

Appendix A: The Greenhouse Effect, Greenhouse Gases, and Climate Change Impacts

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GLOBAL CLIMATE CHANGE

Parts of the Earth's atmosphere act as an insulating blanket of just the right thickness, trapping sufficient solar energy to keep the global average temperature in a suitable range. The 'blanket' is a collection of atmospheric gases called 'greenhouse gases' (GHGs) based on the idea that the gases also 'trap' heat like the glass walls of a greenhouse. These gases, mainly water vapor, carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), ozone, and chlorofluorocarbons (CFCs) all act as effective global insulators, reflecting back to earth visible light and infrared radiation. Human activities such as producing electricity and driving vehicles have contributed to the elevated concentration of these gases in the atmosphere. This in turn, is causing the Earth's temperature to rise. A warmer Earth may lead to changes in rainfall patterns, much smaller polar ice caps, a rise in sea level, and a wide range of impacts on plants, wildlife, and humans.

Leading scientists around the world agree that Global Warming Potential is a reality and that human activities are disrupting the earth's climate by intensifying the greenhouse effect.

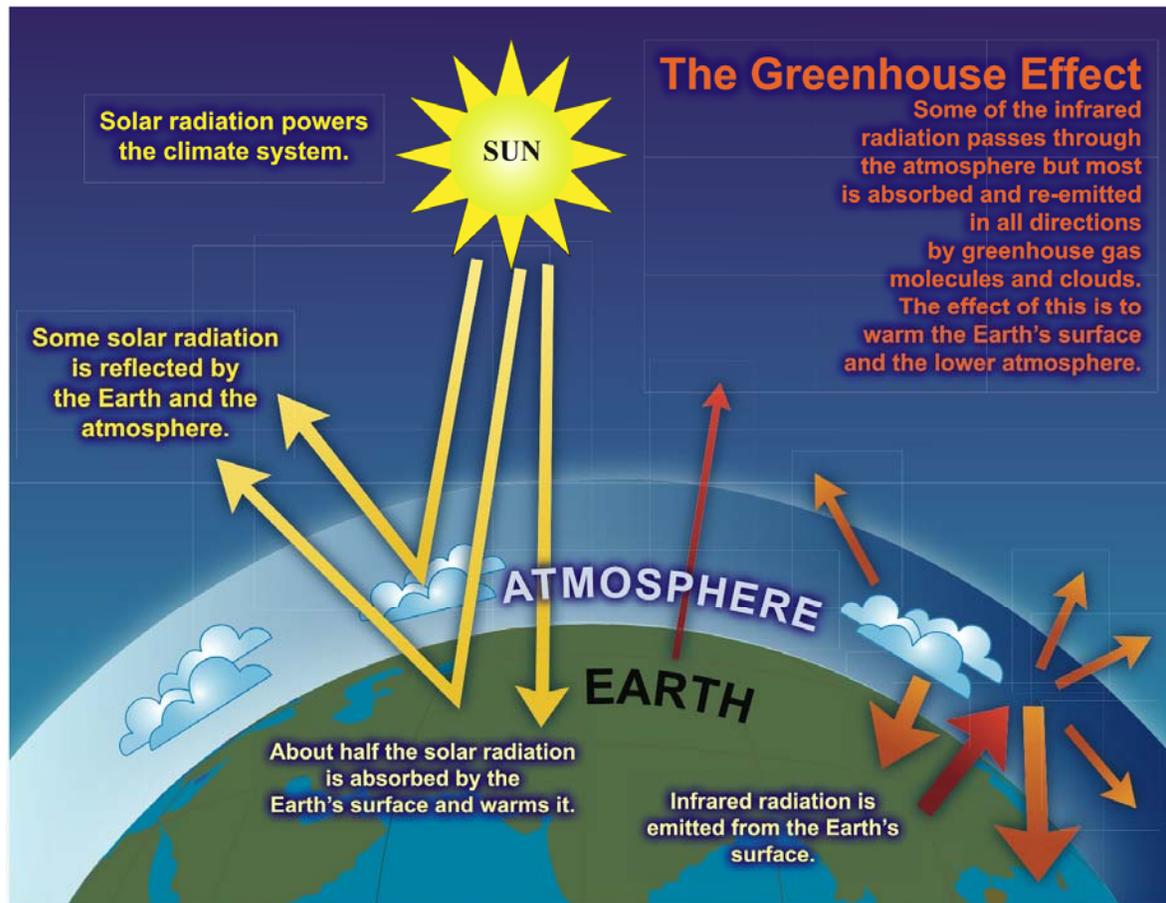
1. THE GREENHOUSE EFFECT

A balance of naturally occurring gases dispersed in the atmosphere determines the Earth's climate by trapping solar heat. This phenomenon is known as the greenhouse effect. As sunlight passes through our atmosphere, the incoming solar radiation is radiated from the earth's surface as heat energy. Greenhouse gases like carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, and water vapor trap some of this reradiated energy. This trapped heat warms the earth, much as the glass of a greenhouse traps reradiated energy from sunlight and thereby warms the interior of the structure. Figure 1-1 illustrates the Greenhouse Gas Effect.

2. GLOBAL WARMING

The natural "greenhouse effect" allows the earth to remain warm and sustain life. Greenhouse gases trap the sun's heat in the atmosphere, like a blanket, and help determine the existing climate. The increased consumption of fossil fuels (wood, coal, gasoline, etc.) has substantially increased atmospheric levels of greenhouse gases. As atmospheric concentrations of greenhouse gases rise, so do temperatures. Over time this rise in temperatures would result in climate change. Theories concerning climate change and global warming existed as early as the late 1800s. By the late 1900s the understanding of the earth's atmosphere had advanced to the point where many climate scientists began to accept that the earth's climate is changing. Today, many climate scientists agree that some warming has occurred over the past century and will continue through this century.

