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THE POTENTIAL EFFECTS OF GLOBAL CLIMATE CHANGE ON THE UNITED STATES

DRAFT

REPORT TO CONGRESS

Executive Summary

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United States Environmental Protection Agency

Office of Policy, Planning, and Evaluation

Office of Research and Development

October, 1988

DRAFT

EXECUTIVE SUMMARY

SCIENTIFIC THEORY SUGGESTS THAT THE ADDITION OF GREENHOUSE GASES TO THE ATMOSPHERE WILL ALTER THE GLOBAL CLIMATE. THE RESULT WILL BE INCREASING TEMPERATURES AND CONSEQUENT CHANGES IN RAINFALL AND OTHER WEATHER PATTERNS. BASED ON CLIMATE MODEL PREDICTIONS, THE NATIONAL ACADEMY OF SCIENCES ESTIMATED, IN 1979, THAT A DOUBLING OF CARBON DIOXIDE CONCENTRATIONS OVER PREINDUSTRIAL LEVELS WOULD CAUSE GLOBAL TEMPERATURES TO RISE 1.5 TO 4.5°C. IN 1985, THE WORLD METEOROLOGICAL ORGANIZATION (WMO), THE UNITED NATIONS ENVIRONMENT PROGRAMME (UNEP), AND THE INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS (ICSU) REAFFIRMED THESE ESTIMATES. SUCH A CLIMATE CHANGE WOULD HAVE SIGNIFICANT IMPLICATIONS FOR MAN AND THE ENVIRONMENT. AMONG OTHER EFFECTS, GLOBAL CLIMATE CHANGE WOULD RAISE SEA LEVELS, ALTER PATTERNS OF WATER AVAILABILITY, AND AFFECT AGRICULTURE AND GLOBAL ECOSYSTEMS.

TO HELP IDENTIFY THE EFFECTS OF SUCH A CLIMATE CHANGE, CONGRESS ASKED THE U.S. ENVIRONMENTAL PROTECTION AGENCY TO UNDERTAKE TWO STUDIES ON THE GREENHOUSE EFFECT. ONE OF THE STUDIES WOULD FOCUS ON "THE POTENTIAL HEALTH AND ENVIRONMENTAL EFFECTS OF CLIMATE CHANGE INCLUDING, BUT NOT BE LIMITED TO THE POTENTIAL IMPACTS ON AGRICULTURAL, FORESTS, WETLANDS, HUMAN HEALTH, RIVERS, LAKES, ESTUARIES AS WELL AS SOCIETAL IMPACTS." THE SECOND STUDY WOULD EXAMINE "POLICY OPTIONS THAT IF IMPLEMENTED WOULD STABILIZE CURRENT LEVELS OF GREENHOUSE GAS CONCENTRATIONS." THE SECOND STUDY IS A COMPANION REPORT TO THIS DOCUMENT.

IN ADDITION TO THESE REPORTS, THE FEDERAL GOVERNMENT IS CONDUCTING OTHER ACTIVITIES ON GLOBAL CLIMATE CHANGE. THE GLOBAL CLIMATE PROTECTION ACT OF 1987 CALLS FOR A SCIENTIFIC ASSESSMENT OF THE GREENHOUSE EFFECT WHICH IS TO BE COMPLETED BY 1989. THIS WORK WILL BE SPONSORED BY EPA AND OTHER FEDERAL AGENCIES SUCH AS NASA, NOAA, AND NSF. ALSO, DOE AND THE EPA HAVE BEEN REQUESTED TO REPORT TO CONGRESS ON POLICY OPTIONS FOR REDUCING CO_2 EMISSIONS IN THE U.S. IN ADDITION, VARIOUS FEDERAL AGENCIES CONDUCT SIGNIFICANT RESEARCH PROGRAMS ON CLIMATE. THESE RESEARCH EFFORTS ON CLIMATE CHANGE ARE COORDINATED BY THE NATIONAL CLIMATE PROGRAM OFFICE AND THE COMMITTEE ON EARTH SCIENCES. FINALLY, THE U.S. GOVERNMENT HAS STRONGLY SUPPORTED THE ESTABLISHMENT OF AN

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC) BY UNEP AND WMO. IT IS EXPECTED THAT IPCC WILL ESTABLISH A PROCESS FOR GOVERNMENTS TO FOLLOW IN REVIEWING SCIENTIFIC INFORMATION AND POLICY OPTIONS.

