COMMITTEE REPORT

The Impacts of Global Warming on California

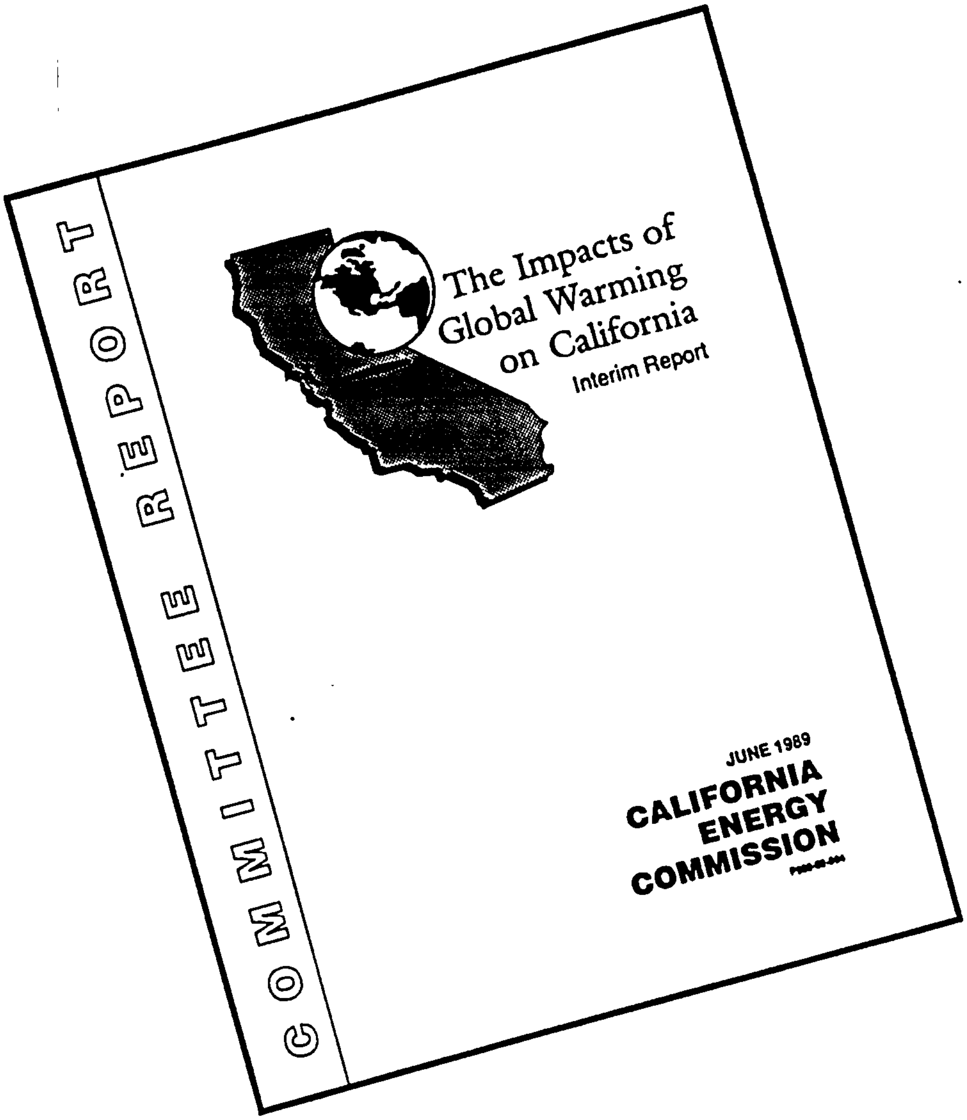
Interim Report

JUNE 1989

CALIFORNIA ENERGY COMMISSION

George Deukmejian, Governor

P500-89-004



INTERGOVERNMENTAL RELATIONS COMMITTEE

Warren D. Noteware, *Presiding Member*
Charles R. Imbrecht, *Chairman*

ENERGY TECHNOLOGY DEVELOPMENT DIVISION

Nancy Deller, *Acting Chief*

TECHNOLOGY EVALUATION OFFICE

Greg Newhouse, *Manager*
Allen Edwards, *Project Manager*

ACKNOWLEDGEMENTS

The Commission Committee for Intergovernmental Affairs

Warren D. Noteware, Commissioner and Presiding Member
John Wilson, Advisor

Charles R. Imbrecht, Chairman and Second Member
B.B. Blevins, Advisor
Gwen Quigg, Advisor

Linda Waits, Committee Counsel

Richard Ratliff, Office of General Counsel

Project Staff

Allen Edwards, Project Manager
Kari Smith, Assistant Project Manager
Susan Patterson, Copy Editor
Eileen Allen/Bob Eller, Siting Division Project Managers
Suzanne Wesley, Project Secretary
Madeleine Meade, Project Secretary

Principle Authors

Jeff Anderson
Les Baxter
Bob Dahlquist
Allen Edwards
Jim Nelson
Marc Sazaki
Kari Smith
Tom Tanton
Gary Walker
Bart Croes (ARB)
Tony VanCuren (ARB)

Contributing Staff

Al Alvarado
Ezra Amir
Jim Brownell
Zene Bohrer
Dennis Fukumoto
Susanne Garfield
Bob Haussler
Roger Johnson
Melissa Jones
Jim McCluskey
Dave Maul
Sandy Miller
Greg Newhouse
Pat Perez
Tony Rygg
Bob Therkelsen
Mike Messenger

Contributing Staff from Other Agencies

California Air Resources Board
Frank DiGenova
John Holms
Kathy Tonnessen

California Board of Forestry
Dean Cromwell

California Coastal Commission
Lesley Ewing
Richard McCarthy
Jaime Michaels

California Public Utilities Commission
Dave Morse

Department of Food and Agriculture
Gergory Beals
Vashek Cervinka
Steven Shaffer

Department of Water Resources
Maurice Roos

Lawrence Livermore National Laboratory
Robert Buddemeier
Joseph Knox
Michael McCracken

GLOBAL WARMING STUDY
INTERIM REPORT DRAFT

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Human activities are changing the composition of the earth's atmosphere. The concentrations of trace atmospheric gases termed "greenhouse gases" are increasing, and there is conclusive evidence that human consumption of fossil fuels, conversion of forests to agricultural land, and the emission of industrial chemicals are responsible for most of the increases.

The increases in greenhouse gases may make the world hotter. Over the last two decades, there has been a growing consensus in the scientific community that increased concentrations of greenhouse gases could dramatically increase the overall global temperature.

The California Energy Commission, in consultation with several other state agencies and the University of California, is analyzing whether California faces a significant risk from greenhouse gas-induced global warming, what types of impacts the state might experience if warming does occur, and what state government policies are appropriate for responding to warming. The Commission's Intergovernmental Relations Committee has directed the global warming analysis. This is the Committee's first report on that analysis.

The Committee first examined the debate over whether or not there will be greenhouse gas-induced warming. Scientists who feel warming is likely are supported by substantial data and rigorously applied theory. Using the most current understanding of the earth's climate, scientists have developed complex global climate models that predict significant climatic warming will result from increased concentrations of greenhouse gases. However, some scientists, unconvinced that the models or the data are completely accurate, question whether the globe faces much, if any, warming.

While the Committee was unable to find absolute proof that the earth will warm significantly during the next century, it did reach a general conclusion on the potential risks California faces in terms of global warming. The Committee findings on the risk of significant warming are as follows:

- There is a high degree of risk that California will experience a 1.5° to 4.5° Celsius (2.7° to 8.1° Fahrenheit) warming by the middle of the 21st Century.

- A .5° to 2° Celsius (.9 to 3.6° Fahrenheit) warming may already be unavoidable.

- There are indications (but no absolute proof) that recent weather phenomenon are the result of greenhouse warming.

- It may be 10 to 15 years before it is certain whether or not greenhouse gas-induced warming has arrived. During that time, the commitment to warming may be steadily increasing.

- The timing and magnitude of warming will be influenced by the amount of greenhouse gases that are emitted in the future as a result of human activities.

The Committee also examined the impacts California might experience if greenhouse gas-induced warming was to occur. This analysis looks at the impacts resulting from an effective doubling of carbon dioxide (one of the major greenhouse gases) and assumes this would lead to a 3° Celsius (5.4° Fahrenheit) increase in California's annual average temperature. The Committee found the state is at risk from the following impacts:

- Water Resources -- There is no clear indication whether there will be an increase or decrease in total precipitation. It is, however, likely that a warming-induced decrease in snowpack storage will increase winter stream flows (and flooding) and decrease summer flows. This, along with an increased evapotranspiration rate, is likely to cause a decrease in water deliveries and an increase in warm weather surface water pollution problems. Significant Risk.

- Electrical Energy -- There are strong indications that warming would cause electricity demand to increase and hydroelectric supplies to decrease. Moderate Risk

- Agriculture -- The agriculture industry may be hurt by lower water supplies, but it may also be helped by a longer growing season and increased growth stimulated by higher levels of carbon dioxide. Agriculture may also be troubled by increased weather variability. No Clear Picture

- Forestry -- Like agriculture, forestry may benefit from increased concentrations of carbon dioxide. But the expected increase in summer heat and dryness is likely to stress many of the state's forest areas. Overall, California's forests are likely to experience lower growth and higher susceptibility to fires, insects, and disease. Significant Risk

- Rising Ocean Level -- Thermal expansion of the ocean and glacial melting are likely to cause a .5 to 1.5 meter rise in the ocean level. This rise, however, would follow atmospheric warming by several decades. A 1 meter rise, without increased protection, would triple the size of the San Francisco Bay system. Significant Risk

- Natural Habitat -- Rising ocean levels and reduced summer river flows are likely to reduce coastal and delta wetland habitat. These changes could also adversely affect resident and spawning fish populations. The general increase in temperature and accompanying increase in summer dryness could also adversely affect wildland plant and animal species. Significant Risk

- Regional Air Quality and Human Health -- Higher temperatures may worsen existing air quality problems. The higher heat may also increase health risks for many Californians Possible Risk

- The California Economy -- The state's economy could also be affected by warming. Warming could cause increased prices, decreased trade, increased population growth (in-migration), decreased tourism, diversions of investment money into warming response activities, and increased uncertainty of investment returns. Moderate Risk

Overall, the Committee finds that the risks and consequences of global warming are great enough to warrant a thorough examination of possible policy measures for delaying or preventing further warming, as well as policies to prepare the state for warming that may come in any event. The results of that examination will be presented in the final report of this study, which is due to the Legislature on June 1, 1990.

CHAPTER I

INTRODUCTION

In mid-1988, the "greenhouse effect" burst onto the national scene with a flurry of articles in magazines and newspapers and a series of hearings in the U.S. Congress. Yet for decades scientists and policy makers have been researching and discussing what might happen if increased greenhouse gases in the atmosphere caused substantial warming of the world's climate.

Early in 1988, before the issue capitivated the national media, California's Legislature introduced AB 4420 (Sher) calling for the California Energy Commission to study how global warming trends may affect the state's energy supply and demand, economy, environment, agriculture, and water supplies. The bill, which was signed by the Governor in September 1988, specifies that the study include recommendations for avoiding, reducing, and addressing the impacts which are identified. With a final report, due on June 1, 1990, the study is to be completed in consultation with the Air Resources Board, the University of California, the Department of Food and Agriculture, and the Department of Water Resources. So far, the Commission staff have also consulted with a number of other state and federal agencies for information and advice.

The global warming study requires detailed investigation into a number of impact areas. While the staff have largely relied on secondary research to acquire impact data, they have often needed to translate global impact data into impacts specific to California. The primary analytical work of the project (as opposed to impacts research) will occur during fiscal year 1989/90 and will cover the implications and effectiveness of policies that respond to global warming.

This is the committee draft of the interim report. The report defines the theory of global warming (Chapter I) and presents the arguments for and against the theory that increased concentrations of greenhouse gases will lead to a significant warming (Chapter II). Chapter III describes the potential impacts of warming on California. Chapter IV summarizes the policy areas that will be analyzed for the final report. The interim report is designed to be an encyclopedia of the most likely impacts warming would have on California. It is also intended as the basis for analyzing policies designed to either prevent or accommodate warming.

The completed interim report should be transmitted to the Legislature and the Governor in July of this year. The final report (due June 1990) will include a refined assessment of the impacts of warming on California. It will also include analysis of the state's options for responding to the warming issue, and will recommend specific response policies.

DEFINITION OF GREENHOUSE EFFECT

<u>Since the earth's infancy, gases in the atmosphere have trapped heat in a physical process termed the "greenhouse effect."</u>

For over a century, scientists have known that certain trace atmospheric gases make the earth warmer than would direct sunlight alone. These gases allow visible and ultraviolet light to pass through the atmosphere and heat the earth's surface. This heat is re-radiated from the earth in the form of infrared energy. Trace gases (greenhouse gases) absorb part of that energy before it escapes into space in a process termed the greenhouse effect (see Figure 1).

Greenhouse gases have been absorbing infrared energy for most of the earth's four-plus billion year history. Scientists estimate that without the greenhouse effect, the earth's surface would be roughly 30° Celsius (54° Fahrenheit) colder--too cold to support life as we know it ("Overview on the Effects of Changing Atmosphere," James G. Titus and Stephen R. Seidel, EPA).

Five naturally occurring gases have been responsible for most of the historic greenhouse-induced warming: carbon dioxide, ozone, methane, nitrous oxide, and water vapor.

- Carbon Dioxide (CO_2) - The atmosphere contains over 700 billion tons of carbon in the form of CO_2. In addition, land plants and soils hold over 2,250 billion tons and the surface ocean water holds over 600 billion tons. By comparison, there are an estimated 10-15 million billion tons of carbon deposited worldwide as fossil fuels. In a naturally occurring cycle plants take up carbon dioxide from the atmosphere as they grow and release it when they die and decompose. A natural cycle also occurs where the carbon skeletons of marine animals are deposited as sedimentary rock, and eventually return to into the atmosphere through volcanic activity (Trabalka, 1985).

- Ozone (O_3) - Produced naturally in the stratosphere from the photodissociation of molecular oxygen.

- Methane (CH_4) - Naturally produced from anaerobic decomposition of plant material and enteric fermentation in animals.

- Nitrous Oxide (N_2O) - Naturally produced in soils and oceans.

- Water Vapor (H_2O) - Produced from the natural evaporation of oceans and other surface water sources. (It is worth noting that water vapor is responsible for approximately three-quarters of the total greenhouse warming.)

The concentrations of these naturally recurring gases have been increasing over the past century, while other artificially produced greenhouse gases such as chlorinated fluorocarbons (CFCs) have been added to the atmosphere only over the last 30 years. Page 8 discusses these increases in detail.

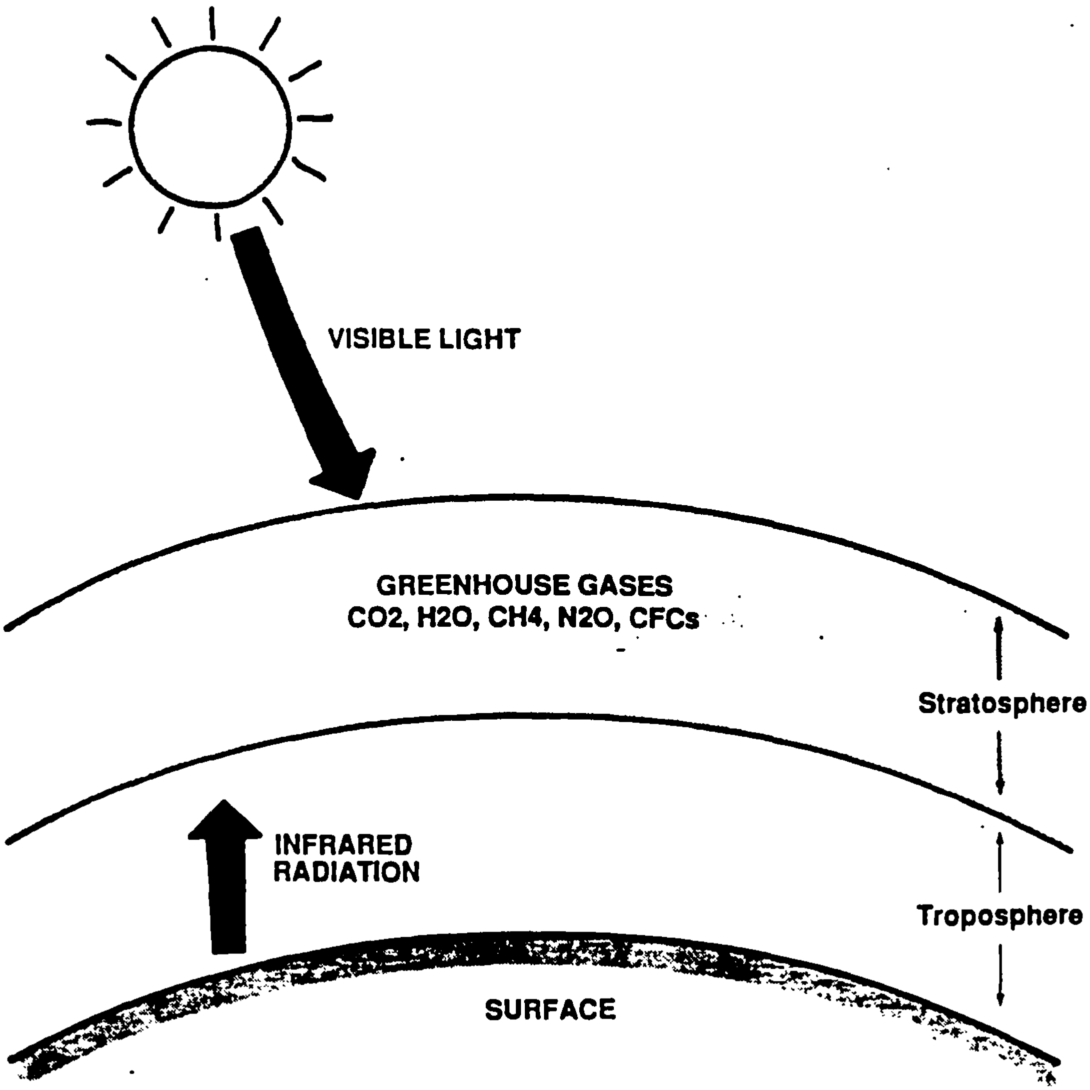


Figure 1

World Meteorological Organization, 1985

CHAPTER II

Chapter II explains why many scientists think the earth is entering a period of rapid warming. The chapter also outlines the concerns of some scientists who question whether warming will be as extreme as many predict, or if it will come at all.

OVERVIEW

Most atmospheric scientists agree that the earth faces significant climatic warming as a result of the activities of man.

There is undisputed evidence that concentrations of the most important greenhouse gases are increasing--primarily as a result of human activities. Carbon dioxide concentrations have gone from roughly 280 parts per million (ppm) a hundred years ago to 350 ppm today, and are now increasing at almost .5 percent per year. During the same period the concentration of methane has doubled. The other gases are also increasing at rates from 0.2 to 5 percent per year. In recent years, the rates of increase of many of these gases have been increasing. Over the next 50 to 100 years, concentrations of these gases are expected to increase substantially unless there are economic and government policy changes on a global scale (Wuebbles and Edmonds, 1988).

Each greenhouse gas has the ability to absorb infrared radiation (heat which the earth radiates back into space after being heated by the sun). Thus, like carbon dioxide, each of the gases has the ability to contribute to global warming. When the median estimates of future concentrations and effects of all the gases are aggregated, they have the same consequences (in terms of greenhouse effect) of doubling pre-industrial concentration of carbon dioxide between the years 2030 and 2050. There are, however, estimates showing an effective CO_2 doubling as early as 2010 and as late as the end of the next century (Mintzer, 1988).

Atmospheric scientists have used effective CO_2 doubling as a benchmark from which to gauge the rate of global warming. Using only the radiation-absorbing properties of these gases, an effective CO_2 doubling would increase global average temperatures by 1.2° Celsius (2.2° Fahrenheit)(see Figure 2). However, this number does not account for many secondary effects (feedback effects) that are known to exist (see Table 1)[1].

To account for these feedbacks, scientists have developed complex computer models that mathematically represent the global atmosphere. Incorporating all that is understood about feedbacks, these models calculate that an effective CO_2 doubling would result in a global average temperature increase of between 1.5°C and 4.5°C (2.7°F and 8.1°F) and many scientists expect that gas concentrations will continue to increase beyond a doubling (Mintzer, 1988).

Most atmospheric scientists do not yet feel there is conclusive evidence that greenhouse-induced warming has begun. Still, there are several atmospheric trends that are consistent with the concept of global warming:

- Global average temperature has increased by about .6°C (1°F) over the last 100 years;

---

[1] *Feedback effects are ways the environment responds to an initial greenhouse gas induced warming. Some feedback effects are positive--lead to more warming, while some are negative--tend to counterbalance the initial warming.*

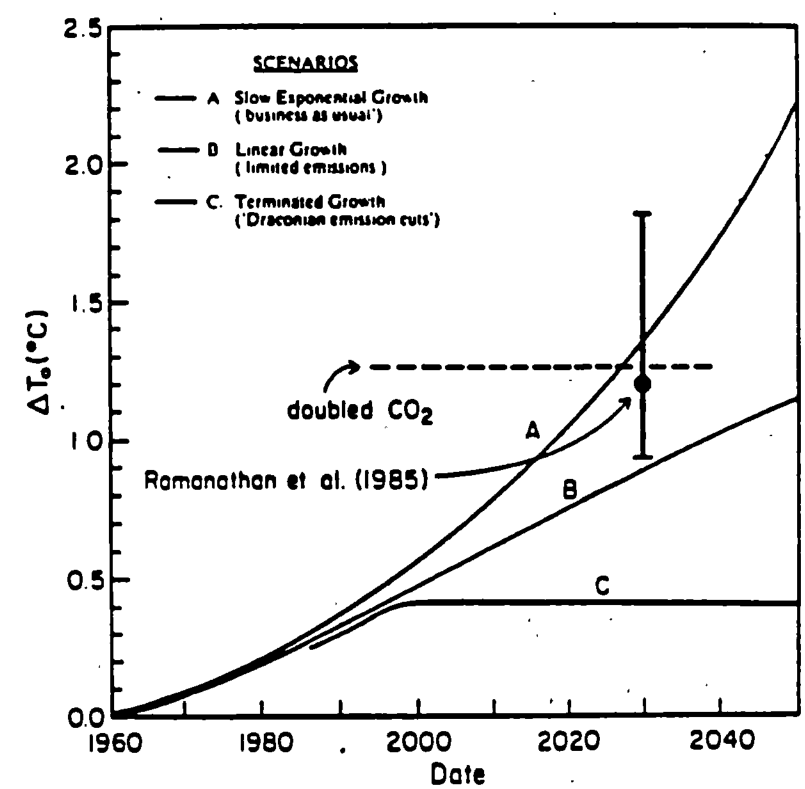
- Sea level appears to have risen by about six inches in the last century; and

- Land-based glaciers have been shrinking over the last century.

These trends do not prove the existence of greenhouse-induced warming; absolute proof may be years away. But the combination of the model projections and atmospheric trends has heightened concern that the earth may become rapidly warmer in the foreseeable future.

Figure 2

GREENHOUSE FORCING FOR TRACE GAS SCENARIOS



Three trace gas scenarios used for simulations of future climate with the GISS GCM. ΔT_o is the "greenhouse forcing", specifically the equilibrium global mean warming that would occur if there were no climate feedbacks. The doubled carbon dioxide level of forcing, $\Delta T_o \sim 1.25$°C, occurs when the carbon dioxide and trace gases added after 1958 provide a forcing equivalent to doubling carbon dioxide from 315 ppm to 630 ppm. The carbon dioxide + trace gas forcing estimated by Ramanathan et al. [J. Geophys. Res., 90, 5566, 1985] for 2030 is also illustrated

Hansen, 1987

Table 1

FEEDBACKS

Oceans:	- As oceans warm, their capacity to absorb and hold airborne CO_2 in solution diminishes (positive-warming)
	- Warmer oceans inhibit the mixing of deep and surface waters, slowing transfer of CO_2 to ocean depths (positive-warming)
	- As oceans warm, phytoplankton, which absorb CO_2, may decline (positive-warming)
	- Warmer oceans make the release of methane from ocean sediments more likely (positive-warming)
Atmospheric Temperature:	- Temperature rise increases water evaporation, humidity, and atmospheric water vapor content (positive-warming)
	- Rising humidity leads to increased cloud cover; low-altitude clouds tends to reflect solar radiation away from the earth (negative-cooling), while high-altitude clouds tend to absorb radiation (positive-warming)
	- Warmer temperatures speed the chemical transformation of methane, a powerful greenhouse gas, into less damaging CO_2 (negative-cooling)
	- Faster temperature rise in high latitudes reduces the temperature differential between the equator and poles, stalls ocean currents and reduces pumping of CO_2 to deep oceans (positive-warming)
Plant Life:	- Plants grow faster in a high CO_2 atmosphere and absorb more carbon (negative-cooling)
	- Vegetation decays faster when it is warmer and releases CO_2 and methane more quickly into the atmosphere (positive-warming)
Glaciers:	- Glacial and snowcover retreat decreases reflectivity at the poles (positive-warming)
	- Polar thawing speeds decay and release of carbon and methane now held in permafrost (positive-warming)

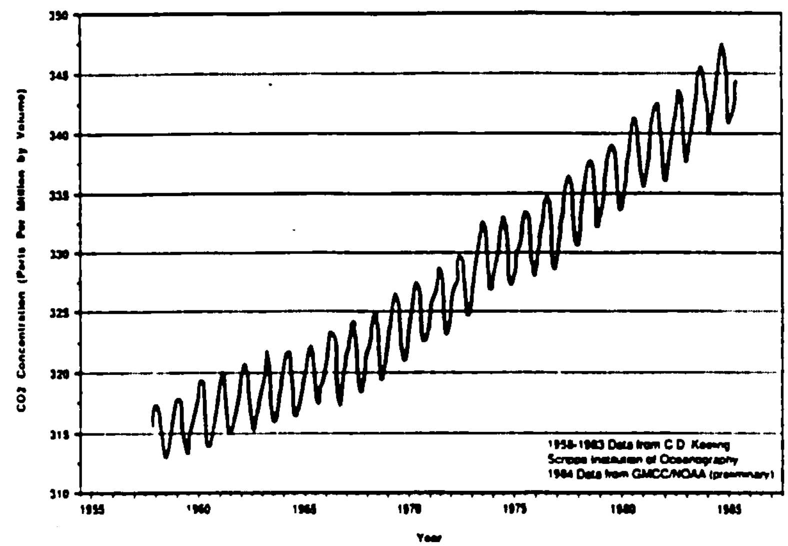
GREENHOUSE GAS BUILD-UP

<u>Human activities are causing increases in concentrations of most, if not all, of the major greenhouse gases.</u>

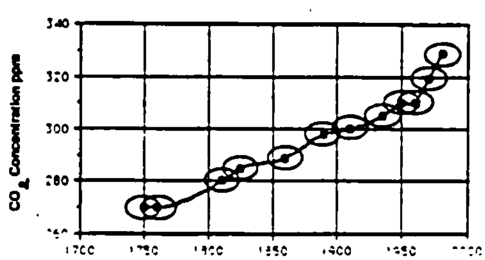
The atmospheric concentrations of most, if not all, of the major greenhouse gases are increasing (see Figure 3 for an illustration of CO_2 increase). Most, if not all, of the increases are due to human activities. Without significant economic, technical, or social changes, they are all expected to increase in the future. The combined effect of these growing concentrations could lead to the equivalent of a doubling of CO_2 in the early- to mid-21st century.

Figure 3

MONTHLY CONCENTRATIONS OF CARBON DIOXIDE AT MAUNA LOA, HAWAII



Estimated Atmospheric Concentration of CO_2 (parts per million)



Atmospheric CO2 concentrations measured in glacier ice formed during the last 200 years (Neft et al. 1985)

Neftel et al 1982

Carbon Dioxide (CO_2) - Since the inception of the industrial revolution, human activity has added CO_2 to the atmosphere through fossil fuel combustion. Currently, humans burn more than 5 billion tons of fossil fuel carbon each year--all of it going into the atmosphere in the form of CO_2 or CO. In addition, deforestation (and subsequent burning) adds another 1.5 billion tons. Scientists feel that about 40 percent of the CO_2 released into the atmosphere is taken up by the oceans or plant growth. The remaining 60 percent stays in the atmosphere, and is responsible for the 0.4 to 0.5 percent yearly growth in CO_2 concentration.

Carbon Monoxide (CO) also results from fossil fuel combustion as well as the combustion of biomass (in forest clearing and agricultural operations). While CO is not in itself a significant greenhouse gas, its presence acts to increase tropospheric (lower atmosphere) concentrations of methane and ozone, which are both greenhouse gases.

Methane (CH_4) is also a significant greenhouse gas whose concentration is growing more than one percent a year. Most scientists feel that this growth is resulting from a combination of increases in petroleum, natural gas, and coal extraction, increased flooded rice farming, and increases in global population of domestic ruminant animals (cows, sheep, etc). Some of the increases may also be due to increased termite activity in areas that are being deforested.

Chlorofluorocarbons (CFCs) are a family of manmade chemicals receiving much attention for their role in stratospheric ozone depletion. In addition, on a per molecule basis, these chemicals are several thousand times more effective as greenhouse gases than CO_2. Since they were introduced in the mid-1930s, CFCs have become economically important as refrigerants, solvents, and in the production of foam material. Their atmospheric concentrations are growing at about 5 percent per year. (The 1987 Montreal protocol seeks to reduce CFC production by one-half by the year 1998. However, because they survive in the atmosphere for decades, even if stringent proposed regulations are effected, the atmospheric concentrations of CFCs will remain high for the next 50 to 100 years.)

Nitrous Oxide (N_2O) is increasing at 0.2 to 0.3 percent each year. This increase is primarily due to fossil fuel combustion and soil fertilization.

Ozone (O_3) is increasing in the troposphere (lower atmosphere) and decreasing in the stratosphere (upper atmosphere). Emissions from fossil fuel combustion react to form tropospheric O_3, the main component of photochemical smog. In the troposphere, O_3 acts as an infrared absorber, and hence contributes to global warming.

In the stratosphere, O_3 is being broken down through chemical reaction with components of CFCs. Since stratospheric O_3 is an ultraviolet radiation screen, its decrease allows more radiation to reach the earth, again contributing to global warming.

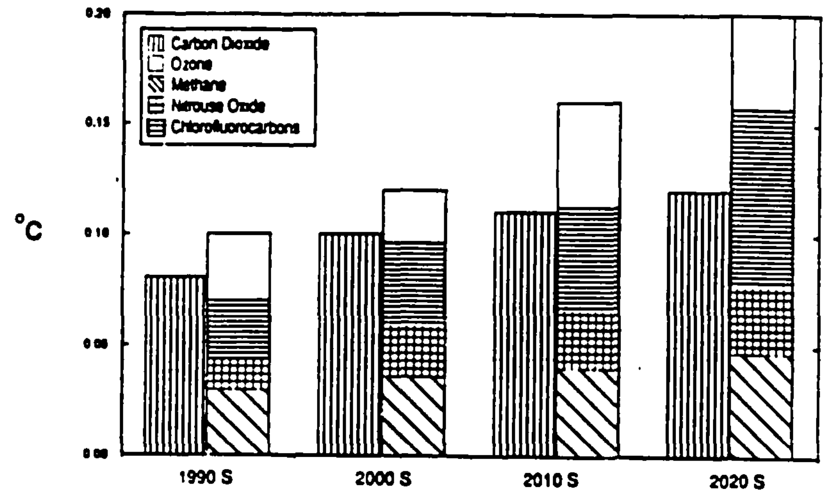
Water Vapor (H_2O) in the atmosphere increases or decreases depending primarily on the overall atmospheric temperature level. Since H_2O is a greenhouse gas, and its concentrations depend on the heat generated by other greenhouse gases, H_2O acts as a positive feedback to greenhouse-induced warming.

Based on their current concentrations, these gases are expected to contribute to a global warming. However, since these concentrations are growing at differing rates, their future relative contributions are shown in Figure 4.

It is important to keep in mind that the concentrations of some gases, particularly CO_2 and CH_4, may increase due to rising atmospheric temperatures. This results because plant material will decompose faster and entrapped gas (in solution or loosely bound in chemical compounds) will escape more readily in a warmer environment (Houghton & Woodwell, 1988).

Figure 4

RELATIVE INFARED ABSORBTION CAPACITY OF GREENHOUSE GASES



The chart shows how each greenhouse gas will contribute to global warming. Various climatic feedbacks, such as reduced reflectivity of the Earth as ice melts, warm the planet further.

MODEL PREDICTIONS OF FUTURE GLOBAL WARMING

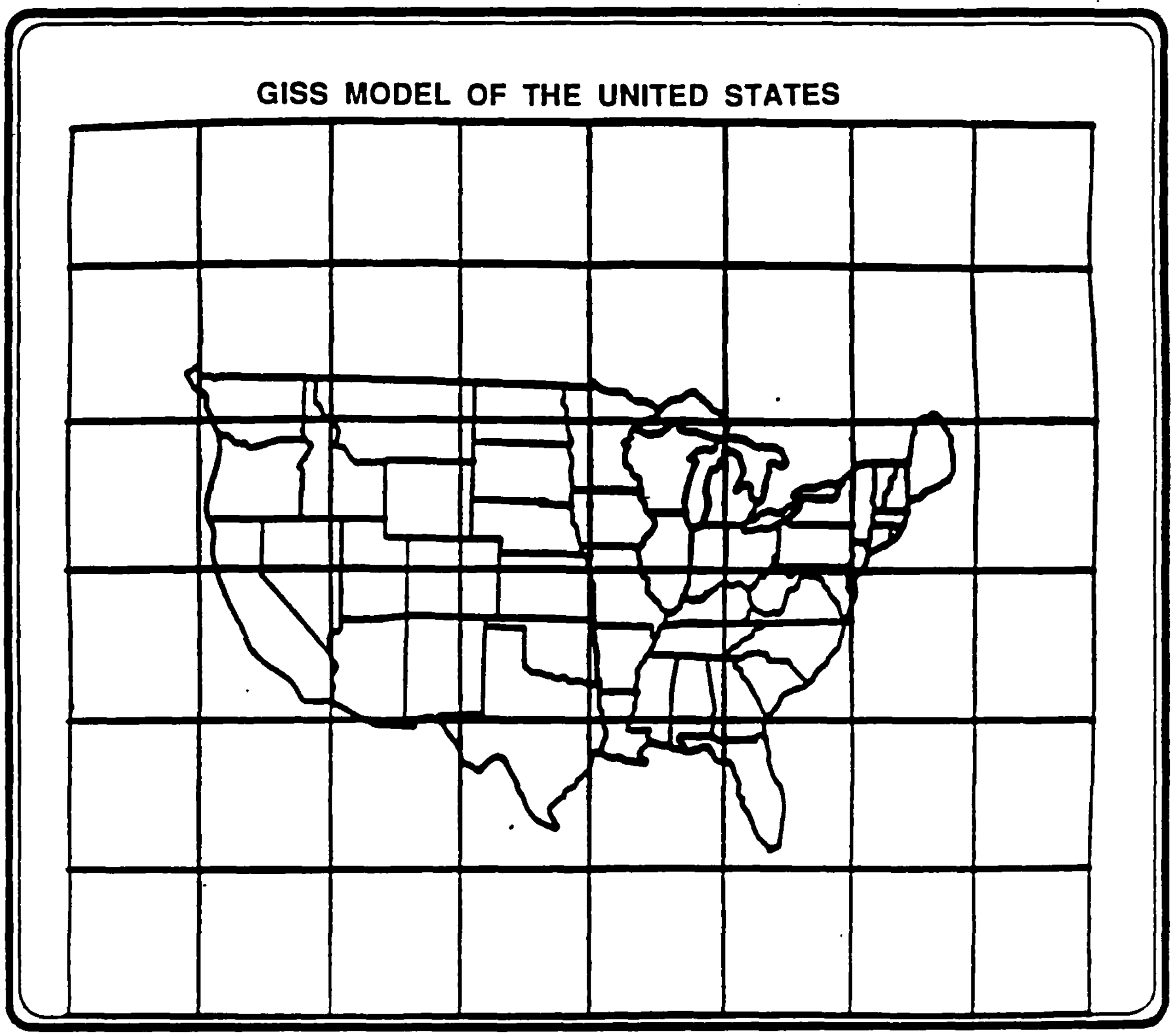
Complex atmospheric models estimate that greenhouse gas increases will lead to significant global climate warming.

Scientists calculate that without considering feedback mechanisms, an effective doubling of carbon dioxide would lead to a global temperature increase of 1.2°C (2.2°F) (Kerr, 1986). But the net effect of positive and negative feedback appears to cause substantially more warming than would the change in greenhouse gases alone.

Unfortunately feedback patterns are much too complex for accounting by simple calculations. As a result, atmospheric scientists have developed computer-driven models which mathematically describe how the global atmosphere functions, including the major feedbacks. Scientists have used these three dimensional climate models to calculate how the global atmosphere would respond to an effective CO_2 doubling.

The more complex models divide the globe into cells that measure several hundred kilometers on a side (see Figure 5). They also divide the atmosphere into a series of layers. Finally, they simulate the effect of the ocean on the atmosphere. It should be noted that some of the feedback effects are not fully understood. For example, most scientists think warming will increase cloud cover. They also think that warming will increase high clouds, which would exacerbate warming, rather than low clouds which would dampen warming. In addition, scientists only have a sketchy understanding of the interrelationship between the oceans and the atmosphere (Ramanathan, 1988).

Figure 5



EPA, 1988

Most global warming analysis is conducted by arbitrarily raising the atmospheric concentrations of the greenhouse gases (except water vapor) described in the model. The model is then run to see how the global climate reacts, e.g., which areas get warmer, cooler, wetter, or dryer.

Four complex climate models (three dimensional models) are currently used in the United States : Geophysical Fluid Dynamics Lab (GFDL), Goddard Institute of Space Studies (GISS), Oregon State University (OSU), and a model at the National Center for Atmospheric Research (CCM). Each has been used to calculate the global average temperature that would result from an effective doubling of CO_2. Figure 6 displays the results of these calculations using the GISS, GFDC, and OSU models. One of the models, GISS, has been used to calculate the temperature increases which would occur during a transition to a CO_2 doubling (see Figure 7).

The equilibrium temperatures calculated by the models would not necessarily occur immediately after a doubling. Temperature increases may be delayed by the heat absorption capacity of the earth's surface, particularly by oceans. Consequently the anticipated temperature increases may be 10 to 20 years behind an effective CO_2 doubling (Science Article, May 2, 1986). Increases in greenhouse gas concentrations may also continue to increase beyond an effective CO_2 doubling. Some analysts predict that concentrations could reach and exceed the equivalent of triple the preindustrial CO_2 levels.

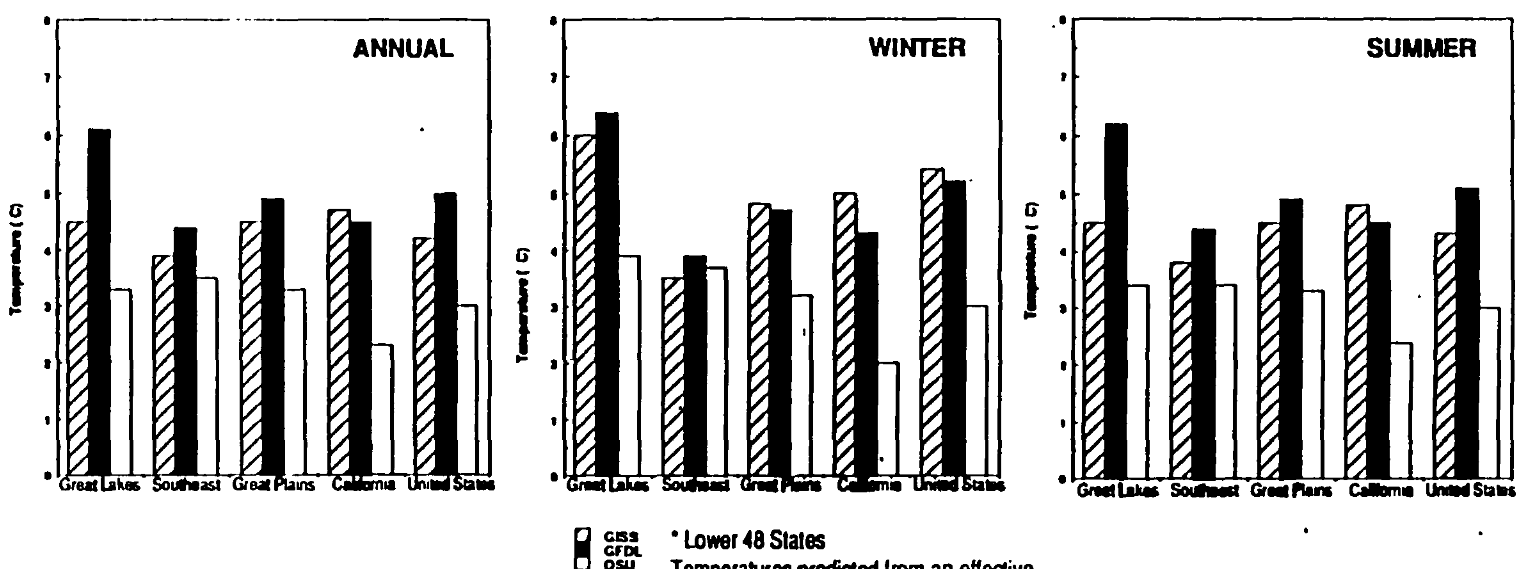
These calculations are not predictions of warming but rather warming scenarios. The warming that might occur at any particular future date depends more on human behavioral patterns (the amounts of greenhouse gases society emits) rather than atmospheric mechanics.

The models are not precise predictive tools. Scientists are uncertain about some feedback mechanisms (cloud cover response and ocean/atmosphere interaction, for example). Other potential feedbacks are described very crudely. The models agree on global scale climate changes but disagree on many local impacts. As a result, most scientists are reluctant to use the models to predict how global warming would affect a local area, such as California (Keepin, 1986).

Finally, it is important to keep in mind that the models are not well designed to estimate climate changes for a limited geographic area such as California. The models can be used to give a general indication of regional climate change, but should not be considered as true predictions of future California climate.

Figure 6

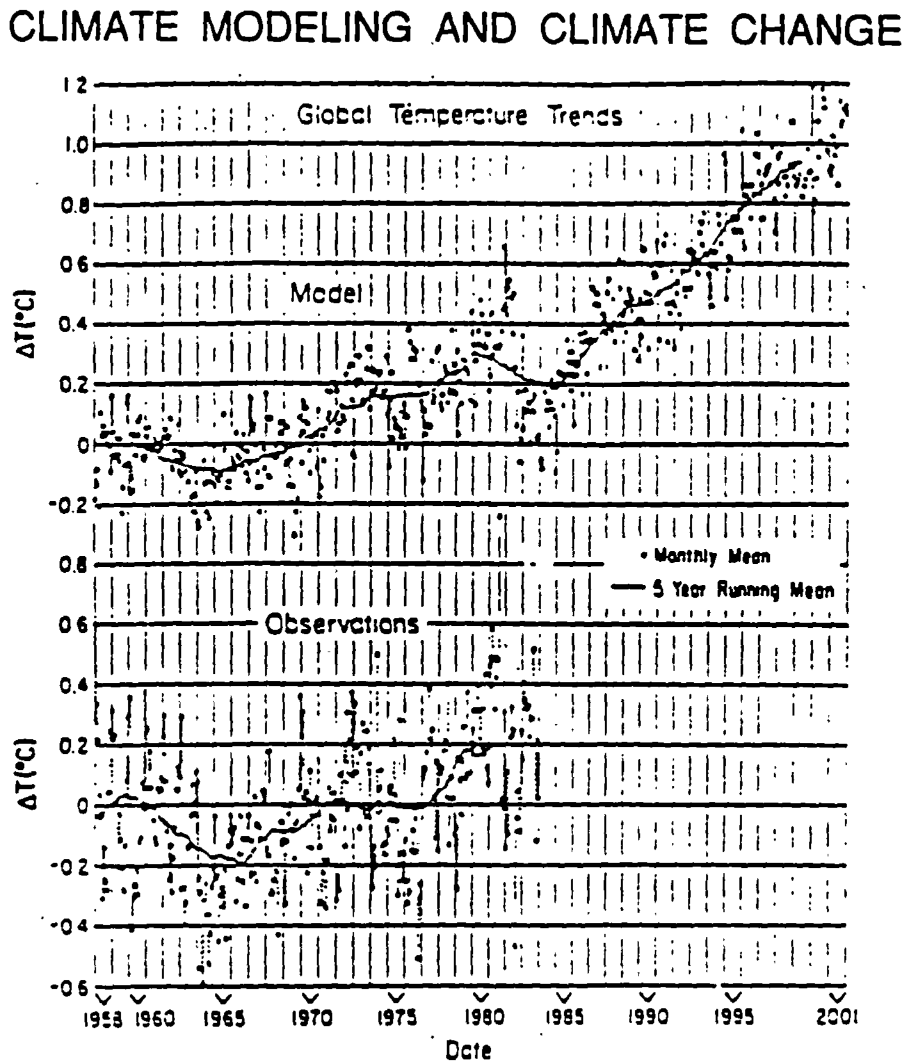
TEMPERATURE SCENARIOS



* Lower 48 States
Temperatures predicted from an effective doubling of preindustrial CO_2.

EPA, 1988

Figure 7



Modeled and observed global mean surface air temperatures. The zero point for the model temperature is the mean for that month from the last 10 years of a 35 year control run. The zero point for observation of data is the mean for that month from the period 1958-1983. A five year running mean represents the average of the temperature over a five year interval centered on the plotted year.

Hansen, 1986

HISTORIC ANALOGS OF TEMPERATURE CHANGE

The strong historic link between atmospheric carbon dioxide and global temperature supports the conclusion that current and future increases in greenhouse gases will lead to a global warming.

There is increasing evidence that carbon dioxide has played a key role in the shaping of the earth's climate. Early in its history, the earth appeared to have very high atmospheric concentrations of CO_2 (20-50 times current concentrations). This high concentration was thought to have resulted in a greater greenhouse warming than today, but was occurring during a time when the sun's energy was 25 percent weaker. Thus, these high concentrations of CO_2 seem to have contributed to a climate which was warmer than today and was conducive to the development of early life forms.

Geologic evidence shows that over time, much of the atmospheric CO_2 was converted into carbon-based rock, fossil fuel deposits, or living biomass, while portions of the oxygen in CO_2 became the atmospheric O_2 we now breathe. Concurrently, the sun's radiation was gradually strengthening. As a result, it is thought that through the sequestering of carbon, the earth's temperature remained within the range that would support life throughout the last few billion years.

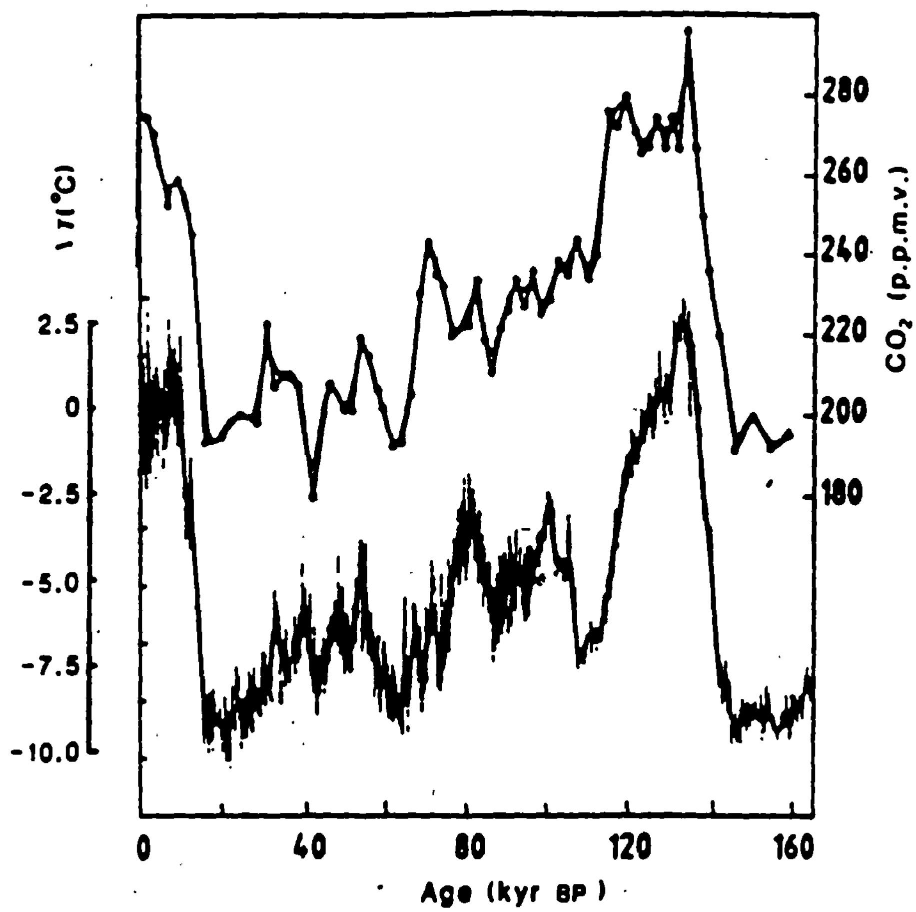
The decline of carbon dioxide in the atmosphere has not been uniform, nor has the earth's temperature been stable. The current amount of CO_2 in the atmosphere is only a small fraction of the total carbon on the earth. This carbon is returned to the atmosphere through two mechanisms: a biological cycle where carbon is taken up by plants that eventually die and either decompose back into the atmosphere or are laid down as fossil fuel deposits; or a geochemical cycle, where the carbon is taken up in the skeletons of marine organisms, laid down in sedimentary deposits, and put back into the atmosphere through the weathering of carbonate rocks or through volcanic activity.