Figure A.1 - The Greenhouse Gas Effect



Source: IPCC, 2008

The United Nations Intergovernmental Panel on Climate Change predicts that changes in the earth's climate will continue through the 21st century and that the rate of change may increase significantly in the future because of human activity. Many researchers studying California's climate believe that changes in the earth's climate have already affected California and will continue to do so in the future.

3. GREENHOUSE GASES

Parts of the Earth's atmosphere act as an insulating blanket of just the right thickness, trapping sufficient solar energy to keep the global average temperature in a suitable range. The 'blanket' is a collection of atmospheric gases called 'greenhouse gases' (GHGs) based on the idea that the gases also 'trap' heat like the glass walls of a greenhouse. These gases, mainly water vapor, carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), chlorofluorocarbons (CFCs), hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, ozone, and aerosols all act as effective global insulators, reflecting back to earth visible light and infrared radiation.

The accumulation of GHGs in the atmosphere regulates the earth's temperature. Without the natural heat trapping effect of GHGs, the earth's surface would be about 34 degrees Centigrade (°C) cooler (CAT 2006). However, it is believed that emissions from human activities have elevated the concentration of these gases in the atmosphere beyond the level of naturally occurring concentrations. This in turn is causing the Earth's temperature to rise. A warmer Earth may lead to changes in rainfall patterns, much smaller polar ice caps, a rise in sea level, and a wide range of impacts on plants, wildlife, and humans.

Individual GHGs have varying global warming potential (GWP) and atmospheric lifetimes. The reference gas for GWP is carbon dioxide; carbon dioxide has a GWP of one. Compared to methane's GWP of 21 it is clear that methane has a greater global warming effect than carbon dioxide on a molecule per molecule basis (EPA 2006b). As shown below in Table 1.1 GWP ranges from 1 (carbon dioxide) to 23,900 (sulfur hexafluoride).