TO RESPOND TO THE CONGRESSIONAL REQUEST FOR A REPORT ON THE EFFECTS OF A GLOBAL WARMING, EPA HELD WORKSHOPS WITH ATMOSPHERIC SCIENTISTS TO DISCUSS HOW GLOBAL CLIMATE CHANGE MODELS SHOULD BE USED IN IMPACT ANALYSES AND WITH ECOLOGISTS, HYDROLOGISTS, AND FORESTRY AND AGRICULTURAL SPECIALISTS TO IDENTIFY TOPICS FOR THIS STUDY. A MAJOR PURPOSE WAS TO BRIDGE THE GAP IN OUR ABILITY TO RELATE A RISE IN AVERGE ANNUAL SURFACE TEMEPERATURES TO EFFECTS ON FORESTS, AGRICULTURE, AND OTHER RESOURCES. AS A RESULT OF THE WORKSHOP, EPA DECIDED TO TAKE OUTPUTS OF CLIMATE MODELS, COMPARE THE OUTPUT TO WHAT IS KNOWN ABOUT HISTORICAL CLIMATE PATTERNS, AND TO SELECT PLAUSIBLE SCENARIOS. BASED ON THESE AND OTHER DISCUSSIONS, EPA DECIDED TO USE COMMON SCENARIOS OF CLIMATE CHANGE TO ANALYZE THE POTENTIAL IMPACTS ON SEA LEVEL RISE, WATER RESOURCES, AGRICULTURE, FORESTS, BIODIVERSITY, HEALTH, AIR POLLUTION, AND ELECTRICITY DEMAND ON A REGIONAL AND NATIONAL SCALE (SEE FIGURE 1). THESE SYSTEMS WERE CHOSEN FOR ANALYSIS BECAUSE THEY ARE SENSITIVE TO CLIMATE AND SIGNIFICANTLY AFFECT OUR QUALITY OF LIFE. EPA DECIDED TO CONDUCT REGIONAL ANALYSES FOR THE SOUTHEAST, THE GREAT PLAINS, CALIFORNIA, AND THE GREAT LAKES. THESE REGIONS WERE CHOSEN BECAUSE OF THEIR CLIMATOLOGICAL, ECOLOGICAL, HYDROLOGICAL, AND ECONOMIC DIVERSITY. LEADING SCIENTISTS IN THE RELEVANT FIELDS ESTIMATED THE IMPACTS ON BOTH THE REGIONAL AND NATIONAL SCALES.

THIS REPORT USED REGIONAL DATA FROM ATMOSPHERIC MODELS KNOWN AS GENERAL CIRCULATION MODELS (GCMs) AS A BASIS FOR CLIMATE CHANGE SCENARIOS. THE GCMs ARE LARGE MODELS OF THE OCEAN-ATMOSPHERE SYSTEM THAT PROVIDE THE BEST SCIENTIFIC ESTIMATES OF THE IMPACTS OF INCREASED GREENHOUSE GAS CONCENTRATIONS ON CLIMATE. THE GCMs GENERALLY AGREE CONCERNING GENERAL GLOBAL AND LATITUDINAL INCREASES IN TEMPERATURE, BUT THEY DISAGREE CONCERNING OTHER AREAS SUCH AS THE LOCATION OF HYDROLOGICAL CHANGE. IN FIGURE 2, THE TEMPERATURE CHANGES FROM THREE DIFFERENT GCMs ARE SHOWN BOTH FOR THE UNITED STATES AND SEVERAL REGIONS. THESE RESULTS ARE ESTIMATES OF CHANGES CAUSED BY A DOUBLING OF CARBON DIOXIDE LEVELS. THE ESTIMATES SUGGEST GOOD AGREEMENT ON THE