There is increasing evidence that, because of variations in carbon cycles, the concentrations of atmospheric CO_2 has fluctuated widely during the earth's history. Geophysical researchers have found they can only explain certain geologic warm periods (e.g., the age of the dinosaurs--the Cretaceous period from 135 to 65 million years ago) if the concentrations of CO_2 were much higher than today (in this example, 4 to 8 times higher).

The close connection between atmospheric temperature and CO_2 concentrations over the last 600 million years gives strong support to the idea that the greenhouse effect has affected the earth's climate throughout history. The evidence of this relationship is even stronger for the last 100,000 years. Here, data collected from glacial core samples shows a consistent correlation between atmospheric carbon dioxide and temperature (see Figure 8).

Overall, available evidence indicates a link between global climate and greenhouse gases throughout the earth's history. Current projections of increasing greenhouse gases suggest that, due to the greenhouse effect, future temperatures will meet and ultimately exceed temperatures which occurred 6,000 to 120,000 years ago (see Figure 9).

Figure 8

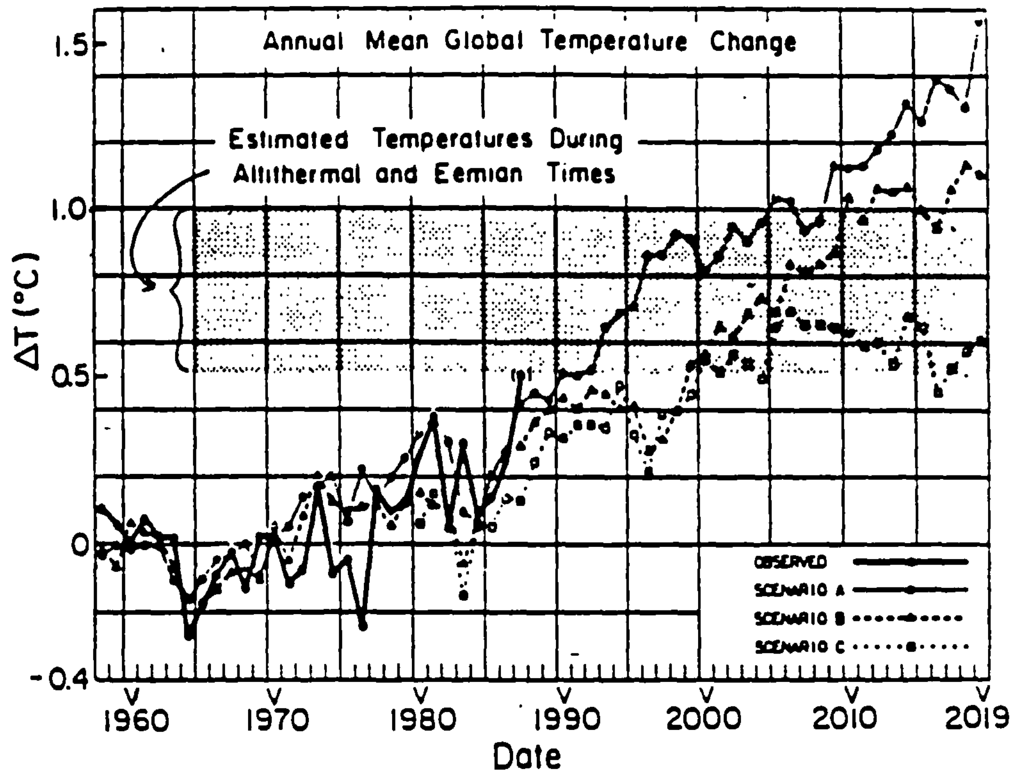


Relationship between CO2 and air temperature according to Vostak ice core measurements.

The Vostak ice core shows that carbon dioxide levels (top line) and Antarctic temperature have fluctuated in synchrony over the last 160,000 years. Scientist are trying to sort cause from effect to determine whether changes in the atmosphere drove the temperature jumps, or vice versa.

Science News, Vol 134

Figure 9



Annual mean global surface air temperatures computed for scenarios A, B, and C. Observational data is from Hansen and Lebedeff [J. Geophys. Res., 92, 13,345 1987]. The shaded range is an estimate of global temperature during the peak of the current and previous interglacial periods, about 6,000 and 120,000 years before present, respectively. The zero point for observations is the 1951-1980 mean; the zero point for the model is the control run mean. Observed temperature anomaly for 1987 is based on available station data for January 1 to November 1.

Hansen 1987

EVIDENCE OF A GLOBAL WARMING (SIGNATURE)

Although most climatologists agree we face a significant warming, most also agree that there is not sufficient evidence it has arrived. Still, recent climate trends in various parts of the globe are consistent with the global warming theory.

The heat spells and droughts of the mid- and late-1980s are only part of what some perceive as increasing climatic turmoil. The popular press often points to this turmoil as evidence that greenhouse-induced warming has begun and, based on projections, will intensify. But few scientists researching the issue are willing to unequivocally conclude global warming has arrived.

Still, climatologists are observing climate trends which are consistent with global warming projections. And while erratic weather patterns do not prove the existence of warming, they do reinforce the concerns of the scientists, as well as provide a preview of what may lie ahead.

The most notable trends are:

- Increasing Global Temperatures - Records over the last century show that the global average temperature has increased approximately .6°C (1°F) (see Figure 10). While some contend the records are flawed, analyses designed to filter out any distortions still show a distinct temperature increase. (It is worth noting that this is a global average; temperatures in any particular region may have been warmer or colder.)

- Record Temperatures in the 1980s - Globally, the six warmest years on record were, in descending order: 1988, 1987, 1983, 1981, 1980, and 1986. This heating occurred during a time of relatively low solar activity (few sunspots) which theoretically should have brought relative cooling to the globe (Jones, 1989).

- Rising Ocean Level - During the last century, the mean global ocean level rose approximately six inches. In addition, some studies show the rate of rise has increased during the past few decades (Peltier, 1989).

- Decreases in Arctic Permafrost - Measurements of permafrost taken from exploratory oil wells indicate that there has been a 2-4°C (3.6-7.2°F) warming in the Arctic during the last 100 years. Climatologists studying global warming predict a greater temperature increase in polar regions than in temperate regions. (Note: these measurements have, to date, been taken from a relatively limited geographic region.) (Lachenbruch, 1987)

- Recent Stratospheric Cooling - Consistent with the concept of greenhouse-induced warming in the lower atmosphere, the stratosphere (high atmosphere) has been cooling over the last few decades (Kerr, 1988).

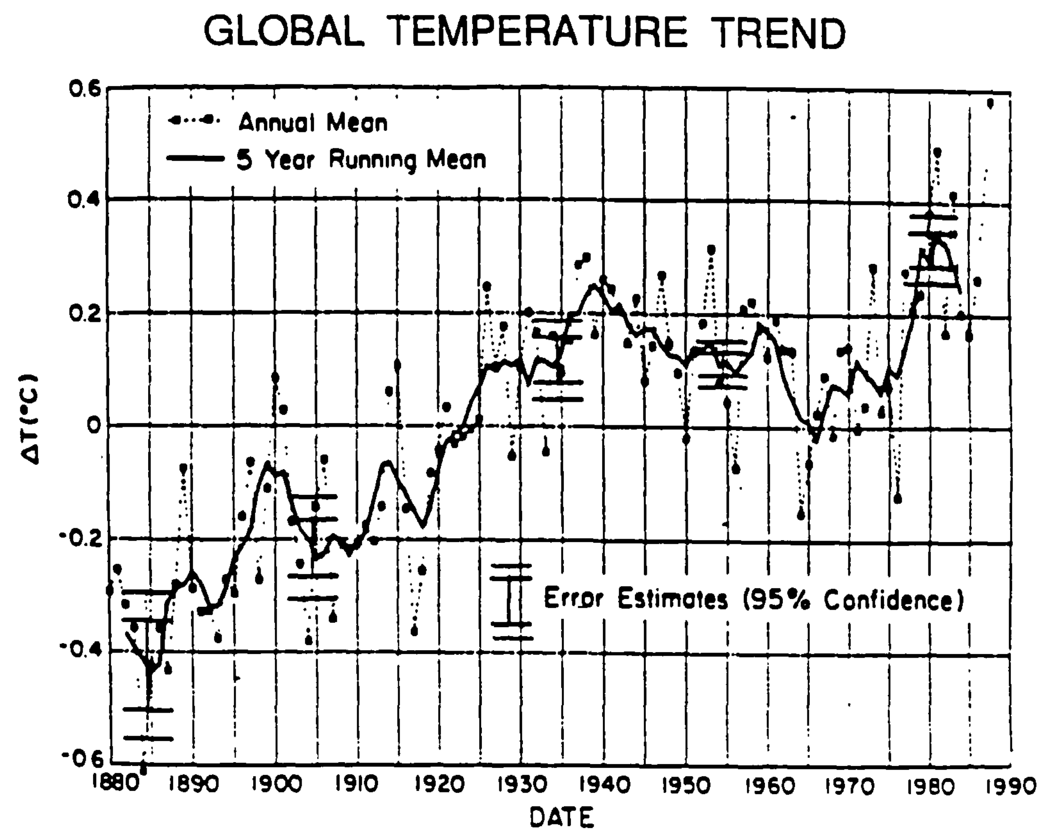
- Changes in Global Precipitation - Consistent with model projections, global precipitation has increased at higher latitudes (35° to 70° north and south), decreased at lower latitudes (5° to 35° north), and remained constant near the equator (Bradley, 1987). (See Figure 11)

- Shrinking Glaciers - Worldwide, glaciers have steadily receded in the past 100 years.

- Melting of the Antarctic Ice Pack - There is some evidence that the ice bridges containing portions of the west Antarctic ice shelf are breaking down (Williams, 1989).

- Decrease in the Sierra Nevada Snowmelt - Over the past 30 years, the average snowpack storage in California's Sierra Nevada mountains has steadily decreased. (This is, of course, evidence from a limited geographic area.)

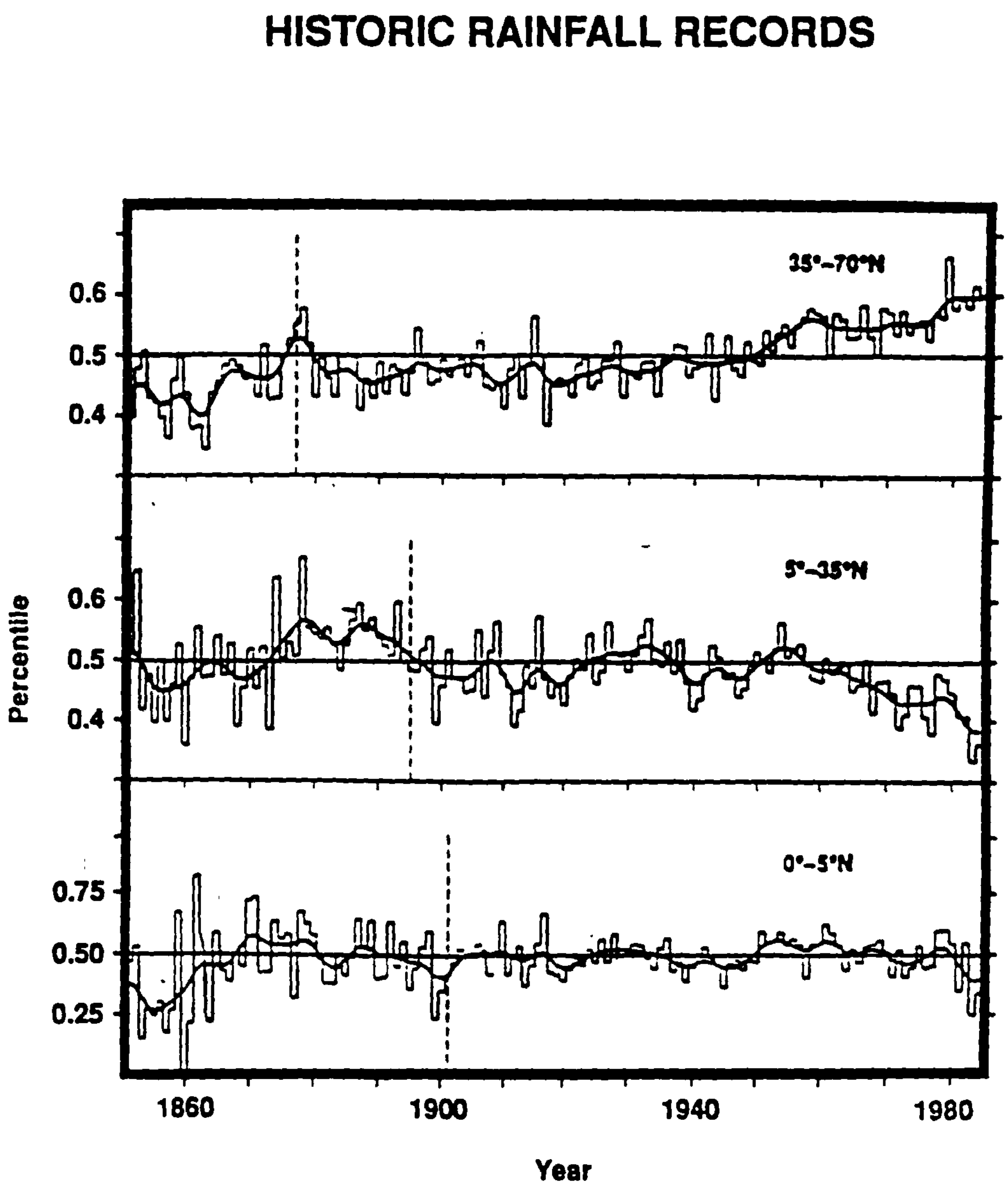
Figure 10



Global temperature trend for the past century. The 1987 point is an estimate based on the data from January 1 to November 1. The five year running mean is the linear average for the five years centered on the plotted year.

Hansen & Lebedeff, 1987

Figure 11



General circulation models predict there will be more worldwide precipitation when carbon dioxide doubles. The historical record from 1860 to 1980 of the northern hemisphere suggests that the weather has become wetter in middle latitudes, drier in low latitudes, and remained unchanged near the equator. These changes are consistent with current computer simulated climate projections.

R.S. Bradley, 1987

CHALLENGES TO THE GLOBAL WARMING CONCEPT

Summary

While most scientists researching global warming agree on the general dimensions of the problem, a few disagree with some, if not all, aspects of the global warming concept.

Even though most atmospheric scientists are unwilling to conclude warming has arrived, most do agree that the historic and continued emission of greenhouse gases could lead to global warming. There are some scientists, however, who disagree with some or all of the basic concepts and data supporting the theory of greenhouse warming. It is important to recognize these disagreements and understand that there is uncertainty regarding some of the data supporting the concept of greenhouse warming.

These disagreements fall into three basic categories:

- Some feel the historic temperature data is flawed. (This data shows a rise of approximately .5°C (1°F) over the last 100 years.)
- Others feel feedback effects will limit substantial warming in spite of increases in greenhouse gases.
- A few think the earth is entering a cooling rather than a warming period.

Some of these global warming critics appropriately point out weaknesses in the atmospheric models used to derive warming projections. Others, particularly those contending global cooling, have little scientific evidence to support their contentions.

Although staff investigation has found some scientists who criticize global warming research, staff has been unable to find studies using a sophisticated climate model that refute the theory that a significant climate warming is a possible result of increasing greenhouse gas concentrations.

Unfortunately, the uncertainty about whether or not the world faces a greenhouse warming may not be resolved for several years. Some scientists believe that greenhouse warming will be demonstrated if the current trend of increasing temperatures persists through the 1990s. Others feel that the concept will only be proven or disproven with much more complex atmospheric models that may not be available for 10-20 years.

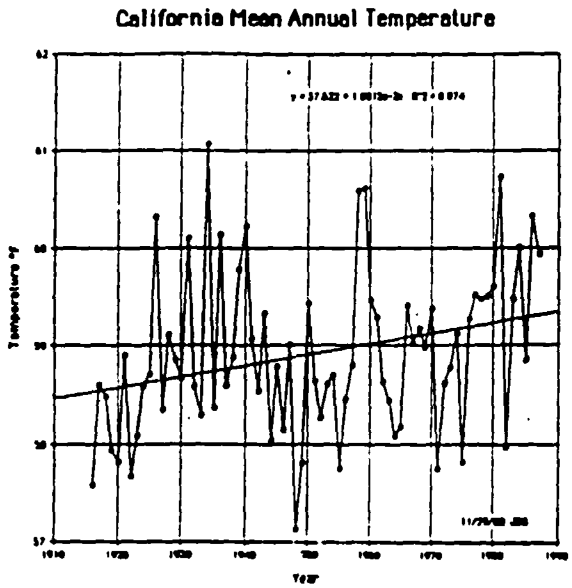
QUESTIONS ABOUT THE DATA

Some scientists question the accuracy of historic temperature data.

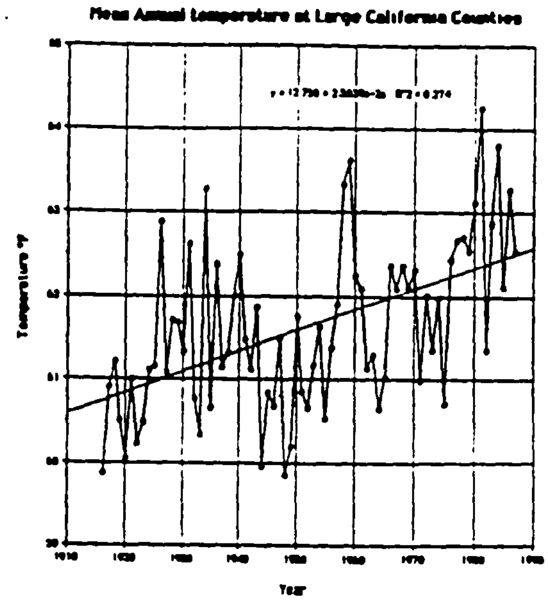
Several of the global warming skeptics feel that the historical temperature data records which indicate a 1°F rise over the last 100 years are fundamentally flawed. They contend many of the measuring stations are, and have been, located in areas that have urbanized, and show unrepresentatively warm readings as a result of the influence of progressive urbanization (the urban heat island effect [see Figure 12]). There are also some indications of changes in instrumentation and methods of temperature observation at some weather stations. In addition, some of these skeptics point to regional temperature records which show no temperature rise.

Of the scientists questioning the accuracy of historic weather data, most only argue that these flaws make it inappropriate to contend that a greenhouse-induced warming has begun. Others

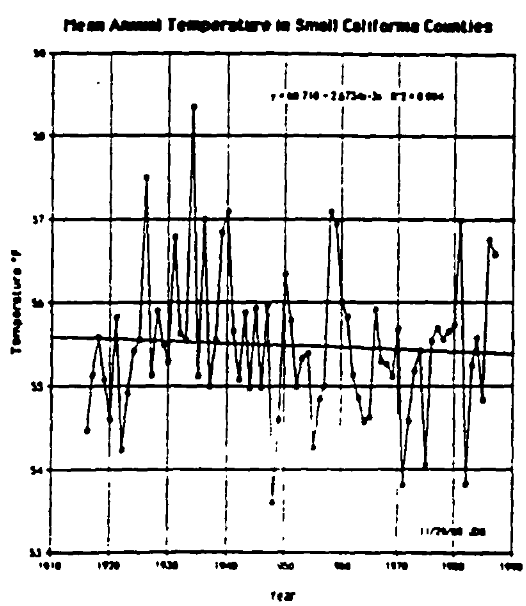
Figure 12



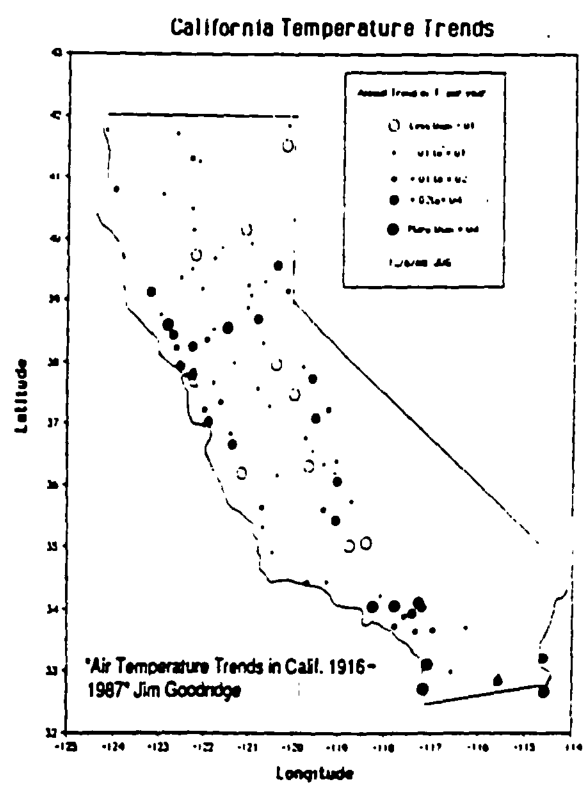
Based on the average of 92 records for the period 1916 to 1987.



Based on 24 records from counties with more than 750,000 people.



Based on 23 records for counties with less than 100,000 people.



Based on 92 records for the period 1916 to 1987.

Goodrich, 1988

however, conclude that because this preliminary sign of warming is questionable, the whole global warming theory is flawed.

The principal warming theorists have several specific responses to these arguments:

- Global warming researchers feel it is inappropriate to base conclusions about global weather conditions on regional temperature records. The continental United States, for example, represents less than 2 percent of the earth's surface. United States weather, be it hotter or colder, is not an analog for global weather.

- In general, climatologists recognize the heat island phenomenon and add that many rural temperature stations have, conversely, been affected by the expansion of irrigated agriculture which tends to cause unrepresentatively cool temperature readings.

- Several researchers have learned to filter out local distortions when analyzing historic temperature data. They conclude that, despite the distortions, the earth has still warmed approximately .5°C (1°F) in the recent past.

- In addition, data from free troposphere temperature measurements, taken at an altitude high enough to avoid local temperature distortions, over the last 30 years show a nearly .3°C (.5°F) global temperature rise. The free atmosphere records of the lower stratosphere show a slight but distinct cooling trend--also consistent with a global warming. (Kerr, 1988)

- Finally, some climatic researchers note that global average temperature seems to change in short jumps over spans of a few years. Between the jumps the average temperature plateaus, and little overall change occurs until the next jump. The existence of these jumps is not consistent with the gradual temperature increases resulting from the urban heat island effect.

POTENTIAL EFFECTS OF FEEDBACK(S) (MECHANISMS)

Some scientists acknowledge the concept of a greenhouse effect but feel feedback mechanisms will keep the earth's temperature relatively constant even in the face of elevated concentrations of greenhouse gases.

As explained earlier in Chapter II, the temperature of the atmosphere is a result of greenhouse gas concentrations and the atmospheric feedbacks they induce. Some scientists contend that even if greenhouse gas concentrations are substantially elevated, the net result of feedbacks (secondary reactions to initial greenhouse warming) will hold global temperatures relatively stable.

These scientists feel two feedback areas are particularly notable. First, they feel the overall precipitation increases expected from a warming would lead to more snow at high latitudes. This snow cover would in turn raise the earth's overall albedo (the fraction of the sun's incoming energy that is reflected back into space). Since less solar energy would be absorbed by the earth's surface, this feedback would compensate for the otherwise warming effect of increased greenhouse gases.

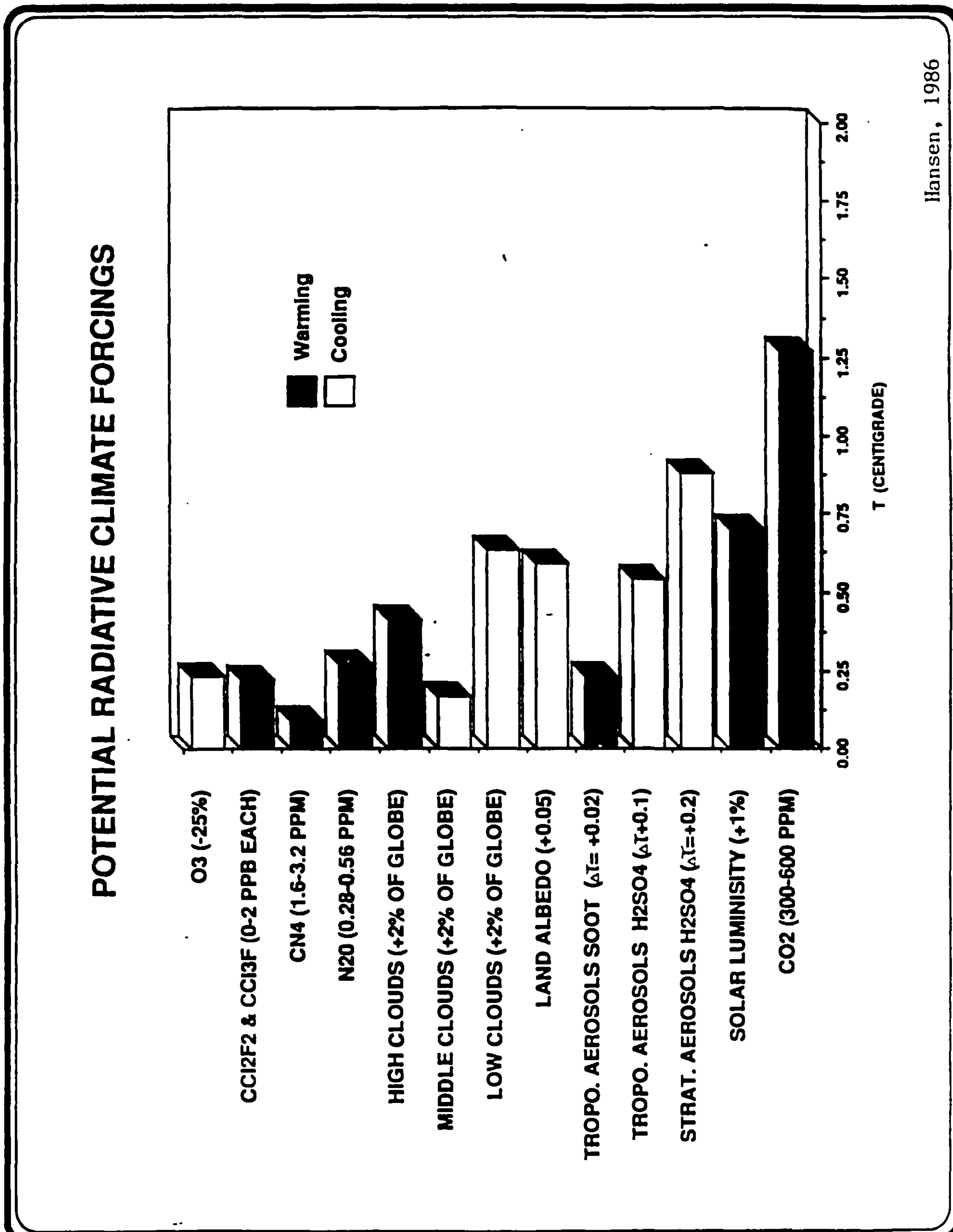
Second, essentially all atmospheric scientists agree that the initial increased heat resulting from elevated greenhouse gas concentrations will accelerate evaporation of surface water, and some feel that greater evaporation will lead to increased cloud cover. Some scientists also contend that these clouds will reflect more of the sun's energy back into space, a feedback which would cool the atmosphere.

Proponents of the global warming concept respond as follows:

- Three dimensional climate models factor changes in evaporation and consequent changes in snowfall into equations which project temperature changes due to an effective doubling of CO_2. The models conclude that snow cover would decrease, not increase, causing global temperatures to rise by 3° to 4.5°C (8.1°F).

- Most scientists studying global warming agree total water vapor in the atmosphere will go up. While there is still uncertainty about how this will change cloud cover, there is a general sense that total cloud cover may go down because clouds are based on relative humidity, not total humidity and the increased atmospheric temperature may actually decrease relative humidity. There is also a general sense that high altitude clouds, which would exacerbate the warming, will increase (McCracken, 1989).

Figure 13



POTENTIAL RADIATIVE CLIMATE FORCINGS
Warming
Cooling
O3 (-25%)
CCl2F2 & CCl3F (0-2 PPB EACH)
CN4 (1.6-3.2 PPM)
N20 (0.28-0.56 PPM)
HIGH CLOUDS (+2% OF GLOBE)
MIDDLE CLOUDS (+2% OF GLOBE)
LOW CLOUDS (+2% OF GLOBE)
LAND ALBEDO (+0.05)
TROPO. AEROSOLS SOOT (ΔT= +0.02)
TROPO. AEROSOLS H2SO4 (ΔT+0.1)
STRAT. AEROSOLS H2SO4 (ΔT=+0.2)
SOLAR LUMINISITY (+1%)
CO2 (300-600 PPM)
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
T (CENTIGRADE)
Hansen, 1986

A GLOBAL COOLING THEORY

<u>There is a very small minority in the scientific world that believes the earth is entering a cooling rather than a warming period.</u>

One minority theory of global climate change contends that the buildup of atmospheric CO_2 is not the result of fossil fuel combustion, but rather due to declining plant matter which has caused a disruption of the carbon cycle. These scientists contend that the root cause of this disruption is a progressive demineralization of the earth's surface. The disruption, they contend, is resulting in more biomass decomposition, and less biomass growth absorbing CO_2 from the atmosphere. This combined effect results in overall higher levels of atmospheric CO_2.

This theory further contends that initial climatic response to elevated CO_2 levels will be a rapid warming at the equator. The equatorial warming would cause increased water evaporation and cloud formation. These clouds will then drift towards the poles, causing increased precipitation, and rapidly cover the high latitudes with snow. Once covered with snow, the increased reflection of solar energy would cool the earth, plunging the globe into a new ice age.

The proponents of this theory feel that past ice ages have been caused by similar disruptions in the carbon cycle, and that the earth could enter a new ice age in as few as seven years. They also feel there are signs we may already have entered that period.

Most scientists studying climate change respond in the following ways:

- There is conclusive evidence that part of the increasing atmospheric CO_2 concentrations is the result of fossil fuel combustion. There is also strong evidence that some of the CO_2 increase comes from deforestation. There is little evidence, however, that the existing biosphere is taking up less carbon; in fact, there is some evidence that portions of the North American forests are growing somewhat faster as a result of the higher levels of CO_2 (increased concentrations of CO_2 can increase growth for some plants). (Trabalka, 1985)

  The economies of the world consume approximately five billion tons of fossil fuel carbon each year, converting the fuel into energy while emitting virtually all the carbon into the atmosphere as CO_2 or CO. Deforestation is thought to add approximately another 1.5 billion tons. Based on atmospheric CO_2 measurements, about 60 percent of these emissions stay in the atmosphere, while the other 40 percent are absorbed by the oceans or by plant growth. (Trabalka, 1985)

- Increased evaporation in the tropical oceans will not necessarily mean increased overall cloud cover, nor does it mean an increased transport of air and water toward the poles.

- The cycle of ice ages over the last million or so years is an anomaly, at least for the past 250 million years. This historical data contradicts the basic hypothesis of demineralization cycles on which the above ice age theory is based. (McCracken, 1989)

- Climatologists have used their complex models to both replicate the earth's current (and recent past) climate and to calculate greenhouse gas-induced climate change. Because their models do a good job replicating the current and past climate, these researchers are confident their projections of climate change are also generally correct.

  Climate modelers believe the climate will respond positively (warmer) to increases in greenhouse gases, with temperature increases that are more pronounced at the high latitudes than at the equator. They feel this will happen for three reasons: first, the initial warming will cause more precipitation to fall as rain rather than snow. This, in more earth surface heating. Second, the initial heating will cause more stratification in the Northern latitude atmosphere. This, in turn, will result in warmer air staying close to the earth's surface rather than mixing with colder air from higher in the atmosphere. Third, because there is relatively less solar energy used in evaporation at high latitudes than near the equator, the increased greenhouse gas concentrations can trap relatively more infrared heat in the areas near the poles. (McCracken, 1989) As a result of these factors, they foresee less, rather than more snow cover in high latitudes (both north and south). And they consistently envision global warming rather than cooling in response to increased levels of greenhouse gases.

- While most atmospheric scientists agree that the increasing temperatures, rising sea levels, shrinking glaciers, and regional droughts of recent years do not prove a global warming has begun, they do see these events as consistent with warming, and not consistent with cooling.

CHAPTER III

IMPACTS OF GLOBAL WARMING ON CALIFORNIA

Chapter III is a discussion of what could happen to California as a result of warming due to an effective doubling of CO_2. The chapter is not a prediction of what will happen to California, but rather a discussion of the potential impacts that may result from a specific climate scenario (a hypothetical set of climate circumstances).

For the purpose of this analysis, the Commission has chosen to use an effective doubling of CO_2 in order to present a snapshot of global warming impacts. However, it is important to keep in mind that California could begin to see impacts from global warming during the next decade. If the model predictions are correct, the impacts will gradually become more intense over time. Since increases in greenhouse gas concentrations will not necessarily stop at an effective CO_2 doubling, the resulting impacts may eventually become more intense than those described in this report. In addition, some impacts may occur at a steadily increasing rate; others may come in dramatic jumps; and some may be delayed for years or decades. Unfortunately, there is not sufficient data to know exactly how the impacts will occur, or even if they are certain to occur.

The scenario used for this analysis is a "medium intensity" scenario. Some estimates of warming from an effective CO_2 doubling are lower than this scenario, others are higher. As a result, while warming impacts may not be as severe as described, there is a possibility they will be more severe.

It should be noted that the impacts described below assume no attempt at mitigation. This is necessary in order to understand the underlying consequences of global warming. However, it is partially the reason for the negative nature of this report. If the state does experience severe impacts, mitigation policies would certainly be developed. The final report of this study will focus on which policies would be most effective. The scenario used to guide the impact analysis is as follows:

EFFECTIVE CO_2 DOUBLING

This is the state of the atmosphere when the growth of all the greenhouse gases, including CO_2, will equal a doubling of CO_2 alone. As a primary scenario for the study, <u>CO_2 will effectively double between the years 2030 and 2050</u>.

TEMPERATURE

The primary temperature scenario will be based on the equilibrium temperature resulting from an effective doubling of CO_2. The atmospheric models predict a temperature rise of 1.5° to 5.0°C (9°F) under this condition. For the primary scenario, <u>we will use a temperature increase of 3.0°C (5.4°F)</u>. This temperature increase is expected to occur one to two decades after the date of effective CO_2 doubling.

RAINFALL

<u>The primary scenario will use a zero change in annual precipitation.</u>

OCEAN LEVEL RISE

<u>The primary scenario will use three to three and one-half feet (one meter) as the rise in the ocean level resulting from an effective CO_2 doubling.</u>

THE ECONOMY AND GENERAL SOCIETY

<u>The primary scenario will assume no change in current economic and social trends.</u>

TEMPERATURE PREDICTIONS FOR CALIFORNIA

Global climate models predict that the average annual temperature will increase by 2°C to 5°C (3.6°F to 9°F) as a result of CO_2 doubling).

The major three dimensional climate models all predict that California will become significantly warmer as a result of an effective CO_2 doubling. The models do not, however, exactly agree on the magnitude of the increase. Projections of wintertime temperature increases range from 1.9°C to 4.9°C (3.4°F to 8.8°F). Summertime increases range from 3.1°C to 4.5°C (5.6°F to 8.1°F). Figure 14 displays the temperature change calculated by three of the major American models for each season.

Analysis for the remainder of this interim study has generally assumed that the earth will effectively double its atmospheric CO_2 concentration sometime between the years 2030 and 2050. The analysis also conservatively assumes that an effective doubling will lead to an average annual temperature increase of 3°C (5.4°F).

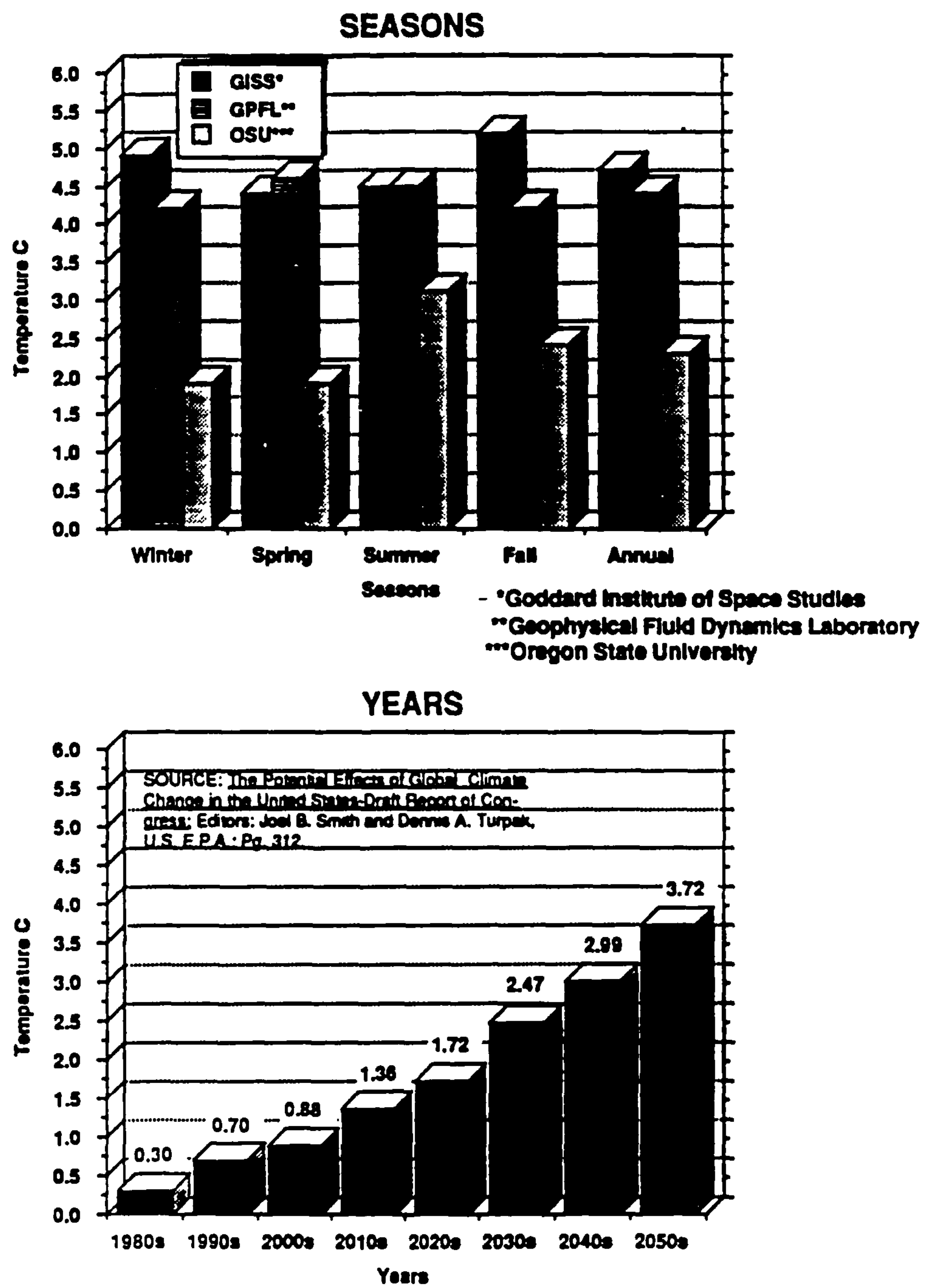
There may be a lag of 10-20 years between the time certain concentrations of greenhouse gases are reached (effective doubling of CO_2 for example) and when the climate responds fully. Thus, if a CO_2 doubling were to occur in 2040, the predicted temperature levels may not be reached until after the middle of the century.

It is important to remember that these models only estimate average temperature change over a broad region. As discussed in Chapter II, the three dimensional climate models divide the earth's surface into fairly large grids. They calculate a single temperature for an individual time period for each grid. In the American models, California takes up parts of only a few grids. Thus, the calculated temperatures for California represent broad geographic averages that do not account for local variations. To date, the models do not reveal information about possible local variations which may deviate from the calculated projections. Climate change in coastal areas may be moderated by the influence of the ocean, while interior parts of the state may warm more than the predicted statewide average warming. There are also indications that winter warming may be somewhat greater than summer warming.

A final note: there are some indications (although no consensus) that climate warming may result in greater weather variability. If so, the extreme hot weather in the state may increase by more than the predicted average temperature increases.

Figure 14

CALIFORNIA TEMPERATURE PROJECTIONS



EPA, 1988

WATER IMPACTS

Summary

__Global warming may decrease water supplies from surface sources, increase water demand, increase the occurrence of winter flooding, and make water pollution problems more severe.__

Even if the amount of precipitation does not change, global warming may diminish surface water supplies in California. Higher winter temperatures could cause more precipitation to fall as rain and less as snow. Instead of being stored in snowpack, the winter rainfall would run off immediately, filling downstream reservoirs earlier. Because of flood storage requirements, a portion of the early runoff would not be stored, but would be passed through in accordance with flood control requirements. During the spring when the reservoirs ordinarily fill, reduced snowmelt runoff and consequently reduced storage for use in the summer and fall would occur.

In addition, higher average temperatures would increase agricultural and urban demands through increased surface evaporation and irrigation water use, and winter flooding may be more frequent and cover a greater area because of increased winter rainfall, attendant runoff and rising sea levels.

Finally, global warming may magnify water quality problems by reducing spring and summer flow in streams and rivers and their ability to dilute existing and anticipated pollutant loading. Projected sea level rise may require a greater volume (up to twice the volume) of releases from upstream reservoirs to repel salt water intruding into the Sacramento/San Joaquin River Delta.

PRECIPITATION

__Although the General Circulation Models (GCMs) all agree there will be a temperature increase, they do not fully agree in their predictions of California precipitation.__

If CO_2 concentrations double between 2030-2050, then precipitation may increase or decrease (depending on the GCM used) as shown in Figure 15. The GCMs generally agree there will be global increases in temperature but they disagree on regional hydrologic changes. Predicting California water supply conditions using different models and data bases has provided varying results (see Figure 15). However, regional studies indicate general agreement in the following areas:

- higher average temperatures
- increased precipitation in the form of rain rather than snow
- more runoff during the winter and less during the spring and summer
- a rising snowline with correspondingly reduced snow pack

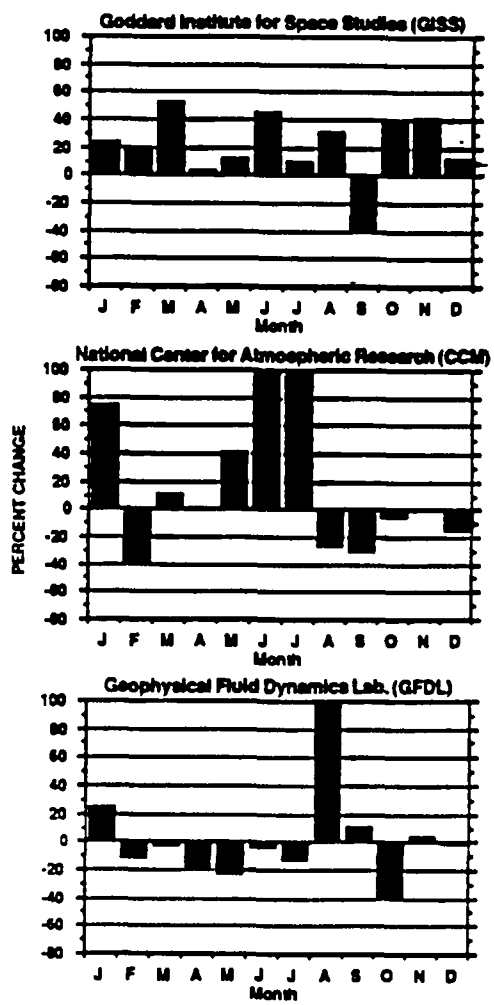
In previous studies, hydrologists have predicted that if temperatures increase by 4°C (7.2°F), the increased evapotranspiration will result in a 10 percent decrease in annual runoff even if overall precipitation remains constant. This is based on the assumption that California will experience an increase in temperature, but no increase in spring and summer rainfall. If precipitation increases by 10 percent, it would offset the decrease in runoff if this extra amount of water can be managed. However, if precipitation decreases by 10 percent, then annual runoff in Northern California could drop by 21 percent.

It is not clear whether or not warming will bring more weather variability. However, California could be severely affected by more frequent or more intense droughts.

Average annual precipitation in California is presently about 250 billion cubic meters or 200 million acre-feet. Using the drought during the mid-1970s as a point of comparison, in 1976 precipitation decreased to 160 billion cubic meters and in 1977 to 135 billion cubic meters. This reduced runoff to 47 percent of normal in 1976 and to 22 percent of normal in 1977. More frequent droughts of this magnitude could affect the state's agriculture, fisheries, energy production, and many areas of manufacturing, as well as the general quality of life in California.

Figure 15

CHANGE IN PRECIPITATION ACCORDING TO THREE GENERAL CIRCULATION MODELS



Percent change over control precipitation estimated by three general circulation models for northern California following a doubling of atmospheric carbon dioxide. Note the significant degree of variability between the different model projections. Due to the variability it is difficult to accurately determine how global changes in precipitation will affect California

RUNOFF

A 3 C (5.4 F) warming would significantly affect the timing of surface water flows by changing the area of snowpack storage in California's mountains.

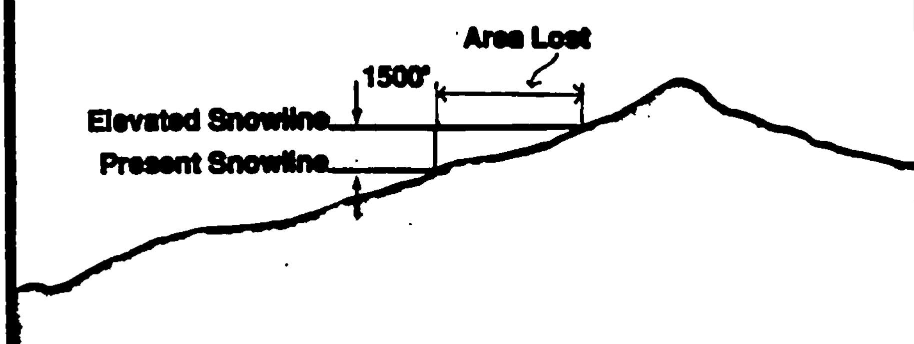
It is not known whether the warmer temperatures predicted by GCMs would change the total amount of precipitation in California, but warmer winters are expected to increase the amount of precipitation falling as rain and decrease the amount falling as snow. This would be particularly true at lower altitudes, where temperatures are more likely to remain above freezing. Since the amount of water stored in mountain snowpack is primarily a function of winter snowfall, a 3 C (5.4 F) temperature rise resulting from increases in greenhouse gas concentrations is expected to raise California's historical snowlines approximately 1,500 feet (see Figure 16).

Raising existing snowlines by 1,500 feet would reduce the maximum average April 1 snowpack area in California from the present 12,700 square miles to about 5,800 square miles, a decrease of 54 percent. The Sacramento River Drainage Basin (Northern Sierra) snowpack area would be reduced by about 75 percent while the San Joaquin-Tulare Lake Drainage Basin (Southern Sierra) would decrease by about 33 percent (see Figure 17).

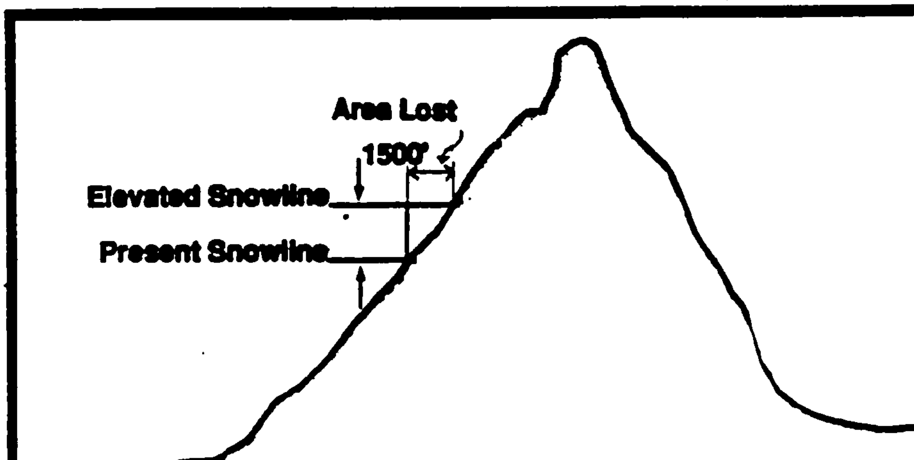
Estimates show that, assuming no change in statewide precipitation, global warming would reduce total April through July unimpaired runoff by about 33 percent. Sacramento Valley river unimpaired runoff would be reduced 40-45 percent. San Joaquin Valley river runoff would drop about 25 percent. Very large changes in seasonal runoff may be expected due to the reduction of snowpack water storage. The loss of April to July snowmelt runoff will greatly reduce the total annual storage of California's water system. Even if total precipitation may be greater than before global warming, much of the rain-generated runoff may have to be released prior to April 1 to guarantee flood protection. Post April 1 runoff from snowmelt would be lessened, and water available for summer use reduced accordingly. The estimated change in the monthly distribution of annual runoff for the Sacramento Basin is illustrated in Figure 18. This change could result in a 7-16 percent decrease in State Water Project Deliveries.