Atmospheric lifetimes vary from 1.5 (HFC-152a) to 50,000 years (tetrafluoromethane). One teragram (equal to one million metric tons) of carbon dioxide equivalent (Tg CO₂ Eq.) is the mass emissions of an individual GHG multiplied by its GWP. The atmospheric lifetime and GWP of selected greenhouse gases are also summarized in Table 1.1.

Table A.1 Global Warming Potentials and Atmospheric Lifetimes

Gas	Atmospheric Lifetime (years)	Global Warming Potential (100 year time horizon)
Carbon Dioxide	50 - 200	1
Methane	12 ± 3	21
Nitrous Oxide	120	310
HFC-23 264		11,700
HFC-134a 14.6		1,300
HFC-152a 1.5		140
PFC: Tetrafluoromethane (CF ₄)	50,000	6,500
PFC: Hexafluoroethane (C ₂ F ₆)	10,000	9,200
Sulfur Hexafluoride (SF ₆)	3,200	23,900

Source: U.S. Environmental Protection Agency, 2006.

Of all greenhouse gases in the atmosphere, water vapor is the most abundant, important, and variable. It is not considered a pollutant; in the atmosphere it maintains a climate necessary for life. The main source of water vapor is evaporation from the oceans (approximately 85 percent). Other sources include evaporation from other water bodies, sublimation (change from solid to gas) from ice and snow, and transpiration from plant leaves.

Ozone is also a greenhouse gas; however, unlike other GHGs, ozone in the troposphere is relatively short-lived and therefore is not global in nature. It is difficult to make an accurate determination of the contribution of ozone precursors (nitrogen oxides and volatile organic compounds) to global climate change (GCC) (CARB 2004b).

Aerosols are suspensions of particulate matter in a gas emitted into the air through burning biomass (plant material) and fossil fuels. Aerosols can warm the atmosphere by absorbing and emitting heat and can cool the atmosphere by reflecting light. Cloud formation can also be affected by aerosols. Sulfate aerosols are emitted when fuel containing sulfur is burned. Black carbon (or soot) is emitted during biomass burning and incomplete combustion of fossil fuels. Particulate matter regulation has been lowering aerosol concentrations in the United States; however, global concentrations are likely increasing.

Carbon Dioxide

The natural production and absorption of carbon dioxide (CO₂) is achieved through the terrestrial biosphere and the ocean. However, humankind has contributed to the alteration of the natural carbon cycle by burning coal, oil, natural gas, and wood. Since the industrial revolution began in the mid 1700s, each of these human-caused activities has increased in scale and distribution. Carbon dioxide was the first GHG demonstrated to be increasing in atmospheric concentration with the first conclusive measurements being made in the last half of the 20th century. Prior to the industrial revolution, concentrations were fairly stable at 280 ppm. Today, they are around 370 ppm, an increase of well over 30 percent (EPA 2006). Left unchecked, the concentration of carbon dioxide in the atmosphere is projected to increase to a minimum of 540 ppm by 2100 as a direct result of anthropogenic sources (IPCC 2001). This will result in an average global temperature rise of at least two degrees Celsius (3.6 °F) (IPCC 2001).

Carbon dioxide emissions are directly generated primarily in the form of vehicle exhaust and in the consumption of natural gas for heating. Carbon dioxide emissions are also generated from natural gas combustion and indirectly through the use of electricity. Other indirect sources of carbon dioxide include the use of potable water and generation of wastewater (potable water and wastewater treatment generates greenhouse gases), and the generation of solid waste.

Methane

Methane (CH₄) is an extremely effective absorber of radiation, though its atmospheric concentration is less than carbon dioxide and its lifetime in the atmosphere is brief (10-12 years), compared to some other GHGs (such as carbon dioxide, nitrous oxide, and CFCs). Methane has both natural and anthropogenic (human) sources. It is released as part of the biological processes in low oxygen environments, such as in swamplands or in rice production (at the roots of the plants). Over the last 50 years, human activities such as growing rice, raising cattle, using

natural gas and mining coal have added to the atmospheric concentration of methane (EPA 2006b).