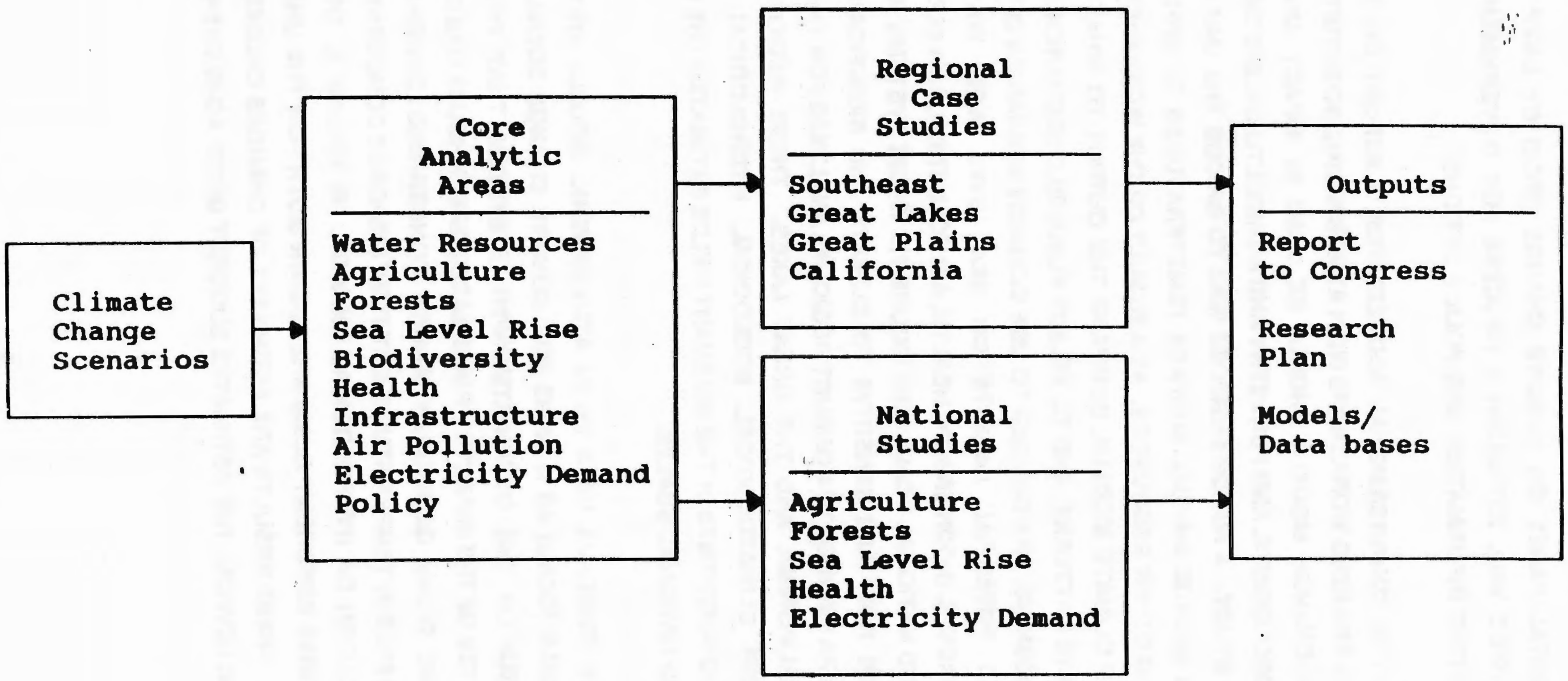
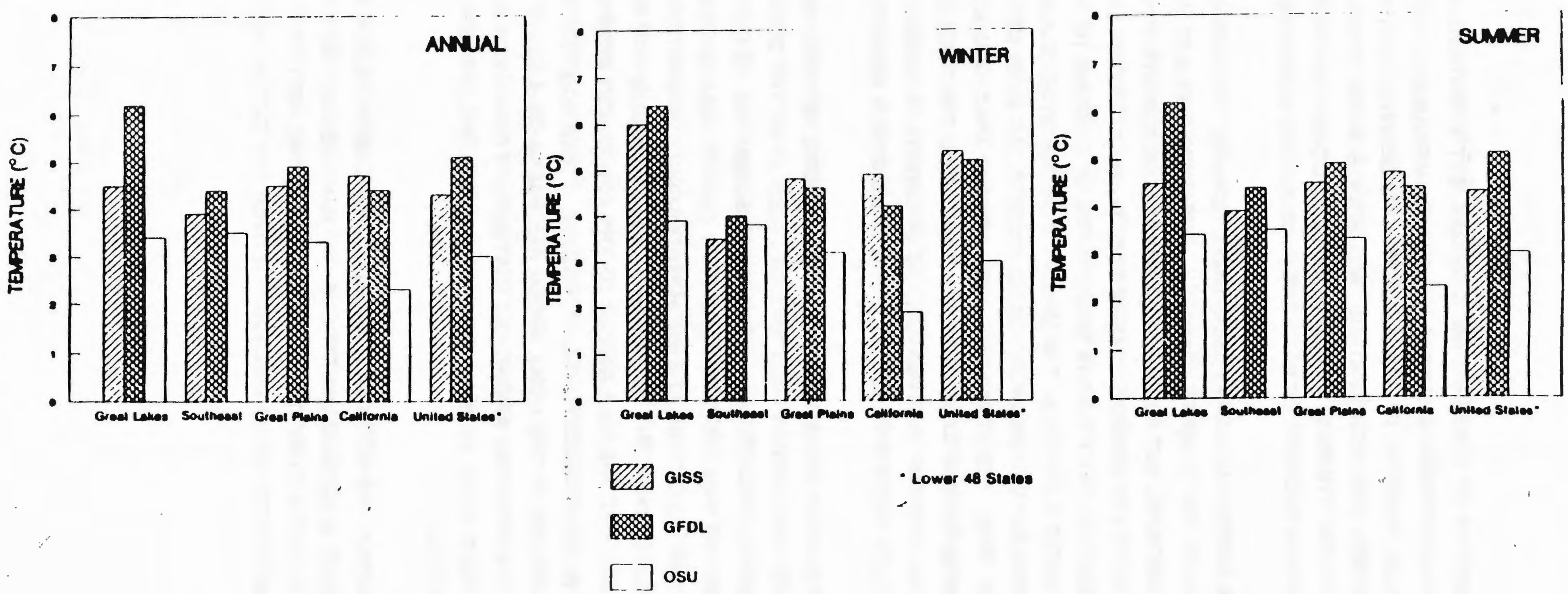