Figure 16

RELATION BETWEEN SLOPE OF SNOWPACK AREA AND AREA LOST DUE TO SNOWPACK ELEVATION



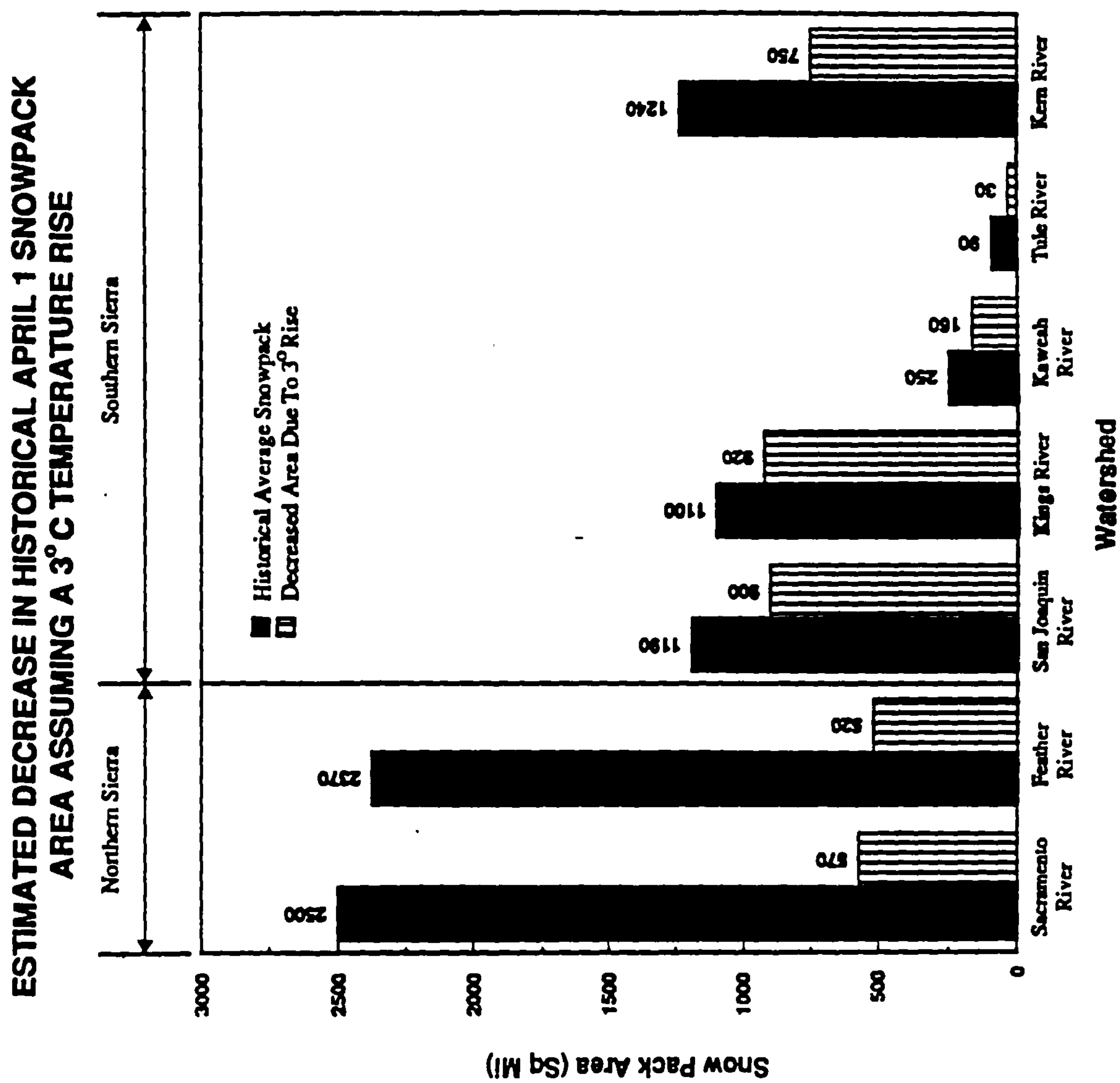
TYPICAL NORTHERN SIERRA WATERSHED



TYPICAL SOUTHERN SIERRA WATERSHED

California Energy Commission

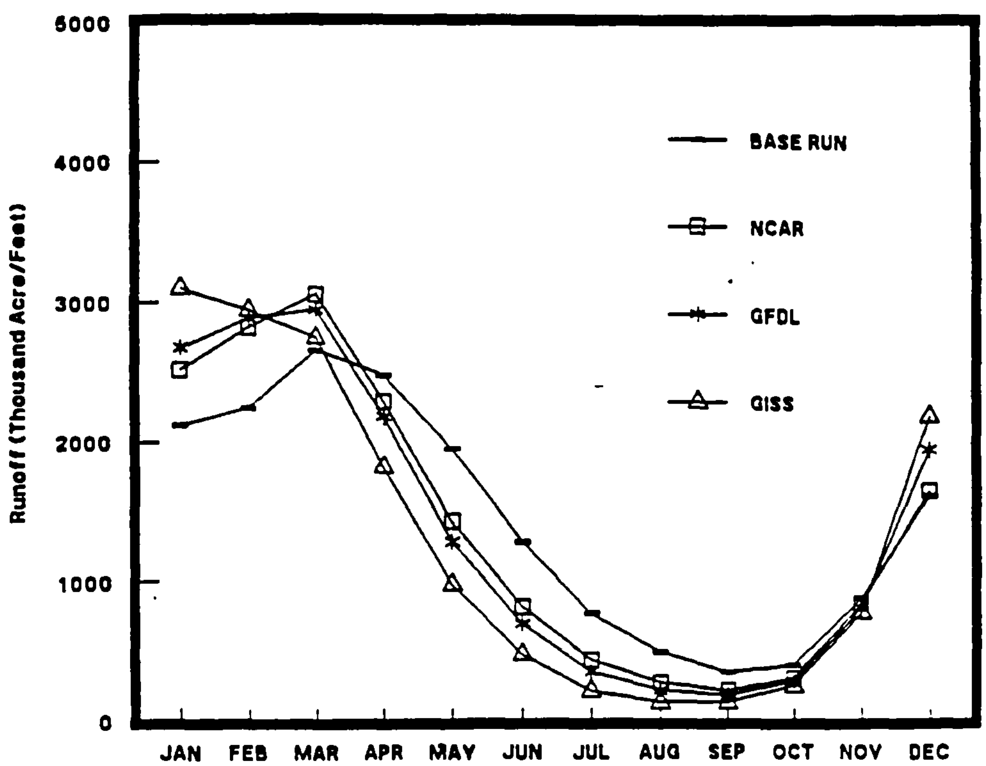
Figure 17



Data from California Department of Water Resources

Figure 18

TIMING OF RUNOFF



Average-monthly model runoff for the base run and the three GCM temperature runs (assuming no change in precipitation). Note that for all three GCM runs, runoff is higher in the winter and lower in the summer than base runoff.

Source Gleick, Peter H., 1987

WATER DEMAND

Higher summertime temperatures resulting from a doubling of CO_2 are likely to increase agricultural and urban water demand.

Temperature increases of 3 C (5.4 F) could affect irrigation water demand through changed agricultural practices, soil moisture relationships and evapotranspiration rates in irrigated agriculture and through increased evaporative and evapotranspiration rates in urban areas. Agriculture accounts for over 80 percent of California's water demand, consuming approximately 27 million acre-feet/year (see Table 2). The evaporation and plant use of irrigation water in California is driven by solar radiation, wind, air temperature, and relative humidity. If other factors remain the same, increasing air temperatures by 3 C will accelerate evapotranspiration and thus water demand, as well as indirectly increasing the use of irrigation water for crop plant cooling.

The major climatic factor influencing urban demand in California is temperature. Residential water demand is driven mainly by high summer temperatures which causes increased water use for landscape irrigation and evaporative air conditioning. Evaporation losses from swimming pools would also increase residential demand. Commercial demand would be expected to rise due to increased use of water for air conditioning and landscape irrigation and water demand for some manufacturing processes and industrial evaporative cooling (e.g., brewing, food production, energy production, and oil refining).

While water demand in the above areas may increase, California water supplies will still be demanded for in-stream uses such as fisheries, boating, maintaining water quality, etc.

Table 2 -

BUSINESS AS USUAL PROJECTIONS
PROJECTED STATEWIDE USE OF WATER SUPPLIES
BY DECADES TO 2010
(in 1,000s of acre feet)

	1980	1990	2000	2010	Change 1980–2010
NET WATER USE					
Irrigation	27.045	27.865	28.215	28.725	1.680
Urban	4.978	5.670	6.205	6.840	1.862
Wildlife and Recreation	646	700	710	720	74
Energy Production	58	120	160	176	118
Conveyance Losses	1.093	930	885	870	−223
TOTAL	33.821	35.285	36.155	37.330	3.509
DEPENDABLE WATER SUPPLY					
Local Surface Water Development	9.274	9.350	9.350	9.390	116
Imports by Local Water Agencies	1.808	1.455	1.440	1.455	−353
Ground Water	5.839	6.010	5.980	5.990	151
Central Valley Project	7.077	7.680	7.950	8.110	1.033
Other Federal Water Development	5.115	5.110	5.180	5.200	85
Waste Water Reclamation	247	400	560	675	428
State Water Project	2.656 [1]	2.310	2.320	2.315	−341
TOTAL	32.016	32.325	32.780	33.135	1.119
GROUND WATER OVERDRAFT	1.790	1.960	2.245	2.875	1.085
SHORTAGE	15	1.010	1.130	1.320	1.305
RESERVE SUPPLY	1.413	820	880	.955	−458

[1] Includes SWP surplus water deliveries.

Source: California Department of Water Resources

FLOODING

Several million Californians live or work within flood prone areas. Global warming could increase the frequency, magnitude and extent of coastal and inland flooding.

Approximately 75 percent of California communities contain land which lies within Special Flood Hazard Areas (SFHA) or floodplains vulnerable to 1-in-100 year floods (i.e., a flood which has a one percent chance of occurring during any given year)[2] (see Figure 19). Many flood control structures are planned for protection against a 1-in-100 year flood, although flood damage often occurs with less intense floods (for example, the 1986 flood in the Central Valley was estimated to be a 67-year flood).

Global warming could increase flood hazards by causing the following:

- Higher winter temperatures may increase winter rainfall, decrease snowfall, and raise river stages and tides. Elevated stages and/or tides can weaken levees, making the Delta islands and other land dependent on levee protection more vulnerable to flooding.

- Winter flood hazards would be further aggravated by hotter summers and an attendant increase of forest fires. Runoff rates from watersheds denuded by fire would be higher, with greater soil erosion causing heavier deposits of sediment in streams and reservoirs, thereby reducing their flood-carrying capacity.

- Higher sea levels due to melting of continental ice, and warming and expanding ocean water may cause existing coastlines to move further inland, flooding low lying areas.

- Changing precipitation patterns and types could affect the frequency, timing and magnitude of floods resulting in expansion and/or relocation of current floodplains and Special Flood Hazard Areas.

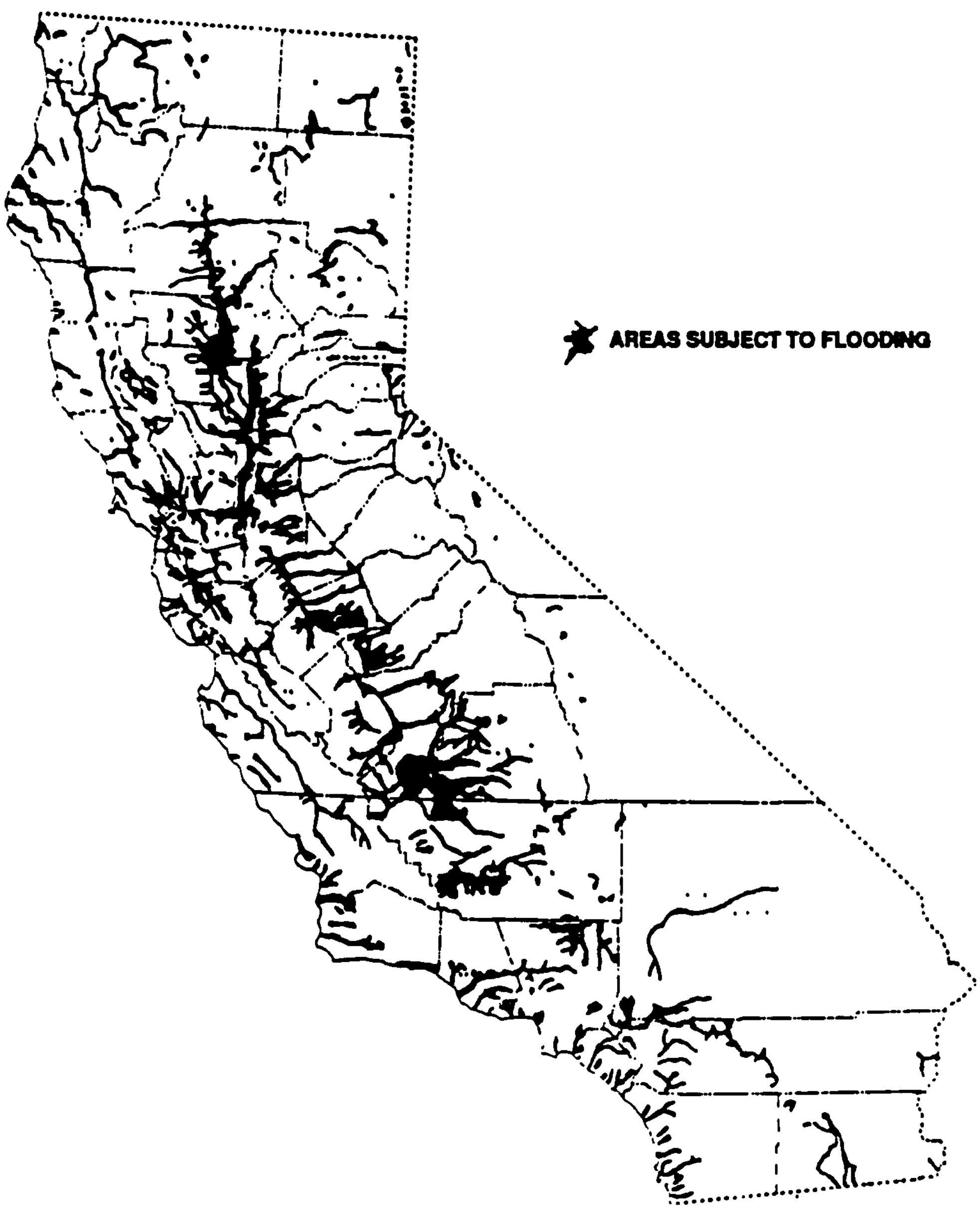
California may also face more intense storms. Most major California floods are produced by slow moving Pacific storm systems which sweep moist subtropical air from the southwest into California. When these moisture-laden air streams run into the mountains, copious amounts of rain and runoff result (orographic storms). The intensity of flooding involves a number of factors including (1) ground wetness, (2) strength of the southwesterly winds being lifted by mountain barriers, (3) moisture content of the air, and (4) snow level and storm activity. The major flood-causing Sierra storms have been predominately orographic processes. Two of the intensity factors are subject to change with global warming. Higher snow levels during storms in the Sierra mean more direct runoff. Also, warmer air can carry more water. A DWR model of orographic precipitation on the Feather River basin indicates a potential for 10 percent more precipitation with a 3 C (5.4 F) rise in temperature of incoming moist southwesterly air masses assuming no change in wind speed. A possible off-setting factor may be reduced strength of southwesterly storm winds because the temperature contrast between warmer tropical regions and the northern latitudes would be less according to climate models. It is unknown whether this overall change would result in slightly weaker Pacific winter storms.

---

[2] *It is possible for 1-in-100 year floods to occur three years in a row or not at all within a span of 500 years.*

Figure 19

FLOOD PRONE AREAS IN CALIFORNIA



SOURCE: Caltrans Map

California Region Comprehensive Framework Study - Water Resources Council

WATER POLLUTION

Reductions of summer flow in streams and rivers may concentrate pollutants discharged to receiving waters and intensify existing pollution problems.

Water pollutants are divided into three main groups: (1) chemical, (2) biological, and (3) physical. Examples of these groups are respectively: (1) industrial and municipal wastes, (2) human and animal wastes, and (3) eroded soil sediments. Pollutants are generated by many forms of human activity and from natural sources, such as mineral deposits and soil erosion. Pollutants affect the quality of both surface and groundwater (see Figure 20).

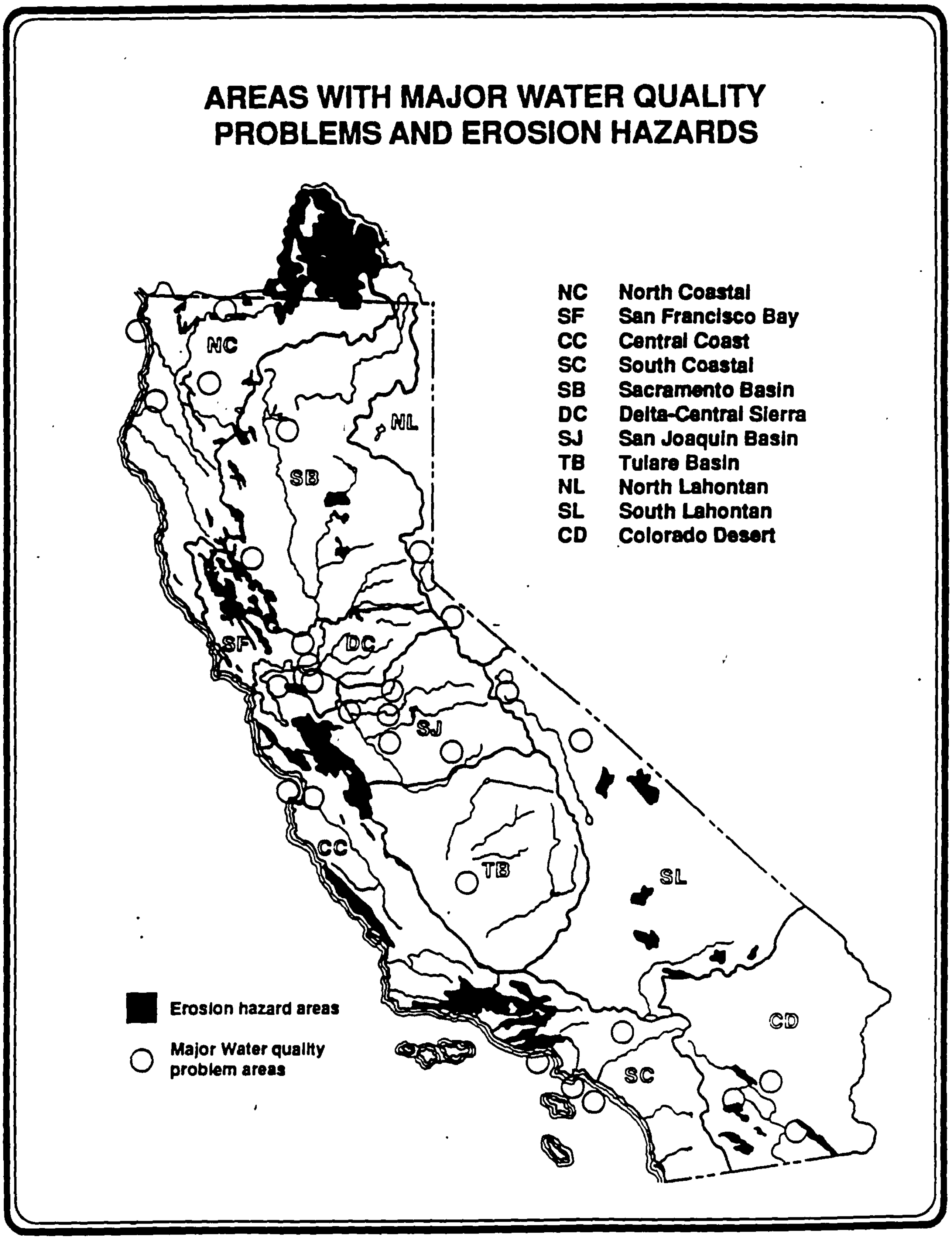
The concentration of water pollutants depends upon: (1) the amount of pollution discharged, and (2) the flow characteristics and volume of the receiving water. If spring and summer streamflows decrease (see snowpack storage section) the dilution capacity of streams will decrease accordingly, while the pollutant concentration will increase. This would result in greater local water quality degradation.

Reduced summertime freshwater inflow, higher pollution levels, and rising sea levels and related sea water intrusion may further degrade the waters of the Sacramento-San Joaquin Delta. Additional releases of carriage water (as much as twice current releases) from the State Water Project and Central Valley Project and other reservoirs may be necessary to maintain acceptable Delta water quality.

The rising sea level could also increase the intrusion of salt water into fresh water aquifers near the coast. This could jeopardize the quality of both urban and agricultural water drawn from wells.

Water quality of California lakes, streams, and rivers could change as water temperatures increase. A study of subalpine lakes indicates that the primary algae production could increase with increasing water temperature. This, in turn, could result in increased periods of stratification, oxygen depletion of bottom water, and stress on aquatic organisms (EPA, 1988). These effects could degrade, improve, or not change the quality of downstream waters, dependent upon specific circumstances of each body of water and associated downstream systems.

Figure 20


AREAS WITH MAJOR WATER QUALITY PROBLEMS AND EROSION HAZARDS
NC North Coastal
SF San Francisco Bay
CC Central Coast
SC South Coastal
SB Sacramento Basin
DC Delta-Central Sierra
SJ San Joaquin Basin
TB Tulare Basin
NL North Lahontan
SL South Lahontan
CD Colorado Desert
NC
SB
NL
SF
DC
SJ
CC
TB
SL
CD
SC
Erosion hazard areas
Major Water quality problem areas

ENERGY IMPACTS

Summary

The temperature increases projected from global warming may increase California's electricity demand while reducing supply.

California spends over $12 billion each year on electrical energy. That power is supplied by one of the most complex and diverse generation systems in the world. The smooth operation of the state's electricity system depends on careful long range planning; careful planning is facilitated if future energy supply and demand are predictable.

But global warming changes the predictability of electricity system demand and output. By the middle of the next century average warming of 3°C (5.4°F) centigrade could increase net annual electricity use by 1.4 to 2.5 percent. Peak demand could increase by 2.9 to 6.7 percent.

At the same time, warming could change the amount and timing of hydro-electricity supplies. By decreasing snow storage, warming would change the timing of runoff in the state's major rivers. For example, a preliminary estimate by DWR of the impact of a 3°C (5.4°F) warming at Oroville Dam indicated that peak electricity production would decline by about 3-7 percent. Perhaps more important is the possible shift in peak hydroelectric availability from summer and spring to earlier in the year when there is less demand for power.

Hydroelectric production in the Pacific Northwest could be similarly affected by a warming. And since California purchases a substantial portion of its electricity from the Northwest, any reduction in Northwest snowpack could further tighten the state's supplies during summertime peak periods.

California also receives electric supplies from the Southwest. There the warming could reduce hydroelectric supplies, and federal policy responses to warming, particularly CO_2 emission controls, could also affect coal-based electric supplies.

Overall California may face higher electricity demand while needing to rely more on its own resources to supply that electricity. This may be accompanied by greater variability in the weather conditions, which could further affect both supply and demand.

ENERGY DEMAND

A warmer climate may lead to increased air conditioning and water pumping, ultimately leading to both increases in both annual and peak electricity demand.

A warmer future climate means California will use energy differently than it does today. Certain energy uses are sensitive to changes in temperature; thus, as temperatures increase, energy requirements will change. The primary temperature-sensitive services in California are the heating and cooling of residential and commercial buildings and the pumping and transport of water for agriculture.

Considering only changes in heating and air conditioning, a 3°C increase in mean temperature may increase net annual electricity use in California from 1.4 to 2.5 percent over use in the absence of warming. This projection of a net increase in electricity use indicates that the decrease in wintertime space heating demand would not offset the much larger increase in summertime air conditioning demand. The percentages translate into an absolute increase of 6,000 to 11,000 gigawatthours (GWH). Table 3 depicts the range of response, which depends on whether the temperature sensitivity of demand is low or high. To put these estimates in context, a 1,000 megawatt baseload power plant operating at 70 percent capacity would generate 6,132 GWH of electricity each year.

Because California's electric utilities experience their peak demands in the summer, any warming-induced increases in projected air conditioning load will lead to higher peak demand. The effect of global warming on peak demand is less certain that it is on overall energy use. This is because peak demand is highly sensitive to changes in weather variability. Again, accounting for only changes in heating and air conditioning, the estimates of increases in peak demand range from 2.9 percent to 6.7 percent above projected demand in the absence of warming (see Table 4). Such a percentage change could lead to a 2,900 to 6,600 megawatt increase in statewide peak load by 2050.

Overall, the effects of global warming on heating and cooling systems appear moderate on a percentage basis. But, because California's electricity system is so large, even moderate percentage increases would result in substantial changes in absolute demand.

Table 3
ESTIMATED EFFECTS OF A 3°C GLOBAL WARMING ON ANNUAL ELECTRICITY USE BY 2050

		Gigawatthour (%) Change from Base Case					
Planning	Base	Low Sensitivity Case			High Sensitivity Case		
Area	Case	Heating[1]	Cooling[2]	Net	Heating[1]	Cooling[2]	Net
PGandE	171841	-2227 (-1.30)	4990 (2.90)	2763 (1.60)	-2351 (-1.37)	7795 (4.54)	5444 (3.17)
SMUD	20733	- 784 (-3.78)	478 (2.31)	- 306 (-1.47)	- 799 (-3.85)	667 (3.22)	- 132 (-0.63)
SCE	164211	-1714 (-1.04)	4099 (2.50)	2385 (1.46)	-1833 (-1.12)	5636 (3.43)	3803 (2.31)
LADWP	41827	- 542 (-1.30)	1044 (2.50)	502 (1.20)	- 602 (-1.44)	1435 (3.43)	833 (1.99)
SDG&E	34931	- 679 (-1.94)	1308 (3.74)	629 (1.80)	- 780 (-2.23)	1861 (5.33)	1081 (3.10)
Total	433543	-5946 (-1.37)	11918 (2.75)	5972 (1.38)	-6364 (-1.47)	17394 (4.01)	11030 (2.54)

Notes:

1. The projected heating impacts are made under the assumption that average winter temperatures increase by 3.6°C.

2. The projected cooling impacts are made under the assumption that average summer temperatures increase by 2.4°C.

3. See Appendix A for further details.

Table 4
ESTIMATED EFFECTS OF A 3°C GLOBAL WARMING ON PEAK DEMAND BY 2050[1]

Planning Area	Base Case	Megawatt (%) Change from Base Case: Low Sensitivity Scenario Nonuniform[2]	Low Sensitivity Scenario Uniform[3]	High Sensitivity Scenario Nonuniform[2]	High Sensitivity Scenario Uniform[3]
PGandE	37144	1070 (2.88)	1756 (4.73)	1515 (4.08)	1970 (5.30)
SMUD	5312	219 (4.12)	247 (4.65)	256 (4.82)	524 (9.86)
SCE	38835	1118 (2.88)	1752 (4.51)	1631 (4.20)	3225 (8.30)
LADWP	10570	152 (1.44)	350 (3.31)	302 (2.86)	396 (3.75)
SDG&E	7313	316 (4.32)	381 (5.21)	388 (5.31)	491 (6.71)
Total	99173	2876 (2.90)	4487 (4.52)	4093 (4.13)	6606 (6.66)

Notes:

1. Under the assumptions used in this energy impact study, a 3°C average annual warming results in a 2.4°C increase in average summer temperatures.

2. The nonuniform case assumes that the pattern of hourly temperature increase is not uniform on the peak day, i.e., the minimum temperature is assumed to increase much more than the maximum temperature.

3. The uniform case assumes that the pattern of hourly temperature increase in nearly uniform on the peak day, i.e., minimum temperature increases only slightly more than the maximum temperature.

4. See Appendix 4 for further details.

IN-STATE HYDROELECTRIC POWER

Global warming could reduce the amount and timing of California hydroelectric power supplies by changing spring and summer runoff patterns. Reduced hydroelectric generation could increase the cost of energy supplies if utilities substitute for the loss of hydropower with thermal generation plants.

Hydroelectric plants within California currently supply nearly 9,000 megawatts of generating capacity. Global warming may reduce California hydroelectric supplies by reducing the volume of winter snowpack area. On a typical central Sierra Nevada river, a 3°C (5.4°F) average rise would reduce average April 1 snowpack area by 54 percent. This would cause the estimated April through July runoff to decrease by about 30 percent (DWR, 1989). The relative change in the runoff season can be expected to be less dramatic in higher basins, where a moderate rise in elevation causes a smaller change in the snow covered area.

Increased winter runoff, and reduced spring and summer runoff, could impact hydroelectric generation because of the limited holding capacity of existing reservoirs. Higher winter flows could force more frequent hydro spills from storage reservoirs to maintain an adequate flood reserve. This would reduce spring and summer hydroelectric power generation, the peak load period. Table 5 illustrates the decline in energy and peak capacity generators at Oroville dam resulting from a 3°C (5.4°F) warming (DWR, 1989). Further, increased winter generation would not capture the full value of hydropower, since the energy would be more available in the winter when demand is low, and less available in the spring and summer when demand is high.

A less certain but potential outcome of global warming is reduced precipitation. While global warming will not necessarily reduce precipitation levels in California on an annual basis, some researchers have suggested that the probability of drought in central and southern California will increase. A higher incidence of drought would further reduce overall hydroelectric supplies, in all likelihood increasing the use of existing fossil fuel-fired plants to make up the shortfall. This, in turn, could lead to increased output of carbon dioxide.

An analogy of the cost of shifting from hydroelectric to thermal-generated plants can be derived by using projections of average and dry water years and determining the cumulative effect of consecutive drought years. These cost estimates are shown in Table 6. It should be noted that a change in the timing of spring and summer snowmelt would compound the projected impact of a decline in precipitation. Also, while some current projections estimating the effect of reduced California precipitation assume a parallel reduction in Pacific Northwest (PNW) water supplies, a global warming would amplify the effect of reduced water supplies in the PNW by also changing spring and summer runoff patterns.

Table 5

EFFECT OF 3° C GLOBAL WARMING, ESTIMATED IMPACT OF REDUCED SNOWPACK ON OROVILLE RESERVOIR COMPLEX HYDROELECTRIC GENERATION

	Base Study	Reduced Snowmelt Maintain Project Releases	Reduced Snowmelt Modify Project Releases
Apr-July Inflow, 1000 AF	1,430	580	580
May-Sept Downstream Releases, 1000 AF	1,341	1,341	1,025
End of May Storage, 1000 AF	3,398	2,799	3,008
End of Sept. Storage, 1000 AF	2,373	1,485	1,928
Total Annual Energy, GWh	2,195	2,050	2,125
Average June-Aug. Capacity, MW	900	840	876
Percent Energy Reduction	---	6.6	3.2
Percent Capacity Reduction	---	6.7	2.7

Table 6

COMPARISON OF PRODUCTION COSTS AND ENERGY GENERATION BETWEEN NORMAL AND ADVERSE HYDRO YEARS

PRODUCTION COSTS IN MILLIONS OF $

3 UTILS	1991	1992	1993
NORMAL YEAR	5471	6002	6584
DRY YEAR	6666	7364	8053
CHANGE IN COSTS	1195	1362	1469

CALIFORNIA HYDRO AND NORTHWEST ECONOMY ENERGY IN GWH

CALIFORNIA HYDRO			
NORMAL YEAR	35905	35905	35905
DRY YEAR	22276	22276	22276
CHANGE IN GWH	-13629	-13629	-13629
NORTHWEST ECONOMY			
NORMAL YEAR	12999	13545	14245
DRY YEAR	0	0	0
CHANGE IN GWH	-12999	-13545	-14245

CALIFORNIA OIL/GAS USE

IN GWH

NORMAL YEAR	23883	25627	28817
DRY YEAR	48562	51766	55883
CHANGE IN GWH	24679	26139	27066

IN TBTUs

NORMAL YEAR	267.6	283.1	313.9
DRY YEAR	502.3	534.1	574.5
CHANGE IN TBTUs	234.7	251	260.6

IN MM BBLS OF OIL EQUIVALENT

	40.5	43.3	44.9

SOURCE: SUPPLY FORECASTING OFFICE ICEM RUNS FOR ER-7

MAJOR ASSUMPTIONS: - BFR PRICE FORECAST
ADOPTED LOADS
W ALSO HAS DROUGHT
HEN CALIFORNIA HAS
ROUGHT.

1. The change in production costs for PGandE, SCE, and LADWP between normal and adverse hydro years can be determined by estimating the hydroelectric production capability during these differing conditions.

2. Global circulation models are limited in their ability to predict regional weather patterns, and hence, it is not known whether California and the Northwest will experience more or less rainfall. Nevertheless, some climatologists believe global warming will cause an increased incidence of drought-like conditions in North America.

   According to streamflow models used by the CEC staff, dry conditions in California and the Northwest would result in a significant loss of California energy supply due to a reduction in hydroelectric production (in-state and imported from the Northwest).

3. The loss in hydroelectric power due to adverse hydro conditions would result in an increased reliance on oil and gas. Fuel use projections suggest that about twice as much energy would need to be produced by burning oil and gas during dry conditions in California and the Pacific Northwest.

OUT-OF-STATE POWER IMPORTS

Warming-induced changes in stream runoff patterns may limit the amount of surplus Pacific Northwest electricity available for purchase by California utilities.

The Pacific Northwest (PNW) electrical generation system consists of about 43,360 MW of installed generating capacity (excluding Canada). This capacity is made up principally of hydropower, and to a lesser extent coal, nuclear, oil/gas, renewable and pump/store resources. On average, hydropower produces about 16,400 aMW[3] of energy annually, approximately 70 percent of the electricity used in the PNW (CEC, 1988). Surplus hydroelectric supplies are typically most available from the PNW in the spring and summer, following annual snowmelt. This period of surplus supply corresponds well with California's summer peak demand period and provides a relatively inexpensive energy resource. Due to the low cost of PNW power, California imports between 30,000 GWh to 35,000 GWh each year. These imports represent inter-regional trade of several hundred million dollars annually and provide economic benefits to both California and the Northwest states.

Only about 40 percent of the average Columbia River Basin runoff, the principal source of runoff in the system, can be stored by United States and Canadian water projects (1986 Northwest Power Plan). Consequently, annual energy production from the system varies widely, depending on annual rainfall and snowpack accumulation. However, when snowpack provides needed storage capacity during winter months, the favorable timing of spring snowmelt ensures that hydroelectric generation occurs when the energy is most needed in California. Current projections of future surplus PNW energy supplies are based on assumptions that existing weather patterns in the region will remain relatively constant. Global warming scenarios, however, suggest that weather patterns may change significantly over the next 50 to 100 years, rendering historic streamflow records less reliable for predicting future water availability.

While it is difficult to predict how "greenhouse" weather patterns are likely to affect specific geographic regions, the current scientific consensus suggests that northern coastal regions are likely to remain relatively cool and wet, while inland areas are expected to experience warmer, more arid conditions (Flasch Ka, et al., 1987). Hotter inland temperatures could reduce the availability of PNW hydroelectric supplies because the headwaters of the Columbia River system and the Snake River systems originate in the eastern Rocky Mountain states. This area includes Idaho and Montana, as well as British Columbia (1986 Northwest Power Plan). Less precipitation due to global warming in this inland region would result in lower water supplies throughout the Western United States, including the PNW. However, the potential of increased precipitation along the coast could conceivably compensate for the decline in water supplies inland. Therefore, a large degree of uncertainty is inherent to any discussion of the effects of global warming in the PNW.

Despite this uncertainty, some studies regarding the potential effect of global warming on water availability in the Western United States have been completed. They suggest that while changes in the total amount of precipitation are difficult to anticipate, warmer winters due to global warming would affect the timing of "spring" runoff. Warmer winter temperatures are expected to cause more precipitation to fall as rain, instead of snow. This would reduce the natural storage capacity provided by winter snowpack and shift the normal runoff period to earlier in the year. An indication of the likelihood of warmer winters occurring in the PNW

---

[3] *The term "average megawatt" or "aMW" refers to an amount of energy equal to the year round production of one megawatt of capacity. Since there are 8,760 hours in a year, one aMW is 8,760 megawatt hours or 8.76 GWh. At times, documents refer to average megawatts for lesser amounts of time (e.g., a month or less). In such cases, the amount of energy is always equal to the number of megawatts times the number of hours involved.*

is already evidenced by steadily retreating glaciers in the region. While glacial melt is not currently referred to as a definitive result of global warming, this phenomena is not inconsistent with global warming scenarios.

The impact to California of an earlier "spring" runoff in the PNW could be to diminish available surplus energy supplies during the time period when California has the greatest need. California electrical loads peak in the summer when air conditioning requirements are highest. An earlier runoff period would reduce the value of purchasing surplus energy supplies, as this supply would no longer coincide well with California's peak demand period. In addition, if new water management measures are not taken, increased competition for limited water supplies during the summer months could further reduce the availability of surplus hydroelectric supplies from the PNW.

Though hydroelectric supplies represent the principal source of power in the PNW, coal-fired facilities produce approximately 54,700 GWh annually (CEC, 1988). Due to the high CO_2 emission per unit of energy produced by coal combustion, coal-fired power plants may be targeted by emerging federal and state laws designed to reduce greenhouse gas emissions. Surplus Northwest hydroelectric supplies may represent a regional energy resource which could potentially compensate for any loss of coal-fired capacity in the PNW. As a result, possible Federal policies restricting coal use could further affect imports of PNW energy to California.

<u>California power imports from the Southwest (SW) may be reduced due to global warming if federal or state policy restrictions on coal-fired generating facilities are implemented.</u>

On an annual basis, California imports between 18,000 and 22,000 GWh from the Southwest (SW). The SW region includes Arizona, Colorado, Nevada, New Mexico, Utah, portions of West Texas, and Mexico, though Arizona and New Mexico represent the most significant export regions to California. About two thirds of California's SW power is purchased under contract or is owned by California utilities holding shares in SW power facilities, while the remainder is purchased on the spot market as economy energy (CEC, 1988).

Energy produced in the SW is generated principally by coal-fired plants, but also depends on nuclear, gas, oil, and hydropower. Because the long-term contracts between the SW and California are generally priced below the long-term marginal costs of California utilities, California has been able to defer the costs of constructing new, in-state power facilities. Further, out-of-state generation allows California to benefit from the low fuel costs provided by coal and provides additional energy supplies which, because of prevailing wind pattern, does not contribute to California's air pollution problems.

However, emerging U.S. Congressional concerns regarding global warming may limit the price and/or the availability of coal-fueled electricity. For example, Senate Bill 2663 (Stafford, 1988) calls for a fuel tax which targets high CO_2 fuels such as coal and oil to create incentives to promote efficiency in fuel combustion and reduce greenhouse gas emissions.

The additional costs incurred by such a tax could raise the price of energy and may reduce the economic incentive to purchase SW power. Further, the construction of additional utility and independent plant proposals may be deferred to avoid the added operational costs imposed by an emission tax or as a result of other coal combustion restrictions. Thus, proposed legislation may not only restrict existing supplies by levying higher operating costs upon coal-fired facilities, but it may also limit new energy supplies to California.

Another possible impact of global warming may be to reduce the surplus generating capacity in the SW which can be used to meet California energy needs. Already, California and the SW both experience peak loads during the summer, when air conditioning and water pumping requirements are greatest. Global warming is expected to increase energy use during these peak demand periods, as summer air conditioning and water use requirements increase. While the total amount of surplus energy available to California may not be dramatically reduced, this surplus may only be available to California during off-peak hours, when utility loads are at a minimum. Because California utilities must maintain minimum generation levels at instate facilities to ensure a reliable power supply when demand fluctuates, even if surplus supplies are available from the SW, California utilities may not be able to use this economy energy. It should be noted, however, that if global warming impacts do not appear within a few decades, surplus capacity in the SW may already be reduced due to population and energy market growth in the SW.

AGRICULTURE

Summary

<u>While global warming may have both positive and negative impacts on California's agriculture, the most significant impact may be the dramatic amount of change itself.</u>

Agriculture plays a major role in California's economy. In 1987 California farmers produced $15.9 billion in food and fiber. The agricultural industry, which absolutely depends on basic farm production, added some $93 billion (over 15 percent of the total) to the California economy. Farm and ranch land occupy 28 million of the state's 100 million acres, with 9.3 million irrigated acres contributing the overwhelming majority of California's farm production (see Figure 21).

While farmers by their nature seek to control the environment, they are also very sensitive to changes in their immediate climate. Excesses of heat, cold, drought, floods, and general weather variations are all the enemies of farmers. Thus, in many ways farmers may be more vulnerable to warming than other Californians.

A warming could present farmers with these serious weather-related changes:

- Heat - A 3°C (5.4°F) increase in summer temperatures may make some crops untenable in their current growing areas.

- Drought - Even if precipitation does not change, less water may be available for farmers. (For example, at double CO_2, the state water project would deliver 7 to 16 percent less water.) At the same time, higher temperatures may increase the need for water (perhaps as much as 25 percent more for some crops).

- A rising ocean level may threaten farm land in low-lying coastal and delta areas and may degrade irrigation water quality through salt water intrusion.

- Warming may lead to increased air pollution, which would in turn result in increased pollution-caused crop damage.

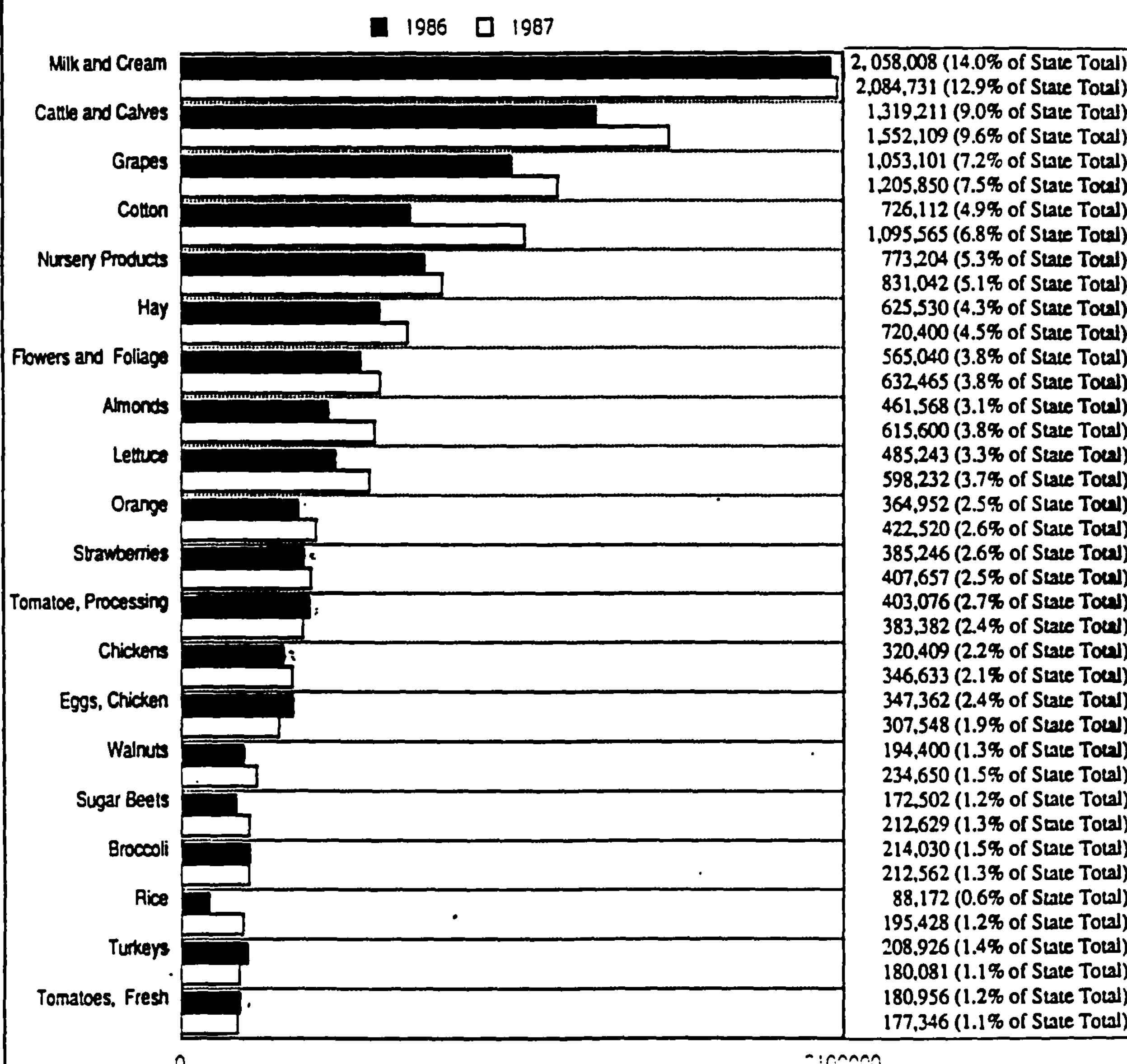
- Weather variation - Some scientists feel the transition to a warmer climate will bring increased weather variability. Possibly the most serious problem the warming may bring, particularly during a transition from current to warmer equilibrium temperatures, is an increase in weather variation. Increased variation can upset farmers' annual and long-term planning, as well as jeopardize their ability to accommodate long-term warming-induced changes.

Farmers could benefit from a greenhouse-induced warming. Increased levels of CO_2 may increase plant growth and the efficiency with which many crops use water. And, while warming will bring higher summer temperatures, it will also bring a longer growing season.

Historically farmers have shown an ability to adapt to a changing climate. And because of our vast water system, agriculture in California is more flexible than in many other parts of the world. The crucial question is whether California farmers can accommodate more total climate change in the next 50 years than farmers have faced over the last 10,000 years.

Figure 21

Ranking and Value, 20 Leading Farm Products, California, 1986-87



* Based on value of quantity harvested for crops and on value of quantity marketed for livestock and poultry products.

** Due to revisions in valuations, the prior-year ranking of acommodity may not match the ranking listed in previous publications.

EFFECT OF HIGHER TEMPERATURE ON AGRICULTURE

Projected temperature increases may make some crops untenable in California's major agricultural areas. Warming should, however, lengthen the growing season throughout the state, allowing some crops to be grown in new areas and allowing double cropping where now only single crops are grown.

A 3°C (5.4°F) rise in temperature will shift the agricultural environment in interior California north about 200 miles. The climate in the Southern San Joaquin Valley would become similar to that in the Imperial Valley, while the climate in the Northern Sacramento Valley would be more like the Southern San Joaquin (see Figure 22).

It is unlikely that temperatures resulting from an effective CO_2 doubling will render any of California's current agricultural areas unfarmable. However, the northward shift of climate could substantially change the kinds of crops different areas can support. Crops such as sugar beets and tree fruits are currently widely grown in the southern San Joaquin Valley but not, to any degree, in the Imperial Valley. Walnuts, common in the northern Sacramento Valley, are rarely commercially grown in the San Joaquin Valley.