Nitrous Oxide

Concentrations of nitrous oxide (N_2O) also began to rise at the beginning of the industrial revolution. Microbial processes in soil and water, including those reactions that occur in fertilizer containing nitrogen, produce nitrous oxide. The use of fertilizers has increased over the last century. Global concentration for nitrous oxide in 1998 was 314 ppb, and in addition to agricultural sources for the gas, some industrial processes (fossil fuel-fired power plants, nylon production, nitric acid production, and vehicle emissions) also contribute to its atmospheric load (EPA 2006b).

Chlorofluorocarbons

Chlorofluorocarbons (CFCs) have no natural source, but were synthesized for use as refrigerants, aerosol propellants and cleaning solvents. Since their creation in 1928, concentrations of CFCs in the atmosphere have been rising. Due to the discovery that they are able to destroy stratospheric ozone, a global effort to halt their production was undertaken and was extremely successful, so much so that levels of the major CFCs in the atmosphere are now remaining static or declining. However, their long atmospheric lifetimes mean that some of the CFCs will remain in the atmosphere for over 100 years. Since they are also a GHG, along with such other long-lived synthesized gases as CF_4 (carbontetrafluoride) and SF_6 (sulfurhexafluoride), they are of concern. Another set of synthesized compounds called HFCs (hydrofluorocarbons) are also considered GHGs, though they are less stable in the atmosphere and therefore have a shorter lifetime and less of an impact (EPA 2006b). CFCs, CF_4 , SF_6 and HFCs have been banned and are no longer available on the market.

4. HUMAN AND CULTURAL CAUSES OF CLIMATE CHANGE

Like all other animals, humans participate in the natural carbon cycle, but there are important differences between human and animal activities. By burning coal, oil, and natural gas, humans are adding carbon dioxide (CO_2) to the atmosphere much faster than the carbon in rocks is released through natural processes. Clearing and burning forests to create agricultural land converts organic carbon to carbon dioxide gas. The oceans and land plants are absorbing a portion, but not nearly all of the CO_2 added to the atmosphere by human activities. Human climate drivers include heat-trapping emissions from cars and power plants, aerosols from pollution, and soot particles.

5. IMPACTS FROM GREENHOUSE GAS EMISSIONS

Global Impacts

While in some cases global climate change may temporarily improve certain aspects of a region, such as lengthening the growing season, it is estimated that the ecology of the natural world will not be able to adjust quickly enough to prevent widespread environmental degradation (IPCC, 2001). In California, it is likely that warmer temperatures will result in frequent and longer periods of drought (UCS 1999). The majority of the scientific community has stated that beyond doubt, global climate change will be one of the most significant challenges the globe will face in the twenty-first century, and will impact almost every system we depend upon for survival.

Just as humans are affected by climate change, so too are plants and animals. Animals must breathe the same air and are subject to the same types of negative health effects as humans. Certain plants and trees may absorb air pollutants that can stunt their development or cause premature death.