FIGURE 1. ELEMENTS OF EFFECTS REPORT

FIGURE 2. TEMPERATURE SCENARIOS

$2xCO_2$ less $1xCO_2$



DIRECTION OF TEMPERATURE CHANGES, BUT VARIATIONS IN THE MAGNITUDE. ESTIMATES OF PRECIPITATION CHANGES ARE SHOWN IN FIGURE 3. THE RESULTS INDICATE THAT MORE ANNUAL RAINFALL IS LIKELY ACROSS THE COUNTRY, BUT THAT REGIONAL AND SEASONAL CHANGES ARE LESS CERTAIN. ALL MODELS SHOW INCREASED EVAPORATION. THERE IS SCIENTIFIC EVIDENCE THAT THE WORLD IS COMMITTED TO BETWEEN 1 AND 2°C OF GLOBAL WARMING BECAUSE OF PAST GREENHOUSE GAS EMISSIONS.

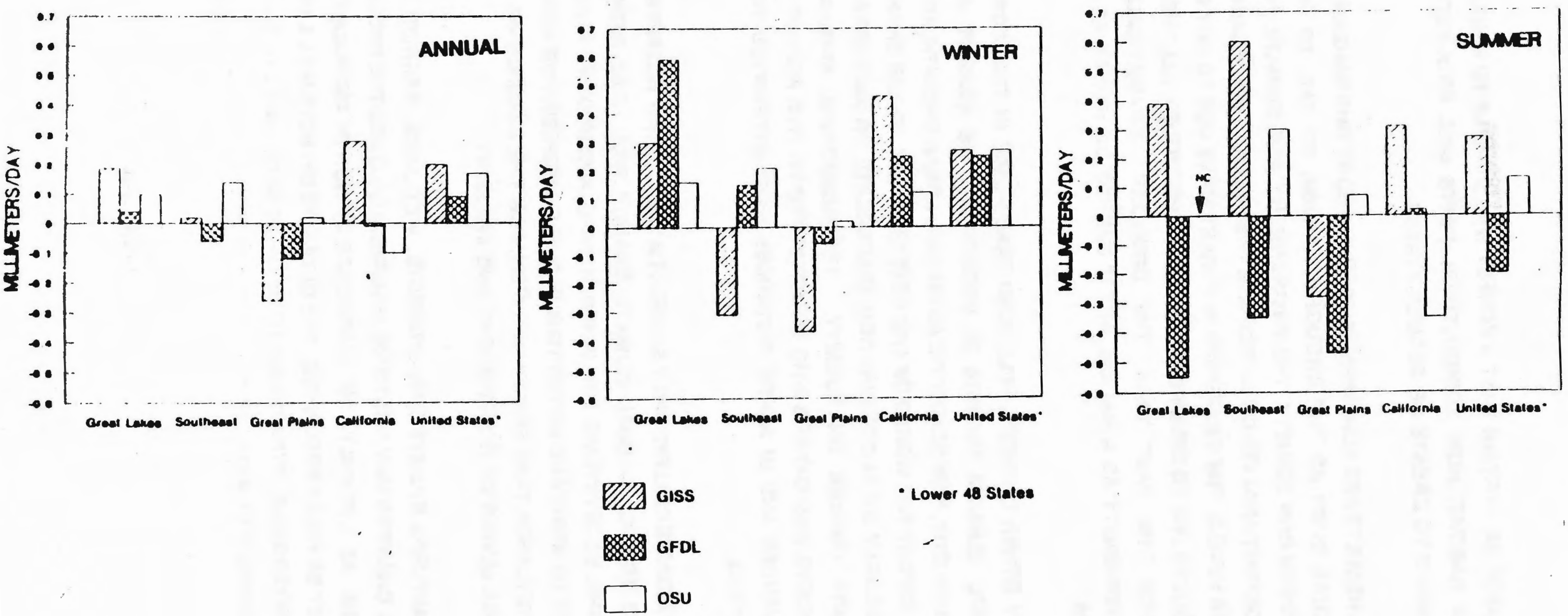
THIS REPORT USES DATA FROM THESE GCMs AS THE BASIS FOR ESTIMATING THE POTENTIAL IMPACTS OF CLIMATE CHANGE. THE GCM RESULTS ARE NOT CONSIDERED TO BE PREDICTIONS, BUT AS SCENARIOS OF FUTURE CLIMATE CHANGE. BECAUSE THE REGIONAL ESTIMATES OF CLIMATE CHANGE BY GCMs VARY CONSIDERABLY, THE SCENARIOS ARE USED TO IDENTIFY THE RELATIVE SENSITIVITIES OF SYSTEMS TO GLOBAL WARMING AND A RANGE OF POSSIBLE EFFECTS. THE MAJORITY OF OUR STUDIES ANALYZE SENSITIVITIES WHEN THE EQUIVALENT OF A DOUBLING OF CO_2 OCCURS, BUT SOME STUDIES ALSO LOOKED AT CHANGES OVER TIME. THE SCENARIOS ALSO ASSUME THAT VARIABILITY IN THE FUTURE WILL NOT CHANGE FROM RECENT DECADES. CHANGES IN THE FREQUENCY OF EVENTS SUCH AS HEAT WAVES, STORMS, HURRICANES, AND DROUGHTS IN VARIOUS REGIONS WOULD AFFECT THE RESULTS PRESENTED IN THIS REPORT AND COULD IMPROVE OR WORSEN THE EFFECTS.