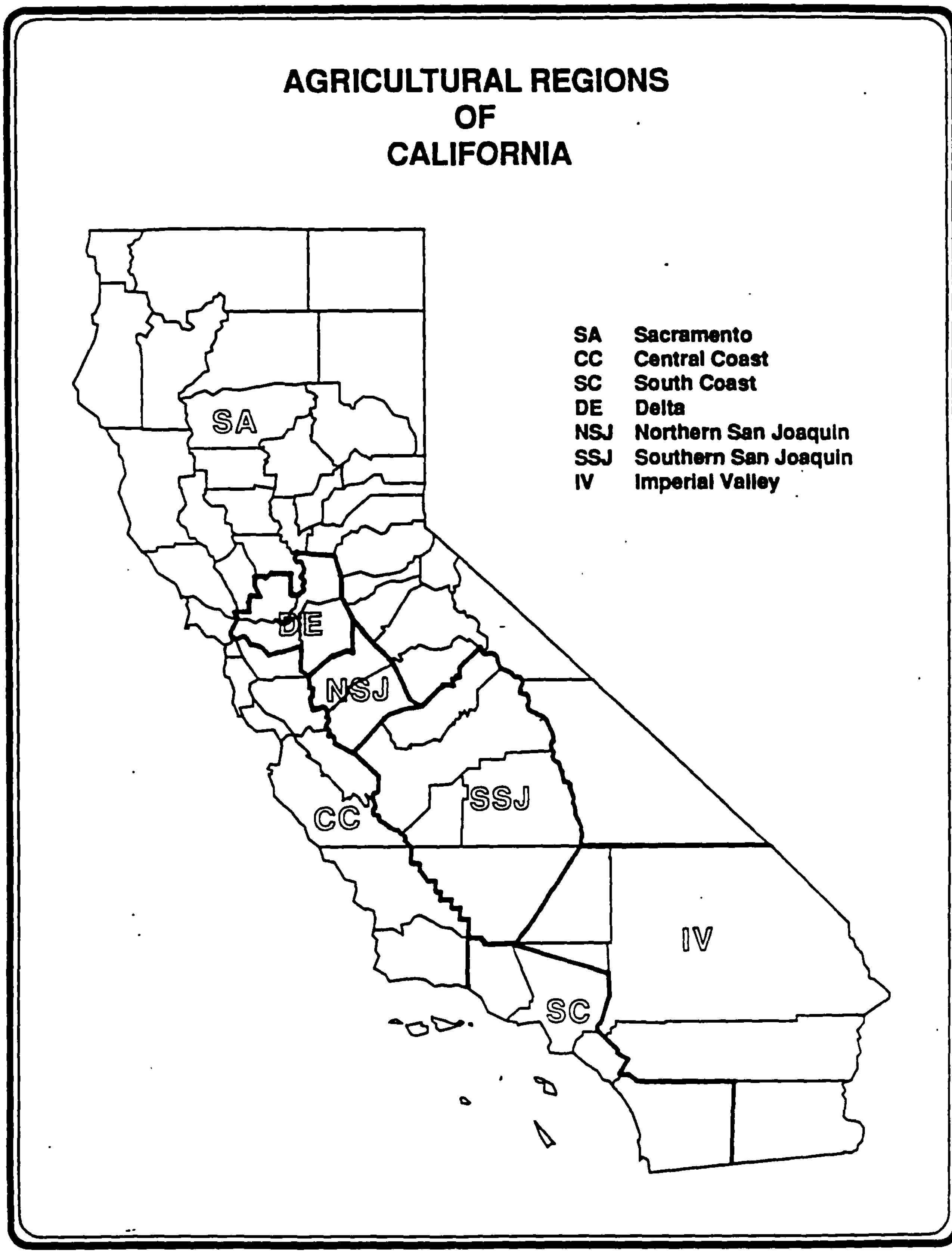
Taken by itself, increased heat can substantially reduce the yield of some crops. For example, the per acre yield of tomatoes could decline by 5-15 percent while that of sugar beets could decline by 20-40 percent. (Note that the growth enhancing effect of increased levels of CO_2--discussed in the section on CO_2 fertilization--could partially or totally compensate for these declines).

On the other hand, specialized crops such as winter vegetables and avocados which are now limited to the most southern parts of California, may become viable in the San Joaquin Valley. Double cropping, which is common in the Imperial Valley, may become more common in the Sacramento Valley. Crops that have been limited to the floor of the Central Valley may become possible in foothill farm regions.

Two other possible impacts of warmer temperatures should be mentioned. First, warmer temperatures over urban areas may exacerbate existing air pollution problems. Crops in several agricultural areas of the state already suffer damage from urban-generated pollutants (especially ozone). This damage is expected to increase for some time into the future under current climate conditions. Global warming may exacerbate pollution problems, and as a result, further increase pollution-caused crop damage.

Second, by increasing evapotranspiration, a warmer climate may exacerbate current problems associated with soil salinity in some areas of the Central Valley. The surface and subsurface salt concentrations in these areas are already affecting crop production and creating drainage problems. While this factor could be partially overcome by applying additional water to the soil, that water may be increasingly difficult to obtain (water supply and agriculture will be discussed in the next section).

Figure 22


AGRICULTURAL REGIONS
OF
CALIFORNIA
SA Sacramento
CC Central Coast
SC South Coast
DE Delta
NSJ Northern San Joaquin
SSJ Southern San Joaquin
IV Imperial Valley
SA
DE
NSJ
SSJ
CC
IV
SC

CHANGES IN WATER SUPPLY AND DEMAND

The expected decreases in irrigation water supplies and increases in demand may have a significant impact on the California agriculture industry.

California farmers irrigate over 7.8 million acres of farm land using over 27 million acre feet of water each year (over 80 percent of the state's annual water use). Sixteen of the top 20 farm products in the state are irrigated. These 16 crops alone account for over half of the state's total crop value.

Global warming may reduce water supplies to agriculture in two ways. First, warmer winters would mean more annual precipitation would fall as rain and run off during the winter, rather than falling as snow and gradually melting and running off during the growing season. This may reduce Central Valley Project water deliveries by 7 to 16 percent in normal years. Second, higher air temperatures may raise the evapotranspiration rate and reduce soil moisture content, and slightly reduce surface water supplies.

At the same time, crops may use/consume more water. The atmospheric climate models generally agree that interior California will remain dry and become hotter during the growing season. This means that the evapotranspiration rate in any particular area will probably increase. For example, by analogy, an acre foot of water produces about two tons of alfalfa in Butte County, while only producing one and one-half tons in Kern County (roughly 3°C [5.4°F] warming). But some crops may experience productivity changes without appreciable changes in water use efficiency. In addition, increased concentrations of CO_2 may improve the water use efficiency of some plants (see section III.D.4 for a more detailed discussion).

There is currently a great deal of competition for water in California. The potential decreases in supply and increases in demand would inevitably lead to even greater competition for existing water supplies. This, in turn, could result in any of the following:

- Higher water prices - Possibly high enough to preclude some irrigated crops.
- Increased efforts by farmers to maximize the value of their water changes in both the crops that are grown and the way they are irrigated.
- Increased water marketing and the transfer of water supplies from uses with low economic value to those of higher dollar value.

If nothing else changed, a decrease in water deliveries would decrease overall farm production. But many other factors such as increased water use efficiency and the ability to switch crops as well as possible increasing competition from urban water users must be considered before concluding that the agriculture industry would suffer from greenhouse-induced warming.

CARBON DIOXIDE FERTILIZATION

While an increased CO_2 concentration may increase atmospheric temperatures, it may also stimulate growth and increase water-use efficiency of some plants.

Carbon dioxide is essential for growing plants. As a part of their growth processes, plants take in carbon dioxide and give off oxygen and water vapor. Provided other resources are available, many plants grow faster and bigger with higher concentrations of CO_2.

Most agricultural crops are either what are termed C3 or C4 plants (these terms refer to the metabolic pathways of the plants). Generally, crops that originated in temperate areas (wheat, oats, rice, soybeans, and alfalfa, for example) are C3 plants. Most C4 plants originated in tropical areas (examples include corn, sugar cane, and sorghum [see Figure 23]).

There is strong evidence that when CO_2 concentrations increase, the photosynthesis of both C3 and C4 plants increases. There is also evidence that C3 plants experience much more growth at a given concentration than C4 plants (see Figure 24).

However, one must be careful about drawing the general conclusion that overall farm production will increase with increased CO_2 concentrations. Corn, for example, is a C4 plant with mostly C3 weeds; thus higher levels of CO_2 may encourage weeds to outcompete corn crops. Also, there is evidence that CO_2-induced increases in growth may increase insect damage. And finally, there is also some evidence that the food value of some crops goes down when grown in higher CO_2 concentrations.

Research also shows that C4, and to some extent C3 plants, use water more efficiently when grown in high concentrations of CO_2. The early research indicates that this effect may increase plant water use efficiency by an average of 10 percent, partially offsetting the increased evapotranspiration most plants experience in a hotter, drier climate.

Overall, plant response to increased CO_2 concentrations should offset some of the negative effects of a warming on agriculture. Unfortunately, there are not sufficient data to determine whether the positive impacts will fully compensate for such negatives as decreases in irrigation water and increases in air pollution (see Table 7).

GLOBAL ANNUAL PRODUCTION OF C3 AND C4 CROPS.

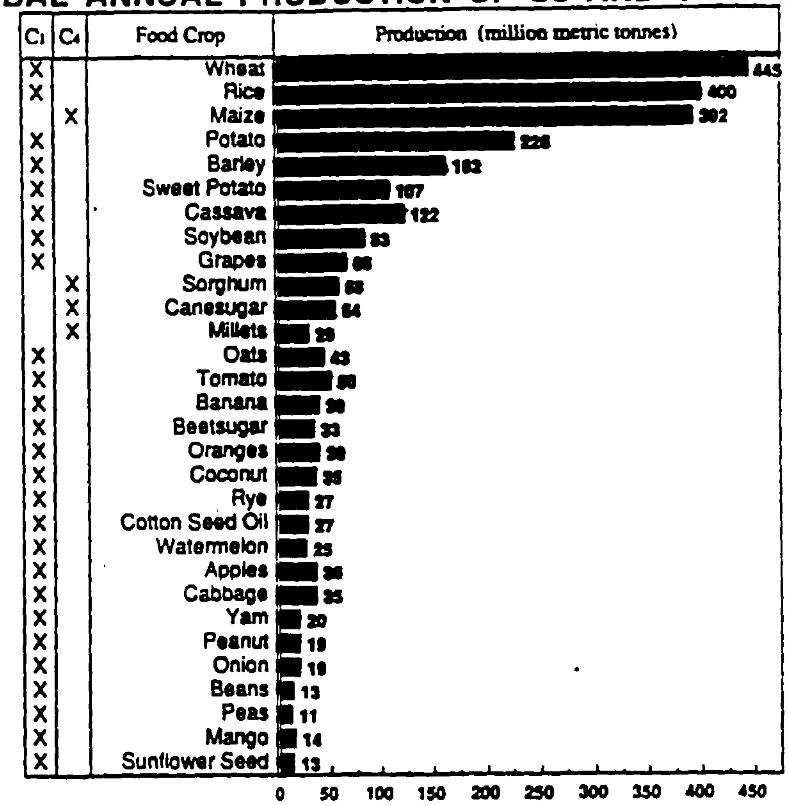


Figure 23

Examples of C3 and C4 crops and their global annual production (fresh weight) as reported by FAO production yearbook 1980 (adapted from Swaminathan. 1984).

RESPONSE TO INCREASE CO_2 CONCENTRATIONS

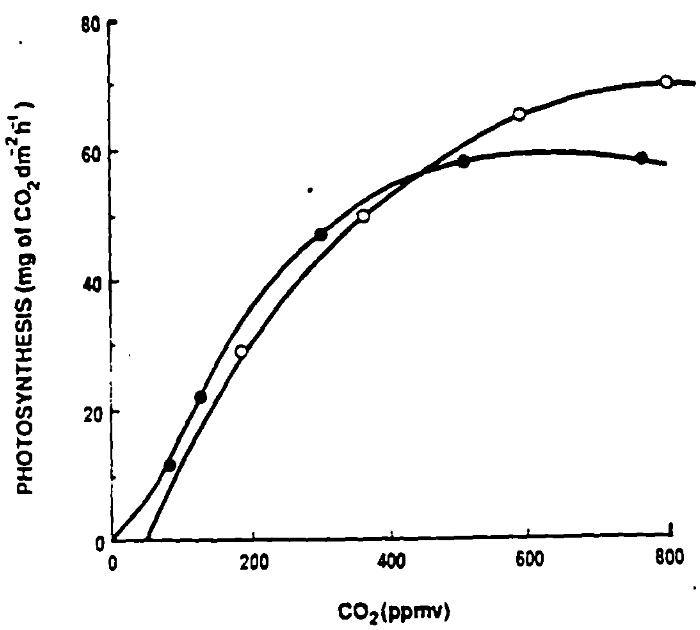


Figure 24

Bolin et al

Table 7

CHANGES IN CALIFORNIA AVERAGE PERCENTAGE CROP YIELD
AS A RESULT OF WARMING

		Crop							
		sugarbeets		corn		cotton		tomatoes	
Region[b]	Scenario	CC	Net	CC	Net	CC	Net	CC	Net
South Coast									
Los Angeles	GISS	-26	21	-41	-37	-22	11	-7	18
	GFDL	-20	30	-26	-22	-4	41	-5	21
North Interior									
Red Bluff	GISS	-28	12	-27	-22	-18	22	-15	11
	GFDL	-23	21	-14	-8	-10	35	-13	13
Sacramento Valley									
Sacramento	GISS	-30	17	-20	-14	-17	25	-12	16
	GFDL	-27	22	-6	0	-11	34	-8	21
Southern San Joaquin									
Fresno	GISS	-33	5	-26	-21	-16	25	-15	11
	GFDL	-39	-8	-14	-8	-10	36	-13	14
Southern Deserts									
Blythe	GISS	-40	-2	-31	-27	-28	6	-13	13
	GFDL	-39	0	-14	-8	-19	21	-12	15
CARM Statewide									
	GISS	-30	12	-21	-17	-17	23	-13	5
	GFDL	-26	15	-9	-4	-10	35	-11	16

Regional and statewide percentage yield changes (relative to 1985) under different General Circulation Model climate scenarios. Regional changes are projected by the Doorenbos and Kassam agricultural productivity model while statewide production changes are projected by the California Agriculture and Resources Model (CARM). The latter estimates include economic adjustment "Net" includes the direct effects of increases in CO_2 and climatic change (CC).

CALIFORNIA RANGELANDS

Global warming may reduce the viability of rangelands in some areas while increasing productivity in other areas.

Assuming an effective doubling of CO_2 by about the year 2050, climatic models have been used to show the potential impacts of global warming on California rangelands. Though the models rely on idealized, uniform geography, and California's regional topography varies dramatically, the model results suggest that range lands could both benefit and suffer from global warming.

Some of the benefits of global warming with respect to California's rangelands include possible increased rainfall in mountanous and foothill areas and warmer winter seasons. Warmer winters could cause earlier melting of mountain snowpack areas and potentially an earlier growing season . Increased precipitation could lead to increased soil moisture in and near mountainous areas, thus increasing the yield of meadows and pasturelands in these areas.

Potential problems associated with a global warming are that drought-like conditions may become more frequent in some rangeland areas. Under drying conditions, there may be a decrease in the nutrients available to plants in grazing lands. This is because with warmer, drier conditions, some nutrients may be below the new wetting level of the soil. Lower soil moisture would also increase soil temperature, which could cause decreased plant production and cover. With less cover, surface temperatures would be further increased and thereby further increase soil temperatures. Loss of plant cover could also cause increased wind and soil erosion.

The total acreage of grazing or range lands could increase or decrease in the event of a global warming. Grazing land may increase due to the destruction of wood lands, which may be more sensitive to climatic changes than rangelands. Or, grazing lands may be lost due to desertification and the deleterious effects of wind and soil erosion. Further, there may be some tradeoff between crop land and grazing land, depending upon the need to increase crop land to meet food demands, and the relative economic return of grazing land and crop land. In any event, the continued commercial use of either grazing or cropland may require the use of more artificial nutrients to maintain the historic productivity of these areas.

WEATHER VARIABILITY

The most significant way a global warming may affect California's agriculture could be through an increase in weather variability.

Weather variability is the bane of farmers. Crops generally have certain times when they are very vulnerable to abnormal weather. Frost during bud set, rain during pollination, hail while the fruit is setting, heat waves when the fruit is maturing, and rain on ripening fruit can all damage crops. Farmers worry about too much cold, too much heat, too much dry, and too much wet. Weather variability brings an unequal distribution of benefits versus risks. Good weather can marginally improve crop yields; bad weather can destroy crops. Over the last several years, even minor variations in "normal weather" have caused hundreds of millions of dollars worth of damage to California's farms.

Some scientists feel that global warming will bring about an increase in weather variability, particularly during the transition from recent weather patterns to a new equilibrium caused by higher greenhouse gas concentrations. And, since stable greenhouse gas levels are not expected for at least several decades, this potentially unstable transition period may extend over many years.

More specific ways that weather variability may affect California are as follows:

Positive Impacts

- Increased rain especially during the spring and summer may reduce the need for irrigation water. Heavier than normal rain could also help recharge ground water.

- Hotter weather in general may increase the growth of some crops.

Negative Impacts

- Drought - Some researchers estimate that as early as the 1990s the United States will experience twice the number of drought years it did in the period from 1950 to 1980. Droughts, of course, can limit the amount of water available for crop irrigation (California had 47 percent of normal runoff in 1976, and 22 percent of normal in 1977).

- Spring Rains - Rain during the bloom period can interrupt pollination.

- Heat Spells - During certain times of the year (transplanting time, for example), plants can be heavily damaged by unseasonably hot temperatures.

- Summer Rains - Rains of any substance during the growing season of many crops can cause substantial damage from mildew and mold.

- High Winds - Wind can interrupt pollination, dry and damage crops, and damage crop trees.

- Flooding - Unseasonal flooding can wash out crops; even wintertime flooding can damage irrigation structures, leveled land, and other agricultural engineering investments.

- Cold Weather Following Early Spring Warming - A global warming may cause sporadic early season warming, but those early warm periods may not be consistent enough to prevent damage from later cold snaps. These cold snaps can damage young crops and forming fruit.

IMPACTS ON FORESTRY

Summary

Global warming may cause significant adverse effects on California's forests.

Warming could cause substantial changes in forest growth and could radically alter the ranges of the state's dominant forest species. The stress and drying expected in California's forests from warming could also increase their susceptibility to destructive forest fires, insects, disease, and pollution.

The scenario used in this report assumes that the amount and seasonal distribution of annual precipitation would be the same as at present and that temperatures will rise 3°C (5.4°F). The temperature rise alone will shift tree ranges northward and higher in elevation. Unless it was accompanied by summer rains, the temperature rise would also intensify summer drought conditions. This would increase water stress in tree species which require more moisture, and decrease their ability to survive and compete with more drought-tolerant species, particularly in the lower elevations and southern fringes of their ranges. Seedlings are especially susceptible to drought, so reproduction could decrease dramatically. Although anticipated increases in atmospheric concentrations of CO_2 may enhance trees' water use efficiency and nitrogen fixation (and thus stimulate growth), it is not clear whether the net effect of increased temperature and CO_2 levels will be to enhance or reduce forest productivity (Sandenburgh et al. 1987). Some feel that the beneficial effect of increased CO_2 will not be nearly as large as the concurrent growth losses resulting from the temperature rise (Solomon et al., 1984).

Tree communities eventually would migrate to new zones. In California, this phenomenon would be most noticeable as an upward shift in elevation of about 1,500 feet. Ranges will also shift northward somewhat. A substantial lag in productivity would occur because of the slow rate of migration of tree communities. Reestablishment would probably not occur on an intense, widespread basis until temperatures attain an approximate steady state. Therefore, if CO_2 generation continues to increase beyond the doubling point, adverse effects to California's forests could continue and intensify through much of the next century. If the seasonal pattern of precipitation shifts to more winter precipitation and summer drought, adverse impacts to forests would be even greater. Even if stable conditions develop, several centuries may pass before forests regain a healthy status (EPA, 1988).

A general decline in forest productivity in California would cause a decrease in employment in the timber industry, as well as decreased tax and other revenues. It is uncertain how competition with wood from outside the state would change, because the potential effect of warming on other areas is unknown. However, a greater scarcity of timber in California, combined with growing demand for wood products, would increase prices, making alternative building and heating materials relatively more attractive. These increased prices would inhibit the building industry to an unknown extent.

Changing species composition and productivity might alter the character of forestry operations. Obtaining adequate regeneration would be a major problem (Woodman, 1987). The large numbers of trees expected to die during shifts in species' ranges may lead to expanded salvage activities. The aesthetic appeal of currently popular recreation areas could be substantially degraded. Some forests could be replaced by grassland or desert conditions which will result in a severe change in existing land use (EPA, 1988).

COMMERCIAL SIGNIFICANCE OF CALIFORNIA'S FORESTS

Global warming may cause significant impacts to the state's forest resources.

The Commercial Importance of California's Forest Industry

California has an important forest industry. Approximately 18 percent of the land in California is productive forest land. Of these 18.6 million acres, about 16.5 million acres are available for commercial use. The state has about 213 billion board feet of standing timber (CDFFP, 1988a).

Lumber production in California declined from its peak of over 6 billion board feet in 1955 to an annual average of about 3.4 billion board feet between 1978 and 1985; it has since risen to about 3.9 billion board feet per year. The average yearly stumpage value during the period was $560 million. California was for many years a net exporter of lumber, but the decline in production combined with the large increase in demand in the state has reduced the proportion of lumber supplied from within the state to about 40 percent of the total used (CDFFP 1988a). About 3 billion board feet of timber, nearly 90 percent of California's annual harvest, is processed into lumber and other wood products in the state. An estimated 100,000 cords of hardwood are also cut each year for use in pulp and paper mills. Up to 725,000 cords of softwood are cut for firewood annually, in addition to a conservative estimate of 160,000 cords of hardwood (CDFFP, 1988a).

Although the role of the forest industries in the state has declined as other industries have grown (CDFFP, 1988a), lumber and wood products employment still totals about 100,000 persons, of whom about 50,000 depend on California-grown timber for their jobs. The forest industry is the mainstay of several rural California counties. Employment in the production of lumber and wood products as a percentage of total employment in 1984 was 41 percent in Sierra County, over 20 percent in Trinity, Plumas, Del Norte, and Siskiyou Counties, and over 10 percent in six other counties (CDFFP, 1988a).

The California Division of Forestry and Fire Protection has presented two different scenarios for future timber production in the state based on different assumptions, unrelated to global warming, regarding forest management policies. Under one scenario total timber production is projected to remain at a relatively constant level of 3.9 billion board feet per year through the year 2000, then decline until 2030, stabilizing thereafter at about 3.2 billion board feet. Under the other scenario, production levels would be at or above the current average annual harvest for the next 40 years (CDFFP, 1988a).

In addition to timber, California's forests also provide habitat for wildlife and represent a recreation resource. These aspects of the forests are discussed in sections of the report on wildlife and the economy. Much of the land in California for which the California Department of Forestry and Fire Protection has responsibility is rangeland. The livestock production which this provides to the state is discussed in the section of the report on agriculture.

Commercially Important Tree Species

Important commercial tree species in California include:

- Douglas-Fir (*Pseudotsuga menziesii*) and Big Cone Douglas-Fir (*P. macrocarpa*)
- White Fir (*Abies concolor*)
- Red Fir (*Abies magnifica* A. Murr)
- Ponderosa Pine (*Pinus ponderosa* Laws)
- Jeffrey Pine (*Pinus jeffreyi*)
- Sugar Pine (*Pinus lambertiana*)
- Incense Cedar (*Libocedrus decurrens*)

- Coastal Redwood (<u>Sequoia sempervirens</u>)
- Oaks (<u>Quercus ssp</u>).

Note: Oak is used primarily for firewood, while the commercial softwood species are used mostly for building and manufacturing.

California's wild lands can be grouped into four major classes based on the dominant form of vegetation (see Figure 24a). The class containing the vast majority of commercial forest species is the conifer class, with a lesser amount in the hardwood class. Each class is composed of numerous cover types, dominated by different species. The cover types with significant acreage and substantial representation of commercial species are shown in Table 8 together with the commercial species in each cover type and the acreage of each cover type in the state.

Table 8

Cover Type	Commercial Species	Acres
Mixed Conifer	Three or more species; no species ≥ 50 percent of the conifer basal area; ponderosa, Jeffrey, and sugar pine; Douglas-fir; white fir; incense-cedar; California black oak	9,268,000
Ponderosa Pine	Ponderosa pine >50 percent of the conifer basal area; Jeffrey and sugar pine, Douglas-fir, white fir, incense-cedar, California black oak, and canyon live oak may be associated	2,651,000
Douglas Fir	Douglas fir >50 percent of the conifer basal area; sugar, ponderosa, and Jeffrey pine, incense-cedar, redwood, tanoak, and canyon live oak may be associated	1,772,000
Jeffrey Pine	Jeffrey pine >50 percent of the conifer basal area; ponderosa and sugar pine, incense-cedar, and red fir may be associated	700,000
Red Fir	Red fir>50 percent of the conifer basal area	1,906,000
Redwood	Redwood >20 percent of the conifer basal area; Douglas-fir and tanoak may be associated	1,570,000
Lodgepole Pine	Lodgepole pine >50 percent of the conifer basal area; red fir may be associated	752,000
Montane Hardwood Conifer	Douglas-fir; ponderosa and Jeffrey pine; redwood; white fir; canyon live oak; tanoak; California black oak; Oregon white oak	1,156,000
Valley Foothill Hardwood	Blue, valley, Englemann, coast live, interior live, and canyon live oaks	7,363,000
Montane Hardwood	Canyon live, California black, and Oregon white oaks; tanoak; Douglas-fir; ponderosa and Jeffrey pine; redwood; white fir	2,049,000

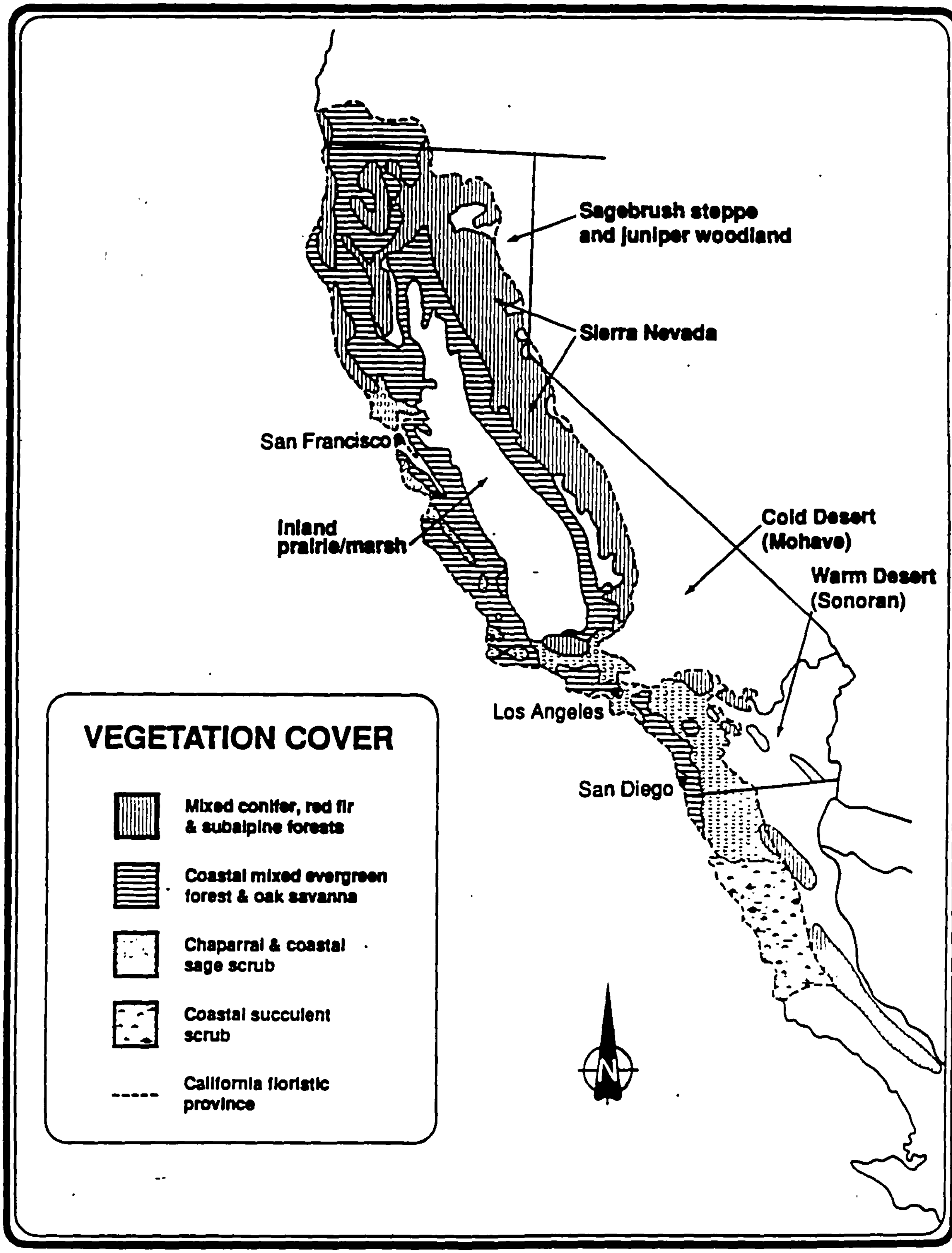
(See Appendix B for a more detailed presentation.)

Possible General Changes in California's Forest Industry

A general decline in forest productivity in California would decrease employment in the timber industry, as well as decrease tax and other revenues relating to the forest industry. It is uncertain how competition with wood from outside the state will change because the potential effect on other sources is unknown. However, the greater scarcity of timber in California combined with growing demand would increase prices, making alternative building and heating materials relatively more attractive. These increased prices could inhibit the building industry to an unknown extent.

Changing species composition and productivity might change forestry operations. Obtaining adequate regeneration would be a major problem (Woodman, 1987). The large numbers of trees expected to be killed during shifts in species' ranges may lead to expanded salvage activities. The aesthetic appeal of currently popular recreation areas will be substantially degraded. Some forests could be replaced by grass land or desert conditions which will result in a severe change in existing land use (EPA, 1988).

Figure 24a


Sagebrush steppe
and juniper woodland
Sierra Nevada
San Francisco
Inland
prairie/marsh
Cold Desert
(Mohave)
Warm Desert
(Sonoran)
Los Angeles
San Diego
VEGETATION COVER
Mixed conifer, red fir
& subalpine forests
Coastal mixed evergreen
forest & oak savanna
Chaparral & coastal
sage scrub
Coastal succulent
scrub
California floristic
province
N

CHANGE IN DISTRIBUTION AND GROWTH

Warming could cause substantial changes in forest growth and could radically alter the ranges of the state's dominant forest species.

The scenario used in this report assumes that the amount and seasonal distribution of annual precipitation will remain constant and that temperatures will rise 3°C (5.4°F). The temperature rise alone could shift tree ranges northward and higher in elevation (see Appendix B for a description of the current ranges of California's commercial forest species). The temperature rise may also increase evapotranspiration, which would intensify summer drought conditions. This would increase water stress in tree species which require more moisture, decreasing their ability to survive and compete with more drought-tolerant species, particularly in the lower elevations and southern fringes of their ranges. Seedlings are especially susceptible to drought, so reproduction could decrease dramatically. Although anticipated increases in atmospheric concentrations of CO_2 may enhance trees' water use efficiency and nitrogen fixation and stimulate growth, it is not clear whether the net effect of increased temperatures and CO_2 levels will be to enhance or reduce productivity (Sandenburgh et al., 1987). Some feel that the beneficial effect of increased CO_2 will not be nearly as large as the growth losses simulated in global climatic models due to temperature rise (Solomon et al., 1984).

Forest communities eventually would migrate to new zones where the environment will support their growth and reproduction. In California, this phenomenon would be most noticeable as an upward shift in elevation of about 1500 feet. The current distribution of forest communities is shown in Figure 25. The effect of a 3°C warming on the main commercial species is depicted in Figure 26.

Ranges would also shift northward somewhat. A substantial lag in productivity would occur because of the slow rate of migration of tree communities. Reestablishment would probably not occur on an intense, widespread basis until temperatures attain a steady state. Therefore, if CO_2 generation continues to increase beyond the doubling point with consequent continued global warming, adverse effects to California's forests would continue and intensify. If the seasonal pattern of precipitation changes to more winter precipitation and summer drought, adverse impacts to forests would be even greater. Even if stable conditions develop, several centuries may pass before forests regain a healthy status (EPA, 1988).

The potential range changes for two of the most important tree species in California, ponderosa pine and Douglas fir, have been estimated in one global warming study. The results of this work suggest that ponderosa pine could increase in range and abundance because of its ability to withstand long summer drought. These results were based on assumptions of increased temperature, decreased water balance, and doubled CO_2 (EPA 1988). However, whether the area of ponderosa pine would in fact increase is questionable. Increased CO_2 levels may enhance water-use efficiency, but the effects on growth reported thus far are quite variable and the amount of data is too small to draw firm conclusions, especially for the long term (Shugart et al. 1986). Photochemical oxidants, especially ozone, are likely to increase, and ponderosa and the related Jeffrey pine are susceptible to injury from these pollutants which inhibit growth. Any upward expansion of the range of ponderosa pine would be offset to an unknown extent by the loss of some of its range at lower elevations, an area that would change to chaparral and grass land (Nelson, 1989).

The same study indicates that Douglas fir would not continue to grow in the lower elevations of its range in California because rising winter temperatures will not meet the species' chilling requirements. The species would move upslope to cooler, wetter sites. It would be replaced at the lower elevations by western pine species (Leverenz and Lev, 1987). However, where Douglas fir remains and moisture is sufficient its productivity should increase due to higher temperatures which stimulate growth in the presence of adequate moisture (Nelson, 1989).

Increased temperatures may cause a decline in the overall productivity of California's forests. An increase in temperature is expected to favor the more drought-tolerant tree species, such as pines, at the expense of fir, hemlock, and spruce species. The effect of warming on redwood trees is uncertain because it is not known how an increase in temperature will affect coastal fog which is the crucial factor in redwood productivity. Even if ponderosa pines expand their range, the total amount of forest biomass may decline. An expansion of ponderosa pine would occur as the result of the replacement of other tree species (Leverenz and Lev, 1987). The ability of the replaced species to establish themselves at higher elevations would be limited by poor soils and a smaller land area (Nelson, 1989). Some species now at the highest elevations would become locally extinct (EPA, 1988). It is expected that forest communities would require at least a century to adjust to the changed conditions. During this time large reductions in the land area of healthy forests are considered to be probable (EPA, 1988). Great uncertainty exists concerning the rates of species' dispersal and the effectiveness of increased CO_2 in offsetting the effects of drought. Some evidence indicates that increased CO_2 substantially increases photosynthesis in ponderosa pine, and that this enhancement is not altered by high temperature or decreasing soil moisture (Green and Wright, 1977). Under the most severe conditions projected for California, the standing biomass would be reduced to about 60 percent of current levels (EPA, 1988).

Figure 25

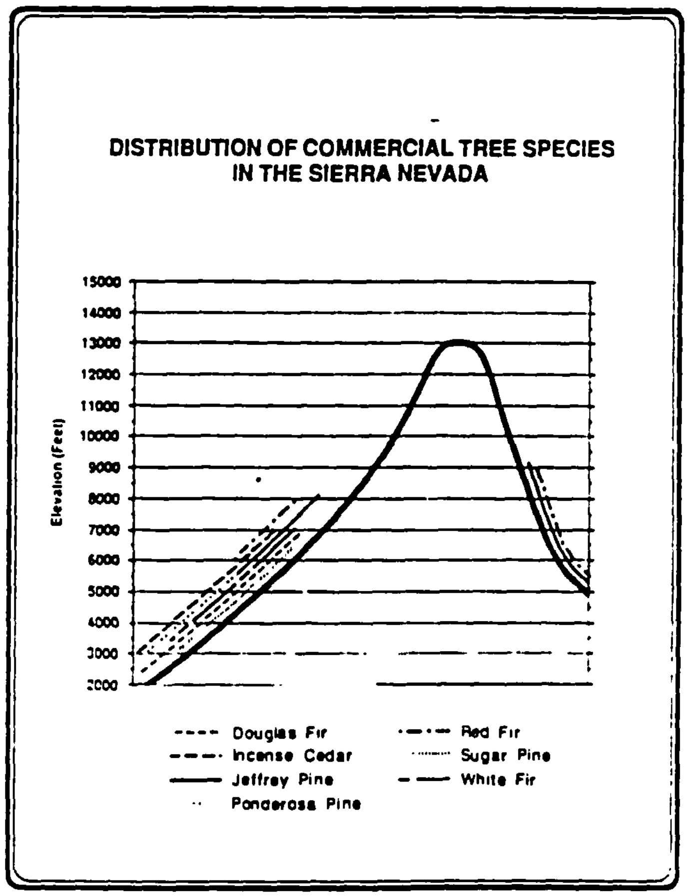
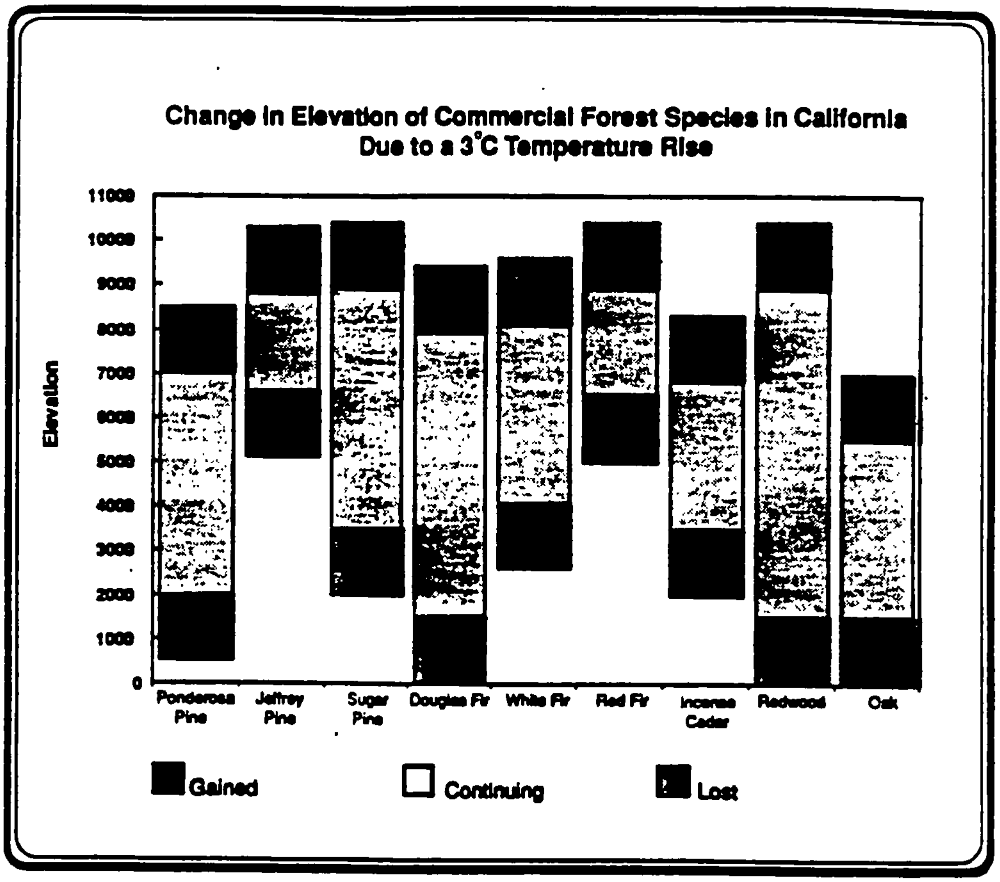


Figure 26



SECONDARY EFFECTS

<u>The stress and drying expected in California's forests from warming will increase their susceptibility to destructive forest fires, insects, disease, and pollution which will further decrease productivity (CDFFP, 1988a).</u>

<u>Changes in the Effects of Fires</u>

Increased temperatures are expected to cause drier forest conditions even if rainfall remains at current levels (EPA, 1988). If regional drought persists, the frequency of fires could increase, significantly reducing the total forested area (EPA, 1988). Dryness may also increase the severity of forest fires. If dead wood rapidly builds up as a result of the decline of one or more tree species, large catastrophic fires could occur, increasing atmospheric pollutant emissions (EPA, 1988). The size of the forces required to fight such fires would increase. The budget for fire management in California's national forests is over 50 million dollars per year (CDFFP, 1988a). Emergency fire suppression expenditures by the California Department of Forestry and Fire Protection were $56,769,000 for fiscal year 1987-88 (CDFFP, 1988b). With drier forests, more funds may have to be provided to maintain adequate protection. The difficulty of protection will be intensified by the trend toward increasing rural residential development which diverts efforts from the protection of trees to the protection of structures. Such development may also make obtaining sufficient water to fight fires more difficult.

<u>Changes in the Effects of Insects and Disease</u>

In addition to fire, insects and disease pose the greatest threat to forests. Damage for the 10-year period between 1954 and 1964 averaged 1.7 billion board feet per year (CDFFP, 1988a). Higher temperatures are expected to increase the adverse effects of insects, both because the weakened condition of trees would make them more susceptible (Miller 1977; Treshow 1980; Dahlsten and Rowney 1980; Shugart et al., 1986) and because increased temperatures would be more conducive to the productivity of some insect pest species. The geographic range of insects currently damaging to trees would probably increase, and some now inconspicuous insect species may become important (Solomon et al., 1984). Of the estimated 2.4 to 8.6 billion board feet lost due to the drought of 1976-1977, about 95 percent were attributed to forest pests attacking trees stressed by drought (CDFFP, 1988a).

The insect species recently causing the most damage in California are western pine beetles, flathead borers, tip moths, and budworms (CDFFP, 1979). The most destructive forest insect pests in the state are bark beetles. In 1967 in California, the bark beetles and the flathead borer caused the loss of 1,676 million board feet of timber valued at $23,235,000 (Miller 1977). In addition to killing commercially important trees, insect outbreaks can increase the damage caused by fires by causing the build-up of dead material, leading to increased fuel loads (CDFFP, 1988a).

Many diseases also affect California's forests. One of the most common is dwarf mistletoe which primarily affects ponderosa pine and firs. More study is needed before predictions can be made as to the likely effect of increased temperature on diseases affecting California forests (Solomon, 1984). However, it is clear that drought weakens trees, making them more susceptible to disease. Disease organisms, including dwarf mistletoes and fungi, whose impacts increase under drought conditions, contributed to widespread mortality in northern California conifer forests during the period from 1975-1977 (Page, 1981). The interaction between micro-organisms and air pollution is quite variable and complex, but some studies have shown greater infestation with higher pollution levels (Miller, 1977).

Changes in the Effects of Air Pollution

Low altitude ozone has caused the greatest pollution damage to California forests (Skelly, 1980). The impact of air pollution on the state's forests is likely to increase. These impacts include direct mortality as well as declining health which could act synergistically with increased stress from temperature, insects, and disease to cause further mortality in some trees and a decline in productivity in others (USDI, 1982). Increased litter from defoliation may encourage fire-sensitive species to develop in the understory which may result in more frequent and hotter fires. Mixed conifer stands may become mixed deciduous and shrub communities at mid-elevations and scrub field communities at higher elevations (CDFFP, 1988a). Higher temperature may also increase the rates at which pollutant gases are converted to deleterious forms (EPA, 1988). However, decreased soil moisture can reduce pollutant injury by decreasing stomatal openings (CDFFP, 1988a). This may counter the effects of pollution, but to a currently unknown extent.

Ponderosa pine, the most commercially important tree species in California, is considered very susceptible to injury from ozone, as is red fir. Species considered intermediate in susceptibility include Douglas fir, big cone Douglas fir, Jeffrey pine, and white fir. Sugar pine and incense-cedar are considered to be resistant (Miller, 1973). In the San Bernardino National Forest, losses of ponderosa and Jeffrey pines have increased dramatically with increased pollution levels (Miller, 1977). Where ozone effects are greatest in Southern California, incense-cedar is expected to dominate sites now dominated by ponderosa pine (CDFFP, 1988a). A study of Jeffrey and ponderosa pine in Los Padres and Sequoia national forests strongly suggests that air pollution is threatening the economic value of forests surrounding the Central Valley as well (Williams, 1980). Ozone exposure is generally considered to increase susceptibility of trees of sensitive species to disease and insect damage because it weakens the trees (Treshow 1980; Dahlsten and Rowney, 1980). (See page 83 for a further discussion of the effects of air pollution on California's forests.)

OCEAN LEVEL

Without additional protection, rising sea levels will inundate coastal wetlands and manmade structures. Higher sea levels could also cause more severe storm damage and coastal erosion as well as jeopardizing water quality in some areas.

Over the past 100 years, mean global sea level appears to have risen by 10 to 15 cm (4 to 6 inches) (Wigley, 1987). The rate-of-change during the last 19-year tidal epoch has been almost double the 100-year historic yearly average, causing some researchers to conclude that the rate-of-rise is increasing (BCDC, 1988). The rise may be attributable to thermal expansion of the ocean surface and glacial melt in Greenland and polar regions, though some researchers also hypothesize that the glacial melt is due to sunspot activity. Regardless of the cause of the current rise, global warming is expected to accelerate the rise in sea level.

Global warming induced sea level rise is expected to occur as a result of thermal expansion of the ocean surface, melting of the earth's glaciers and polar ice fields, and mixing of now stratified ocean waters. The current rate-of-rise would cause the ocean levels in the San Francisco Bay Area to rise by 10 to 13 cm (4 to 5 inches) in the next 50 years (BCDC, 1988). A recent study by the Environmental Protection Agency estimates that if temperatures rise 3°C (5.4°F) by the year 2050, a 1-meter sea level rise can be expected by the year 2100 (see Figure 27).

Other researchers estimate that an effective CO_2 doubling could result in a .5 to over 2 meter (1.5 to over 7 feet) sea level rise. Some glaciologists feel that the warmer temperatures over the poles due to lack of vertical mixing and declining albedo could cause a breakdown of the West Antarctic ice shelf. Deterioration of the ice shelf could lead to a 5 to 7 meter (16 to 23 foot) rise in sea level over several hundred years (Mercer, 1978). On the other hand, an increase in moisture with a warmer earth may cause more snow to fall on interior Antarctica which could, at least for a time, offset melting elsewhere.

Perhaps one of the most significant human impacts to California of a rise in sea level will be its effect upon California's freshwater supply. Approximately 25 percent of the freshwater supply serving central and southern California is transferred through the Sacramento-San Joaquin Delta (DWR, 1988). The state's system of water storage reservoirs currently modulates the flow of water in the lower rivers and helps control salinity caused by tidal inflow entering the western Delta. However, when freshwater runoff is low, water in the western Delta becomes brackish as it mixes with tidal inflow and is then drawn upstream into the San Joaquin River by pumping plants. The current management approach to salinity is to release more water from reservoirs to repel intruding sea water. Progressively lower summer flows due to global warming, as well as rising sea levels which will increase salt water intrusion, may limit this option in the future. It is estimated that, without other protective measures, a one meter rise in sea level would require two times the carriage water to repel the intruding salt water from the river deltas.

Sea level rise may also exacerbate existing flood danger in the San Francisco Bay delta, and intensify existing water quality problems. A 1 meter rise in sea level would increase the area of the Bay estuary by 30 percent if all the levees are strengthened. If the levees are not improved, the size of the Bay will triple (see Figure 28). It may be difficult to adequately strengthen the levees for that magnitude of rise. A 1 meter (3.28 foot) rise would increase pressure on Delta levees by approximately 65 percent (assuming the landward toe is 3.5 meters [11.5 feet] below the channel tidal levels). Thus, without massive strengthening, structural levee failure would be more likely.

Parts of the Delta system are already at risk. The loss of peat soil from oxidation and wind erosion has lowered the center of some Delta islands by as much as 25 feet. This has increased the risk of island flooding and levee failure; since 1980, 24 levees have failed

(CDWR, 1987). Permanent flooding of islands in the West Delta, the region where brackish and fresh water meet, could increase upstream movement of saline water and require more outflow to maintain water quality at the point where water is pumped from the delta for transport to central and southern California. Further, flooding of all eight west Delta islands would result in the loss of 35,000 acres of land. Total agricultural cash receipts from crop production on this land in 1979 was $331 million, or three percent of the state farm total for that year of $12.7 billion (CDWR, 1987). Already, subsidence problems are raising the question of the costs versus benefits of protecting the Delta by fortifying the levee system. Accelerated sea level rise will heighten this concern.

Salt water intrusion due to sea level rise will also negatively affect low-lying wetlands and estuaries. For example, Suisun Marsh encompasses 80,000 acres and is the largest contiguous wetland remaining in California. The marsh serves as a host for migratory waterfowl and as a nursery for many fish and shellfish (CDWR, 1987). The stability of this ecosystem is dependent upon a balance between fresh and salt water which is maintained through tidal movements. The response of tidal wetlands to sea level rise depends upon the local rate of sedimentation. However, rapid inundation of coastal wetlands would drown marsh grasses and cause accelerated erosion of marsh soils. Further, inland migration of wetlands is limited due to the confining effect of man-made structures along the coast. Current EPA estimates suggest that a 1-meter rise in sea level would cause a 30 to 70 percent loss in coastal wetlands. (See the following sections for more details on habitat impacts.)