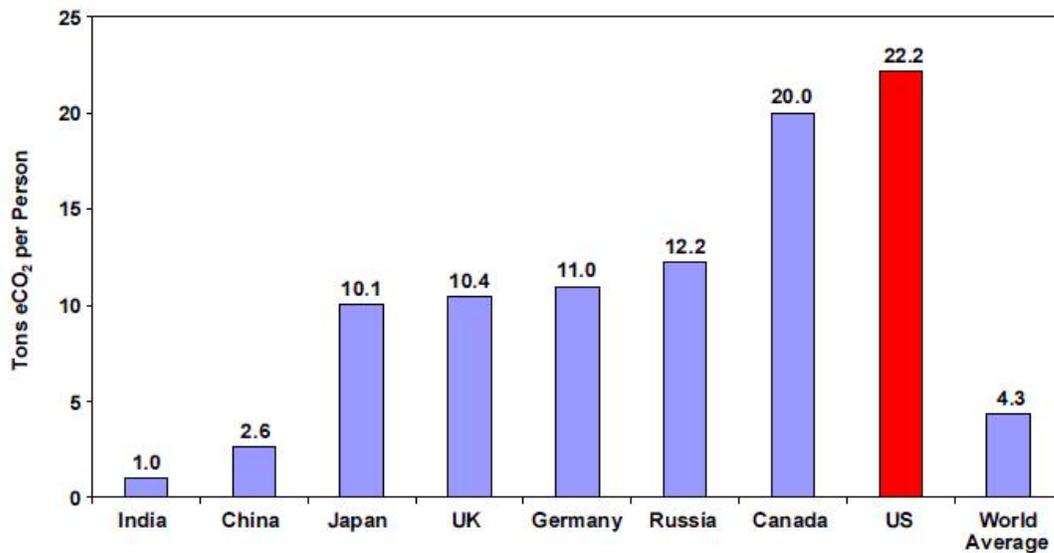
There are also numerous impacts to the human economy including lost workdays due to illness, a desire on the part of business to locate in areas with a healthy environment, and increased expenses from medical costs. Pollutants may also lower visibility and cause damage to property. Certain air pollutants are responsible for discoloring painted surfaces, eating away at stones used in buildings, dissolving the mortar that holds bricks together, and cracking tires and other items made from rubber.

The United States has the highest per capita emissions of GHGs in the world, 22 tons of CO₂ per person per year (see figure 1-2). With only five percent of the world's population, the United States is responsible for 24 percent of the world's CO₂ emissions. California, despite its strong environmental regulations, is the second largest greenhouse gas polluting state in the nation, and emits 2% of global human-generated emissions. Its largest contribution of CO₂ is from vehicle emissions.

According to the International Panel on Climate Change (IPCC), the following are current worldwide statistics for CO₂ concentrations (IPCC, 2008):

- The atmospheric concentration of carbon dioxide (CO₂) during the last two decades has increased at the rate of 0.4% every year.
- Current CO₂ concentrations are higher than they have been in the last 420,000 years, and according to some research, the last 20 million years.
- About three-quarters of the CO₂ emissions produced by human activity during the past 20 years are due to the burning of fossil fuels.

Figure A-2 – Per Capita CO₂ Emissions from 2001



Source: Energy Information Administration, 2001.

Human Health

According to the Pew Center's report on Human Health and Climate Change, health threats may depend on surpassing a threshold level of a climate factor such as significant change in temperature, precipitation, or storm frequency. Once that threshold has passed, the incidence of disease may drastically increase.

Environmental factors play a significant role in some diseases carried by insects. Warming could make tick-borne Lyme disease more prevalent. Mosquito-borne diseases such as West Nile virus, Dengue Fever, and Malaria could acquire new ranges and access to previously unexposed populations (IPCC, 2001). For example, the temperature range at which the malaria-carrying mosquito lives is sensitive to a mere one-degree in temperature change; thus an overall increase in global temperatures will increase the land areas where it may spread disease. These temperature changes affect not only the mosquitoes, but also disturb and in some cases decrease the habitats of its natural predators (Rogers, 2002).

Ecosystems

Scientists predict serious consequences of global warming. The rapid, unprecedented increase in temperatures accelerates the water cycle, which then increases the occurrence, variability, and severity of storms and drought (IPCC, 2008). Such extreme climate events will potentially disrupt ecosystems and damage food and water supplies. In addition, increased temperatures cause thermo-expansion of the oceans and accelerate the melting of the icecaps, thereby raising the overall level of the oceans. The sea-level rise may have multiple outcomes, including significant

environmental disturbances, coastline destruction, major population displacement and economic disruption.

