many areas in California currently exceed standards, there are numerous efforts to decrease PM2.5, PM10, ozone, and greenhouse gas levels to comply with CAAQS for these pollutants. These methods include changes to physical production processes, proposals to replace transit vehicles with more vehicles that create less particulate pollution, and to conduct more stringent and more frequent air quality tests.[529] Emission inventories are taken throughout California and places like the San Joaquin Valley look to improve these emission inventories with new technology, more monitoring sites, and more detailed databases.[530]

AB 32 in accordance with Executive Order S-01-07, signed in September 2006 is a mitigation measures proposed by Governor Arnold Schwarzenegger ultimately aim to improve air quality significantly by 2020. The goal of AB 32 is to reach 1990 GHG levels by 2020. Executive Order S-01-07 calls for a reduction to 2000 GHG emission levels by 2010, which is about 11 percent below levels that would occur without regulation, and a reduction to 1990 levels by 2020 which is about 25 percent below levels that would occur without regulation.[531] AB 32 also calls for greenhouse gas monitoring and for the reporting of emission levels to ensure compliance. If greenhouse gas emissions are limited, it is assumed that climate change will be less severe and future temperatures lower than would be if regulation is not

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[526] Wilkinson, 2002.
[527] Wilkinson, 2002.
[528] "California State Implementation Plan (SIP)." California Environmental Protection Agency. Air Resources Board. 30 June 2008. < http://www.arb.ca.gov/planning/sip/sip.htm>
[529] "Proposed State Strategy for California's State Implementation Plan (SIP)." California Environmental Protection Agency. Air Resources Board. 6 February 2008. < http://www.arb.ca.gov/planning/sip/2007sip/2007sip.htm>
[530] "Revised Proposed 2008 PM2.5 Plan." San Joaquin Air Pollution Control District. Powerpoint. 30 April 2008. <http://www.valleyair.org/Air_quality_Plans/docs/AQ_Final_adopted_PM2.5/PM25_presentation.pdf>
[531] "Assembly Bill No. 32." September 2006.

implemented. In order to attain 1990 greenhouse gas emission levels by 2020 as stated in AB 32, the California Air Resources Board has discerned that emissions must be reduced by 173 million metric tons.[532]

There is much debate as to whether the implementation of AB 32 will, in fact, improve air quality and public health through the reduction of greenhouse gas levels in the air. One argument, made by members of the Natural Resource Defense Council, conveys that the implementation of this measure will result in large economic benefits for Californians in the public health perspective. They argue that if measures are carried out correctly, AB 32 could prevent 700 premature deaths related to all types of air pollution and save Californians a total of $3.2-$5.0 billion a year by 2020.[533] However this is just a small percentage of all premature deaths due to air pollution which is estimated up be up to 24,000 deaths per year, and just a small percentage of total costs associated with health effects. Also, with increasing temperatures and climate change factoring into the situation, AB 32 must account for increasing health effects that are expected as a result of climate change in order to accurately target these public health costs.

Physical adaptations are also being made by Californians to improve health and well-being while breathing overly-polluted air. In order to adapt to climate change and cope with increasing temperatures and more intense heat waves in the summer, Californians are turning to air conditioning. Air conditioning has proved to lower the number of heat-related deaths, and is seen as the most effects means to prevent heat-related illnesses.[534] However, air conditioning also comes at an economic cost to consumers. According to a representative for Southern California Edison, air conditioning costs about $230 each month during a heat wave if on for about 18 hours a day.[535] This cost can become collectively steep in California. There are also studies that have expressed concern that increased air conditioning will lead to increased CO2 emissions, which would counter the positive effects of installing air conditioning systems to decrease the numbers of premature death.[536] However, these measures may be necessary steps to accommodate climate change that California will undoubtedly face in the years to come.

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[532] Towill, Polly, and Oliver Theard. "The Global Warming Solutions Act (AB 32): Raising the Temperature of California Business." California Environmental Insider. 15 March 2008.

[533] Bailey, Diane, Kim Knowlton, and Miriam Rotkin-Ellman. "Boosting the Benefits: Improving Air Quality and Health by Reducing Global Warming Pollution in California." National Resources Defense Council. June 2008. <http://www.nrdc.org/globalWarming/boosting/boosting.pdf>

[534] "Talking About Disaster: Guide for Standard Messages." National Disaster Education Coalition, Washington, D.C., 1999

[535] Becerra, Hector, Tami Abdollah, and Carla Hall. "For heat's victims, a quiet death." *Los Angeles Times*. A-1. 6 September 2007.

[536] "Fact Sheet: Climate Change Emission Control Regulations." California Environmental Protection Agency. Air Resources Board. 4 October 2004.