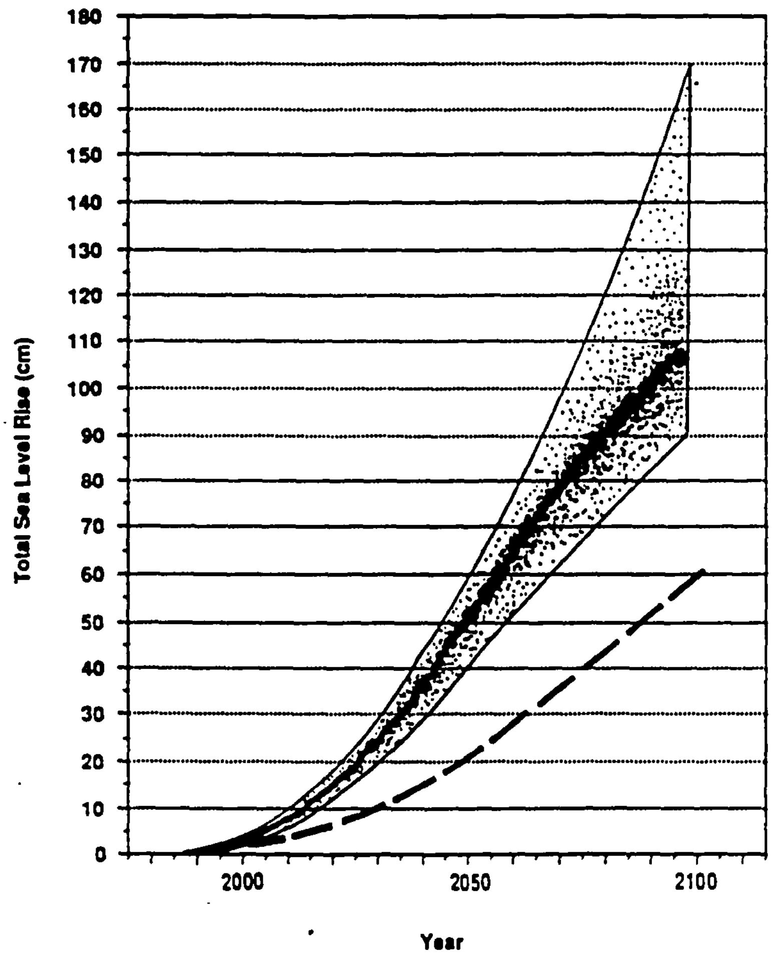
Coastal erosion is also expected to increase due to sea level rise. Higher seas provide a higher base for storm surges and have the potential for more destructive storm activity. Some estimates suggest that a 1-meter sea level rise would enable a 15-year storm to flood an area currently affected by a 100-year storm (Titus, 1988). Man-made developments which would be affected by higher storm surges include port facilities, coastal highways, and airports (all of which affect trade), commercial and residential structures, and low lying agricultural areas. In addition, coastal erosion and shoreline retreat could leave hundreds of hazardous waste sites and landfills under water or battered by waves. Saturation of these facilities could cause the migration of wastes onto neighboring property and the contamination of fresh water aquifers (Flynn, 1986).

Sea level rise increases the risks associated with ocean front development and, beyond a certain level, raises the question of whether it may be more appropriate to hold back the sea, or to allow land to flood to avoid mitigation costs. Current estimates suggest that a 1 meter rise in sea level could flood areas inland as far as Sacramento. An assessment of the areas along California's coast and interior region worth saving is sure to dominate future policy discussion regarding sea level rise.

It is important to keep in mind that warming induced rises in sea level are gradual. As a result, the impacts of a rise should not be severe for several decades.

Figure 27

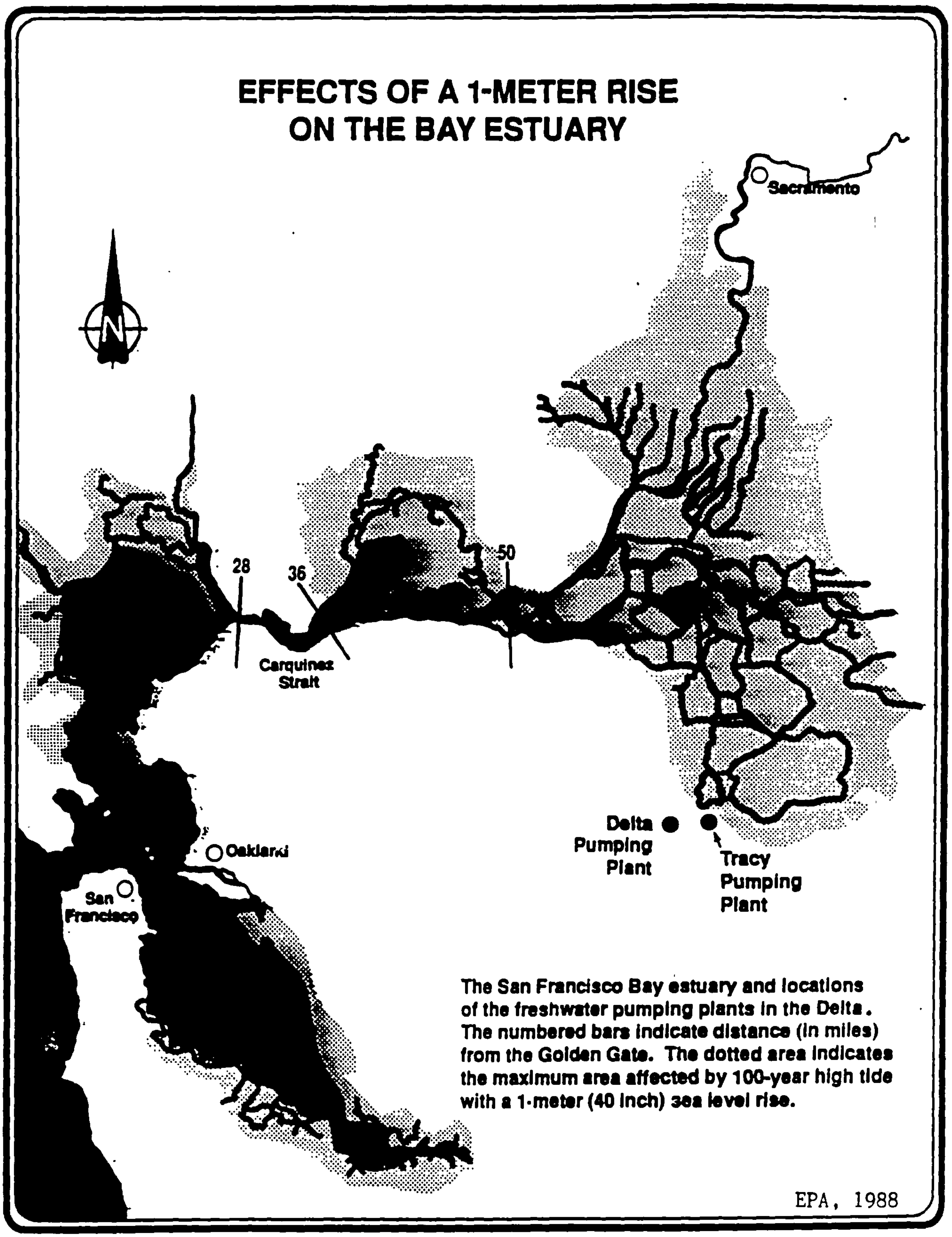
TOTAL SEA LEVEL RISE DURING THE NEXT CENTURY



The dark shading indicates the most probable response to a 3 degree C temperature rise. The broken line depicts the response to a warming trend delayed 100 years by thermal enertia of the ocean. A global warming of 6 degrees C by 2100, which represents an extreme upper limit, would result in a sea level rise of about 2.3 m, but errors on this estimate are very large.

EPA, 1988

Figure 28


EFFECTS OF A 1-METER RISE
ON THE BAY ESTUARY
Sacramento
28
36
50
Carquinez
Strait
Delta
Pumping
Plant
Tracy
Pumping
Plant
Oakland
San
Francisco
The San Francisco Bay estuary and locations of the freshwater pumping plants in the Delta. The numbered bars indicate distance (in miles) from the Golden Gate. The dotted area indicates the maximum area affected by 100-year high tide with a 1-meter (40 inch) sea level rise.
EPA, 1988

NATURAL HABITAT - WETLANDS

Increase in temperature, raising of ocean levels, and changes in water availability could result in substantial changes in coastal wetlands and the species which occupy these habitats.

Global warming will affect coastal wetlands through an ocean level rise and through greater variation in seasonal freshwater inflow. The rise of ocean levels would result in dramatic reduction of coastal wetlands. In many cases (e.g., San Francisco Bay, San Diego Bay), rising ocean waters would not provide for new habitat areas because of topography and/or conflicts with existing urban development (see Figure 29). This would have a profound adverse affect on all of the inhabitants of these ecosystems.

Changes in freshwater inflow may affect the distribution and productivity of estuarine plants and animals. Warmer winters are expected to increase winter flows but substantially reduce summer flows.

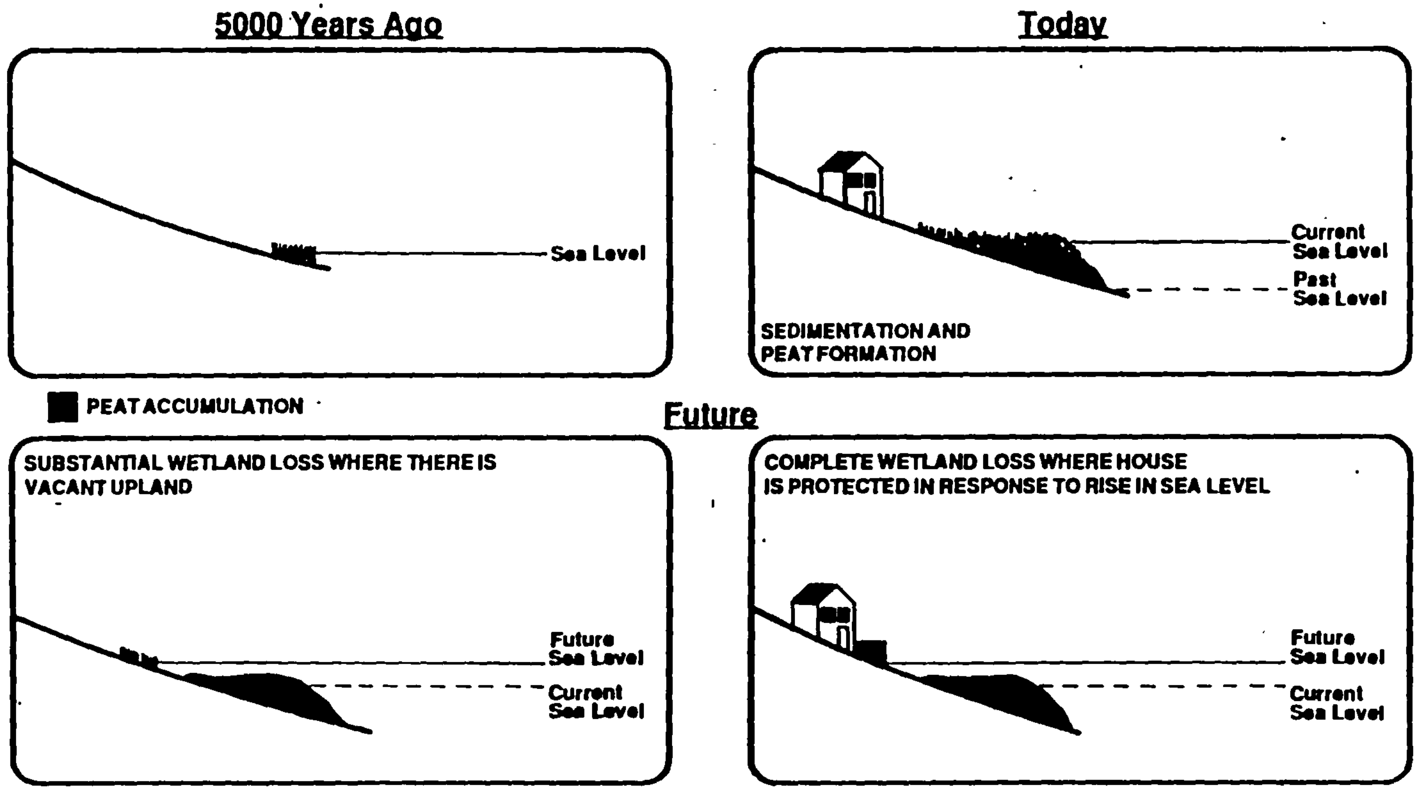
Past losses of coastal wetlands to other land uses (80 percent of the original coastal wetlands in California has been lost) have reduced the amount of land available for wetland habitat replacement. A further reduction of this resource as a result of a 1-meter (3.3 foot) ocean level rise would severely impact species which rely on these habitats. Current wetland preserves may become irrelevant if flooded with salt water. At the same time, there may be little land available to establish new preserves.

Many of the endangered species in California depend on wetland habitats for their existence. Reduction of wetland habitat will have a significant adverse impact on these species, possibly resulting in extinctions of some species. Examples of endangered wildlife species dependent on wetland habitat are the clapper rail and the giant garter snake; an endangered plant species is cordylanthus maritimus maritimus.

Uncertainties surrounding the rate of warming, individual species response, and interactions between species makes accurate prediction of specific impacts impossible.

Figure 29

EFFECT OF SEA LEVEL RISE ON COASTAL MARSHES



Evolution of marsh as sea rises. Coastal marshes have kept with the slow rate of sea level rise that has characterized the last several thousand years. Thus, the area of marsh has expanded over time as new lands were inundated. If in the future sea level rises faster than the ability of the marsh to keep pace, the mash area will contract. Construction of bulkheads to protect economic development may prevent new marsh from forming and result in a total loss of marsh in some areas.

EPA, 1988

SHIFTS IN HABITAT

Increase in temperature, raising of ocean levels, and changes in water availability could result in substantial changes in wildlife species and the vegetation that often forms the basis of wildlife habitat.

A 3°C (5.4°F) rise in temperature could result in a northward shift of the temperate vegetation belts by 300 kilometers or more (approximately 200 miles). A climatic change of this magnitude would require that species shift distribution several kilometers each year or physiologically adapt to the warming. The mobility of some wildlife species may enable them to achieve this rate, but most plant species will not. Because of differing abilities between species to adapt or move, it is unlikely that entire communities or ecosystems would move as a unit. Climatic change resulting in a relocation of communities would most likely result in the disassociation of existing communities and the formation of new species aggregations.

Because of the steep elevational gradients in mountainous areas, plants and animals would need to shift considerably shorter distances than would be necessary on flat terrain. Still the migration of 500 meters (1,500 feet) upslope or more would be required to compensate for a 3°C (5.4°F) temperature rise. The dominant species may not be able to shift their distributional ranges this far upslope over the short time period expected for the temperature to change. As a result, natural communities in mountain regions would have a considerably different relative species composition (Figure 30).

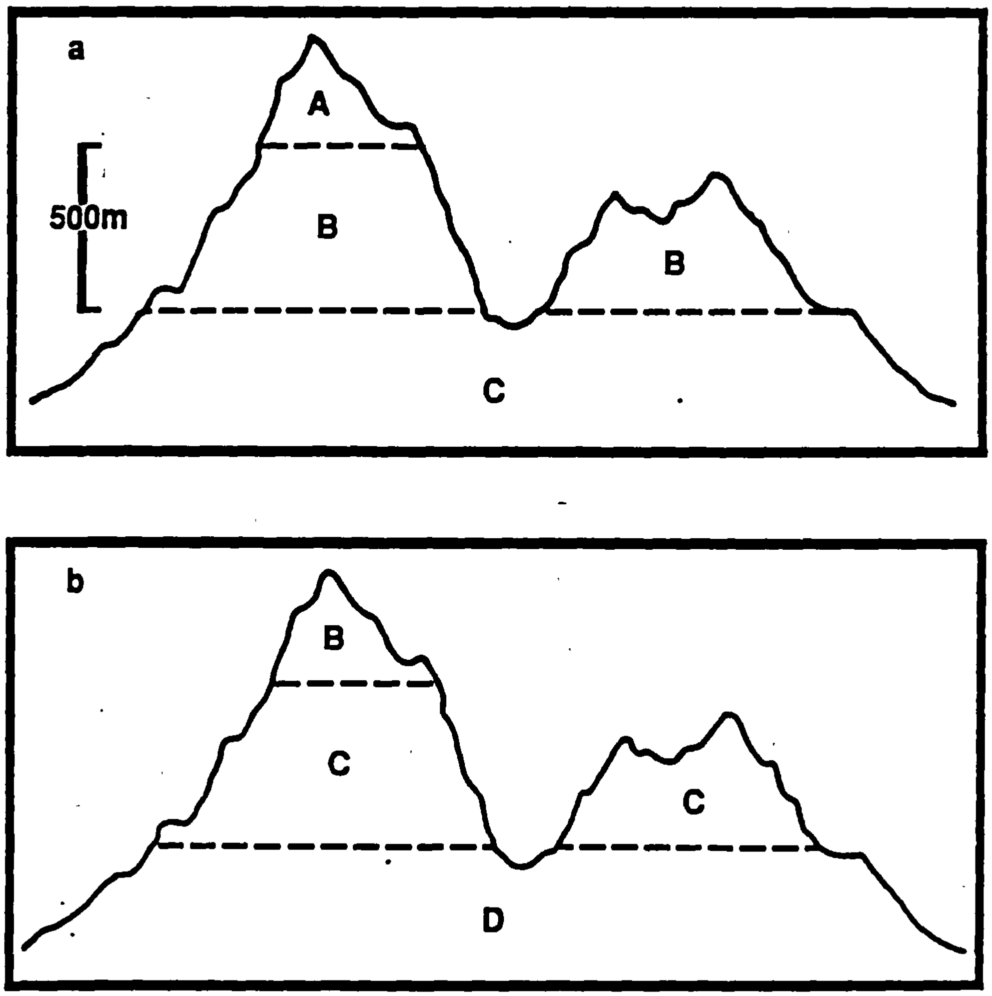
Most wildlife species are better able to shift their distribution than plants. However, there are some highly isolated wildlife species that may be unable to achieve necessary movement rates. Some species that are physically able to move at adequate rates may not move to better locations. In addition, natural and manmade barriers to species movement, including roads, cities, mountains, bodies of water, agricultural land, and other land uses associated with habitat fragmentation, may impede the ability to shift, and thus lead to a decline of species.

The effect of climate change on species and ecosystems will vary. Some species will benefit while others could become extinct. For example, arctic nesting species (e.g., geese) are likely to benefit from a shortened winter season, and from increases in nesting habitat vegetation and ecosystem productivity. On the other hand, island and preserve species and species in areas isolated by urban development may not be able to shift to other suitable locations and may become extinct. Forested areas that appear to be most sensitive to change are those that support threatened or endangered species, species sensitive to heat or drought, and species inhabiting coastal areas and wetlands.

In many cases, the indirect effects of climate change on a population (e.g., changes in habitat, food availability, and predator/prey relationships) may have a greater impact than the direct physiological effects of climate change. This, along with the increasing human population in California, will result in increased conflict with native species and may confound efforts to prevent extinctions. Uncertainties surrounding the rate of warming, individual species response, and interactions between species makes accurate prediction of specific impacts impossible.

Figure 30

CHANGE IN ECOSYSTEMS DUE TO CLIMATE CHANGE



(a) Initial altitudinal distribution of three species, A, B, C.

(b) Species distribution after a 500 m shift in altitude in response to a 3 degrees C. rise in temperature (based on Hopkin's bioclimatic law; MacArthur 1972). Species A becomes locally extinct. Species B shifts upward, and the total area it occupies decreases. Species C becomes fragmented and restricted to a smaller area, while species D successfully colonizes the lowest altitude habitats.

BioScience Vol 35, 1985

FISHERIES

The envisioned ocean level rise coupled with salinity intrusion into estuaries, and a shift in river run-off to greater volumes in winter and less in spring/summer, could diminish the viability of marine and anadromous fisheries. The shift in river runoff could also contribute to a decline in natural trout production in Sierra streams.

Global warming may shift ocean upwelling patterns and associated nutrient transport. The shift could precipitate a distributional change in the location of traditionally productive fishing areas along the coast. The resulting effects would be species specific and affected fisheries would likely be localized.

Increase in the ocean level could reduce the availability of intertidal habitat along the coast and diminish overall productivity in this zone as it relates to fish and shellfish. But salinity intrusion connected with ocean level rise and expansion of the area of bays could increase the number of marine species in these waters. Brackish water species would be forced upstream into reduced estuarine areas.

Anadromous fish are fish that live in ocean water but spawn in fresh water. In particular, the Sacramento-San Joaquin Rivers and delta anadromous species, including king salmon, striped bass, and American shad, could be affected in various ways by higher winter runoff and lower spring runoff (see figure 31). Also, the status of the salt/fresh water interface or tidal prism (a nutrient rich area) could affect the species that use these waters as a nursery area, principally striped bass and shad.

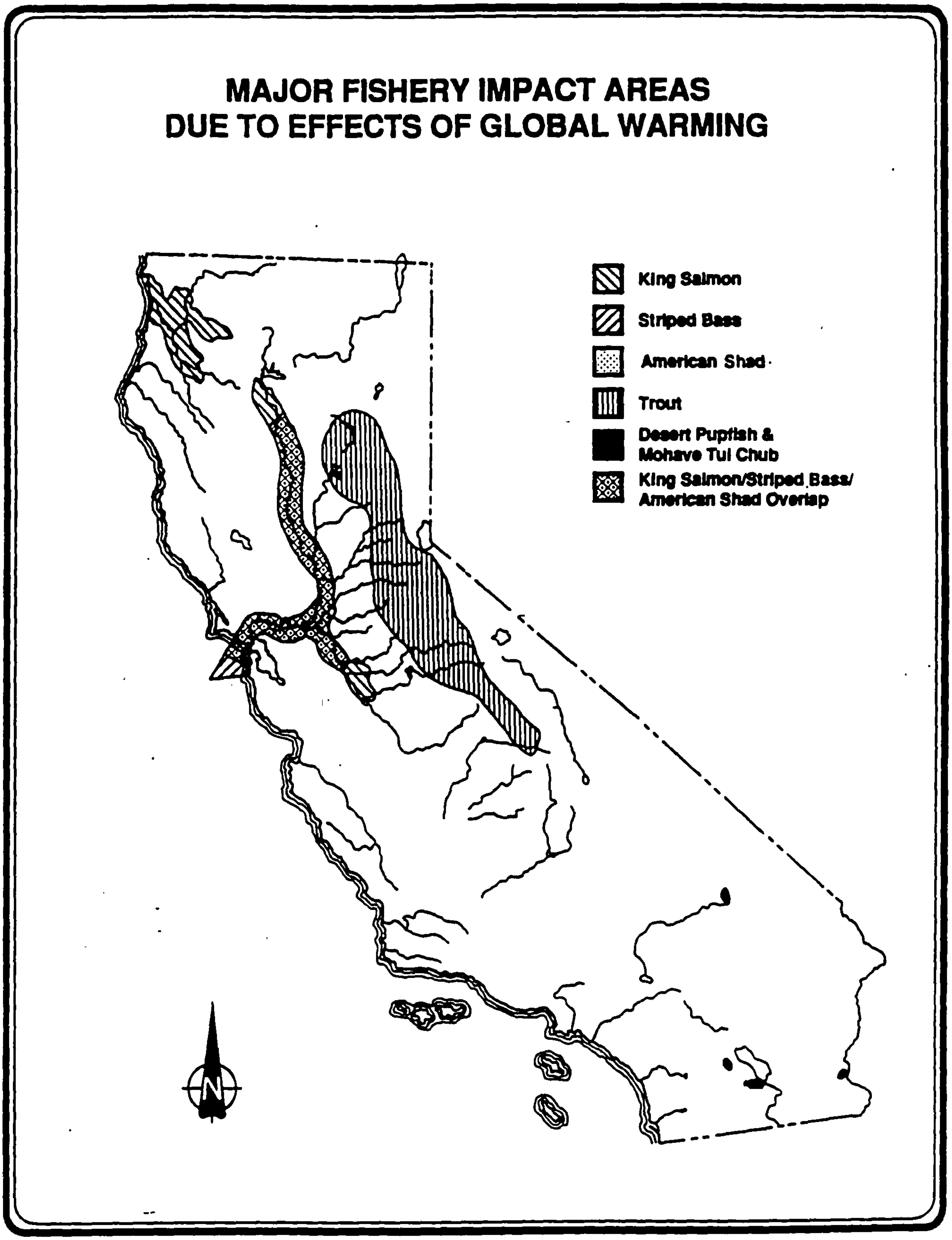
King salmon spawning may benefit from higher winter flows that could moderate the effects of high temperature problems that often occur in low runoff years. Also, higher winter flows could inundate additional spawning gravel areas making them more available for egg deposition, increasing opportunities for hatchling production. However, once flood storage requirements are satisfied and subsequent flow reductions are instituted, many incubating eggs may be dewatered and suffer significant mortality. Reductions in spring/summer runoff due to lower snow pack may not provide sufficient flushing flows to assist out-migrant young salmon on their journey downstream past water diversion intake structures and through the estuary to the ocean. Consequently, the overall salmon population could decline.

Reduced spring/summer outflows could subject striped bass eggs to greater loss at diversions along the rivers where they are spawned. Bass eggs are released and fertilized in open river water and travel downstream with the flow undergoing embryonic development along the way. As the ratio of diverted water to river flow gets larger, more striped bass eggs will likely be lost to the diversions with a subsequent reduction in recruitment to the adult population. Also, the nursery area that juvenile bass depend on may be reduced because of the salinity intrusion related to ocean level rise pushing it upstream to narrower reaches. Conversely, if new areas become flooded with fresh water runoff due to ocean level rise and these new areas persist throughout the summer, bass nursery areas may actually expand and somewhat counteract the potential losses associated with salinity intrusion.

Spawning runs of American shad into important Sacramento River tributaries (Feather and Yuba) seem to be affected by the ratio of tributary flow to main stream flow; i.e., the higher the ratio, the more likely shad will move into the tributaries and spawn. With reduced spring/summer flows, the shad may remain in the main stem Sacramento River and spawn, thus eliminating sport fishing opportunities in the tributaries.

If reservoirs that supply salmon and steelhead hatcheries and spawning channels with water are unable to provide sufficiently cool water over the summer months, yearling production could be considerably reduced by increased incidence of disease and thermal stress. This

Figure 31



MAJOR FISHERY IMPACT AREAS
DUE TO EFFECTS OF GLOBAL WARMING
King Salmon
Striped Bass
American Shad
Trout
Desert Pupfish & Mohave Tui Chub
King Salmon/Striped Bass/ American Shad Overlap
N

setback in yearling production would diminish the contribution hatcheries have toward increasing recruitment to the commercial and sport fishery.

Many small tributary streams in the Sierras provide spawning and nursery habitat for trout that inhabit the larger perennial streams. If spring flows are both lower in quantity and shorter in duration, trout may not have suitable habitat to maintain populations capable of sustaining desirable sport fisheries. Trout hatcheries would more than likely be unable to supplant this loss of natural production. This is because of the potential problem trout hatcheries would face with increased disease outbreaks and thermal stress associated with excessively warm water temperatures during summers characterized by low flows.

On a final note, endangered fish species, particularly those in the arid regions of the state (desert pupfish and Mojave tui chub), could be subjected to additional stress during warmer summer periods with lower runoff and reduced water availability. Greater effort and expenditure of funds would be required to preserve these animals.

ENDANGERED SPECIES

Increase in temperature, raising of ocean levels, and changes in water availability could result in extinction of endangered species.

California supports over 250 plant and animal species which are either federally or state listed as threatened and endangered, and approximately 700 species which are candidates for state or federal listing. Increased air temperatures could result in increased water stress and subsequent changes in the habitat conditions of endangered species. Because of their inherently limited distribution, the limited distribution of their habitat, and restricted migration opportunities, changes in temperature, rainfall, or other significant climatic effects could have devastating effects on endangered species.

Preserves that have been established for endangered species are, in nearly all cases, too small to compensate for the effect of significant changes in habitat conditions due to climatic change. Species which are endemic to isolated habitats of extremely limited distribution would be especially susceptible to extinction under significant climate change. The Channel Islands are an example of such a habitat which supports over 100 endemic plants and animals which would have no opportunity to migrate in the face of changing climate.

RECREATION ON PUBLIC LANDS

The effects of global warming on California's outdoor recreational areas could diminish the aesthetic appeal and accessibility of these areas.

California's outdoor recreation sites attract visitors from all over the United States and the world. The unique natural beauty and convenient access to most recreational areas make these some of California's most valuable assets. Recreation visits to California's national forests, national parks, and state parks exceed those of all other states in the United States.

National forest recreation in California is estimated to represent about 25 percent of nationwide national forest recreational use, though California national forest land represents only 11 percent of the national total. San Bernardino National Forest supports the most recreational use of any national forest in the state, most likely due to its close proximity to major population centers in Southern California. Mammoth Mountain Ski Area in Inyo National Forest ranks first nationwide in the number of annual skier visits; within the state there are 42 developed downhill ski areas operated by private concessionaires who lease national forest land. Based on projected population changes, California is expected to experience the greatest increase in recreational use of any National Forest Service region in the United States into the next century (CDFFP, 1988).

Use of California's national and state parks is also continuing to increase. National park service use in California accounts for 17 percent of national park use nationwide, though only 6 percent of national park land is in California (USDI, National Park Service, 1986). Yosemite is the most popular of California's national parks, and accounts for 33 percent of national park use in California. High use of the state parks occurs along the coastal and southern areas of the state.

Global warming may impact recreational use in the State of California by diminishing the aesthetic value of and accessibility to California's national forests, national parks, and state parks. As has been described, global warming is expected to cause an increased incidence of forest fires and may cause increased vulnerability of forests to disease and pests. Increased forest fires would limit accessibility to California's forests and parks, while the combined effect of fires and disease would diminish the aesthetic appeal of these natural areas. Also, warming induced damage to forested areas may reduce the diversity of wildlife, a significant attraction for many visitors to California's public lands. Warmer winters would also have a negative effect on California's ski season by reducing snow pack and potentially resulting in a shorter ski season.

A warming induced sea level rise would limit accessibility to state parks along California's shoreline. Natural wetlands, tidepools, and beach areas, as well as campsites located along the beach, may be lost or submerged due to rising sea levels. Further damage to seashore recreational sites could be caused by increased intensity of coastal storms, which are expected to occur due to higher sea levels and more variable weather patterns. Since the public lands along the coast are surrounded by private development, it may be difficult to replace these areas if they are lost due to rising sea levels.

AIR POLLUTION

<u>Changes in temperature, atmospheric ventilation, solar radiation and precipitation expected to accompany global climate change could affect air pollution levels in California, both adversely and positively. However, since we are unable to confidently predict changes in local climate, the magnitude of these effects is unknown.</u>

The costs of air pollution to California are enormous, affecting human health, ecosystems, agriculture, materials and visibility (Rowe, et al. 1986). California currently exceeds state and national standards for ozone, PM_{10} (particulate matter less than 10 microns in diameter), carbon monoxide, and visibility reducing particles by a large margin. To a lesser extent, standards for nitrogen dioxide and particulate sulfate are also exceeded. While no standard exists for acid deposition, there is potential for damage (ARB, 1988).

Emissions, climate, and geography are key elements in California's unique air pollution problems. Emissions from motor vehicles, industry, and utilities are high. To a lesser degree, emissions from landfills, natural vegetation, and livestock also contribute to the problem. Persistent stagnant weather conditions during much of the year because of the Pacific high pressure system result in low atmospheric ventilation of pollutants. The Pacific high is also responsible for clear skies, maximizing the amount of time precursor gases are exposed to sunlight, which prompts the chemical reactions that create smog. Major urban areas of the state are surrounded by mountains which trap pollution in stagnant air (see Figure 32).

Global climate change may adversely affect air pollution levels because of higher temperatures, increased ultraviolet radiation (due to stratospheric ozone depletion) and possible increases in precipitation. However, there may also be changes to local wind patterns. These changes could make pollution problems worse, or they could help flush pollutants from urban areas. In addition, if there is an increase in low cloud cover there could be a decrease in UV radiation.

The potential impacts of global warming on the state's major air pollutants are as follows:

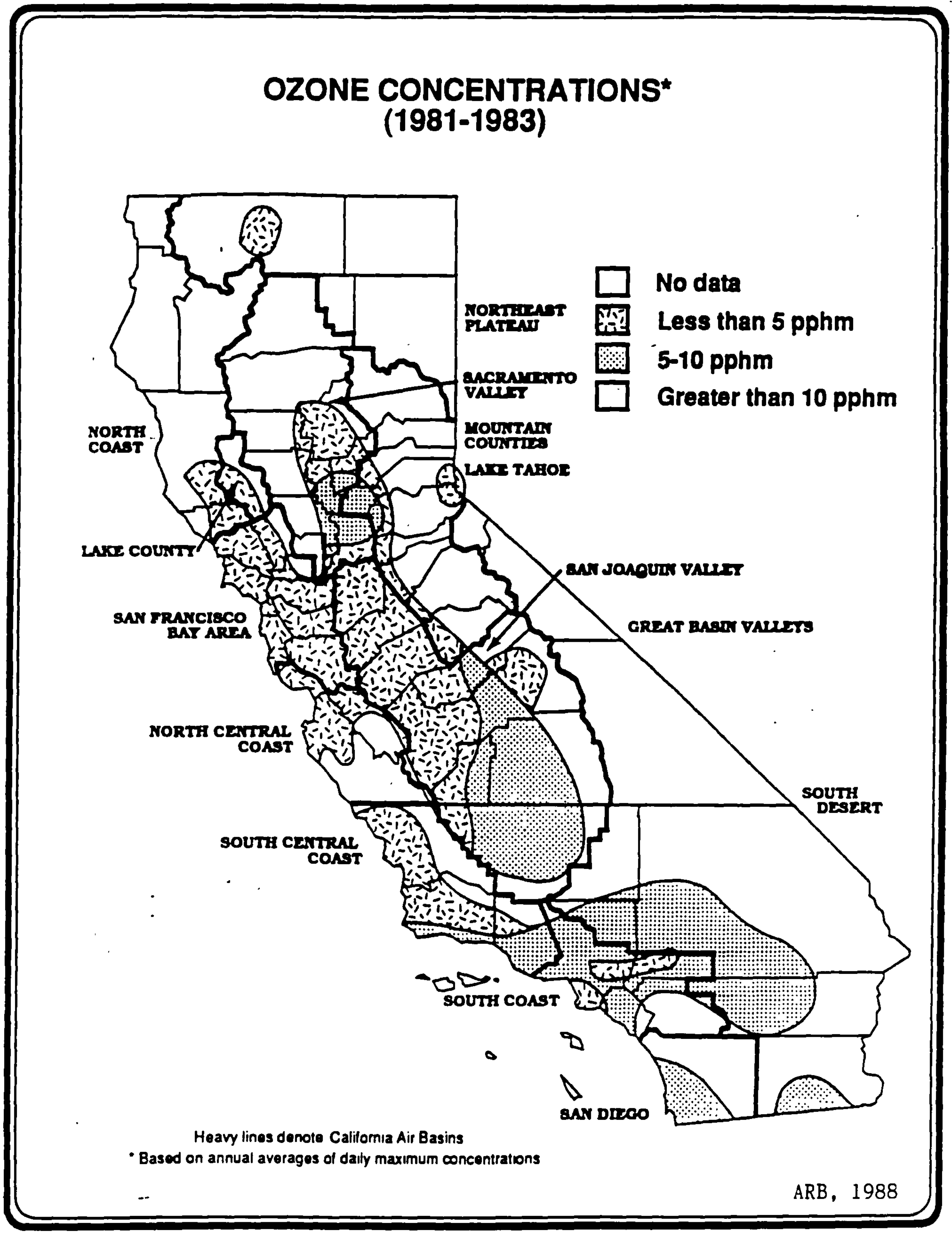
- <u>Ozone</u> -- Higher temperatures and increased ultraviolet radiation accelerate the chemical rates of reaction in the atmosphere, leading to higher ozone concentrations (Finlayson - Pitts and Pitts, 1986). Higher temperatures also cause increases in emissions of oxides of nitrogen (NO_x) and hydrocarbons, the two precursors for ozone. More electricity demand in summer months leads to higher NO_x emissions from utilities. Evaporative emissions of hydrocarbons from motor vehicles, refueling, and deciduous trees also increase with temperature.

- <u>PM_{10}</u> -- Increased chemical rates of production due to higher temperatures and increased ultraviolet radiation lead to higher PM_{10} concentrations. Precursor emissions of NO_x, sulfur oxides (SO_x), and soot and ash from stationary and transportation sources may rise in summer because of increased energy demand for air conditioning. Nitrate may increase or decrease depending on both temperature and relative humidity.

  In winter, changes in the frequency and intensity of inversions (and possible reduced energy demand for heating) may work to reduce wood smoke exposure and trapping of vehicle exhaust. And since human outdoor activity is greater in summer than winter, longer warm seasons and less intense winters may increase the comparative importance of summer-type aerosol exposure in major urban areas. In rural and mountain locations currently experiencing severe wood smoke pollution in winter, total annual PM_{10} exposure may decrease slightly.

  Changes in rainfall and soil moisture (predicted by some climate models to decrease) may lengthen the season for fugitive dust from farmland, and possibly increase the aerial transport of soil-related human pathogens (e.g. valley fever). Decrease in

Figure 32



ARB, 1988

rainfall or wider interannual variation will result in increased fallow acreage and associated fugitive dust. Changes in hydrologic regimes of interior drainage lakes (e.g. Tulare Lake, Goose Lake, Owens Lake, Mono Lake, etc.) may cause increases in fugitive dust associated with dry lake beds. Changes in agricultural practices (crops, cultural practices, crop calendars) may increase or decrease tillage dust.

- Acid Deposition -- Possible increases due to more electricity demand (higher NO_x and SO_x emissions), higher temperatures, and drier, warmer conditions (less acid to particle conversion). There will be a probable increase in altitude of the zone of highest acid deposition in Sierra; total seasonal deposition may also increase.

- Carbon Monoxide -- CO is a product of incomplete combustion, and is primarily a winter problem in California. Air pollution levels may benefit from increased atmospheric ventilation (higher wind speeds and more vertical mixing) at night. A shorter winter season and possible reduced frequency of inversions may reduce frequency, but not necessarily severity, of CO "hot spots" due to motor vehicles. A warming may also slightly reduce CO exposure from residential wood combustion.

AIR POLLUTION: HUMAN HEALTH AND WELFARE EFFECTS

Air pollution causes serious health hazards for Californians. Increases in air pollution caused by global warming will intensify these hazards. Conversely, global warming may decrease some of these effects.

Each of the state's major air pollutants is associated with a set of health problems. The following is a discussion of these problems in relation to global warming:

- Ozone -- Ozone exposures of several hours, at levels currently experienced in California, cause airway constriction in as many as 20 percent of healthy exercising adults and children. Other lung changes indicative of actual lung injury also occur. Increased duration and level of ozone exposure increases both the severity of the response and the number of individuals who respond.

  Years of ozone exposure can result in structural alterations in the lung and contribute to a cumulative lifetime decrease in lung function. Increased frequency and severity of ozone exposure will most likely increase the rate at which long term changes occur and also increase the total ozone contribution to lifetime lung injury.

- PM_{10} -- Adverse health effects of fine particles include chronic reduction of lung function and specific toxic effects of various components of the aerosol mass. Clinical and epidemiologic studies indicate PM_{10} contributes to increased incidence of emphysema, aggravation of asthma, and transmission of airborne pathogens.

- Carbon Monoxide is a toxic gas that acts by blocking transport of oxygen by the blood. Exposure has been shown to aggravate chest pain in patients with coronary heart disease. Both individuals with chronic heart disease and respiratory problems are at greatest risk.

As discussed in the previous section, warmer air could increase concentrations of these pollutants. On the other hand, global warming may change air currents in ways that help flush pollutants away from populated areas.

AIR POLLUTION - BIOLOGICAL AND PHYSICAL DAMAGE

Increases in air pollution will increase damage to California's ecosystems, crops, forests and structures.

If global warming occurs, it may lead to an increase in ozone and acid deposition. These pollutants have been associated with damage to ecosystems, crops, forests, and materials as described below:

- Ecosystem Sensitivity -- Acid deposition has been shown to adversely affect fish populations in sensitive lakes and streams. It is suspected as a cause of forest decline. Changes in hydrologic regimes may affect timing and buffering of acidification events in streams and lakes; in conjunction with probable ecological stress caused by climate change, effects may be different than currently observed. Lengthened growing season and altered rainfall/snow patterns may alter forest sensitivity to acids.

- Crop Damage -- Ozone causes visible injury, reduced quality, and yield loss in many California crops. At present levels, ozone causes yield losses up to 20% for such major crops as cotton, citrus, grapes and alfalfa in the San Joaquin Valley, and has eliminated very sensitive crops (such as beans) from southern California farms.

  Season-long cumulative ozone exposure, even at levels generally below the state and federal ambient air quality standards, is more significant to crop loss than short-term high ozone concentrations; thus, the probable lengthening of the ozone season associated with global warming and increased UV radiation poses a major threat to agriculture.

- Forest Damage -- Timber productivity and general forest health are at risk from ozone exposure. Ponderosa and Jeffrey pine, red fir, white fir, giant sequoia, black oak and other California trees have been shown to be injured by ozone; severe forest injury and widespread tree mortality have been observed in the San Bernardino Mountains, and similar symptoms have been found on pines in the Sierra as far north as Lake Tahoe. Ozone is indicated as the likely cause of tree growth reduction in Yosemite and Sequoia National Parks. A longer and more intense ozone season will probably intensify the injury to trees in central and northern California, and may reduce total timber available under "sustained yield" management.

  A longer, warmer summer will likely further increase ozone transport from the San Joaquin Valley into the forest belts of the Sierra. Increases in the frequency, intensity, and altitudinal extent of ozone exposure are all likely consequences of global warming and increased UV radiation. Coupled with the stresses of a changing climate, major ecological deterioration is a likely consequence, both for economic forest resources and general wildland values (watershed, parklands, recreation, etc.). (See page 66 for further discussion of the effects of air pollution on California's forests.)

- Materials Damage -- Ozone causes deterioration of paints, rubber, plastics and many other organic materials; damage is a function of cumulative exposure. The economic consequences of shorter material life and the need to replace some traditional materials with more ozone resistant ones are not well quantified, but a prolonged ozone season will surely increase these costs.

WARMING EFFECTS ON HEALTH

Increased warming may endanger the health of thousands of California citizens.

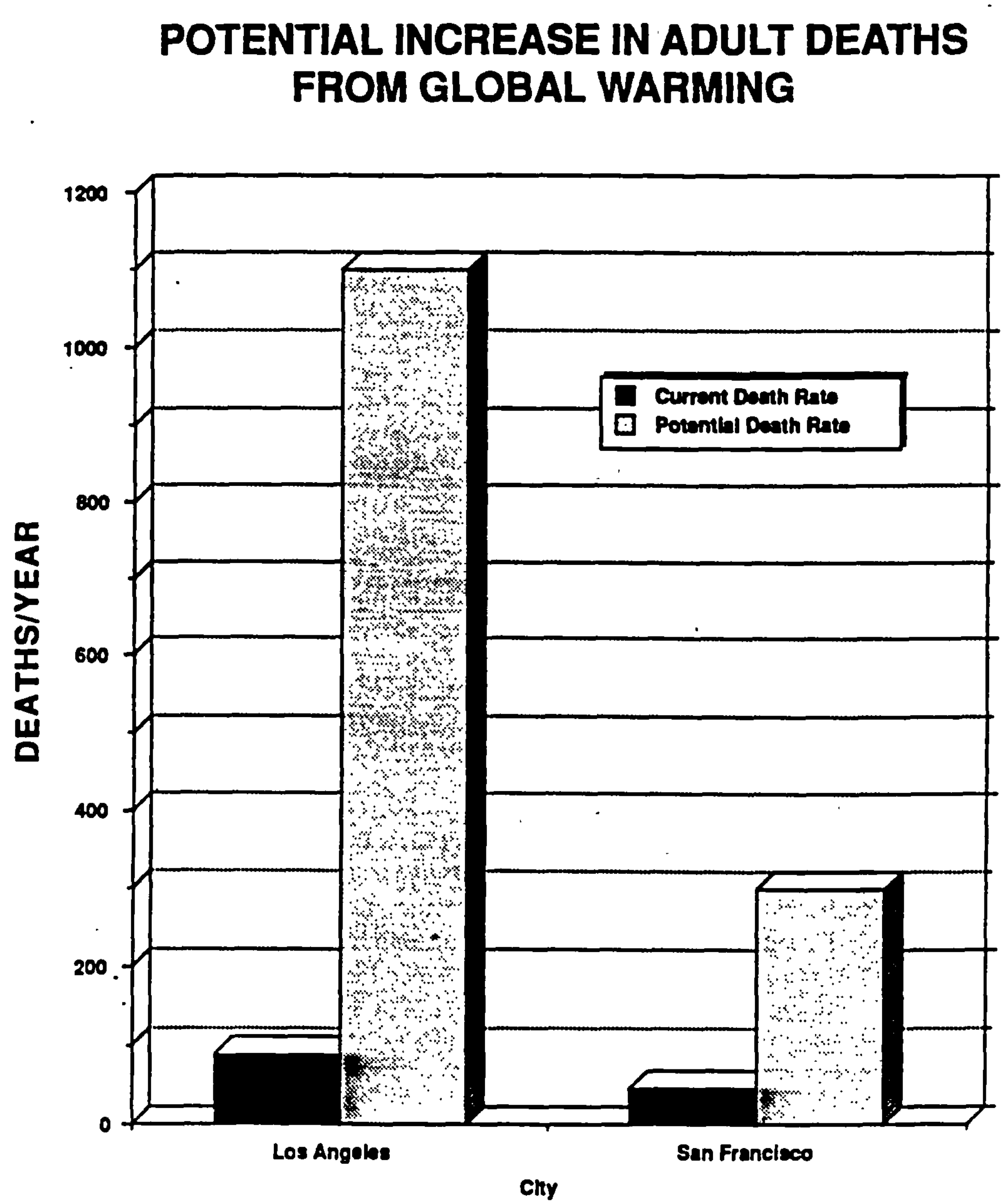
Global warming of the magnitude presently projected would likely result in both increased morbidity (illness) and mortality (death) among California citizens (see Figure 33). The elderly and the very young would be the most severely affected. More than 70 percent of the increased mortality in adults would occur in persons above the age of 65 (Kalkstein, 1988). Most of these deaths would result from exacerbation of coronary heart disease and cerebrovascular disease (stroke). Based on one study, the number of excess deaths in California could exceed 2,000 per year statewide among those at greatest risk. It has also been suggested that acclimatization to increased temperature may moderate these impacts (Kalkstein, 1988).

Global warming may also indirectly lead to an increase in the number of premature births and perinatal deaths (deaths occurring before, during, or just after birth [see Figure 34]). Increases in the number of preterm births and perinatal deaths are generally associated with the warmer summer months (Keller and Nugent, 1983; Copperstock and Wolfe, 1986). These are thought to result from increased incidence of genital infections in the mother during warmer months of the year (Keller and Nugent, 1983). It is likely that global warming would increase the duration of ambient conditions which are conducive to an increased incidence of infection. Using available data on preterm births and perinatal deaths, and estimating 36,000 persons at risk in any month in California, leads to an estimated excess perinatal death rate of approximately 10 per year statewide and an estimated excess preterm birth rate of approximately 43 per year statewide. It should be noted that preterm birth increases the risk of both morbidity and mortality in developing infants (Cavanagh and Talisman, 1969; Babson and Benson, 1966). Thus, further increased morbidity and mortality should be expected in these infants.

Changes in soil moisture (as a result of increased summer heat) may lengthen the season for fugitive dust from farmland, and possibly increase the aerial transport of soil-related human pathogens (e.g. valley fever).

Global warming may also affect the transmission of vector-borne diseases. At present, such diseases are not a major public health problem in the United States or in California. This is due to effective vector control programs and adequate hygienic practices. Global warming could result in conditions which are more favorable to the spread of vectors such as mosquitoes and ticks. This could lead to reintroduction or increased incidences of diseases such as malaria, dengue fever, and encephalitis (Wiseman and Longstreth, 1988).

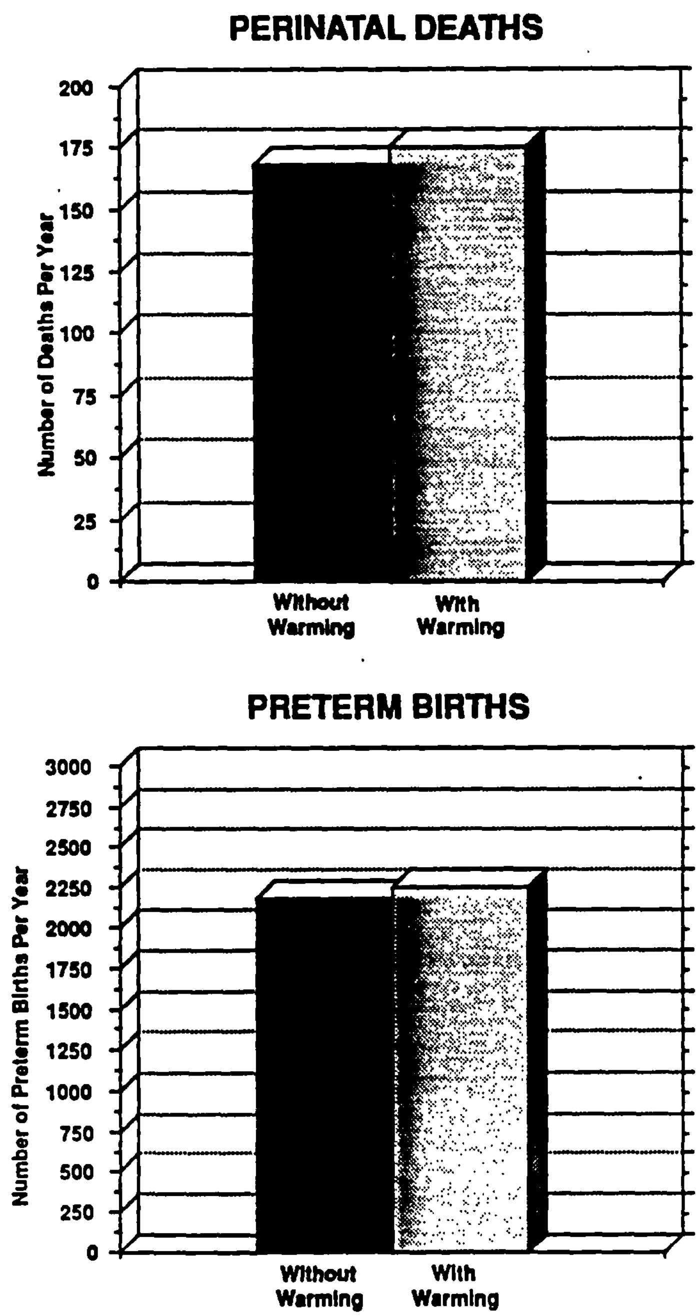
Figure 33



SOURCE: EPA, 1988.