While there is some degree of uncertainty, scientists are able to predict many of the challenges that climate change presents to ecosystems. Warmer temperatures may force some species to higher altitudes or more northern latitudes. This migration may be prevented by human developments that literally block the path as well as non-native species that can out-compete native plants and animals in new locations or make those areas uninhabitable. For example, there is evidence that certain butterflies, often a species that is used to indicate the health of an ecosystem, are moving further north, and are seldom seen in the southern reaches of their range. In addition, warmer temperatures have enabled the Jeffrey pine beetle to have more than one birth cycle per season, lengthening the amount of time this pest is able to damage trees (USC, 200 Pg 1-6). Furthermore, human impact other than greenhouse gas emissions will exacerbate challenges to ecosystems attempting to reestablish at higher elevations or new locations. According to the UCS report, "In many parts of California, fragmentation of the landscape by human developments, invasions by nonnative species, and air pollution may limit the reestablishment of native ecosystems." (UCS, 200 Pg 1-6).

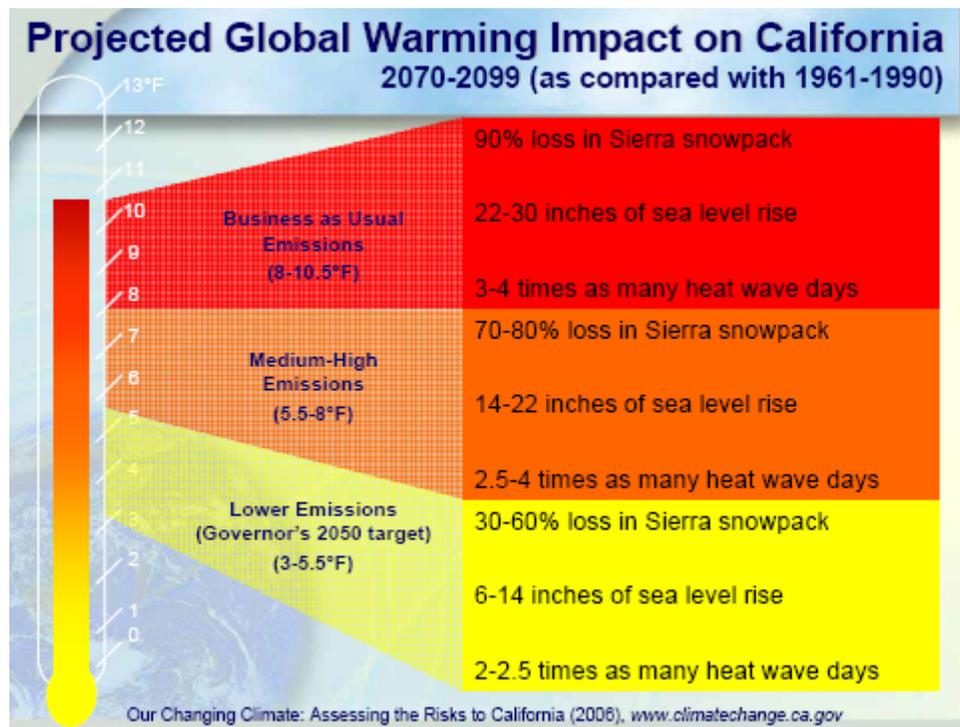
Impacts to California

While it is a global problem, influenced by an array of interrelated factors, climate change is also a regional and local problem, with serious impacts foreseen for California, the Southern California Area.

The impacts of climate change will be variable and widespread. Global and local climate change will impact weather, sea-level rise, water resources, ecosystems, human health, economy, and infrastructure.

Projected future climate change may affect California in a variety of ways. Public health can suffer due to greater temperature extremes and more frequent extreme weather events, increases in transmission of infectious disease, and increases in air pollution. Agriculture is especially vulnerable to altered temperature and rainfall patterns, and new pest problems. Forest ecosystems would face increased fire hazards and would be more susceptible to pests and diseases. The Sierra snowpack that functions as the state's largest reservoir could shrink by one third by 2060, and to half its historic size by 2090. Run off that fills reservoirs will start in midwinter, not spring, and rain falling on snow will trigger more flooding. The California coast is likely to face a rise in sea level that could threaten its shorelines. Sea level rise and storm surges could lead to flooding of low-lying property, loss of coastal wetlands, erosion of cliffs and beaches, saltwater contamination of drinking water, and damage to roads, sewers, and bridges. Figure 1-3 illustrates potential impacts from global warming on California (2070-2099).