Figure 34

POTENTIAL INCREASE IN PERINATAL DEATHS & PRETERM BIRTHS FROM GLOBAL WARMING



EPA, 1988

ECONOMIC IMPACTS

Summary

<u>Global warming could have a dramatic impact on California's economy.</u>

Most of the impacts discussed in this report would ultimately have economic consequences. Changes in the energy, agricultural, and forest industries directly affect the economy. Changes in other areas, water supplies and air quality for example, have direct and indirect economic consequences. The California economy and its relationship to the world economy is extremely complex. The ways in which global climatic change will affect the California economy are similarly complex and difficult to conceptualize, much less quantify (see Figure 35). The following is a summary of the ways in which a global warming could affect the state's economy:

- Higher prices -- for water, electricity, wood, fuels, farm products, and for goods requiring input of these primary goods.

- Changes in trade -- resulting from changes in the availability and prices of some goods, changes in the economies of our trading partners, and changes in the overall global economy.

- Changes in demographics -- as a result of an increase of "economic and environmental refugees" from areas in the world that experience significant climate drying, warming or economic disruption. This may be of particular significance for areas in North America, where immigration to California may be easy. The possibility of emigration out of California as a result of these trends must also be recognized. A larger difference between income levels and economic strata within California may result.

- Shift of investments -- from normal investments in the economy to investments necessary for accommodating a warming, thereby reducing available capital necessary for maintaining a robust and growing economy.

- Changes in the riskiness of investments -- as a result of climate circumstances outside the experience of most investors, may cause upward pressure on interest rates and cost of capital, further constricting the availability of discretionary capital.

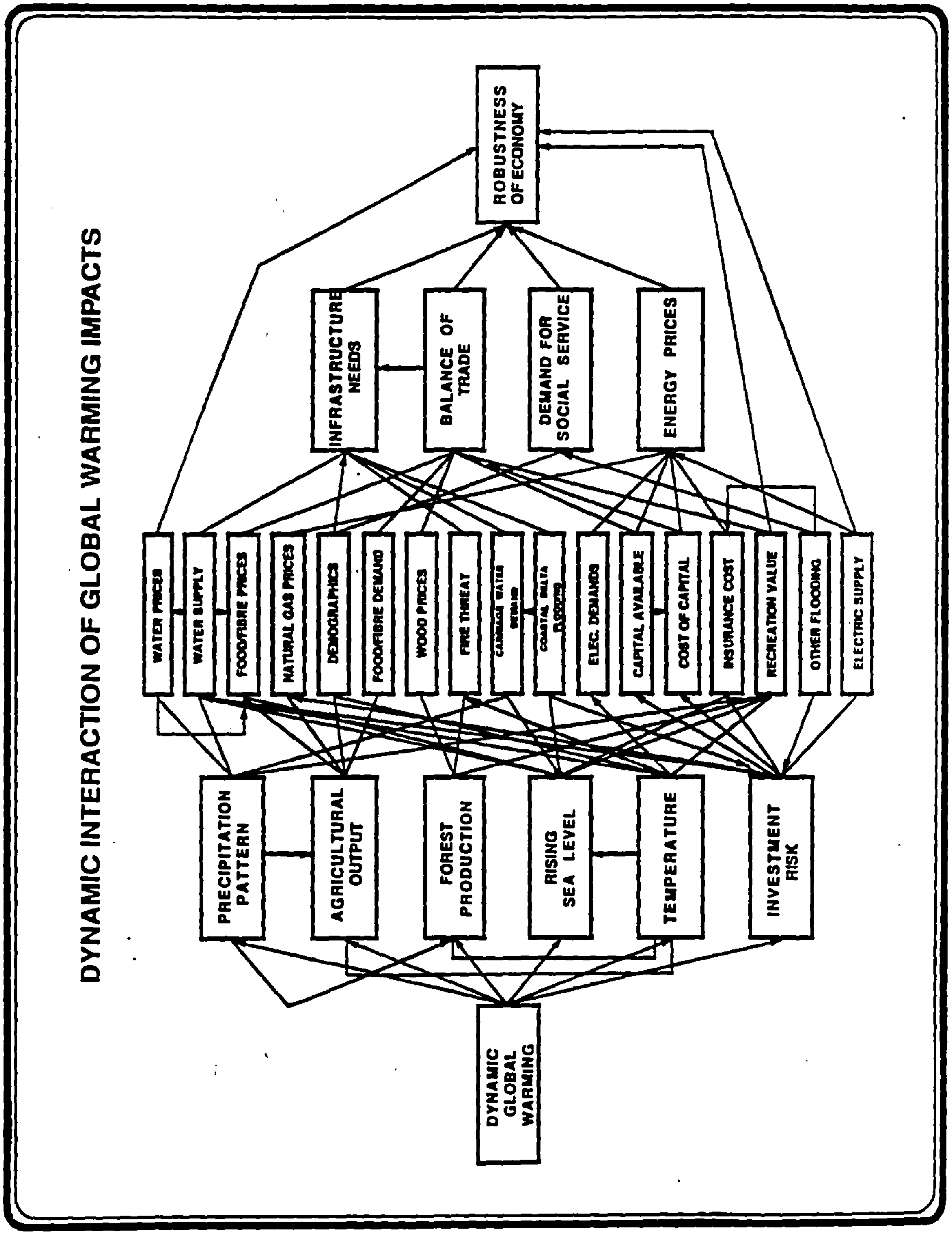
A healthy economy should be able to accommodate any one of these changes. But, the economy is built on a foundation of stability, and, to a large extent, predictability. Global warming and its effects will be characterized mainly by rapid change, instability, and very little predictability. It is extremely important to remember that global warming is not likely to be a <u>single</u> shift (rapid or otherwise), but rather will continue to effect the fundamental aspects of our economic and social structure. This discussion of the possible impacts on our economy is only the first step in preparing to respond to the fundamental changes which may occur.

COST OF GOODS

<u>Global warming may cause changes in the cost of goods and services which will have a negative impact on California's economy.</u>

The effects of a major climate warming, as discussed throughout Chapter III, can have a wide variety of effects on the costs of goods and services provided in California. The following are the major goods and service areas that may be subjected to price changes:

Figure 35



DYNAMIC INTERACTION OF GLOBAL WARMING IMPACTS
ROBUSTNESS OF ECONOMY
INFRASTRUCTURE NEEDS
BALANCE OF TRADE
DEMAND FOR SOCIAL SERVICE
ENERGY PRICES
WATER PRICES
WATER SUPPLY
FOOD/FIBRE PRICES
NATURAL GAS PRICES
DEMOGRAPHICS
FOOD/FIBRE DEMAND
WOOD PRICES
FIRE THREAT
ELEC. DEMANDS
CAPITAL AVAILABLE
COST OF CAPITAL
INSURANCE COST
RECREATION VALUE
OTHER FLOODING
ELECTRIC SUPPLY
PRECIPITATION PATTERN
AGRICULTURAL OUTPUT
FOREST PRODUCTION
RISING SEA LEVEL
TEMPERATURE
INVESTMENT RISK
DYNAMIC GLOBAL WARMING

- Water prices may rise as a result of market pressure from lower deliveries, lower seasonal supplies, and higher demand. Prices of goods that require water in their production may also increase. Water supply, quality, and cost are already becoming extremely sensitive policy areas, even without potential impacts from climatic change.

- Electricity prices may rise because of higher demand as well as higher cost supply (eg. the use of more fuel based generation compared to hydroelectric.) The price of goods and services requiring electricity may also rise.

- Natural gas prices may rise if the federal government restricts coal burning, either through direct regulation or imposition of a "carbon tax". If coal is partially replaced with natural gas, the increased pressure on the gas market could lead to price increases. This could raise the price of gas for home heating, as well as for goods requiring gas in their production, and in industries which rely on those goods as intermediate inputs. An example of this latter category would be in the agricultural sector which relies on fertilizers derived from natural gas.

- Some food and fiber goods may cost more but a warming may not uniformly raise the price of California-grown foods and fibers. While there may be less irrigation water, higher CO_2 concentrations may lead to higher water use efficiency. And there should be longer, warmer growing seasons. However, most analysts expect the world production of cereal grains to decline, which would lead to higher prices for grain products, for most meats, and fiber. The balance of trade for California may be positively or negatively affected depending on the relative price increases in California as well as other parts of the world with which we trade.

- Building materials, particularly wood products, may become more expensive as overall forest growth is reduced and forests are exposed to increased disease, insect, and fire damage.

- Higher transportation costs may result if there are national or international restrictions on fossil fuel burning, particularly oil-based fuels.

- Heavy manufactured goods, both industrial and consumer goods, may become more expensive if the federal government places use restrictions on fossil fuels (especially coal). Because California currently does not have extensive heavy industry that relies on coal, this is likely to affect our balance of trade with states and countries having concentrations of such industries.

It is worth noting that many of the above price changes are expected as a result of tighter supplies of some goods. Keep in mind, however, that increased prices themselves can lead to reduced market demand. Generally, tighter supplies will lead to an equilibrium of somewhat higher prices and somewhat lower demand.

The differential inflation resulting from the above price changes could have widespread impacts on the California economy including:

- Changes in the distribution of income; and increased differential between economic strata.
- Possible increases in forced savings, investment, and growth;
- Changes in the international economy, which would, in turn, affect the California economy;
- Increases in production and business uncertainty.

FOREIGN TRADE

Global warming may result in major changes in California's imports and exports.

Trade plays a critical role in California's economy. In 1988, California exported $34.6 billion in goods and services (out of a total earning of $630 billion). In comparison, California imported $38.5 billion in goods and services. Last year, exports were directly responsible for 233,000 jobs. Directly and indirectly, 935,000 Californians were employed in trade-related activities.

Some researchers estimate that the climate changes resulting from an effective CO_2 doubling will reduce global economic growth by three percent per year (somewhat more than current average growth). If this becomes the case, the world economy, and California's trade relations with the rest of the world, could be severely affected.

Global warming could affect California's trading activities in the following ways:

- Reduced Production of Export Goods - For example, there may be lower production of goods from industries that require water in the production process, in particular agriculture.

- Supply Reduction of Some Imported Goods - The global production of some goods may shrink (for example, cereal grains as well as goods that are produced using coal), with a corresponding increase in price.

- Increased Demand for Some Imported Goods - A decline of in-state production of some goods, such as forest products and energy, may lead to increases in imports.

- Increases in the Costs of Some Imported Goods - Physical and policy changes resulting from global warming may substantially change the price of some goods. For example, the price of imported natural gas may increase if the federal government places policy restrictions on coal use. California currently relies on imports for over 50 percent of its gas needs. Without considering climate change, this figure is expected to increase to over 70 percent by 2010. Decreased production in source countries for imported goods may raise the cost of those goods.

- Decreased Demand for California Exports - Changes in the indigenous production of goods typically provided by California exports may reduce the demand for goods from California. For example, increases in the rice production of Asian countries may decrease the demand for California grown rice in those areas.

- Changes in the Economies of Our Trading Partners - Some countries may suffer serious and fundamental economic declines as a result of global warming. Our trade with these countries could suffer as a result.

- Changes in the Global Economy - Global warming is an issue that could ultimately affect most aspects of the world economy. The California economy could be affected to the extent that the global trade environment is affected.

As a final note, global warming may result in a shift in the global mix of goods traded. Trade dollars may be more necessary for food and other essential goods, and less for non-essential goods. Of particular note is that as more dollars are spent by necessity on food and other essential goods, less dollars will be available for investments in the technological improvements fundamental to California remaining competitive. California, as well as the entire U.S., currently has the lowest savings rate as a percentage of GNP of all industrial nations. Savings provide the capital for investments in new and advanced tooling for industry as well as fundamental research and product development. Currently, for example, Japan's savings rate is approximately 18 percent of GNP while that of the U.S. is under 2 percent. The availability of capital to make improvements suffers and the competitiveness of the U.S. has been steadily eroding. Some industries, particularly those providing food and essential services, may gain in the short run, but many other industries may suffer.

DEMOGRAPHICS

Global warming may cause significant changes to the demographics of North America, with an influx of economic and environmental refugees coming to California. These refugees may bring additional labor into the state, but may also stress the state's basic social services.

There are currently over 27 million Californians. By the turn of the century, the population is expected to reach over 32 million. And based on current trends, the population may reach 40 million by the middle of the next century.

Global warming may change existing demographic patterns over most of North America and the world. Climate models project substantial drying in the midwestern United States grain belt, and some projections indicate that parts of Northern Mexico will also become dryer. Similarly, significant changes are likely throughout the world, differing only in type and timing. The economies of many of these areas are, in large part, based on agriculture. Thus, to the extent that the warming affects their agricultural productivity, it will affect the ability of their economies to support current and projected populations.

If history is any guide, many of the people living in these areas will leave to seek a better life. During the dust bowl period of the 1930s, California's population increased by 1.2 million, or 22 percent, as people from the drought-stricken Midwest migrated to California and their children were born. While this was not the greatest percentage increase of this century (other factors like World War II had larger increases), the demographic makeup of the environmental refugees was unlike that of other periods. Future warming-induced droughts could lead to similar migrations. Again, California may be an enticing destination for at least some refugees. At the same time, changes within California may cause current residents to emigrate in search of the "California of old". It is possible that only the most able people will choose to emigrate, creating a financial and capability drain on the California population.

An influx of economic refugees could have positive and negative implications for California. On the positive side, a larger pool of labor is often good for business. New people can bring outside perspectives to bear on existing social and economic problems. On the negative side, many of the major social problems California now faces are directly or indirectly the result of population growth. Even without a refugee influx, California may have some difficulties overcoming these existing problems. Further population increases may only add additional stress to the state's social, political, and economic infrastructure. An area needing particular attention may be education and job training, since many of the refugees may be coming from areas dominated by job types for which there are insufficient substitute opportunities in California. This will place additional pressure on social programs, an area already under stress.

Thus, as a result of warming, the stable fabric of California's social structure may experience substantial and continuing upheavals.

INVESTMENTS

Investments may be required to accommodate warming-induced changes; investments to maintain our infrastructure could become a major drain on California's economy.

One of the underlying reasons for California's economic success is its well-developed infrastructure. The state's water, energy, transportation, public safety, and associated systems have been developed over decades, and have required hundreds of billions of dollars in investments. However, our infrastructure is becoming increasingly difficult to maintain and expand. We currently spend billions of dollars to maintain our roads, levees, ports, and sewage treatment facilities. Even so, many aspects of the infrastructure are rapidly deteriorating even without the effects of climatic change.

There are two portions of our infrastructure; the physical aspects and the fiscal and legal framework. Portions of either system may be further jeopardized by a climate warming.

The areas of the physical infrastructure that may require investment because of a warming are as follows:

- Delta and coastal protection structures (protection from an ocean level rise).
- Runoff flood protection structures such as levees and dikes (protection from higher winter runoff).
- Structures near the coast such as port facilities, roads, airports, and waste water outflows (protection from a rise in the ocean level).
- Water storage structures (protection from floods and increased storage to replace lost snowpack).
- Temperature control facilities at the release works of large dams (provide cold water necessary for some fisheries).
- Electric generation facilities (to respond to increased demand and reduced hydroelectric supply).
- Forest fire protection infrastructure (to protect against the increased risks of forest fires in a dryer climate), and population increases in rural areas.
- Reforestation investments (possible use of more drought and heat tolerant species in reforestation).
- Desalinization facilities may need to be designed and built to provide fresh water, particularly in coastal areas subject to intrusion of salt water into underground aquifers. This will become more acute as sea level rises increase hydrostatic pressures.

Investments in some of these areas, reforestation for example, may need to start during the next decade. Others, those responding to an ocean level rise for instance, might not be needed for several decades.

The fiscal and legal framework within which the physical infrastructure is developed is likely to also undergo significant reexamination and changes. Fundamental legal issues will arise as global warming changes the location of navigable waters, intertidal zones, and flood-prone areas. With the potential sea level rise and change in precipitation patterns, flood-prone areas are likely to expand and move, and may involve areas already developed. This will raise issues associated with flood protection responsibility and ownership rights.

In addition, the insurance industry is likely to undergo significant upheaval. The insurance industry is based on years of actuarial data, from which risks and premiums are determined. Because global climatic changes will create additional uncertainties and instabilities in all facets of business, the validity of this historical data base will become less and less relevant. Insurance risks will become greater by being more uncertain. This may raise rates and, in some cases, make insurance coverage unobtainable. Adequate insurance at affordable rates is crucial to most business endeavors, from farming, transportation, and consumer products to education.

Both the additional investments and the institutional changes may divert funds, human capital, and expertise from other areas of the state's economy, ultimately jeopardizing its continued overall health (see Figure 36).

ECONOMIC UNCERTAINTY

<u>Perhaps the most significant economic impact of warming will be its effect on risks of long-term investments.</u>

Investments are critical to California's economy. The state depends on consistent investment to replace and enhance the engines of the economy. Those who would invest need an understanding of the risks and returns of an enterprise before they make investments.

Investors thrive on stability. The more stable the environment around an enterprise, the more able the investor can be in assessing its risks and returns. Historically, during periods of economic uncertainty, investors have been reluctant to make investments. The result has often been a significant decline in economic activity.

The most certain conclusion that can be made about California in light of global warming is that we will face uncertain and unstable surroundings (see Figure 37). There are strong indications that the atmosphere will be warmer, but there is uncertainty about how much. It is unclear if we will have more or less rain, or how much or how fast the sea level will rise. But most scientists studying the warming are convinced that significant climate changes are coming.

The climatic uncertainty may lead to uncertainty in the following investment areas:

- Agricultural investments - For example, whether or not to invest in establishing new orchards.

- Energy investments - How much energy generation will be needed in the future; and when will it be needed? What type of facilities will be needed and can they be built and operated in an era of environmental constraints?

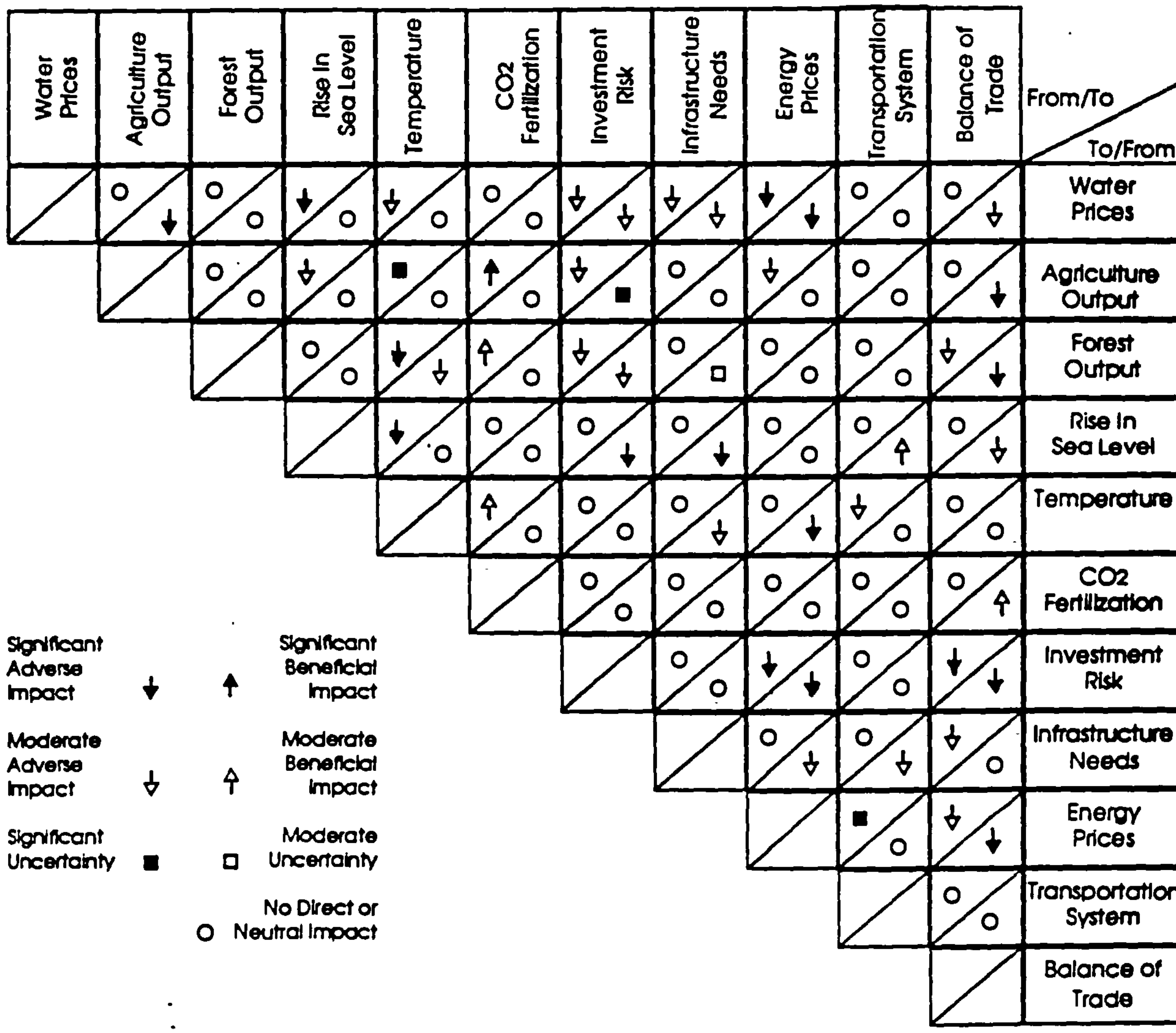
- Water storage investments - How much additional water storage will the state need to meet its future water demands? What alternatives or adjuncts to increased storage will be feasible?

- Investments in flood-prone areas - How much will the 50- and 100-year flood plains change; how risky will it be to invest in structures or other land uses in or near these flood-prone areas?

- Investments near the coast - How quickly will the sea level rise? What will happen to the coastline?

Figure 36

Significance of Impacts from Global Warming

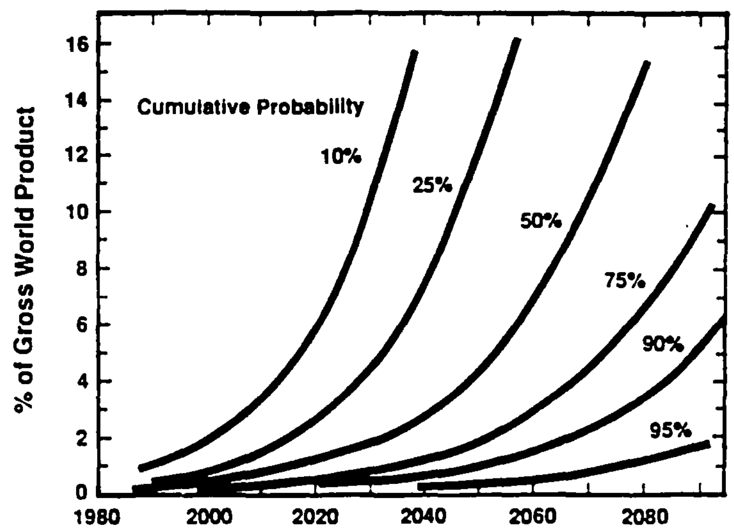


* Some crops may do better due to longer growing season, but also may be stressed from high temperatures.

** While agriculture output may increase, the food value may decrease due to CO_2 fertilization.

Figure 37

POTENTIAL IMPACT OF GLOBAL WARMING ON WORLD ECONOMY



Effect of uncertainty in climatic change predictions on capital asset loss rate. 3% per annum increasing CO2 release rate.

Laurmann, 1988

In addition to uncertainty from climate changes, investors may face uncertainty surrounding government response to global warming. There are, for example, several independently-owned (nonutility) power plants proposed for construction in the Southwest United States. These plants, proposed to serve the California electricity market, would use coal as their primary fuel. Yet the federal government, in responding to the global warming issue, may place restrictions on the use of coal, since coal produces more CO_2 per unit of energy than any of the other standard fossil fuels. Such restrictions could severely constrain or even stop new coal/electric development.

Already businesses have exhibited a surge of interest in long-term climate trends. Some firms are using global warming information to make strategic investments in preparation for a warming. For example, Archer Daniels Midland Company has purchased a stake in a Midwest rail company in anticipation that the warming could jeopardize barge traffic on the Mississippi River. Weyerhauser Company has begun planting more drought-tolerant trees in case precipitation decreases (Cahan & Bremner, Business Week, February 13, 1989).

If the uncertainty increases, California businesses will need increasingly specific information about climate changes and their impacts if they are to remain competitive. Will the information be available when California needs it?

CHAPTER IV

POLICY ANALYSIS TO BE COMPLETED FOR THE FINAL GLOBAL WARMING REPORT

The following policies will be analyzed in the next phase of the global warming study. The final report (due to the Legislature in June 1990) will describe this analysis and make recommendations on policies for delaying future warming as well as on those for accommodating any California warming experiences.

(Note: While all the policy areas described below will be analyzed, the Commission may conclude that no recommendations are warranted for many areas.)

<u>Policies for delaying possible future warming</u>:

The first step in determining the best policies for delaying possible warming will be to inventory the greenhouse gas emissions that can be attributed to California. This inventory would include CO_2, CH_4, CFCs, CO, N_2O, and tropospheric O_3. Once the inventory is complete, the following analyses are needed:

- <u>Understanding the need for emission reductions</u> -- determine the level of emission reductions required to sustain various levels of warming delay (note: this area will include an assessment of probably national and international greenhouse gas policies).

- <u>Greenhouse gas reduction opportunities</u> -- determine the effectiveness of policy intended to reduce greenhouse gas concentrations. The areas that will be examined include:

  -- Energy policies, including energy conservation, developing renewable energy resources, and entrapping carbon.

  -- Policies for reducing non-energy carbon emissions, such as those from waste burning, as well as the possibility of reducing emissions by recycling material.

  -- Carbon sequestering, removing carbon from the atmosphere and storing it, primarily in growing trees.

  -- Reducing CFC emissions through recycling, limiting CFC use, and displacing CFCs with other materials.

  -- Reducing methane emissions from landfills, industrial and mobile sources, and agricultural and wildland sources.

  -- Reducing the emissions of nitrogen oxides, carbon monoxide, and tropospheric ozone through further controls of industrial and mobile sources, as well as by controlling agricultural and wildland sources.

  -- <u>Recommend emission reduction goals for the major greenhouse gases</u>.

  -- <u>Recommend a specific set of policies to achieve the recommended emission reduction goal</u>.

<u>Policies to Accommodate Warming</u>

In addition to policies to delay further warming, the study will analyze policies to help the state adapt to warming that may come in any event. The following are policy areas that will be examined for each of the impact areas described earlier in this report:

- Water policy measures including conservation, storage development, flood planning, and environmental monitoring and control.

- Energy policy measures for accommodating warming will be essentially the same as those for reducing CO_2 emissions.

- Agricultural policy measures, including those that increase water use efficiency, help farmers adapt to a warmer climate, and use agriculture as a source of energy feedstocks.

- Forestry policy measures including reforestation; urban forestry; and wildfire, disease, and insect protection.

- Coastal and delta protection measures including expanded coastline and delta protection planning.

- Natural habitat measures including more extensive environmental monitoring and planning.

- Air quality measures including more stringent air quality management and enforcement (Note: many of the measures to reduce emissions of greenhouse gases will also help improve regional air quality.)

- Human health measures including close monitoring of heat-related health problems and warm weather disease vectors.

- Economic measures including more aggressive trade programs (particularly those that promote the export of technologies that help reduce greenhouse gas emissions), and incentives for investments that rebuild the California economy's infrastructure in ways that minimize the impacts of warming.

Many of the policies listed above could also help alleviate existing problems that have no connection with global warming (for example, reducing most greenhouse gases will help reduce regional air pollution). As a result, the analysis of this study will also explore the usefulness of global warming policies in addressing other issues.

The final goal of the policy analysis is to develop a set of recommendations that integrates prevention and accommodation policies and ties these in with efforts to address significant issues not related to global warming.

Appendix A

THE EFFECT OF GLOBAL WARMING ON SPACE CONDITIONING IN CALIFORNIA BY 2050

Lester W. Baxter
California Energy Commission
1516 Ninth Street
Sacramento, CA 95814

April 26, 1989

Written as a Technical Appendix for the Interim Report of the CEC Global Warming Study. The CEC study was prepared in response to Assembly Bill 4420, which directed the CEC to assess how warming trends may effect California. This Appendix is the basis for the energy demand impacts described in the CEC Global Warming Study.

Acknowledgements: This project was possible through the technical support of Raul Herrera, Margaret Miller, and Glen Sharp. I thank Sy Goldstone and Karen Peterson for their review of an earlier draft and Susan Mattox for her preparation of this manuscript.

THE EFFECT OF GLOBAL WARMING ON SPACE CONDITIONING IN CALIFORNIA BY 2050

Lester W. Baxter
California Energy Commission

INTRODUCTION

A warmer future climate will change electricity use patterns in California--the question is how much will current patterns change. This paper examines changes in California's electricity use patterns if average global temperatures increase 3° Centigrade (C) by 2050.

A few key uses of electricity are quite sensitive to changes in temperature. These key uses are the heating and cooling of buildings (i.e., space conditioning) and the pumping and transport of water for agricultural and urban uses. Other uses, such as refrigeration and water heating, are also affected by temperature changes but not nearly as much as space conditioning and water use.

This paper focuses on the changes in the space conditioning of California's residential and commercial buildings that could result from an increase in mean global temperatures. Because agricultural and urban water use is not considered in this analysis[1], the results probably understate the overall effect of global warming on electricity use.

In the only comprehensive assessment of the potential effects of global warming on electricity demand, Linder et al. (1988) describe two techniques that can be used to estimate the sensitivity of demand to weather conditions such as temperature: the statistical approach and the structural approach. In both approaches, the goal is to estimate quantitative relationships between changes in temperature and changes in annual electricity use and peak demand, i.e., temperature sensitivity relationships.

The statistical approach develops temperature sensitivity relationships using temperature data and aggregate electricity use data. Statistical techniques, such as regression analysis, are applied to estimate quantitative relationships between historical temperatures and electricity use. Using the statistical approach, Linder et al. find that annual electricity use in New York and at a Southeastern utility will increase 0.12 percent and 3.58 percent, respectively, for each 1°C increase in temperature.[2] The temperature sensitivity of peak demand is estimated to be 2.14 percent in New York and 6.77 percent in the Southeast.

---

[1] An agricultural and urban water use study is underway, but will not be completed in time for inclusion in the CEC Global Warming Study.

[2] The temperature sensitivity of demand is expressed as the percent change in total demand for a 1°C increase in average annual temperature.

Temperature sensitivities are higher in the Southeast due to the heavy use of air conditioners in that part of the country.

The structural approach, in contrast, operates at a much greater level of disaggregation. This approach measures the underlying temperature sensitivities of end-use energy models. These underlying temperature and energy use relationships are derived from statistical techniques and detailed computer simulations of building thermal performance. The temperature sensitivities, in conjunction with data about appliance saturations and use rates, are used to develop detailed end-use energy forecasts. Forecasts of utility system loads are made by aggregating across end uses, building types, and customer sectors. Using the structural approach, Linder et al. estimate that annual electricity use in New York will increase 0.43 percent and peak demand will increase 4.09 percent for each 1°C increase in average annual temperature. The structural approach yielded higher temperature sensitivities than the statistical approach in the one area, New York, where both were applied.

Although both the statistical and structural approach provide temperature sensitivity estimates, the interpretation of the temperature sensitivities depends on the assumptions underlying each application. The statistical approach estimates a short-term response to temperature increase because the relationships estimated by Linder et al. are made over a short enough time period that air conditioning stocks are essentially fixed. In contrast, the structural approach accommodates changes in air conditioning stocks. For example, Linder et al. assume that in a warmer world New York residents will purchase more air conditioners than they would in the absence of climate change. Of course, the structural approach will also provide short-term temperature sensitivities if air conditioner purchases are assumed to follow historical trends.

This study uses the structural approach to estimate the temperature sensitivity of space conditioning demand in California. Temperature data from weather stations throughout California are used in conjunction with the CEC's end-use energy demand models to quantify the relationship between temperature and electricity use. A long-run electricity forecast recently published by CEC Staff serves as the Base Case for the development of the temperature sensitivities and the starting point for electricity projections to the year 2050. The increase in air conditioner saturations in the long-run forecast is consistent with recent historical patterns. California's new homes already have high air conditioner saturations compared to older homes; thus, the global warming scenarios are not assumed to increase air conditioner saturations over those contained in the Base Case.[3]

[3] In California's warmer climate zones, the majority of new homes have space cooling equipment. For all but one of these climate zones, space cooling equipment is found in 88 percent or more of the new homes.

As a result, the temperature sensitivities applied here reflect California's short-term response to global warming.

The temperature sensitivities estimated for California suggest that a 3°C warming will increase statewide annual electricity use by 1.38 percent to 2.54 percent, depending on whether the temperature sensitivity of demand is low or high. These percentage changes translate into an absolute increase of 6,000 gigawatthours (GWh) [4] to 11,000 GWh by 2050 over the Base Case projection. Statewide noncoincident peak demands[5] will increase by 2.90 percent to 6.66 percent with a 3°C increase in average annual temperature. Statewide peak demands will be 2,900 megawatts (MW) [6] to 6,600 MW greater than the Base Case projection by 2050. The peak demand results are quite sensitive to the assumed change in daily temperature patterns associated with a warming trend. Different assumptions will produce substantially different estimates.

The following discussion describes the underlying study that developed the temperature sensitivities used to make the 2050

---

[4] A gigawatthour is one million kilowatthours, which has the heat content of 3.34 million cubic feet of natural gas or 586 barrels of oil.

[5] California's utilities all experience their peak demands during the summer, but rarely all peak at the same time. Thus, the statewide peak impacts are reported as the sum of each individual planning area's impact.

[6] A megawatt is one thousand kilowatts, or enough energy to provide electricity for about 250 households.

projections (Baxter et al., in press). The development of the temperature sensitivities required the adoption of temperature change scenarios and the estimation of electricity use impacts. The description of the background study therefore presents annual electricity and peak demand impacts for 2010.[7] Second, the method used to project Base Case electricity use to 2050 is outlined. Third, the basic assumptions and limitations of the 2050 projections are discussed. Finally, the projected changes in California's electricity use by 2050 are presented for both a low sensitivity and high sensitivity case.

A REVIEW OF THE 2010 STUDY

The 2010 study projects the effect of global warming on space conditioning use in California and estimates the temperature sensitivity of space conditioning demand. The estimated temperature sensitivities are used to project the effect of global warming on electricity demand in 2050. Temperature sensitivities are estimated using the structural approach. The CEC's detailed end-use forecasting models and tri-hourly temperature data from nine California weather stations are used to estimate the temperature sensitivity of demand. CEC Staff's most recently published long-run electricity forecast is used to derive the Base Case forecast for 2010. The Base Case forecast is made in the absence of climate change. Two temperature increase

---

[7] Hereafter the background study is referred to as the 2010 study.

scenarios are adopted and the end-use models are then run to produce annual electricity and peak demand projections for the year 2010. The energy projections provide estimates of the absolute changes in electricity use for each global warming scenario as well as estimates of the temperature sensitivity of space conditioning demand.

Data and Methods Used in the 2010 Study

The analysis in the 2010 study consists of three steps. First, two global warming scenarios are adopted. Second, the temperature data used by the CEC for long-run energy forecasting are modified to be consistent with the two global warming scenarios adopted. Finally, CEC Staff's end-use models are used to project annual electricity use and peak demand in 2010 using the modified temperature data. A Base Case electricity projection is made under the assumption that the current climatic conditions remain unchanged in the future.[8]

The two global warming scenarios adopted in the 2010 study are based on scenarios developed at the World Climate Programme's workshop on climate change held at Bellagio, Italy in November 1987 (Jaeger 1988). The Low Temperature Scenario (LTS) and High Temperature Scenario (HTS) result in increases in average

[8] The assumption of a stable climate is the assumption currently used in all CEC long-run energy forecasts.

temperature of 0.6°C and 1.9°C, respectively, by 2010.[9] These temperature changes are made with respect to a reference climate. The reference climate used by the CEC is derived from the long-run average weather conditions observed over the 1976-1987 period. Thus, Base Case electricity projections are made with the assumption that future climate will resemble the conditions observed in California from 1976 to 1987. Table 1 provides a summary of the climate assumptions used in the 2010 study.

Table 1

Climate Change Scenarios

Increase in Average Temperature by 2010 (°C)

	Low Temperature Scenario	High Temperature Scenario
Winter	0.72	2.28
Spring	0.60	1.90
Summer	0.48	1.52
Fall	0.60	1.90
Average Annual	0.60	1.90

Note: The reference climate is the average conditions observed in California from 1976 to 1987.

A synthesis of General Circulation Model (GCM) results suggests that the amount of predicted warming differs by season (Jaeger

[9] The Low and High Temperature Scenarios in this analysis are consistent with the Medium and High Scenarios described in the Bellagio Report.

1988).[10] For mid-latitude areas, such as California, winters are predicted to exhibit somewhat greater warming than summers. Table 1 shows the seasonal temperature changes assumed in each scenario. Average winter temperature increase 20 percent more than the annual average and average summer temperatures increase 20 percent less than the annual average.

The climate change scenarios from Table 1 are incorporated differently into the annual energy models and the peak demand model. The annual energy models use average annual heating and cooling degree days to project annual space conditioning use. The climate change scenarios are incorporated into these models by increasing the daily maximum and minimum temperatures by the amounts shown in Table 1.[11] In the HTS, for example, daily maximum and minimum winter temperatures are increased 2.28°C and annual degree days are recalculated using the new daily values.

The peak demand model projects loads for each hour of the peak day. Projected hourly space cooling demand is sensitive to hourly temperature patterns on the peak day. Thus, an assumption

[10] A General Circulation Model attempts to represent the complex three-dimensional behavior of the earth's atmosphere and, in some cases, the earth's oceans. The GCM results reviewed in Jaeger (1988) are selected to reflect the range of results obtained from recent advanced scientific studies. The two models reviewed are from Hansen et al. (1984) and Manabe and Stouffer (1980).

[11] Annual degree days are calculated using daily maximum and minimum temperatures.

must be made about how global warming might alter temperature patterns on the peak day. An examination of California's historical temperature records since 1901 by Karl et al. (1988) suggests that daily minimum temperatures have increased over time. If such a pattern persists future temperature increases will be concentrated during that part of the day when temperatures are at their lowest, i.e., the late evening and early morning hours.

Unfortunately, GCM results provide little guidance in this area. Very preliminary work by Hansen et al. (1988) suggest that it may be appropriate to assume that global warming will not substantively alter the current day-to-day variability in weather. Thus, it may be appropriate to simply superimpose any future temperature increase on existing weather patterns.

The 2010 study assumes two different patterns of temperature change on the peak day. A nonuniform temperature change places most of the temperature increase in the late evening and early morning hours, consistent with Karl's observations. In the HTS, for example, the nonuniform change yields a 2.22°C increase at 3 a.m. and a 0.56°C increase at 3 p.m. on the peak day. The uniform temperature change results in a nearly uniform increase in temperature throughout the day. For example, in the HTS, the uniform change results in a 1.67°C increase at 3 a.m. and a 1.11°C increase at 3 p.m. Thus, the analysis of peak demand contains two additional scenarios: the LTS and HTS each have a nonuniform and uniform scenario to represent these two possible changes in daily temperature patterns.

The weather data used in the 2010 study are collected at nine weather stations throughout California. The data collected include daily high and low temperatures and tri-hourly temperature data. Daily highs and lows are used to estimate annual heating and cooling degree days and the tri-hourly readings are used to approximate daily temperature patterns. These data are collected over the 1976 to 1987 period and are used to represent the local climate conditions in thirteen California climate zones.

These weather data are used directly in the detailed end-use energy models developed at the CEC. The residential and commercial models generate forecasts by energy end use, building type, and climate zone. The space conditioning portion of the residential model includes four conditioning end uses, three building types, and thirteen climate zones (Hogstad et al. 1988). The space conditioning portion of the commercial model includes two conditioning end uses, eleven building types and thirteen climate zones (Nguyen et al. 1988).

The peak demand model operates at the same level of detail as the residential and commercial models (Baxter 1988). The peak model estimates daily air conditioning load shapes using the hourly temperature and humidity profiles on the peak day in conjunction with air conditioning response matrices. These matrices contain measured or estimated air conditioning loads for virtually any possible combination of temperature and hour of the day.

The Base Case electricity forecasts are derived from a recently published CEC staff forecast (CEC 1988). The final year of the published forecast is 2007; these forecasts are extrapolated to 2010 using the long-run growth rates in electricity demand contained in the 2007 forecasts. The thirteen climate zones are combined into the five largest electricity planning areas in California.[12] As indicated earlier, the Base Case forecast is made under the assumption that the climate represented by the 1976 to 1987 period remains unchanged in California. The only assumption changed in the projection scenarios is that of future climate, i.e., average temperatures. All other major assumptions, such as population and economic growth, building and appliance stocks, and the operation of appliances, are unchanged from the Base Case.

---

[12] A planning area is a geographic region around each of the state's major investor-owned or municipal utilities that includes the utility's retail customers as well as resale customers and self-generators. The CEC divides California into eight planning areas, but the five largest planning areas account for over 95 percent of total statewide electricity use and demand. The five largest planning areas are Pacific Gas and Electric Company (PGandE), Sacramento Municipal Utility District (SMUD), Southern California Edison Company (SCE), Los Angeles Department of Water and Power (LADWP), and San Diego Gas and Electric (SDG&E).

Temperature Sensitivity of Space Conditioning Demand

The key results of the 2010 study are estimates of the temperature sensitivity of space conditioning demand. Tables 2 and 3 provide these temperature sensitivity estimates for annual electricity use and peak demand, respectively.

Table 2 reveals that in every planning area but SMUD the increase in cooling from global warming more than offsets the decrease in heating. The temperature sensitivities of cooling in the LTS are all nearly 1.0 or greater and range from 0.96 percent to 1.56 percent. The HTS values are greater than the LTS estimates and range from 1.34 percent to 2.22 percent. These values imply that a 1°C increase in average summer temperature will result in a 0.96 percent to 2.22 percent increase in total planning area electricity use due to the greater need for space cooling. In the LTS the temperature sensitivity of heating ranges from -0.31 to -1.07. For the HTS, the temperature sensitivities are very similar to the LTS, albeit slightly smaller.

The net result for most planning areas is an increase in electricity use that ranges from about 0.50 percent or less in the LTS to over 1.10 percent in the HTS. Electricity use for cooling is much greater than for heating in most of California.

Table 2

Temperature Sensitivity of
Annual Electricity Use

Percent Change in Total Demand per
1°C Temperature Increase

Planning Area	Low Temperature Scenario			High Temperature Scenario		
	Heating	Cooling	Net[1]	Heating	Cooling	Net[1]
PGandE	- .38	1.21	.52	- .36	1.89	1.09
SMUD	-1.07	.96	-.52	-1.05	1.34	- .18
SCE	- .31	1.04	.47	- .29	1.43	.80
LADWP	- .40	1.04	.35	- .36	1.43	.70
SDG&E	- .62	1.56	.50	- .54	2.22	1.14

Notes:

1. The net temperature sensitivity does not equal the sum of the sensitivities for heating and cooling because the winter temperature increase is 1.2 times the average annual increase and the summer temperature increase is 0.8 times the average annual temperature increase.

This trend is especially pronounced in commercial buildings, which use six to seven times more electricity for cooling than heating.

Table 3 provides temperature sensitivities of peak demand for the five planning areas. The temperature sensitivities range from nearly zero to 4.11 percent. In the HTS, the temperature sensitivities range from 1.19 percent to 2.80 percent. In both scenarios, the temperature sensitivities are higher if the temperature increase occurs more uniformly throughout the day. The nonuniform case causes air conditioning demands to increase considerably at night. The proportionate increase in load is much lower during the afternoon, the time when California utilities typically experience system peaks.

Table 3

Temperature Sensitivity of
Peak Demand

Percent Change in Total Demand per
1°C Temperature Increase

Planning Area	Low Temperature Scenario		High Temperature Scenario	
	Nonuniform[1]	Uniform[2]	Nonuniform[1]	Uniform[2]
PGandE	0.09	2.21	1.70	1.97
SMUD	1.72	4.11	2.01	1.94
SCE	1.20	3.46	1.75	1.88
LADWP	0.60	1.56	1.19	1.38
SDG&E	1.80	2.17	2.21	2.80

Notes:

1. The nonuniform case places most of the temperature increase on the peak day in the early morning hours. The nonuniform case attempts to reflect the pattern of change observed in California's historical temperature records by Karl et al. (1988).

2. The uniform case assumes that the temperature increase on the peak day occurs nearly uniformly across the hours of the day. The uniform case attempts to incorporate the preliminary GCM results of Hansen et al. (1988).

The range in sensitivity between the nonuniform and uniform cases tends to be greater in the LTS. The peak demand model provides more stable estimates of temperature sensitivity when the average temperature increase is greater than 0.6°C. The model is less sensitive to temperature changes under 0.6°C because the temperature data used to simulate air conditioning load shapes are in 1° Fahrenheit (0.56°C) increments. A temperature increase smaller than 1°F does not change the pattern of the simulated air conditioning load shape. Thus, the sensitivity ranges produced from the HTS are more stable estimates of the underlying temperature sensitivity of the model. Nevertheless, considering sensitivities from both the LTS and HTS suggests that total planning area peak demand will increase by about 1.0 percent to 3.0 percent for each 1°C increase in average temperature due to the increase in air conditioning demand.

Annual and Peak Impacts by 2010

Table 4 reports the planning area changes in annual electricity use from the Base Case due to global warming. The PGandE planning area exhibits the largest changes in heating, cooling, and net electricity use. On a statewide basis, the LTS results in a net increase of 758 GWh, which represents 0.25 percent of total demand. The HTS yields a more dramatic net increase of nearly 5,000 GWh or 1.69 percent. The net increase in the HTS consists of a 7,500 GWh increase in statewide cooling requirements and a 2,500 GWh decrease in heating needs.

Because California utilities typically peak in the summer these increased cooling requirements lead to higher peak demands. Table 5 shows projected effects of global warming on planning

Table 4

Estimated Effects of Global Warming
on Annual Electricity Use by 2010

Planning Area	Base Case	Low Temperature Scenario: Heating[1]	Low Temperature Scenario: Cooling[2]	Low Temperature Scenario: Net	High Temperature Scenario: Heating[1]	High Temperature Scenario: Cooling[2]	High Temperature Scenario: Net
		Gigawatthour (%) Change From Base Case					
PGandE	118330	-315 (-0.27)	684 (0.58)	369 (0.31)	-958 (-0.81)	3399 (2.88)	2441 (2.07)
SMUD	12492	- 96 (-0.77)	57 (0.46)	- 39 (-0.31)	-298 (2.39)	255 (2.04)	- 43 (-0.35)
SCE	110717	-249 (-0.22)	549 (0.50)	300 (0.28)	-732 (-0.66)	2415 (2.18)	1683 (1.52)
LADWP	30520	- 89 (-0.29)	152 (0.50)	63 (0.21)	-256 (-0.83)	662 (2.17)	406 (1.34)
SDG&E	21598	- 97 (-0.45)	162 (0.75)	65 (0.30)	-263 (-1.22)	729 (3.38)	466 (2.16)
Total	293657	-846 (-0.29)	1604 (0.55)	758 (0.26)	-2507 (-0.85)	7460 (2.54)	4953 (1.69)

Notes:

1. The projected heating impacts are made under the assumption that average winter temperatures increase by 0.72°C in the Low Temperature Scenario and 2.28°C in the High Temperature Scenario.

2. The projected cooling impacts are made under the assumption that average summer temperatures increase by 0.48°C in the Low Temperature Scenario and 1.52°C in the High Temperature Scenario.

Table 5

Estimated Effects of Global Warming on Peak Demand by 2010

Planning Area	Base Case	Megawatt (%) Change from Base Case			
		Low Temperature Scenario		High Temperature Scenario	
		Nonuniform[1]	Uniform[2]	Nonuniform[1]	Uniform[2]
PGandE	24188	10 (0.04)	297 (1.23)	618 (2.56)	742 (3.07)
SMUD	3257	25 (0.77)	74 (2.27)	98 (3.01)	98 (3.01)
SCE	24896	132 (0.53)	479 (1.92)	655 (2.63)	729 (2.93)
LADWP	7455	20 (0.27)	65 (0.87)	134 (1.80)	160 (2.15)
SDG&E	4302	34 (0.79)	52 (1.21)	143 (3.32)	187 (4.35)
Total	64098	221 (0.34)	967 (1.51)	1648 (2.57)	1916 (2.99)

Notes:

1. The nonuniform case places most of the temperature increase in the early morning hours. In the Low Temperature Scenario, early morning temperatures increase by 0.56°C and mid-afternoon temperatures do not increase. In the High Temperature Scenario, early morning temperatures increase by 2.22°C and mid-afternoon temperatures increase by 0.56°C.

2. The uniform case assumes that the temperature increase on the peak day is nearly uniform. In the Low Temperature Scenario, both the early morning and mid-afternoon temperatures increase by 0.56°C. In the High Temperature Scenario, early morning temperatures increase by 1.67°C and mid-afternoon temperatures increase by 1.11°C.

area peak demand by 2010. For the LTS, the total increase in noncoincident peak demand ranges from about 220 MW to 970 MW depending on how daily temperature patterns change. For the HTS, the total increase in noncoincident peak demand range from 1,650 MW to 1,920 MW. Under both scenarios, the largest planning areas, PGandE and SCE, exhibit the greatest absolute increase. The percentage change in demand is generally 2.0 percent or less in the LTS and 2.0 percent to 3.0 percent in the HTS.

SPACE CONDITIONING USE AND GLOBAL WARMING IN 2050

The temperature sensitivities estimated in the 2010 study are used to project changes in California's annual electricity use and peak demand by 2050 due to a 3°C increase in average annual temperature. The major assumptions and limitations of the 2050 analysis are briefly discussed and then followed by summaries of the projected effects of global warming on California's annual electricity use and peak demand in 2050.

Basic Assumptions of the 2050 Projections

The electricity projections for 2050 are made in two steps. Projections are first made to 2010 using the CEC's detailed energy forecasting models. These projections are based on Staff's most recently published forecast (CEC 1988). The second step, projecting electricity use to 2050, is made under the assumption that future electricity needs are related to overall economic growth. Planning area economic growth is assumed to be related to U.S. economic growth. Further, planning area electricity use is assumed to be related to planning area economic growth. The electricity projections for the Base Case (i.e., electricity demand in the absence of climate change) assume growth in U.S. gross national product of 1.65 percent per year from 2010 to 2050.[13]

The assumed temperature increase to 2050 is consistent with the 3°C increase in average annual temperature used in the CEC Global Warming Study. The warming scenario used for this energy impact analysis differs from the assumption in the CEC study, however, in that mid-latitude regions are assumed to experience somewhat greater warming in winter than in summer. Unlike the assumption of uniform warming across seasons used elsewhere in the CEC Global Warming Study, the energy impact portion assumes that the amount of warming differs by season. Specifically, this energy impact analysis assumes that average winter temperatures increase by 3.6°C and summer temperatures increase by 2.4°C.

As in the 2010 study two possible assumptions about changes in daily temperature patterns are examined: a temperature increase concentrated in the early morning hours and a temperature increase that is nearly uniform throughout the day.

---

[13] This GNP growth rate is conservative, but is within the range of growth rates used by the Environmental Protection Agency in its Report to Congress on atmospheric stabilization, Policy Options for Stabilizing Global Climate (draft), Office of Policy Planning and Evaluation, February 1989.

The change in electricity use due to global warming is equal to the assumed temperature increase (°C) times the temperature sensitivity of demand (percent change in demand per °C). A Low Sensitivity Case (LSC) and High Sensitivity Case (HSC) are projected for both annual electricity use and peak demand. The LSC is based on low range of the temperature sensitivities estimated in the 2010 study.[14] The HSC is derived from the high range of temperature sensitivities from the 2010 study.

Limitations to the 2050 Projections

Linder et al. (1988) note that many uncertainties exist in developing and applying estimates of temperature sensitivities of demand. Many of the limitations they describe apply to this study. For example, temperature sensitivities estimated in the 2010 study are derived from only two climate change scenarios. Different sensitivities may result from the use of smaller or larger temperature changes than those adopted in that analysis. In addition, the sensitivities represent direct and short-term responses to temperature increases. They do not, for example, assume that a long-term warming results in the purchase of additional air conditioning equipment over that assumed in the Base Case. Nor do the sensitivities reflect that the existing air conditioners will operate somewhat less efficiently at higher temperatures. Finally, the sensitivities do not include the

[14] In the LSC, peak impacts for PGandE under a nonuniform temperature change are estimated using the temperature sensitivity calculated for SCE.

response due to agriculture's increased demand for water in a warmer world, and the energy required to deliver this water.

Of course, other uncertainties abound as well. Utilities face tremendous uncertainties with respect to economic, regulatory, technological and other conditions over a 60-year forecast horizon. Climate change may have substantial long-term macroeconomic consequences, yet no attempt is made to include those consequences in the 2050 projections. To do so simply raises more questions than answers at this stage of analysis. For these reasons, the percentage effects of global warming on electricity use are perhaps more meaningful than the absolute effects, for the absolute effects are inextricably tied to assumptions about the state of the world in 2050.

<u>Effect of Global Warming on Space Heating and Cooling</u>

<u>Annual Electricity Use</u>. A 3°C increase in mean temperature will increase net annual electricity use in California from 1.38 percent to 2.54 percent over the Base Case. Given Base Case assumptions, this percentage increase translates to an absolute increase of 6,000 to 11,000 GWh by 2050. Table 6 shows the range of response, which depends on whether the temperature sensitivity of demand is low or high. To provide perspective on this increase in demand, an 800 MW baseload power plant operating at 70 percent capacity will generate about 5,000 GWh of electricity.

Table 6

Estimated Effects of a 3°C Global Warming on Annual Electricity Use by 2050

Planning Area	Base Case	Gigawatthour (%) Change from Base Case: Low Sensitivity Case Heating[1]	Cooling[2]	Net	High Sensitivity Case Heating[1]	Cooling[2]	Net
PGandE	171841	-2227 (-1.30)	4990 (2.90)	2763 (1.60)	-2351 (-1.37)	7795 (4.54)	5444 (3.17)
SMUD	20733	- 784 (-3.78)	478 (2.31)	- 306 (-1.47)	- 799 (-3.85)	667 (3.22)	- 132 (-0.63)
SCE	164211	-1714 (-1.04)	4099 (2.50)	2385 (1.46)	-1833 (-1.12)	5636 (3.43)	3803 (2.31)
LADWP	41827	- 542 (-1.30)	1044 (2.50)	502 (1.20)	- 602 (-1.44)	1435 (3.43)	833 (1.99)
SDG&E	34931	- 679 (-1.94)	1308 (3.74)	629 (1.80)	- 780 (-2.23)	1861 (5.33)	1081 (3.10)
Total	433543	-5946 (-1.37)	11918 (2.75)	5972 (1.38)	-6364 (-1.47)	17394 (4.01)	11030 (2.54)

Notes:

1. The projected heating impacts are made under the assumption that average winter temperatures increase by 3.6°C.
2. The projected cooling impacts are made under the assumption that average summer temperatures increase by 2.4°C.

As discussed earlier, the temperature sensitivity of cooling is greater than that of heating in California. The relative size of the cooling and heating sensitivities is rooted in California's greater demand for air conditioning than space heating, particularly in commercial buildings. A long-term warming trend simply amplifies existing differences in demand: air conditioning will be in even greater demand and space heating demand will decrease.

Peak Electricity Demand. Because California's electric utilities experience their peak demands in the summer, the projected cooling increases from global warming lead to higher peak demands. Projecting peak demand changes is even more uncertain than projecting changes in annual energy use because people's use of air conditioning equipment is highly dependent on daily temperature patterns. Thus, the effects of a nonuniform and a uniform temperature change are examined within both the LSC and HSC.

As Table 7 indicates, the LSC results in a 2.90 percent to 4.52 percent increase in statewide noncoincident peak demand. These changes in peak demand are based on a 2.4°C increase in average summertime temperatures. A nonuniform temperature change results in a smaller increase than a uniform change. The absolute increase in demand ranges from about 2,900 MW to 4,500 MW over the Base Case projection.

Results from the HSC suggest that peak demand will increase by 4.13 percent to 6.66 percent, depending on whether the temperature increase is nonuniform or uniform. In the HSC the change in summertime temperatures will increase peak demand by roughly 4,100 MW to 6,600 MW over the Base Case projection.

These results suggest that not only is the temperature sensitivity of peak demand important, but so is the effect of global warming on the day-to-day variability in temperature conditions. Peak demand is less sensitive to a nonuniform temperature change if most of the increase occurs during off-peak periods. This analysis considers only the case of a nonuniform or a nearly uniform change in daily temperature patterns. Yet the results clearly suggest that a uniform warming will increase demand by 50 to 60 percent more than will a nonuniform warming.

Table 7

Estimated Effects of a 3°C Global Warming on Peak Demand by 2050[1]

Planning Area	Base Case	Megawatt (%) Change from Base Case: Low Sensitivity Scenario Nonuniform[2]	Low Sensitivity Scenario Uniform[3]	High Sensitivity Scenario Nonuniform[2]	High Sensitivity Scenario Uniform[3]
PGandE	37144	1070 (2.88)	1756 (4.73)	1515 (4.08)	1970 (5.30)
SMUD	5312	219 (4.12)	247 (4.65)	256 (4.82)	524 (9.86)
SCE	38835	1118 (2.88)	1752 (4.51)	1631 (4.20)	3225 (8.30)
LADWP	10570	152 (1.44)	350 (3.31)	302 (2.86)	396 (3.75)
SDG&E	7313	316 (4.32)	381 (5.21)	388 (5.31)	491 (6.71)
Total	99173	2876 (2.90)	4487 (4.52)	4093 (4.13)	6606 (6.66)

Notes:

1. Under the assumptions used in this energy impact study, a 3°C average annual warming results in a 2.4°C increase in average summer temperatures.

2. The nonuniform case assumes that the pattern of hourly temperature increase is not uniform on the peak day, i.e., the minimum temperature is assumed to increase much more than the maximum temperature.

3. The uniform case assumes that the pattern of hourly temperature increase in nearly uniform on the peak day, i.e., minimum temperature increases only slightly more than the maximum temperature.

SUMMARY

Because of California's need for cooling relative to heating, global warming increases annual electricity use. The estimates presented here indicate a net increase of 1.38 percent to 2.54 percent for a 3°C temperature increase. Further, because California's electric utilities are summer peaking, these increases in cooling demand lead to higher peak demand in a warmer world. The effect of warming on peak demand depends on how daily temperature patterns might change. A uniform temperature change yields increases that range from 4.52 percent to 6.66 percent; a nonuniform increase results in a lower range, from 2.90 percent to 4.13 percent. Overall, the effects of global warming on the heating and cooling of buildings appears moderate on a percentage basis, but because California's electricity system is so large, moderate percentage increases result in substantial changes in absolute demand.

REFERENCES

Baxter, L. W.
1988 "Peak Demand Forecasting Model," in California Energy Demand 1987-2007: Electricity Demand Forecasting Methods, pp. 7-1 to 7-53, California Energy Commission, P300-87-014.

Baxter, L. W., R. Herrera, M. Miller, G. Sharp
in press "Global Warming and Space Conditioning Use in California: Effects and Mitigation." Forthcoming as part of a Lawrence Berkeley Laboratory Report on the Urban Heat Island Workshop, held February 23-24, 1989 at University of California, Berkeley.

California Energy Commission
1988 California Energy Demand 1987-2007: Revised Electricity Demand Forecasts, California Energy Commission, P300-88-005.

Hansen, J., I. Fung, A. Lacis, D. Rind, S. Lebedeff, R. Ruedy, G. Russell, and P. Stone
1988 "Global Climate Change as Forecast by Goddard Institute for Space Studies Three-Dimensional Model." Journal of Geophysical Research 93:9341-64.

Hansen, J., A. Lacis, D. Rind, G. Russell, P. Stone, I. Fung, R. Ruedy, and J. Lerner
1984 "Climate Sensitivity: Analysis of Feedback Mechanisms," in Climate Processes and Climate Sensitivity, Geophysical Monograph Series, Vol. 29, pp. 130-163, J. Hansen and T. Takahashi (Eds.).

Hogstad, J., R. Herrera, E. Mulberg, and M. Jaske
1988 "Residential Energy Demand Forecasting Model," in California Energy Demand 1987-2007: Electricity Demand Forecasting Methods, pp. 2-1 to 2-44, California Energy Commission, P300-87-014.

Karl, T. R., R. G. Baldwin, and M. G. Burgin
1988 "Time Series of Regional Season Average of Maximum, Minimum, and Average Temperature, and Diurnal Temperature Range Across the United States: 1901-1984." National Climate Data Center, Asheville, NC.

Jaeger, J.
1988 Developing Policies for Responding to Climate Change. World Climate Programme Impact Studies, WMO/TD-No. 225.

Linder, K. P., M. J. Gibbs, and M. R. Inglis
1988 Potential Impacts of Climate Change on Electric Utilities. Energy Authority Report 88-2, New York State Energy Research and Development Authority.

Manabe, S. and R.J. Stouffer
1980 "Sensitivity of a Global Climate Model to an Increase of CO_2 Concentration in the Atmosphere." Journal of Geophysical Research 85:5529-54.

Nguyen, H. D., G. P. Occhiuzzo, and E. Hamzawi
1988 "Commercial Building Energy Demand Forecasting Model," in California Energy Demand 1987-2007: Electricity Demand Forecasting Methods, pp. 3-1 to 3-123, California Energy Commission, P300-87-014.

APPENDIX B

Current Range of California's Commercial Species

Global warming will affect not only temperature but also rates of evapotranspiration. This will generally increase summer drought conditions, which are often an important limiting factor in tree productivity. Therefore, the precipitation requirements of commercial tree species are also crucial. Global warming is likely to result in shifts in the latitudinal and elevation range of tree species, so it is also important to know the current parameters of these species. The following depicts the current elevational distribution of commercial trees in the Sierra Nevada, and climate conditions within the ranges of California's commercially important tree species.

Ponderosa Pine

General Climate	Prolonged winter freezing apparently sets the upper limit of the vertical range, while a minimum of 25 inches of annual precipitation apparently sets the lower limit.
Elevation	500 to 7,000 ft.
Distribution:	The commonest and most widely distributed of western conifers; in California, it defines the main forest on the western slope of the Sierra Nevada; also found on the eastern slope from Lake Tahoe northward, as well as in the Cascades, on the Modoc Plateau, and to a lesser extent in the Klamath Mountains and the Coast Range.

Jeffrey Pine

Elevation	5,200 to 9,000 ft.
Distribution	In the Sierra Nevada on the west slope at higher elevations than ponderosa pines; on the east slope often in pure stands; generally more prevalent than ponderosa pines in southern California; scattered throughout the Coast and north state ranges.

Sugar Pine

Overall Climate	Generally humid
Annual Precipitation	Lower limit may be about 20 in.; usually about 25 inches or more, part of which falls as snow; summers characteristically dry, with July and August precipitation usually less than 1 in. per month.
Annual Temperature Extremes	<-5.5°C to >55.5°C (-10°F. to >100°F); lower temperature limit has not been determined but probably is below -16°C (-30°F).
Elevation	2,000 to 9,000 ft.
Distribution	Mainly in the yellow pine belt on the western slope of the Cascade-Sierra Nevada Ranges.

Douglas-fir	
(P. menziesii)	
Overall Climate	Mild with dry summers
Average Annual Temperature	25-30.5°C (45-55°F)
Absolute Maximum Temp.	About 61°C (110°F)
Absolute Minimum Temp.	About -14°C (-25°F)
Annual Precipitation	20-90 in.
Elevation	Coastal to 7,000 ft.
Distribution	Coastal: Oregon border to Santa Cruz Mountains. Sierra Nevada: Western slope in the yellow pine belt south to the San Joaquin River. Klamath Mountains: extensive stands
Douglas-fir	
(P. macrocarpa)	
Overall Climate	Long, hot summers; short, unpredictable winters
Average Annual Temperature	30.5-33°C (55-60°F)
Absolute Maximum Temp.	>55.5°C (100°F)
Absolute Minimum Temp.	Seldom <5.5°C (<10°F)
Annual Precipitation	14-30 in.
Elevation	900 to 8,000 ft.
Distribution	Southern California from Kern County to San Diego County.
White fir	
Overall climate	Long winters with moderate to heavy snow deposits; summers dry
Absolute Maximum Temp.	50°C (90°F) in Southern California
Annual Precipitation	Minimum: 20 in.; the best stands grow in areas receiving 40 to 60 in.
Elevation	2,500 to 8,000 ft.
Distribution	Sierra Nevada and northwestern California

Red fir	
Overall Climate	Long winters with a heavy snowpack and short, dry summers
Absolute Maximum Temp.	Seldom exceeds 44°C (80°F), and very rarely exceeds 50°C (90°F).
Absolute Minimum Temp.	May be -14°C (-25°F) or lower
Annual Precipitation	30-60 in.; average 40-50 in. in areas with optimal development of the species
Elevation	5,000 to 9,000 ft.; pure stands typically occur at relatively high altitudes within a narrow belt of about 1,000 ft.
Distribution	The upper main forest belt of the Sierra Nevada, mainly on the western slope; mountain ranges of northern California
Incense-cedar	
Overall Climate	Dry summers, usually with less than 1" of precipitation per month
Annual Precipitation	About 20 in. or more, part of which falls as snow; the lower limit may be about 15 in.
Annual Temperature Extremes	<-5.5°C to >55.5°C (<-10°F to >100°F); the lower limit has not been determined but is probably below -11°C (-20°F)
Elevation	2,000 to 7,000 ft.
Distribution	In the Sierra Nevada, an important part of the mixed conifer forest, in the yellow pine belt; more common on the western slope; also scattered across other ranges
Coast redwood	
Overall Climate	Mild; humid or superhumid; frequent summer fogs seem to be more important than the amount of precipitation (fog decreases water loss from evaporation & transpiration & adds to the soil moisture supply to some degree)
Annual Precipitation	25 to 122 in.
Mean Annual Temperatures	27-33°C (50-60°F)
Mean Annual Maximum and Minimum	Differences between mean annual maximum & mean annual minimum temperatures range from 5.5 to 8°C (10 to 15°F) for coastal points to 16°C (30°F) for the eastern edge of the redwood type. Temperatures rarely fall below 8°C (15°F) or climb above 55.5°C (100°F). The frost-free period lasts from 6-11 months.
Elevation	Sea level to about 3,000 ft., but most are found between 100 and 2,500 ft.

Distribution	From the southern boundary of Monterey County north to the Oregon border; the main stands are close to the ocean but protected from it

Oaks

California has seven species of native oaks which reach tree size and are widely distributed across the state: coast live oak, canyon live oak, interior live oak, California black oak, valley oak, Oregon white oak, and blue oak. Their elevation ranges vary, but as a whole they grow from sea level up to at least 5,600 feet, generally below but overlapping the conifers.

APPENDIX C

CALIFORNIA GREENHOUSE EMISSIONS

Even though California contributes only a small percentage of the total global output, in the area of CFC and transportation emissions, California is a significant contributor.

Greenhouse gas emissions differ from other types of atmospheric pollutants because the source and impacts of greenhouse pollutants must be managed on a global, rather than regional scale. Further, greenhouse pollutants influence global climate patterns as a whole, while more traditional air pollution problems simply affect ambient air quality in distinct air basins. Because regional emissions contribute to the global climate change, managing emissions in California, while it may not solve the global warming problem, still plays an important role in mitigating the impacts of warming on all regions of the world.

An evaluation of greenhouse gases produced in California is being conducted at this time. Given the importance of understanding the quantity, source, and relative warming contribution of various gases, a complete summary of the primary greenhouse gases released in California will be presented in the final global warming report. Currently available information regarding California and United States carbon emissions is presented below.

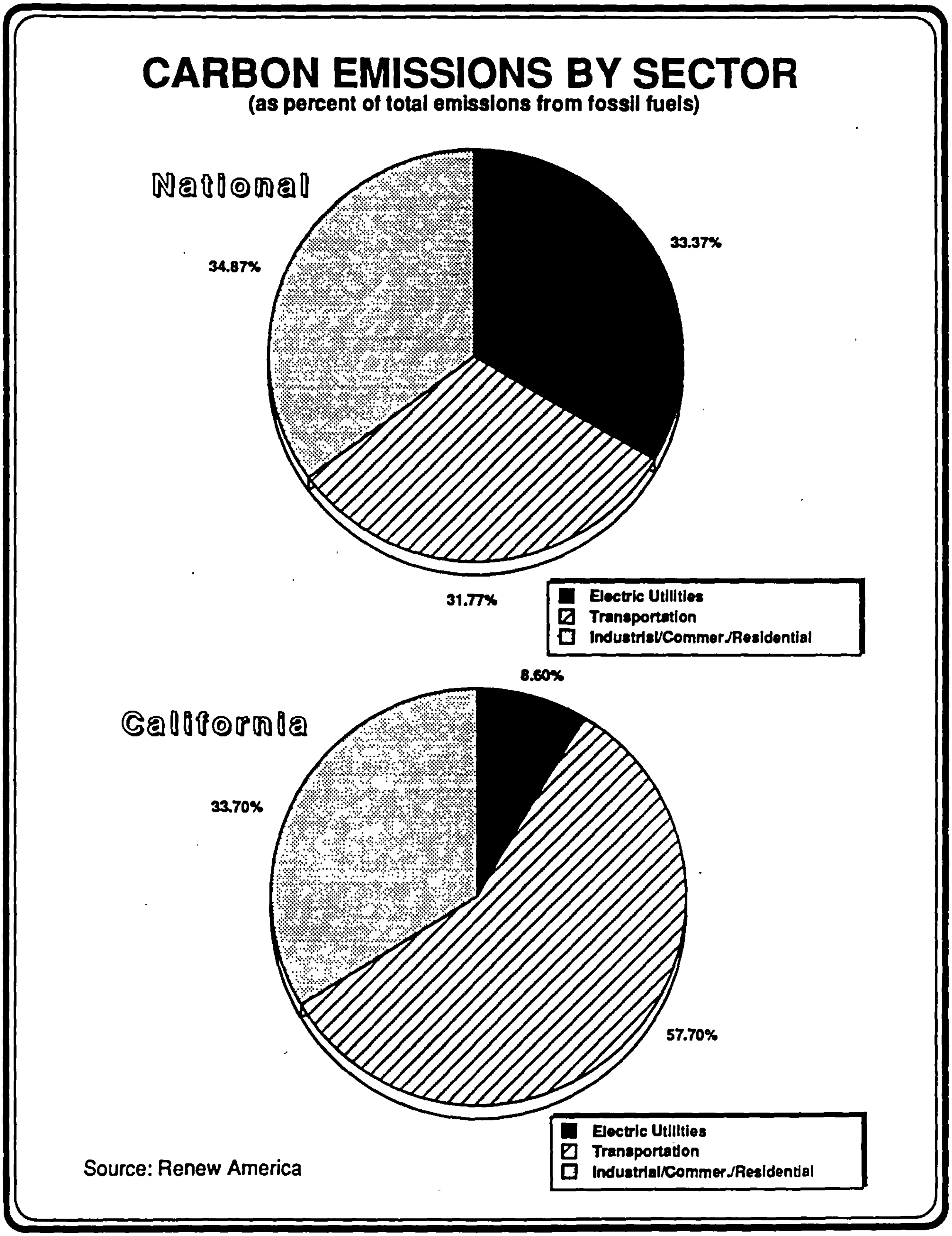
California carbon emissions from fossil fuel use in 1986 measured 85.23 million metric tons (mmt), while total United States 1986 carbon emissions from fossil fuels measured 1,275.30 mmt and the global total was over 5,000 mmt. Fuel sources contributing to total California carbon emissions include coal at 1.1 mmt, or 1.3 percent of the California total, natural gas at 22.6 mmt, 26 percent of the total, and oil at 61.8 mmt, 72.1 percent of the total. Carbon emission sources by commercial use sector include transportation at 57 percent of the California total, residential at 18 percent of the total, industrial/commercial at 17 percent of the total, and electric utilities at 9 percent of the total. By contrast, 1986 United States carbon emissions by commercial sector measured 32 percent for transportation, 27 percent for industrial/commercial, 7 percent for residential, and 33 percent for electric utilities (Renew America, 1988 [see Figure 38]).

Significant to California is the relative importance of the transportation sector in contributing to greenhouse gas emissions, as opposed to emissions produced by electric utilities, which are a more important source in the rest of the United States. Emission sources for the California transportation sector include cars, buses, trucks, trains, and airplanes, with gasoline emissions accounting for 34 percent of total CO_2 emissions. Emission sources for the California utility sector include natural gas at 8 percent, and oil at 1 percent of total state emissions. Note that coal emissions are negligible in California, though California does benefit from imported coal-fired electricity.

Because of the global nature of the warming problem, a future inventory of California greenhouse gases should take into account the contribution of greenhouse gases which are emitted in other states in the production of products used or consumed in California. Similarly, greenhouse gases emitted in California in the production of computers or other products which are consumed throughout the United States should be factored into the equation depicting the relative greenhouse gas contribution of other states.

Chlorofluorocarbons (CFCs), the most long-term of greenhouse gases, are used extensively in California. CFCs are used as a cleaning solvent in the manufacture of computer boards, as well as in refrigerants, home and auto air-conditioning systems, foam insulation, packaging material, and industrial degreasing solvents. Data on the amount and type of CFC emissions in California has recently become more readily available due to new federal reporting forms required by amendments to Federal Superfund law regulating hazardous waste sites. Current data suggests that California generates 5 percent of the global total of CFC emissions (Citizens for a Better Environment, 1988).

Figure 44


CARBON EMISSIONS BY SECTOR
(as percent of total emissions from fossil fuels)
National
33.37%
34.87%
31.77%
Electric Utilities
Transportation
Industrial/Commer./Residential
California
8.60%
33.70%
57.70%
Electric Utilities
Transportation
Industrial/Commer./Residential
Source: Renew America

APPENDIX D

EFFECT OF GLOBAL WARMING ON OROVILLE DAM HYDROELECTRIC POWER PRODUCTION

A crude approximation of the effect of 3°C (5.4°F) global warming on the Feather River Basin snowpack and snowmelt runoff indicated a 55 percent reduction in April - July natural runoff. Neglecting changes in evapotranspiration, the loss in spring runoff is changed into direct winter rain runoff.

The portion above Lake Almanor would presumably be contained and re-regulated there because of its ample storage to runoff ratio. However, much of the increase in winter runoff at Oroville Dam would have to be released at lower flood control levels, compared to current operation. Greatly reduced spring inflow would then preclude filling the reservoir in most years with generally lower summer, fall, and early winter water levels. The reduction in summer and fall reservoir levels is most severe if operators attempt to maintain current dry season release amounts.

A modified strategy which attempts to maintain average minimum autumn storage around 1.9 million acre-feet reduces the loss in power, but also reduces summer water supply for the SWP. Results of the three studies are as follows:

	Base Study	Reduced Snowmelt Maintain Project Releases	Reduced Snowmelt Modify Project Releases
April-July Inflow, 1000 AF	1430	580	580
May-Sept. Downstream Releases, 1000 AF	1341	1341	1025
End of May Storage, 1000 AF	3398	2799	3008
End of Sept. Storage, 1000 AF	2373	1485	1928
Total Annual Energy, GWH	2195	2050	2125
Average June-Aug. Capacity, MW	900	840	876
Percent Energy Reduction	---	6.6	3.2
Percent Capacity Reduction	---	6.7	2.7

These figures are for average conditions. Consequences to firm power during dry periods will probably be worse.

Appendix E

SUMMARY OF FEDERAL GLOBAL WARMING LEGISLATION

The following is a summary of the federal global warming bills which have been introduced in the 101st Congress. The bills have been divided according to "comprehensive" and "targeted" bills; the comprehensive bills address a fairly broad spectrum of global warming mitigative policies, while the targeted bills focus more closely on distinct problem areas associated with global warming.

A matrix illustrating individual bills and the policy areas addressed by each bill is provided at the end of this appendix. The matrix distills the more detailed description of each bill provided in the summary down to more readily identifiable subject areas, such as "energy conservation," "increased research," and "reforestation."

<u>Comprehensive Bills</u>

HR 1078, Schneider, "Global Warming and Prevention Act of 1989"

This Act establishes national policies and supports international agreements to implement energy and natural resource conservation strategies to prevent global warming. The primary purpose of the Act is to establish a national "least-cost" energy policy that will achieve a 20 percent reduction of 1988 United States CO_2 emission levels by 2000 and promote an international global agreement on the atmosphere by 1992 to reduce CO_2 emissions by 20 percent of 1988 levels by 2000.

<u>Title I</u> changes the National Energy Policy Plan (NEPP) into the National Least-Cost Energy Policy Plan (NLCEPP) and mandates DOE to prioritize policies in accordance with least-cost options, including consideration of additional energy supplies or greater efficiency of energy use. The Plan would rank in order of cost-effectiveness and CO_2 reductions energy saving technological options that reduce energy use per unit of GNP by two, three, four, five, and six percent per year. A two-year Action Plan, and a research and development plan to work on promising energy efficient renewable technologies, shall be used to meet the goals of the Least-Cost Plan.

<u>Title II</u> establishes 10 research centers to achieve improvements in energy-intensive industrial processes that reduce energy, labor and capital costs, and pollutants, particularly CO_2 and other trace gases. The bill calls for improvements in the energy efficiency of federal buildings and federally-assisted housing by requiring a 25 percent energy saving per square foot by 1995, and 40 percent by 2000 from 1988 levels. It further establishes a uniform home energy rating system, provides technical support to state and local governments, and directs federal lending institutions to provide loans for energy improvement measures to make homes more energy efficient. The Title also establishes efficiency standards for incandescent and fluorescent lamps, and calls for labels on the efficiency of window systems. Finally, this Title establishes a research program to both reduce CFCs and increase the energy efficiency in energy-related applications of halogenated materials.

Title II also expands DOE's Least-Cost Electric Utility Planning Initiative and directs the Federal Energy Regulatory Commission to pursue rigorous least-cost utility planning in arrangements. In addition, it requires the Department of Transportation to review and report on Least-Cost Transportation options. Finally, it requires a power survey of the electric utility industry to determine the feasibility of implementing requirements that at least 50 percent of new capacity needs are met through energy efficiency and renewable resources.

Title III amends the Energy Policy and Conservation Act to create state goals of reducing by 10 percent or more the amount of energy consumed in each state in the year 2000 through a variety of energy efficiency programs. (Ten percent refers to the projected amount of energy consumed in the year 2000.)

Title IV establishes new national vehicle energy-efficiency performance standards based on percentage improvements for each manufacturer's vehicle fleet, raises federal vehicle fleet average fuel economy, and raises the gas-guzzler tax on inefficient light cars and trucks through 2004. This Title also provides tax rebates to consumers for purchase of efficient vehicles.

Title V requires DOE to prepare a report detailing long-term research, development, and demonstration programs and policies to achieve a doubling, tripling, and quadrupling of national renewable energy use by 2015. Areas of targeted research include photovoltaic, solar thermal, solar buildings, wind energy, geothermal, and ocean energy. It also provides a three-year authorization to continue efforts by the Committee on Renewable Energy, Commerce, and Trade (CORECT) to establish a joint government/industry plan identifying promising technologies and promoting the export of renewable technologies. It further promotes research and development to promote integrating renewable energy sources with fuel cells and demonstrating biomass-gasified, steam-injected gas turbines for the purpose of increasing energy savings and reducing CO_2, NO_2 and SO_2 emissions.

Title VI creates a five-year authorization for research and development on domestic production, distribution, and use of hydrogen, and for the development of renewable energy sources to be used in production of hydrogen.

Title VII provides financial assistance to parties to demonstrate the commercial operation of advanced gas turbines with units not exceeding 115 megawatts each. It also creates a three-year authorization to demonstrate the feasibility of using natural gas as a fuel for mass transit in urban areas, and a three-year authorization for research on preventing, reducing, recycling, or offsetting CO_2 emissions from coal combustion.

Title VIII requires the EPA to evaluate the potential for offsetting new CO_2 emissions through establishing and maintaining tree plantations. It also establishes an urban tree planting program designed to reduce the "heat island" effect in communities which would lead to reduced energy costs and CO_2 emissions. This Title requires a report on the linkages between agricultural production and global climate change and the possible effects of climate change on global food production. It calls for an expansion of the Conservation Reserve Program to 80 million acres. And finally, it mandates a comprehensive report on research and development needed to establish a National Ethanol Program, as well as an analysis of incentives necessary to stimulate production of ethanol feedstocks.

Title IX establishes a Bilateral Tropical Forestry and Agroforestry Program to slow deforestation, promote forest conservation and management, and adopt reforestation, afforestation, and agroforestry policies. This Title also bans the import of wood and wood products for countries failing to implement the programs defined above. It amends the Foreign Assistance Act of 1961 by establishing a Bilateral Least-Cost Energy Program to assist aid-recipient countries implement national least-cost energy plans, and establishes a Multilateral Least-Cost Energy Program to encourage multilateral development banks to promote the implementation of least-cost energy policies. In addition, it promotes government and private debt reduction for developing countries implementing environmental conservation measures such as forest conservation and end-use energy efficiency.

Title X encourages the adoption of a binding multilateral global climate protection convention to reduce global carbon dioxide emissions to 20 percent below 1988 levels by 2000, and further reductions beyond 2000 as deemed necessary by review. The Title adopts binding multilateral agreements requiring reductions of not less than 30 percent over 1987 levels in emissions of oxides of nitrogen by 1988, and the adoption of additional control measures requiring the elimination of CFC production identified in the Montreal protocol within five to seven years of enactment of this Act.

Title XI initiates an international conference on population growth to examine policies necessary to achieve sustainable world population levels, and to advance the scientific understanding of the interrelationship between population, resources, environment, and economic development. This Title also establishes a National Commission on Population Environment, and Natural Resources, which is comprised of the Chairman of the President's Council on Environmental Quality, the Director of OTA, and three other Presidential appointees. It further provides funds for family planning services through the United Nations Population Fund.

Title XII establishes the Office of Recycling Research and Information within the Department of Commerce to promote recyclable materials programs, and to report on the nation's progress in using recyclable materials. It also initiates a study of federal, state, and local government policies and practices in recycling government-generated wastes, and in procuring recyclable materials, and recommends changes in public policy to increase such efforts. The Title also bans the production or sale of certain designated nonrecyclable consumer goods, and creates a pilot project on municipal waste and sewage sludge composting.

S 201, Gore, "World Environmental Policy Act of 1989"

This bill focuses on policy responses to problems related to the greenhouse effect, destruction of the ozone layer, and the loss of biodiversity. It includes measures to reduce greenhouse gases, introduces reforestation programs, promotes recycling and international cooperation in addressing environmental problems.

Title I replaces the Council on Environmental Quality with a new Council on World Environmental Policy to better link policy making with scientific research.

Title II supports research regarding the process of global change and designates 1990 as the "International Year of the Greenhouse Effect."

Title III proposes the complete phase out of the production of chlorofluorocarbons, with exceptions for medical and national security reasons. Title III also amends the Solid Waste Disposal Act to control methane emissions from landfills and instructs EPA, NASA, and NOAA to identify methane emission sources and recommend control measures.

Title IV mandates improvements in fuel economy standards for passenger cars and light trucks. Modifications for passenger cars for model year 1993 to 1996 call for 33 miles per gallon, through model year 1999 40 miles per gallon, and for model year 2000 and thereafter 45 miles per gallon.

Title V creates a research program to examine alternatives for recycling, establishes a clearinghouse for information on existing recycling programs, and a national recycling education program. Title V also introduces a program for the complete phase out of nonrecyclable packaging within five years except where EPA determines recycling is not feasible or threatens national security.

Title VI directs the Secretary of the Treasury to work with major contributors to the World Bank to develop a method to assess the environmental soundness of lending projects prior to final bank approval.

Title VII provides support for family planning efforts.

Title VIII establishes a national policy for conservation of biodiversity and coordinates federal strategy for preserving biodiversity among federal, state, and private initiatives.

Title IX proposes a phased-in ban on the importation of tropical wood products not obtained from regimes of sustained yield management. This Title also instructs the director of AID to assess the potential gains and costs of programs to help small landholders with the capital needed to make improvements that could stop global deforestation, and calls for a report identifying the potential for expanded areas of reforestation around the world, an estimate of costs, and plans for allocating these costs internationally. Title IX directs the Secretary of State to propose to the Government of Brazil that they take the lead in protecting the Amazon Basin by convening a conference designed to identify programs to conserve the Basin's resources. This title also calls on Congress to direct United States directors of multilateral development banks to urge reconsideration of and restraint in lending that would exacerbate deforestation.

Title X promotes United States participation in international environmental policy initiatives.

S 324, Wirth, "The National Energy Policy Act of 1989"

The overall purpose of this Act is to establish a national energy policy that will reduce the generation of CO_2 and trace gases as quickly as possible in order to slow the pace of global climate change. The bill focuses on energy efficiency, fuel switching, and conservation; use of nuclear, clean coal, and renewable energy technologies; reforestation and natural resource management policies; and international development and population practices to promote national and international growth and development, achieve a secure energy supply, and protect the global environment.

Title I requires the development of a Least-Cost National Energy Plan designed to meet the goal of a 20 percent reduction in CO_2 generation by the year 2000 through a mix of federal and state energy policies. The Plan would establish policies for conserving fossil fuel energy and expanding the use of renewable energy sources in order to meet short-, medium-, and long-term domestic energy demands without exceeding the CO_2 emissions levels outlined in this bill. Title I assigns priorities among energy resources according to cost-effectiveness and impacts on global climate.

Title II establishes an Office of Climate Protection at the Department of Energy for purposes of monitoring United States energy policy for atmospheric and global warming effects, and for directing Departmental policy with regard to strategies for reducing the generation of CO_2 and trace gases.

Title III provides for the establishment and financing of energy efficiency research and development projects, and for the establishment of eight regional centers which will develop techniques for improving the energy efficiency of industrial processes. This Title also provides for the repeal of energy conservation measures by utilities and for the purchase of "qualifying conservation" by utilities under section 210 of PURPA.

Title IV establishes national energy research and development priorities for the Secretary of Energy designed to reduce the generation of CO_2 and trace gases.

Title V is designed to update and revitalize the state energy conservation programs (SECP) established in 1976 under EPCA. The Title requires states to update their energy conservation plans and establish new energy conservation targets to replace those which expired in 1980. In addition, Title V consolidates the Energy Extension Service and the Supplemental State Energy Conservation Plans into the SECP, establishes State Energy Advisory Boards to recommend programs and policies to achieve energy conservation goals and to coordinate state and federal efforts, and authorizes several new optional programs for inclusion into State Energy Conservation Plans.

Title VI would authorize research and development of renewable energy sources such as wind, solar, photovoltaic, biomass, geothermal, and hydrogen fuel cells. Title VI also establishes a program for additional research on fuel cell technologies that employ alternative fuel sources.

Title VII creates a research and development program designed to provide the basis for a second generation of nuclear reactors that would be passively safe, modular, and cost-effective.

Title VIII provides for a comprehensive report to Congress on international collaboration in research, development, and demonstration of the production of electricity from thermonuclear fusion.

Title IX provides for a comprehensive report to be submitted to Congress on the Department of Energy's Clean Coal Program and the Program's likely implication for CO_2 generation, atmospheric warming, and global climate change.

Title X funds demonstration projects on the feasibility of using natural gas as a fuel for mass transit systems, fleet use, and training programs for conversion of gas- and diesel-fueled vehicles to natural gas. The program also encourages research, development, and demonstration of high efficiency heat engines including, but not limited to, advanced gas turbine cycles for generating electricity.

Title XI directs the Secretary of the Interior to conduct a study of the ecological and environmental resources that would be affected by global climate change. This Title directs the Secretary of Energy, in consultation with the Secretary of Agriculture, to submit an analysis of the potential for reducing the air conditioning needs of buildings by undertaking targeted urban tree plantings. In addition, it provides for the management and conservation of the Tongass National Forest.

Title XII provides additional funding for new and continued research initiatives at NOAA, USGS, and NSF to study the mechanisms and implications of global warming and atmospheric change. In addition, the National Institute of Standards and Technology would receive funding for the development of safe, nonozone depleting substitutes for CFCs.

Title XIII directs the Administrator of AID, in conjunction with other federal agencies, to provide Congress with a comprehensive report on the world's tropical rain forests, and to establish inventory, conservation, and forest plans for each tropical country. This Title also directs the appropriate agencies to create incentives to encourage afforestation and disincentives to discourage deforestation. AID, the Export-Import Bank, and the Overseas Private Investment Corporation would be instructed to promote private investment in energy-efficiency technologies in developing countries.

Title XIV calls for convening a multilateral global climate protection conference, the convening of an international conference on nuclear power, a multilateral agreement to reduce emissions of oxides of nitrogen, a reassessment of the Montreal Protocol on Substances that Deplete the Ozone Layer, and the establishment of a special office at UNEP and WMO to monitor global CO_2 emissions.

Title XV establishes the importance of population growth as a contributory factor in global warming and climate change and authorizes funding for international family planning and information services programs.

S 333, Leahy, "Global Environmental Protection Act of 1989"

This Act focuses on the regulation of global change pollutants (specifically choloroflurocarbons, carbon dioxide, ground level ozone, and methane), global change mitigation through amendment to the National Environmental Policy Act of 1969, increased efforts toward international cooperation, and the development of nonpolluting energy sources, specifically "safe nuclear energy."

Title I regulates the emission of global change pollutants.

Part A controls the emissions and international trade of chlorofluorcarbons (CFC) and other substances with ozone- depleting potential, with the goal of complete elimination of halogenated CFC use and sale by 1999. Substances are targeted according to their ozone depletion potential and through a prioritized production phase-out list. Exemptions are granted for those products deemed necessary for medical or national security purposes. Part A also requires the labeling and safe disposal of CFCs to better control the production and handling of these substances, and promotes scientific research to develop safe substitutes to replace ozone depleting substances.

Part B recognizes that between 20 percent and 25 percent of worldwide CO_2 emissions originate in the United States and proposes a 50 percent reduction in emissions of CO_2 by the year 2000. This section regulates new and existing sources of CO_2 and targets vehicles, power plants, industrial/commercial, and residential sources. Vehicles are required to achieve progressive CO_2 emission reductions, with a 75 percent reduction by 2010. Fossil fuel-fired electricity generating plants are also required to achieve progressive reductions, with up to 75 percent emission reductions by 2010. The bill requires revised standards to the Clean Air Act so that standards are expressed in terms of CO_2 emissions per unit of electricity output through increases in combustion, generation, transmission, and utilization efficiencies, and it establishes the mandatory retirement of power plants at age 30. The Administrator of the EPA is required to identify the best available residential control technology for central furnaces, air conditioners, and hot water heaters in single-family dwellings.

Part C finds that elevated temperatures will cause increased production of ground level ozone and requires a revision of Clean Air Act "standards of performance" for emissions of oxides or nitrogen from fossil fuel-fired electricity generating units and vehicular sources. Vehicular sources: establishes a tailpipe NO_x limit of 0.4 grams per mile. Stationary sources: requires an emission rate equal to or less than 0.1 lb per million Btu of heat, or a reduction of not less than 90 percent from an uncontrolled state. The Administrator of the EPA shall also establish guidelines to regulate emissions of hydrocarbons which are designed to accommodate all available fuels for light-duty vehicles and engines, as well as stationary sources. Vehicular sources: establishes a tailpipe HC limit of 0.25 grams per mile. Stationary sources: requires 50-state "best available control technology" (BACT) for new facilities, and requires each existing facility to install BACT on its 30th anniversary. Finally, the Administrator of the EPA shall prohibit the manufacture and sale of any engine that requires leaded gasoline.

Part D requires the Administrator of the EPA to submit a report prepared in consultation with NOAA and NASA on the contribution of methane to global climate change, the source and sinks of methane, and the relationship between methane and other trace gases. The Solid Waste Disposal Act is amended by requiring all disposal facilities constructed after January 1, 1994 to minimize methane emissions. The Act is further amended to modify all existing facilities to minimize methane emissions. Also, by 1995, flaring and venting of methane shall be prohibited.

Title II amends the National Environmental Policy Act of 1969 by adding the "Atmospheric Protection Act of 1989." The new section requires all federal agencies to assume an interdisciplinary approach in planning and decision making with respect to pollutants which contribute to global climate change, and to include in every recommendation for legislation a detailed statement on the potentially adverse environmental impacts of the proposed action. In addition, it requires each agency to undertake a survey of all federal lands and public works to determine their vulnerability to global warming. Following the study, federal actions may preclude public or private investment in areas susceptible to damage due to global environmental change. The authorities of the Army Corps of Engineers are expanded to include climate change mitigation measures, including identification and mapping of areas likely to be affected by sea level rise and ground water changes.

Title III recognizes the need for international agreement and action in order to eliminate chlorofluorocarbons and other greenhouse gases. The President is directed to request that the United Nations establish a temporary new agency to provide financial and technical assistance to developing nations to 1) facilitate an improved standard of living and contribute to global environmental damage abatement and 2) to establish a temporary global program of reforestation.

Title IV establishes a temporary National Commission on Inherently Safe Nuclear Energy. The Commission shall review nuclear industries in the United States and other countries to report on the comparative safety and reliability of these nuclear programs, to review incidents of safety violations and the nature of public opposition to nuclear power, and to consider options to respond to public fears. The Commission shall evaluate inherently safe passive control technologies associated with nuclear power which might become available by the year 2010 and state whether it is possible to develop a nuclear industry in the United States capable of supplying not less than 50 percent of the nation's electricity needs through the year 2000. This Act establishes as a national goal to derive 100 percent of the nations's energy supply from nonpolluting technologies and practices by the year 2050.

Targeted Bills

HCR 44, Bates

This bill calls on the International Bank for Reconstruction and Development to encourage banks to reduce the debt service burden of debtor nations in exchange for those nations to take steps to protect tropical rain forests from destruction or depletion. Banks are encouraged to reduce the debt service burden through 1) forgiveness of principal, 2) reduction in interest rates, 3) deferral of payment, or 4) lengthening of the loan term.

The premise of this bill is that the global warming trend is exacerbated by the destruction of tropical rain forests in Latin America; increased unemployment in this region has forced more people into subsistence agriculture which draws heavily on the natural resource base; government austerity programs in developing nations often reduce expenditures on environmental agencies which in turn undermine environmental planning efforts; and international cooperation is needed to deal with the economic and ecological problems of developing nations.

Fazio, HJR 207, "National Global Warming Policy Act"

This Act establishes the goal of reducing CO_2 emissions from 1988 levels by 20% by the end of the year 2000, and encourages other nations to reduce greenhouse gas emissions. The Act proposes hosting an international summit meeting on global warming to develop multilateral agreements with other nations to reduce the global generation of greenhouse gases and to assist in the worldwide protection of tropical forests. The Act also requires each federal agency to examine its programs to determine the impact of global warming on its missions and to evaluate policies under its authority which could reduce greenhouse gas emissions. Finally, it promotes developing new technologies to provide energy supplies, while reducing the generation of greenhouse gases.

The premise of this Act is that the majority of greenhouse gases are generated in the production of energy. Further, the DOE National Energy Policy Plan projects that the United States generation of CO_2 will increase 38 percent from 1985 levels by the year 2010. Action by the United States to reduce the generation of greenhouse gases is hoped to encourage other nations to take similar action.

HR 503, Stark

This bill requires that products which contain, are produced with, or are produced from chlorofluorocarbons are labeled. Products which are not labeled shall be considered a misbranded hazardous substance subject to the Federal Hazardous Substance Act.

HR 711, **Sharp, "State Energy Conservation Programs Improvement Act of 1989"**

This Act amends the existing Energy Policy and Conservation Act to increase the effectiveness of state energy conservation programs. Each state energy conservation plan would contain the goal of reducing the amount of energy consumed by 10 percent or more in the year 2000 from projected energy consumption as of October 1, 1990; each would establish an energy emergency planning program for an energy supply disruption, and would ensure coordination between local, state, and federal energy and conservation programs within the state. Optional elements of the plan include programs to accelerate the use of alternative transportation fuels, programs for energy audits with respect to buildings and industrial plants within the state, and programs to promote energy efficiency in residential housing such as 1) energy efficiency rating systems for newly constructed housing and existing housing; and 2) incentives to build, service, or finance energy-efficient housing. The Act would also establish a State Energy Advisory Board within the Department of Energy to serve as a liaison between the states and DOE and to recommend appropriate changes to state and federal energy policies.

HR 842, Coble

This bill authorizes the President of the United States to maintain membership in the International Tropical Timber Organization.

The premise of this bill is that 1) the International Tropical Timber Organization (ITTO) is important because tropical rain forests are an important component of world trade, and unchecked tropical deforestation disrupts the indigenous culture in affected regions, and 2) tropical deforestation is growing at a rapid rate with the effect of contributing to the greenhouse effect. The International Tropic Timber Agreement, which is administered by the ITTO, provides an organizational framework for cooperation between timber-producing and consuming nations and provides statistical data to support forest management.

Jones (N.C.), HR 980, "Global Environment Research and Policy Act of 1989"

This Act requires the Federal Coordinating Council on Science, Engineering, and Technology to develop a 10-year program of national research on global environmental change. The "National Global Change Research Plan" shall be conducted and/or funded by the federal government to provide a basis for policy decisions relating to global change.