Figure A- 3 – Projected Global Warming Impacts on California (2070-2099)



Ultimately, in the next few decades, the impacts of climate change on weather in California will see warmer overall temperatures and an increase in precipitation events, with an increase of intensity and frequency of rainstorms.

Climate and Weather

There is a key difference between climate and weather. According to the National Science Foundation report on climate change in California, “Weather is the day-to-day phenomena we experience—sun, rain, fog, warm, cold, wind—that vary greatly. Climate is long term statistical patterns of weather...and is reflected in average temperatures, rainfall, and other weather events at a given location, and climate change is signaled by long-term changes in those averages” (CRA, 2002).

In 1999, the Union of Concerned Scientists and the Ecological Society of America published a report called *Confronting Climate Change in California*, which describes the predicted impacts of climate change in California. According to this report, California has had a 2°F increase in temperature over the past 100 years, and annual precipitation has decreased by 10-25% in some regions. The report also noted that most climate change models predict a temperature increase of 4°F in California in the next 20 to 40 years. These models also projected a decrease in the

number of long dry spells, and an annual precipitation increase of 20-30% (with a range of 10-50%) in spring and fall, with somewhat larger increases in winter. One model reveals a large increase in precipitation over California, particularly in the form of rain, but with dry areas to the east of the Sierra. This regional model projects that winter precipitation over the coastal areas and the Sierra will increase by 25% or more, with an associated risk of increases in winter mud slides and flooding (UCS, 1999).

Much of the anticipated changes in climate will depend on the frequency and strength of the El Niño-Southern Oscillation phenomenon (ENSO). Most global climate change models indicate the possibility of more frequent ENSO events. El Niño historically happens every two to seven years off the west coast of South America, as a result of changes in ocean currents and prevailing winds over the Pacific Ocean. These changes bring warm water from the western oceans, displacing the nutrient-rich cold water that normally wells up on the western coasts of the Americas from deep in the ocean. These changes bring more frequent and extreme weather anomalies, including severe droughts and floods, hurricanes and winter storms. According to the National Science Foundation, "the invasion of warm water disrupts both the marine food chain and the economies of coastal communities that are based on fishing and related industries" (CAR, 2002). The effects of El Niño in California vary across the state, but in the past have included an abnormally frequent winter rains and storms, and an abnormally dry summer and associated wildfires (UCS, 1999). The 1982-83 El Niño, the strongest event in recorded history, brought \$8 billion in economic impacts and \$100 million in California alone (CAR, 2002).

Water Resources

Climate change impacts will bring an additional burden to California's already over-taxed water supply system. According to the IPCC there will be an increase in the number of intense precipitation days and flood frequencies in basins driven by snowmelt, such as California's Central Valley (IPCC, 2001). For this type of basin, the accumulation of snow in winter is the essential "water tower" that stores water until the spring's warmer temperatures begins to melt the snow, forming the streams and rivers that supply the entire watershed with water for the duration of the summer.

Even under normal climatic conditions, 80% of California's annual rainfall occurs in the winter and is stored in the snowpacks of the various mountain ranges (UCS, 2005). The warmer temperatures associated with climate change will increase rainstorms and decrease snowstorms, shorten the overall snowfall season, and accelerate the rate of spring snowmelt, ultimately leading to more rapid, earlier, and greater spring runoff (Frederick, 1999). The anticipated early spring floods are likely to be followed by excessively dry summers.

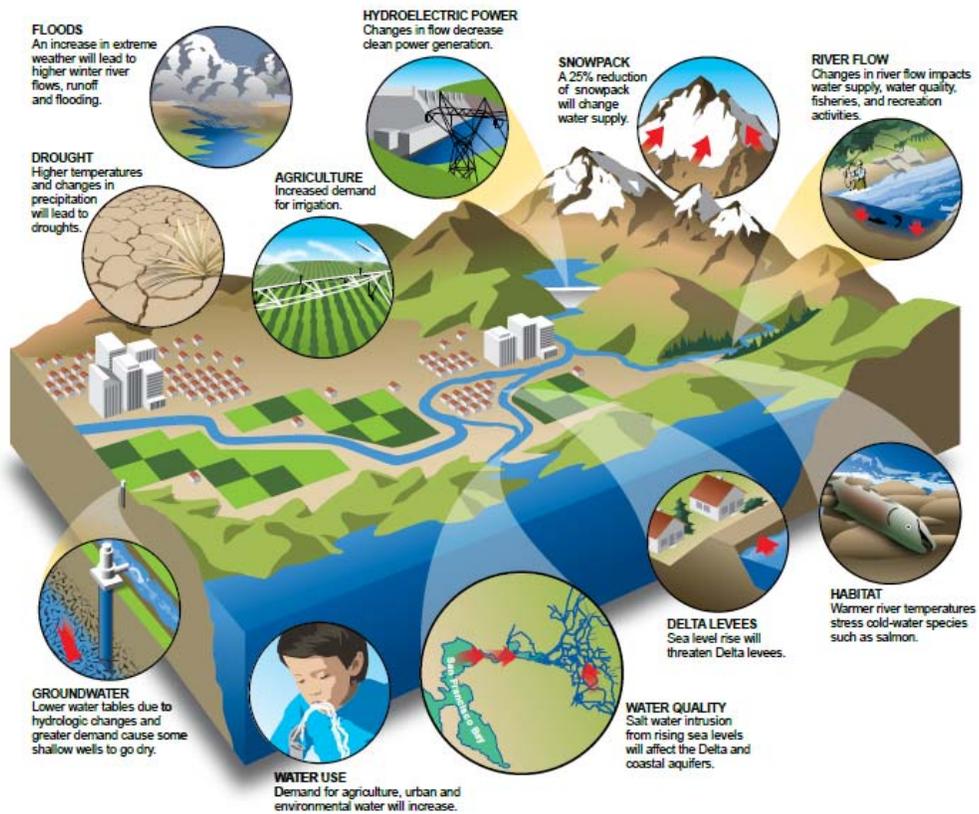
California's water supply is already under stress. According to the National Science Foundation report on climate change in California, "Every major water supply source in California is [decreasing in capacity and] currently over-allocated (CRA, 200 Pg 1-5). A combination of natural and human activities is causing this depletion of California water supplies as well as water intrusion and chemical contamination. According to the Union of Concerned Scientists (UCS), 95% of the state's wetlands have already been destroyed.

In the past, California Water Resources on a statewide basis has allowed California to meet most of its agricultural and urban water management objectives and flood management objectives in most years. Generally, during a single dry year or two, surface and groundwater storage can maintain most water deliveries, but can result in critically low water reserves. Longer droughts can create numerous problems, including extreme fire danger, economic harm to urban and rural communities, loss of crops, and the potential for species collapse and degraded water quality in some regions. Water demand in California is already increasing because of population expansion. In addition, demand for water for irrigation rises with warmer temperatures. Summers with higher temperatures and even less rainfall and runoff than usual will exacerbate demands for water in California.

Climate change magnifies the problems that exist with an aging water infrastructure and growing population. While recent bond measures have provided a down payment for improving California's water and flood systems, climate change presents an ongoing risk that requires a long-term commitment of funding that is properly matched to anticipated expenditures, beneficiaries and responsible parties.

Figure A-4 – How Climate Change Impacts a Watershed

How climate change impacts a watershed



Source: California Department of Water Resources 2008