Title I identifies the type of research to be completed and allocates responsibilities among federal agencies including NOAA, NSF, NASA, and USGS. The Federal Coordinating Council shall oversee and coordinate research among the federal agencies, as well as agency participation in international activities. The council shall report annually to the President and the Congress.

Title II establishes within the Executive Office of the President the Council on Global Environmental Policy. The Council shall advise the President regarding domestic and international policies related to global environmental change, and within a five-year period shall submit to the Congress and President a national global environmental policy report consisting of a program to mitigate and adapt to the impacts of global warming.

Title III amends the National Environmental Policy Act of 1969 by including reference to the impact on the oceans, the atmosphere, and other aspects of the global environment.

S 169, Hollings, "National Global Change Research Act of 1989"

This Act establishes a coordinated federal research program to assess the causes and effects of global climate change by amending the existing "National Science and Technology Policy, Organization, and Priorities Act of 1976" (42 USC 6601 et seq). The amendment requires the development of a National Global Change Research Plan which would establish goals for federal research over a 10-year period, describes levels of funding required to achieve the identified goals, and takes into consideration existing programs and activities undertaken by agencies such as NSF, NASA, NOAA, USGS, EPA, and DOE. Research findings of the federal agencies involved in the program shall be made available to the EPA for use in the formulation of a coordinated national policy on global climate change pursuant to Section 1103 of the Global Climate Protection Act of 1987.

The premise of this Act is that human activities may lead to significant global warming and to the depletion of the stratospheric ozone, and development of policy to mitigate human-induced global change will rely on greatly improved scientific understanding of global environmental processes.

S 251, Moynihan, "Global Environment and Climate Change Assessment of 1989"

This bill creates a 10-year global environment and climate change research program. The program establishes 1) a long-term atmospheric monitoring and data gathering system, 2) the formation of a federal interagency task force to provide a description of all programs relating to climate change research, and 3) a comprehensive plan to focus the work of all participating agencies and institutions. During the course of the program, the task force is expected to publish various research reports which provide a description of activities and findings of the program.

The premise of this Act is that human activities contribute significantly to observed and predicted climate change; the United States has a special responsibility to adopt a leadership position on the research required to understand the cause and effect of global climate change; and existing federal research programs into global environmental change are too small and insufficiently coordinated.

S 491, Chafee, "Stratospheric Ozone and Climate Protection Act of 1989"

This Act requires the Administrator of the EPA to publish a priority list of manufactured substances which contribute to atmospheric or climate modification, including stratospheric ozone depletion. The initial list shall include CFC-11, CFC-12, CFC-113, CFC-114, CFC-115, methyl chloroform, halon-1211, halon 1301, and halon 2402. The Administrator shall also assign a numerical value representing the ozone depletion potential of each listed substance. Each person producing a listed substance shall file a report with the Administrator stating the production levels. Also, 18 months after a substance is listed, any container used to transport, any product containing, and any product manufactured with a process which uses a listed substance must be labeled before these products are introduced into interstate commerce.

Beginning July 1, 1989 a production phase out of listed substances will begin, with a complete phase out by 1997. Exceptions are granted for products used for medical purposes or deemed necessary for national security. The Administrator shall set forth regulations regarding standards for the use of manufactured substances that reduce the energy efficiency of a product and thus exacerbate the problem of human induced global climate change.

Before January 1, 1994 the Administrator shall establish standards for the recycling and safe disposal of substances covered by this Act. Any appliance containing a substance covered by this Act shall not be manufactured unless equipped with a servicing aperture which will allow recapture of the substance during service or repair.

The premise of this bill is that no level of stratospheric ozone depletion or global climate change can be deemed safe; that there is undisputed observational evidence that atmospheric concentrations of gases controlling stratospheric ozone levels are increasing as a result of human activities; and that the control measures set forth in the Montreal Protocol may not be adequate.

S 870, Gore, "Consumer Ozone Protection Act of 1989"

The bill would label, regulate, and in some cases eliminate the sale of certain consumer products (such as auto air conditioners) that have been shown to deplete the stratospheric ozone layer. In addition, it promotes the development of a Chlorofluorocarbon and Halon Reclamation Plan for the purpose of encouraging recapture and recycling of ozone-depleting substances.

S 871, Gore, "Ozone Layer Conservation Act of 1989"

The bill calls for a manufacturer's excise tax on certain chemicals that deplete the stratospheric ozone layer; establishes an Ozone Layer Conservation Trust Fund in the Treasury Department; and directs half of the revenues from the excise tax into the Trust Fund for the purpose of promoting research, development, and market incentives for technological alternatives to ozone-depleting chemicals.

S 872, Gore, "Upper-Ozone Chemicals Act of 1989"

The bill provides for a 5-year phase out of 6 substances that deplete the stratospheric ozone layer (CFC-11, CFC-12, CFC-13, halon-1211, halon-1301, carbon tetrachloride), and a 10-year phase out of other ozone depleting substances (CFC-22, CFC-114, CFC-115, methyl chloroform, methylene chloride), with exceptions for medical and national security reasons. There are provisions for certifying that nations from which we import products that contain ozone-depleting chemicals have a similar phase-out program in place, and a requirement for safe disposal of ozone-depleting substances. Finally, the bill calls for developing a safe alternatives policy for replacing the substances to be phased out with chemicals, product substitutes, or alternative manufacturing processes that reduce overall risk to public health and the environment.

	Global Climate Change Research	Inter-Disci-plinary Federal Research Planning	CFC Label-ing/ Regu-lation	CFC Phase Out/ Sub-stitute	Re-stricts Utility Emis-sions	Restricts Mobile Source Emissions	CO2 Regu-lation	CH4 Regu-lation	NO2 Regu-lation	Energy Conser-vation/ Efficiency Program	Alterna-tive/ Renewable Energy Program	Nuclear Power	Clean Coal	Natural Gas
HR 1078* Schneider (R-RI)			X	X	X	X	X		X	X	X			X
S 201* Gore (D-TN)		X		X	X					X				
S 324* Wirth (D-CO)	X						X		X	X	X	X	X	X
S 333* Leahy (D-VT)		X	X	X	X	X	X	X	X	X		X		
HCR 44** Bates (D-CA)														
HJR 207** Fazio (D-CA)							X							
HR 503** Stark (D-CA)			X											
HR 711** Sharp (D-IN)										X	X			
HR 842** Coble (R-NC)														
HR 980** Jones (D-NC)	X	X												
S 169** Hollings (D-SC)	X	X												
S 251** Moynihan (D-NY)	X	X												
S 491** Chafee (R-RI)			X	X										
S 870** Gore (D-TN)			X											
S 871** Gore (D-TN)				X										
S 872** Gore (D-TN)				X										

*Comprehensive Bills

**Targeted Bills

	Introduces "Least-Cost" Energy Planning (Go with Fuels)	Recycling Policies	Emphasis on State Implementation	Urban Tree Planting and Reforestation	Creates Council on Environmental Policy in the Executive Office	Promotes International Cooperation in Environmental Policy Making	Protection of Tropical Rainforest	Encourages Leading International Institutions to Consider the Environmental Implications of	International Population Control	Conservation of Biodiversity
HR 1078* Schneider (R-RI)	X	X	X	X		X	X	X	X	
S 201* Gore (D-TN)		X			X	X	X	X	X	X
S 324* Wirth (D-CO)	X		X	X		X	X	X	X	
S 333* Leahy (D-VT)						X				
HCR 44** Bates (D-CA)							X			
HJR 207** Fazio (D-CA)						X	X			
HR 503** Stark (D-CA)										
HR 711** Sharp (D-IN)				X						
HR 842** Coble (R-NC)							X			
HR 980** Jones (D-NC)					X	X				
S 169** Hollings (D-SC)										
S 251** Moynihan (D-NY)										
S 491** Chafee (R-RI)										
S 870** Gore (D-TN)										
S 871** Gore (D-TN)										
S 872** Gore (D-TN)										

*Comprehensive Bills

**Targeted Bills

GLOSSARY

1. Acre-foot: The quantity of water required to cover one acre to a depth of one foot; equal to about 325,851 gallons.

2. Albedo: The ratio of reflected solar radiation to the total incoming solar radiation where both streams are measured across the complete wavelength range of solar radiation.

3. Central Valley Project: This project transports water from the Sacramento, Trinity, American, and San Joaquin River Basins to the Southern Sacramento and San Joaquin Valleys. The project stores and coveys water for river regulation, navigation and flood control; irrigation and domestic uses; and for power.

4. Effective CO_2 Doubling: A level of increase in all greenhouse gases which is equivalent in terms of its effect on atmospheric warming to a doubling of CO_2.

5. Electrical Energy: An amount of energy; generally used in reference to the amount of electrical energy used or supplied during any time period.

6. Electricity Peak Demand: The highest demand for electricity during any period of time.

7. Evapotranspiration: The total water loss from the soil, including that by direct evaporation and that by transpiration from the surfaces of plants.

8. Fossil Fuels: Fuels that are derived from the fossilized deposits of plants and animal remains. These fuel primarily include oil, natural gas, and coal.

9. Infrared Light: Invisible rays just beyond the red end of the visible spectrum. These waves are longer than those of the spectrum colors, but shorter than radio waves, and have a penetrating heating effect.

10. Interglacial: The period between the two ice ages. The earth has been in the current interglacial for about 12,000 years.

11. KYR BP: One thousand years before present

12. KW: Kilowatt, 1000 watts

13 Latitude: The angular distance, measured in degrees, north or south from the equator.

14. MW: Megawatt, 1,000 kilowatts

15. Stratosphere: The atmospheric zone extending form six to fifteen miles above the earth's surface.

16. Thermal Generating Plant: A type of electric generating facility in which the source of energy for the prime mover is heat. These plants include those powered by fossil fuels, geothermal heat and nuclear fuels.

17. Troposphere: The atmosphere from the earth's surface to the tropospause, extending to six miles at the equator and 12 miles at the poles; in this stratum clouds form, convective disturbances occur and temperatures usually decrease with altitude.

18. Ultraviolet Light: Invisible rays just beyond the violet end of the visible spectrum with

Wavelengths shorter than approximately 4,000 angstroms.

19. Watt: The electrical unit of power or rate of doing work. It is analogous to horsepower or foot-pounds per minute of mechanical power. One horsepower is equivalent to approximately 746 watts.

REFERENCES

Abrahamson, Dean, and Peter Ciborowski. "Harvest of Sand." Amicus Journal, Volume 15, No.4, Spring 1984.

Adler, Jerry. "Stretched to the Limit." Newsweek, July 11, 1988.

Baddemeier, R.W. and S.V. Smith,"Coral Reef Growth in an Era of Rapidly Rising Sea Level: Predictions & Suggestions for Long-term Research." Coral Reefs, Spring 1988.

Barry, R.G., and R.J. Chorley. Atmosphere, Weather, and Climate, Holt Rinehart, and Winston, Inc., New York, pages 275-28.

Beardsley, Tim. "Getting Warmer?" Scientific American, July 1988, p.32.

Begley, Sharon. "A Gaping Hole in the Sky." Newsweek, July 11, 1988.

Begley, Sharon. "A Long Summer of Smog." Newsweek, August 29, 1988, pp. 46-48.

Begley, Sharon. "The Endless Summer?" Newsweek, July 11, 1988

Bemis, Gerry. "Control of Global Warming from Conventional Sources." Memo, California Energy Commission, July 7, 1988.

Bolle, Seiler. "Other Greenhouse Gases and Aerosols." The Greenhouse Effect, Climatic Change and Ecosystems, Ed. B. Bolin, John Wiley & Sons, 1986.

Booth, William. "Johnny Appleseed and the Greenhouse." Science, October 7, 1988, p. 242.

Bradley, R.S., and H.F. Diaz. "Precipitation Fluctuations over Northern Hemisphere Land Areas Since the Mid-19th Century." Science, Volume 237, July 10, 1987.

Brown, Lester and Christopher Flavin. "Earth's Vital Signs." The Futurist, July 1988, pp. 13-20.

Bryan, Kirk. "Man's Great Geophysical Experiment," Oceanus.

Butt, Arthur, and Bonnie Brown. "Civilizations and Sea Level Change: Present and Past." Oceans '86.

California, University of, Division of Agriculture and Natural Resources, State of California Department of Water Resources, Irrigation Water Use in the Central Valley of California, A Report of the Central Valley Water Use Study Committee, Undated.

California State of, Department of Water Resources, Bulletin No. 68-73, Inventory of Waste Water Production and Waste Water Reclamation in California, 1973.

California Department of Fish and Game. At the Crossroads - A Report on the Status of California's Endangered and Rare Fish and Wildlife, 1980.

California Air Resources Board, "Health and Welfare Effects of Acid Deposition in California: an Assessment." 1988.

______________________________, DWR, Drought, Contingency Planning Guidelines for 1989, January 1989.

________________________, DWR Bul. No. 118, California's Ground Water, September 1975.

________________________, DWR Bul. 160-83, The California Water Plan, Projected Use and Available Water Supplies to 2010, December 1983.

________________________, DWR Bul. 120-87, Water Conditions in California, Special Dry Year Report, October 1987.

________________________, DWR Bul. 73-79, Evaporation from Water Surfaces in California, Nov. 1979.

________________________, DWR Bul. No. 113-3, Vegetative Water Use in California, 1974, April 1975.

________________________, DWR Bul. 124-3, Water Use By Manufacturing Industries in California 1979, May 1982.

________________________, DWR Bul. 120-83, Water Conditions in California, Fall Report, October 1983.

________________________, DWR Bul. No. 80-5, Reclamation of Water from Wastes in Southern California, November 1975, With Appendices.

________________________, DWR Bul. No. 120-83, Water Conditions in California, Report 4, May 1, 1983.

________________________, DWR, The California Drought 1977, An Update February 15, 1977.

________________________, DWR Bul. 199, California Flood Management: An Evaluation of Flood Damage Programs, September 1980.

________________________, DWR Bul. 166-3, Urban Water Use in California, October 1983.

________________________, DWR Bul. No. 160-70, Water for California, The California Water Plan Outlook in 1970, December 1970.

________________________, DWR, The 1976-1977 California Drought, A Review, May 1979.

________________________, DWR Bul. No. 189, Waste Water Reclamation, State of the Art.

________________________, DWR Bul. 160-87, California Water: Looking to the Future, November 1987.

________________________, DWR Drought Assistance, A Report to the Legislature in Response to Senate Bill 32, January 21, 1989.

________________________, DWR Bul. 198-84, Water Conservation in California, July 1984.

________________________, DWR Bul. 113-4, Crop Water Use in California, April 1986.

Cess, R., and S. Goldenberg. "The Effect of Ocean Heat Capacity Upon Global Warming Due to Increasing Atmospheric Carbon Dioxide." Journal of Geophysical Research, Volume 86, January 20, 1981.

Charles Petit, "Why the Earth's Climate is Changing Dramatically." S.F. Chronicle, August 8 1988.

Choudhurg, Bhaskar. "Impact of CO_2 on Cooling of Snow and Water Surfaces," , Nature, Volume 280, August 23, 1979, p.280.

Congressional Record, Senate, S2663, Stafford, "Global Environmental Protection Act." July 27 1988.

Congressional Record, Proceedings and Debates of the 100th Congress, 2nd Session, Volume 139, October 6 1988.

Conversation with Paul Faeth of the World Resources Institute re: WRJ proposal to plant 52 million trees in Guatemala.

Cowley, Geoffrey. "Ozone Breakaway." Newsweek, August 29, 1988, pp.48-49.

Crockett, Stephen. "NRC Urges Standard Designs, One-Step Licensing for Orojects." Office of the General Counsel, NRC, Washington D.C. 20555.

David Greene, Director of Transportation Research. "Transportation Efficiency and Alternative Fuels: Road to the Future." Oak Ridge National Laboratory, September 1 1988.

David Bordin. "What if Methane's Inexhaustible?" Wall Street Journal, January 1984.

de Sylva, Donald. "Increased Storms and Estuarine Salinity and Other Ecological Impacts of the Greenhouse Effect." Effects of Changes in Stratospheric Ozone & Global Climate, Vol. 4: Sea Level Rise, Ed. James Titus, EPA, 1986.

Deborah Blum. "Thriving Pines Hint at Change on Planet." Sacramento Bee, page A1, September 1984.

Deborah Blum. "Trees May Save the World from 'Greenhouse Effect' Threat." Sacramento Bee, November 25 1988.

Delcourt, Hazel. "Dynamic Plant Ecology: the Spectrum of Vegetational Change in Space and Time." Quaternary Science Reviews, Volume 1, November 28, 1988.

Deluchi, Mark, et al. "A Comparative Analysis of Future Transportation Fuels." Inst. of Transportation Studies, UCB, Research Report, UCB-JTS-RR-87-13, October 1987, pp. 1-17.

DeLuchi, M.A., et al. "Transportation Fuels and the Greenhouse Effect." UERG California Energy Studies Report, UC Davis, December 1987.

Denard, Maurice, and T.S. Murty. "Some Recent Trends in Precipitation in Western Canada and Their Possible Link to Rising Carbon Dioxide." Atmosphere-Ocean, Volume 26, 1988.

Dickinson, Robert, and Ralph Cicerone. "Future Global Warming from Atmospheric Trace Gases." Nature, Volume 319, January 9, 1986.

Dickinson, Robert. "Ice Albedo Feedback in a CO_2-Doubling Simulation." Climatic Change, 1987.

Dr. John Firor, National Center for Atmospheric Research, statement before the Senate Committee on Agriculture, Nutrition, and Forestry, December 1 1988.

Duncan, Laurie. "Global Warming Imperils State Water Supply, House Panel Told." Los Angeles Times, July 28, 1988.

Finlayson-Pitt and Pitts. Atmospheric Chemistry: Fundimentals and Experimental Techniques, Wiley-Interscience, New York, 1986.

Flaschka, Irmgard. "Climatic Variation and Surface Water Resources in the Great Basin Region." Water Resources Bulletin, Volume 23, No. 1, February 1987.

Flavin, Christopher. "Creating a Sustainable Energy Future." State of the World 1988.

Flohn, H.. "Climatic Prospects in the Case of an Extended, CO_2-Induced Warming." Zeitschrift fur Meteorologie, Volume 35, No. 1, 1985.

Flynn, Timothy. "Implications of Sea Level Rise for Hazardous Waste Sites in Coastal Floodplains." Greenhouse Effect and Sea Level Rise, Ed. Barth, et al.

Freshi, Jim. "Ozone Test Help Fight Cotton Loss." Times Delta, July 21, 1988.

Gerald Potter and Hugh Ellsaesser. "Understanding Why Models Agree (Or Disagree)." Lawrence Livermore Laboratory, December 1981.

Gibbs, Michael. "Economic Analysis of Sea Level Rise: Methods and Results," Greenhouse Effect and Sea Level Rise, Ed. Barth et al.

Glantz, Michael. "The Ogallala Aquifer and Carbon Dioxide: Comparison & Convergence." , Environmental Conservation, Volume 11, No. 2, 1984.

Goodridge, James. "Air Temperature Trends in California - 1916 to 1987." December 14, 1988.

Green, Bill. "Policies on Global Warming and Ozone Depletion." Environment, Volume 29, No. 3, April 4, 1987.

H.R. 5460, introduced by Claudine Schneider, 1989.

Hameed, S., and R.D. Cess. "Impact of a Global Warming on Biospheric Sources of Methane and its Climatic Consequences." Tellus Volume 35, 1983.

Hanchey, J.R. et. al. "Water Resources Planning Under Climate Uncertainty." U.S. Army Institute for Water Resources, Ft. Belvoir, Virginia 22060.

Hansen, J.. "The Greenhouse Effect: Projections of Global Climate Change." Effects of Changes in Stratospheric Ozone and Global Climate" Ed. James Titus, EPA.

Hansen, J.. "Climate Sensitivity: Analysis of Feedback Mechanisms." Geophysical Monograph, No. 29.

Hansen, J., et al. "The Greenhouse Effect: Projections of Global Climate Change." Effects of Changes in Stratospheric Ozone and Global Climate, ed. James Titus, July 1987.

Hecht, Peter. "Officials Say Radical Plan Will Clear Los Angeles' Air." Los Angeles Times, September 1, 1988.

Herbert Girardet, Far From Paradise. "The Amplification of Man," British Broadcasting Corporation, Pages 204-213, 1986.

Hoffman, John. "Estimates of Future Sea Level Rise." Greenhouse Effect and Sea Level Rise, Ed. Barth, et al.

Holden, Constance. "Greening of the World Bank." Science, Volume 240, June 17, 1988, pp.1610-1611.

Houston, Paul. "EPA Moves to Ban New Sources of Smog in Los Angeles Area," Los Angeles Times, August 30, 1988.

Hummel, J.R. and R.A. Reck. "The Direct Thermal Effect of Peroxyacetylnitrate (PAN) on Atmospheric Surface Temperature." , Atmospheric Environment, Volume 18, No. 1, 1984.

Idso, Sherwood. "CO_2 as an Inverse Greenhouse Gas." Proceedings of SPIE-International Society for Optical Engineering, Vol. 430, 1983.

Idso, Sherwood. "The Greenhouse Effect: Reason and Reality Considered." Energy World, April 1984.

Idso, S.B. "What if Increases in Atmospheric CO_2 Have an Inverse Greenhouse Effect?" Journal of Climatology, Vol. 4, 1984.

Idso, Sherwood. "On the Magnitude of the CO_2 Greenhouse Effect." Applied Energy, Volume 14, No. 3, 1983.

Irving Mintzer. "Weathering the Storms in a Warming World." Public Power, December 1988.

Jackson, Michael. "Comparing the Impact of Different Transportation Fuels on the Greenhouse Effect." Prepared for the California Energy Commission, October 1987.

John Gribbin. "There's a Positive Side to the Dreaded Greenhouse Effect." San Jose Mercury News, February 5 1984.

Judd, Bruce and Elizabeth Olmsted. "Analyzing R&D and Policy Options for the Greenhouse Effect." The Energy Industry in Transition, 1985-2000.

Karl, T.R., et al. "Recent Temperature Changes During Overcast and Clear Skies in the United States." Journal of Climate and Applied Meteorology, Volume 26, December 1986.

Karl, T.R., and J. Gavin. "Recent Temperature Changes During Overcast and Clear Skies in the United States." Journal of Climate and Applied Meteorology, December 1986, p.26.

Karl, Thomas. "Relationship Between Decreased Temperature Range and Precipitation Trends in the United States and Canada, 1941-80." Journal of Climate and Applied Meteorology, Volume 25, No. 12, June 14, 1986.

Kasting, James, and David Grinspoon. "Oceans on Venus - the Great Debate." Planetary Report, Volume 8, No. 6, December 1988.

Kasting, James, and Steven Richardson. "Sea Floor Hydrothermal Activity and Spreading Rates: The Eocene Carbon Dioxide Greenhouse Revisited." Geochimica et Cosmochimica Acta, Volume 49, August 1985.

Keepin, Bill. "Greenhouse Warming: Efficient Solution or Nuclear Nemesis?" Rocky Mountain Institute, Snowmass, CO 81654-9199, June 6, 1988.

Keepin, Bill. "Review of Global Energy and Carbon Dioxide Projections." Annual Review of Energy, Volume 11, 1986.

Keepin, Bill and Gregory Katz. "Greenhouse Warming: Comparative Analysis of Two Abatement Strategies." Rocky Mountain Institute, forthcoming in Energy Policy, December 1988.

Keepin, Bill. "Carbon Dioxide Abatement: More Nuclear or Less Energy?" Rocky Mountain Institute, October 24, 1988.

Kerr, Richard. "Greenhouse Warming Still Coming." Science, May 1986.

Kerr, Richard. "How Much Drying From a Greenhouse Warming?" Science, January 23, 1987.

Kerr, Richard. "Is the Greenhouse Here?" Science, Volume 239, February 5, 1988, p.559-561.

Kyner, T.N., and R.M. Sorensen. "The Impact of Selected Sea Level Rise Scenarios on the Beach and Coastal Structures at Sea Bright."

Kyper, T., and R. Sorensen. "The Impact of Selected Sea Level Rise Scenarios on the Beach & Coastal Structures at Sea Bright, NJ." Coastal Zone 1985: Proceedings of the Fourth Symposium on Coastal & Ocean Management, Baltimore, MD, 1985.

Larson, Eric. "Effects of Atmospheric Carbon Dioxide on U.S. Peak Electrical Generating Capacity." IEEE Technology and Society Magazine, December 1984.

Laurmann, J.A.. "Emissions Control and Reduction." , Gas Research Institute, 1987.

Laurmann, John. "Market Penetration of Primary Energy and its Role in the Greenhouse Warming Problem." Energy, Volume 10, No. 6, 1985.

Laurmann, John. "Market Penetration Characteristics for Energy Production and Atmospheric Carbon Dioxide Growth." Science, Volume 205, August 31, 1979.

Laurmann, John. "Recent Developments in the Greenhouse Gas/Climate Change Environmental Problem." Gas Research Institute, November 1987.

Laurmann, J.A.. "Future Energy Use and Greenhouse Gas Induced Climatic Warming." Gas Research Institute.

Laurmann, John. "Scientific Uncertainty and Decision Making: The Case of Greenhouse Gases and Global Climate Change." The Science of the Total Environment, Volume 55, 1986.

Laurmann, John. "Strategic Issues and the CO_2 Environmental Problem." Carbon Dioxide: Current Views, Gas Research Institute, 1983.

Laurmann, J.A.. "The Global Greenhouse Warming Problem: Setting the Priorities." Climatic Change, 1985.

Laurmann, J.A., and J.R. Spreiter. "The Effects of Carbon Cycle Mode Error in Calculating Future Atmospheric Carbon Dioxide Levels." Climatic Change, 1983.

Laurmann, J.A. Draft Editorial, November 1987.

Letter to Claudine Schneider from Mitch Beaver, Chair of the National Association of State Energy Officials, October 14 1988.

Levin, Leonard. "Northern Hemisphere Glacio Chemical/Greenhouse Gas Time Series." Electric Power Research Institute (EPRI), October 26, 1988.

Lincoln, D.. "Response of an Insect Herbivore to Host Plants Grown in Carbon Dioxide Enriched Atmospheres." Oecologia, 1986.

Linda Fisher, Assistant Administrator for Policy, Planning, and Evaluation, U.S. Environmental Protection Agency, testimony on December 1 1988.

Linder, Kenneth, and Michael Gibbs. "The Potential Impacts of Climate Change on Electric Utilities: Project Summary." Energy Technology Conference.

Long, Caroline. "Senate Panels Plan Legislation to Combat Stratospheric Ozone Loss." International Journal of Air Pollution Control and Hazardous Waste Management, Volume 37, No. 3, March 1987.

MacCracken, Michael. "The Reality of the Greenhouse Effect." Twelfth World Petroleum Congress, 1987.

Marshall, Jonathan. "Cool Town, Forest in the City," Pacific News Service/Berkeley Co-Op News, September 26, 1988.

Maschado, Sheila and Rick Piltz. "Reducing the Rate of Global Warming: The States' Role." Renew America, November 1988.

Mayer, Jim. "Greenhouse Effect Clouds Water Future," Sacramento Bee, November 18, 1988.

McKean, Kevin. "Hothouse Earth." Discover, December, 1983, pp.99-102.

McLean, Dewey. "A Terminal Mesozoic 'Greenhouse': Lessons from the Past." Science, Volume 201, August 9, 1978.

Medows, Donella. "Greenhouse: Down to Earth Choices." Los Angeles Times, July 31, 1988.

Mercer, J.H. "West Antarctic Ice Sheet and CO_2 Greenhouse Effect: A Threat of Disaster." Nature, Volume 271, January 26 1978.

Messenger, Mike. "Global Warming: Is It a Problem and If So, What Can the CEC Do About It?" ER-7 White Paper, CEC, August 17, 1988, pp.1-14.

Metropolitan Water District of Southern California, Report No. 948, Water Supply Available to Metropolitan Water District Prior to Year 2000, August 1983.

Michael McElroy. "The Challenge of Global Change." New Scientist, Page 34 July 28 1988.

Michaels, Patrick, and Bruce Hayden. "Modeling the Climate Dynamic of Tree Death." BioScience, Volume 37, No. 8, September, 1987.

Miller, G. Tyler, Jr., Living in the Environment. Concepts, Problems and Alternatives.

Mintzer, J.M.. "A Matter of Degrees." World Resources Institute, April 1987.

Monastersky, Richard. "Clouds Without a Silver Lining." Science News, Volume 134, October 15, 1988.

Moore, Alicia. "A Warming World." Fortune, July 4, 1988.

Murphy, Kim. "Court Orders EPA to Develop Plan to Clean Air in Basin," Los Angeles Times, September 20, 1988.

Nasser Sionit, Paul Kramer. "Woody Plant Reactions to CO_2 Enrichment." Carbon Dioxide Enrichment of Greenhouse Crops, ed. by Herbert Enoch & Bruce Kimball, Volume II.

Neilson, Ronald. "Biotic Regionalization and Climatic Controls in Western North America." Vegetation, Volume 70, No. 3, June 30, 1987.

Neilson, Ronald. "High-Resolution Climatic Analysis and Southwest Biogeography." Science, Volume 232, April 4, 1986.

Newman, James. "Impacts of Rising Atmospheric Carbon Dioxide Levels on Agricultural Growing Seasons and Crop Water Use Efficiencies."Environmental Consequences of a Possible CO_2-Induced Climate Change, Volume 11, Part 8, prepared for U.S. Department of Energy, September 1982.

Nolte, Carl. "Experts Toss Stones at Greenhouse Theory." San Francisco Chronicle, August 20, 1988.

Orville Bentley, Assistant Secretary, Science and Education, U.S. Department of Agriculture, statement before the Committee on Agriculture, Nutrition and Forestry, U.S. Senate, December 1 1988.

Pacific Institute for Studies in Development, Environment, and Security, The Implications of Climate Change for California: A Review by Peter H. Gleick, November 21, 1988.

Park, Richard. "Predicting the Effects of Sea Level Rise on Coastal Wetlands." Effects of Changes in Statospheric Ozone and Global Climate, Volume 4: Sea Level Rise, Ed. James Titus, EPA, 1986.

Paul, Bill. "Power Supply Forecasts Grow Pessimistic." Wall Street Journal, October 12, 1988.

Pendleton, Dennis, and George Van Dyne. "Research Issues in Grazinglands Under Changing Climate." Volume II, Part 16, Environmental and Societal Consequences of a Possible CO_2-Induced Climate Change, April 12, 1983.

Perry, A.M.. "Environmental Effects of Chlorofluorocarbons: Will Restrictions Be Needed?." U.S. Dept. of Energy, October 1986.

Perry, A.M.. "Can We Delay a Greenhouse Warming?" Sixth ORNL Life Sciences Symposium on the Global Carbon Cycles, November 1983.

Peters, Robert, and Joan Darling. "The Greenhouse Effect and Nature Reserves." BioScience, Volume 35, No. 11, December 1985.

Petit, Charles. "Plants Do Well in Greenhouse," San Francisco Chronicle, August 9, 1988.

Petit, Charles. "Greenhouse Effect Will Damage Water Systems." San Francisco Chronicle, August 9, 1988.

Petit, Charles. "Developing Strategies to Minimize the Damage." San Francisco Chronicle.

Pittock, A.B.."Recent Climatic Change in Australia: Implications for a CO_2-Warmed Earth." Climatic Change, Volume 5, No. 4, 1983.

Porter, Gail. "A Watchful Eye is Best Tactic as CO_2 Rises Over Next Century." News Report, November 1983, pg. 8-13.

Postel, Sandra. "A Green Fix to the Global Warm-Up." World Watch, September 1988.

Potter, Robert. "Effect of Global Warming on Water Resources in California." Presented to House Interior and Insular Affairs Subcommittee on Water and Power Resources, October 17, 1988.

Radok, Dave, and Craig Lingle. "Surging as a Potential Response of Ice Sheets to CO_2-Induced Changes in the Polar Environment." Prepared for U.S. Department of Energy, October 1, 1986.

Ramanathan, V. "Trace Gas Trends and Climate Change." Testimony submitted for the Senate hearing on "The Greenhouse Effect and Climate Change" by the Subcommittee on Environmental Protection, January 23 1987.

Ramanathan, V.. "Climate - Chemical Interactions and Effects of Changing Atmospheric Trace Gases." Review of Geophysics, Volume 25, No. 7, August 1987.

Ramanathan, V. "The Greenhouse Theory of Climate Change: A Test by an Inadvertent Global Experiment." Science, Volume 240, April 15, 1988, pp. 293-299.

Ray, Mel. "In the Future." Electrical World, December 1987, p.8.

Reisner, Marc. "America's Newest Old Energy Source: Hydro Power." Amicus Journal, Volume 6, No. 4, Spring 1985.

Reon Green. "Nuclear Gasification of Coal for Control of Carbon Dioxide Emissions." Public Utilities Fortnightly, November 24 1988.

Revelle, P., and P. Waggoner. "Effects of CO_2-Induced Climatic Change on Water Supplies in the Western U.S.."

Revkin, Andrew. "Endless Summer: Living with the Greenhouse Effect." Discover, 10-88, Pages 50-61.

Richard Kerr. "Weather in the Wake of El Nino." Research News or Science, page 883, May 13, 1988.

Rind, D. "Likely Effects of Global Warming on Water Availability and Hydrology in North America." First North American Conference on Preparing for Climate Change, November 29, 1987.

Rind, D. "Climate Modeling and Climate Change." EPA Workshop on Global Atmospheric Change and EPA Planning, Final Report, EPA-600/9-86/016, July 7, 1986.

Robert Cess, Steven Goldenberg. "The Effect of Ocean Heat Capacity Upon Global Warming Due to Increasing Atmospheric Carbon Dioxide." Journal of Geophysical Research, Volume 86, No. C1, July 1987.

Rohin, G. de Q. "Changing the Sea Level." The Greenhouse Effect, Climatic Change and Ecosystems. Ed. Bolin, et al.

Roper, S. and T. Wigley. "Recent Temperature Changes in the Arctic and Antarctic." Nature, Volume 306, December 1983.

Rose, David. "Reducing the Problem of Global Warming." Technology Review, June 1984.

Rosenzweig, Cynthia. "Climate Change and U.S. Agriculture." statement presented to U.S. Senate committee on Agriculture, Nutrition, and Forestry, December 1, 1988.

Rowe, et al. The Benefits of Air pollution Control in California, California Air Resources Board, Contract No A2-118-32, 1986.

Sampson, Neil. "How We All Can Cool the Greenhouse." October 23, 1988.

San Francisco Bay Conservation and Development Commission, Sea Level Rise: Predictions and Implications for San Francisco Bay, December 1987 Revised October 1988.

Schneider, Stephen. "On the Empirical Verification of Model-Predicted CO_2-Induced Climatic Effects." American Geophysical Union, No. 29, 1984.

Schneider, Claudine. "Summary of the Global Warming Prevention Act (H.R. 5460)"

Schneider, Stephen. "Carbon Dioxide Warming and Coastline Flooding." Climate Research Board, National Academy of Sciences, Washington D.C., NSF Publication, 1980.

Schneider, Stephen, and Robert Chen,"Carbon Dioxide Warming and Coastline Flooding." Ann. Rev. Energy, 1980.

Schneider, Stephen. "Doing Something About the Weather." World Monitor, December 1988.

Schönwiese, C.D.. "The CO_2 Climate Response Problem: A Statistical Approach." Theoretical and Applied Climatology, January 2, 1986.

Shabecoff, Philip. "Disturbing Evidence of Global Warming Trend." Sacramento Bee.

Shugart, H.H.. "CO_2 Climatic Change and Forest Ecosystems." Ed. Bert Bolin, John Wiley & Sons, The Greenhouse Effect, Climatic Change, and Ecosystems 1986.

Simons, Marlise. "How Fires in the Amazon Pollute the Atmosphere." San Francisco Chronicle, August 13, 1988.

Sionit, Nassar. "Long-Term Atmospheric CO_2 Enrichment Affects the Growth and Development of Liquidamber Styraciflia and Pinus Taeda Seedlings," Canadian Journal for Resources, Volume 15, 1985.

Sionit, Nassar. "Photosynthesis and Stomatal Conductance with CO_2-Enrichment of Container- and Field-Grown Soybeans." Agronomy Journal, Volume 76, June 1984.

Sionit, Nasser. "Response of Soybean to Two Levels of Mineral Nutrition in CO_2-Enriched Atmosphere." Crop Science, Volume 23, September 1983.

Sionit, Nassar. "Responses of C4 Grasses to Atmospheric CO_2 Enrichment, Effect of Irradiance," Oecologia, 1984.

Sionit, Nassar. "Interaction of Temperature and CO_2 Enrichment on Soybean: Photosynthesis and Seed Yield." Canadian Journal of Plant Science, Volume 67, July 1987.

Sionit, Nassar."Interaction of Temperature and CO_2 Enrichment on Soybean: Growth and Dry Matter Partitioning." Canadian Journal of Plant Science, Volume 67, January 1987.

State Water Quality Control Board Publication No. 3-A, Water Quality Criteria, Second Edition by McKee and Wolf.

State Water Resources Control Board, Regional Water Quality Control Board Santa Ana Region (8), Part 1, Vol. 1, Water Quality Control Plan Report, Santa Ana River Basin (8).

Stockton, C.W.. "Climatic Change and Surface Water Availability in the Upper Rio Grande Basin." Regional and State Water Resources Planning and Management, October 1983.

Stolarski, Richard and Donald Wuebbles. "Depletion of Stratospheric Ozone." Paper 4, EPA Workshop on Global Atmospheric Change and EPA Planning, Final Report, July 1986.

Strock, J. "Adjusting Water Allocation Low to Meet Water Quality and Availability Concerns in a Warming World." Conference, October 29, 1987.

Tangley, Laura. "Preparing for Climate Change." BioScience, Volume 38, No. 1, January 1988.

Teare, J.D.. "Changes in Water Status During Water Stress at Different Stages of Development in Wheat." Physical Plant, 55.

Thomas, Paulette. "EPA Predicts Global Impacts from Warming." Wall Street Journal, October 21, 1988.

Thomas, Robert. "Future Sea Level Rise and Its Early Detection by Satellite Remote Sensing." Effects of Changes in Stratospheric Ozone and Global Climate, Volume 4: Sea Level Rise, Ed. James Titus, EPA, 1986.

Thompson, Anne, and Ralph Cicerone. "Possible Perturbations to Atmospheric CO, CH_4, and OH." Paper 5, EPA Workshop on Global Atmospheric Change and EPA Planning, Final Report, July 1986.

Tim Wirth, et. al. Summary of S2667, "National Energy Policy Act of 1988," by Testimony of T.M. Wigley before U.S Senate Committee on Environment and Public Works, Subcommittee on Environmental Protection and Subcommittee on Hazardous Wastes and Toxic Substances, January 28 1987.

Tirnak, Dennis. "The Role of Nitrous Oxide in Global Climate Change and Stratospheric Ozone Depletion." 1987 Symposium on Stationary Combustion Nitrogen Oxide Control, Prepared for US Environmental Protection Agency, August 1987.

Titus, James. "Planning for Sea Level Rise Before and After a Coastal Disaster." Greenhouse Effect and Sea Level Rise, Ed. Barth

Titus, James. "Sea Level Rise and Wetland Loss." Coastal Zone 1985: Proceedings of the Fourth Symposium on Coastal and Ocean Management, 1985.

U.S. Dept. of Energy. "Biofuels and Municipal Waste Program Events Calendar." November 22, 1988.

U.S. Environmental Protection Agency, The Potential Effects of Global Climate Change on the United States, Chapters 3 and 4, October 1988 Draft Report to Congress.

U.S. Environmental Protection Agency, Executive Summary of the Report "Surface Impoundments and Their Effects on Ground-Water Quality in the United States - A Preliminary Survey," June 1978.

U.S. Department of Health, Education and Welfare, Public Health Service Technical Report W61-4, Estuarine and Marine Pollution, Selected Studies.

United States Department of Energy. Ed. John Trabalka, "Atmospheric Carbon Dioxide and the Global Carbon Cycle," 1986.

V. Ramanathan. "Trace Gas Trends and Their Potential Role in Climate Change." Journal of Geophysical Research, Volume 90, No. D3, June 20 1985.

Wallace Broecker. "Unpleasant Surprises in the Greenhouse?." Nature, Volume 328, Page 123 July 9 1987.

Wang, W.C.. "Natural and Anthropogenic Climate Change." August 1986.

Warride, R.A.. "CO_2, Climatic change, and Agriculture." The Greenhouse Effect, Climatic Change, and Ecosystems. Ed. Bert Bolin, John Wiley & Sons, 1986.

Washington State Energy Office. "Global Warming and Energy in Washington." Briefing to the Committee on Energy and Utilities and Environmental Affairs, July 22, 1988.

Westman, Walter and George Malanson. "Effects of Climate Change on Mediterranean-Type Ecosystems in California and Baja California." To be published in Consequences of the Greenhouse Effect for Biological Diversity, Yale University Press, 1989.

Wigley, T.M.. "The Effect of Model Structure on Projections of Greenhouse Gas-Induced Climate Change." Geophysical Research Letters, Volume 14, No. 11, November 1987.

Wilcoxen, Peter. "Coastal Erosion and Sea Level Rise: Implications for Ocean Beach and San Francisco's Westside Transport Project." Coastal Zone Management Journal, Volume 14, No. 3, 1986.

Radok, Uwe, and Craig Lingle. "Surging as a Potential Response of Ice Sheets to CO_2-Induced Changes in the Polar Environment." University of Colorado, 1986.

William Moomaw. testimony before the Senate Agriculture Committee, December 1 19884

Wingate, P.J.. "Hot and Bothered About Carbon Dioxide." Wall Street Journal, November 17, 1983.

"Air Pollution Hurting Crops, Trees, Report Says." Mercury News, September 11, 1988.

"An Energy Strategy to Stave Off Global Warming." The Energy Daily, January 18, 1984, p. 4.

"An Icy Warning of a Global Warming?" Newsweek, December 28, 1987, p. 65.

"Antarctic's Ozone Loss Cuts Nearby Levels, Studies Say." Sacramento Bee, December 7, 1988.

"Apocalypse When? 'Soon', say Some." San Francisco Examiner, August 21, 1988.

"As Ozone Shield Erodes, Suntan Risks Rise." Sacramento Bee, August 23, 1988.

"Big Chill for the Greenhouse." Time, October 31, 1988.

"Bromines May Be Harming Ozone Layers as much as Fluorocarbons, Report Says." Wall Street Journal, August 30, 1988.

"Conservation, Competition, and National Security," presentation by Dr. Arthur H. Rosenfeld to a Congressional Committee.

"Coolants on the Hot Seat." USA Today, September 29, 1988.

"Denver's Air: Impressive Gain with Minimum Pain." Sacramento Bee, September 18, 1988.

"Diffusion Takes a Controversial Spin." Science News, Volume 134, October 15, 1988.

"Effects of Urban Smog Resulting from Changes in the Stratospheric Ozone Layer and in Global Temperature." Paper 7, EPA Workshop on Global Atmospheric Change and EPA Planning, Final report, July 1986.

"Electrical Rates May Rise to Keep Salmon Eggs Cool." Sacramento Bee, July 21, 1988.

"Energy Policy Statement: A Call for Action for the Next President and Congress." Environmental and Energy Study Institute, Special report, October 5, 1988.

"Energy Efficiency and STructural Change: Implications for the Greenhouse Problem." Workshop sponsored by the U.S. Environmental Protection Agency, May 1983.

"Fact and Fancy on Greenhouse Earth." Wall Street Journal, August 30, 1988.

"Far-Off Clues to Nearby Weather." U.S. News and World Report, January 16, 1989.

"Fighting the Greenhouse Effect," Matthew Wold, New York Times, August 28, 1988.

"Firms Race to Replace Freon." USA Today, September 29, 1988.

"Firms Intensify Race to Find Substitutes for Chemicals Linked to Ozone Depletion." Wall Street Journal, September 27, 1988.

"Future Sea Level Rise and Its Early Detection by Satellite Remote Sensing," Robert Thomas, Effects of Changes in Stratospheric Ozone & Global Climate; Vol. 4: Sea Level Rise, ed. James Titus, 1986.

"Greenhouse Effect Seen as a Media Hype and Peril to Power Development." Cogeneration Report, October 21, 1988.

"Greenhouse Effect? Just the Opposite, says UCD Professor," Davis Enterprise, January 10, 1989.

"Greenhouse Effect is Bridge to Next Ice Age, Scientists Say," Seattle Times, August 22, 1988.

"History of Earth's Climate Traced." Sacramento Bee, September 18, 1988.

"Hothouse Futures?" The Futurist, November, 1987, p.43.

"How Volcanoes Threaten Ozone." San Francisco Chronicle, August 5, 1988.

"Hydroelectric Output Cut Sharply." Journal of Commerce, June 23, 1988.

"Ice Age Insights." Science News, Volume 134, September 17, 1988.

"Increased Storms and Estuarine Salinity and Other Ecological Impacts of the Greenhouse Effect," Donald de Sylva.

"Interactive Effects of CO_2 And Environment on Photosynthesis of Azolla," Agriculture and Forest Meteorology, Volume 42, 1988.

"International Council on Remediation of Greenhouse Gas Environmental Impacts." presented at 5th Meeting of the World Commission on Environment and Development, May 26, 1986.

"Is Rural Electrification Such a Good Idea?" Energy Economist, July 1988.

"It Is Not Just Farmers Who Suffer from Drought," Energy Economist, July 1988.

"Is the Crazy Weather Still Another Sign of a Climate Shift?" Wall Street Journal, August 18, 1988.

"It's Been Hot - But Are We Really in the Greenhouse?" Sacramento Bee, September 11, 1988.

"Learning to Live Without CFCs: Restocking the Fridge," The Economist, October 29, 1988.

"Legislation Would Heat Up the Greenhouse." Mercury News, July 12, 1988.

"Life After Greenhouse: A California You Won't Recognize." San Francisco Examiner, August 7, 1988.

"New Culprit is Indicted in Greenhouse Effect: Rising Methane Level." Wall Street Journal, October 24, 1988.

"New Study Projects Growth in Pollution Control Market." Alternative Sources of Energy, October 1988.

"Policy Update on Global Warming," Greenhouse Effect Report, Volume I, No. 1, November 1988.

"Potential Impacts of Climate Change on Electric Utilities." New York State Energy Research and Development Authority, December 1987.

"Power Supply Forecasts Grow Pessimistic." Wall Street Journal, October 12, 1988.

"Quick Action Urged to Save Atmosphere." San Francisco Chronicle, July 1, 1988.

"Rediscovering Planet Earth." U.S. News and World Report, October 31, 1988.

"Responses of C4 Grasses to Atmospheric CO_2 Enrichment, Effect of Water Stress." Crop Science, Volume 25, June 1985.

"Saving Energy Cools Greenhouse." San Jose Mercury News, September 24, 1988.

"Scientists Fear Air Pollution Killing Mountain Forests." Sacramento Bee, July 24, 1988.

"Sea Floor Hydrothermal Activity Links Climate to Tectonics: The Eocene Carbon Dioxide Greenhouse." Science, Volume 227, January 11, 1985.

"Shake or Bake." The New Republic, September 23, 1988, pp.5-8.

"Skin Cancers Soar as Worries Grow Over Ultraviolet Rays." Sacramento Bee, August 22, 1988.

"South State OKs Smog Plan." Sacramento Bee, September 12, 1988.

"State A Big Culprit in Global Warming Trend, Report Says." Sacramento Bee, November 17, 1988.

"Stones Thrown at Greenhouse Theory." San Francisco Chronicle, August 20, 1988.

"Stratosphere Becoming a Hot Topic." Los Angeles Times, September 1, 1988.

"Sustainability: Conservation and Development in the Third World." Amicus Journal, Volume 5, No. 2, Fall 1983.

"Taking the World's Temperature." The Economist, July 9, 1988.

"The Politics of Climate." Electric Power Research Institute Journal.

"The Vanishing Jungle." The Economist, October 15, 1988.

"The Changing Atmosphere: Implications for Global Security," Conference Statement, Toronto, Ontario, Canada, July 27 1988.

"The Potential Effects of Global Climate Change on the United States." Draft Report to Congress by U.S. Environmental Protection Agency, 1988.

"The Hazards of Coal Dependence," Wallace Broecker, Natural History, October 1977.

"Trace Gases and Climatic Change," EPA Workshop on Global Atmospheric Change and EPA Planning, Final Report, EPA-600/9-86/016, July 1986.

"Transit Department Proposes Relaxed Gas Mileage for 1989-90 Cars." Los Angeles Times, August 27 1988.

"Treasuring Tropical Trees," The Economist, page 57, August 20 1988.

"Utility to Burn Coal--and Plant 52 Million Trees." San Francisco Chronicle, October 13 1988.

"Venus Was Like Earth, Scientists Think, Until It Boiled Under Blanket of Gas." Sacramento Bee, November 25 1988.

"Water and Power Use Set Records." Los Angeles Times, September 9 1988.

"What It's Like Living in the Greenhouse." Sacramento Bee, November 13 1988.

"What would the Greenhouse Effect do to Washington?" A scenario from the Tacoma News Tribune.

"Worst-Case Scenario Spells Disaster in Sierra, Valley." Sacramento Bee, November 25 1988.