HOW QUICKLY CLIMATE MAY CHANGE IS ELUSIVE, BECAUSE SCIENTISTS ARE UNCERTAIN BOTH ABOUT HOW RAPIDLY HEAT WILL BE TAKEN UP BY THE OCEANS AND ABOUT SOME CLIMATE FEEDBACK PROCESSES. GENERALLY SCIENTISTS ASSUME THAT CURRENT TRENDS IN EMISSIONS WILL CONTINUE AND THAT CLIMATE WILL CHANGE GRADUALLY OVER THE NEXT CENTURY, ALTHOUGH AT A MUCH FASTER PACE THAN HISTORICALLY. SOME SCIENTISTS HAVE INDICATED THAT THE IMPACT OF GLOBAL WARMING MAY BE FELT AS SOON AS THE NEXT DECADE, BUT THE FULL EFFECT OF THE EQUIVALENT DOUBLING OF CO_2 PROBABLY WOULD NOT BE EXPERIENCED UNTIL AFTER 2050. OTHER SCIENTISTS SUGGEST THAT THE CURRENT STRUCTURE OF THE GCMs, WHICH ARE BASED ON A SURPRISE-FREE OCEAN-ATMOSPHERE SYSTEM, COULD BE WRONG AND THAT ABRUPT CHANGES ARE POSSIBLE. INDEED, IF CLIMATE CHANGED MORE RAPIDLY THAN ESTIMATED, THE RESULTS WILL BE MORE DYNAMIC AND DRAMATIC.

SIMILARLY, THE METHODS USED TO ESTIMATE IMPACTS (FOR EXAMPLE, HOW FORESTS MIGHT CHANGE) ALSO HAVE LIMITATIONS. WE HAVE NO EXPERIENCE WITH THE RAPID WARMING OF 1.5 TO 4.5°C PROJECTED TO OCCUR DURING THE NEXT CENTURY. WE CANNOT SIMULATE IN A LABORATORY WHAT WILL HAPPEN OVER THE ENTIRE NORTH AMERICAN CONTINENT WE

FIGURE 3. PRECIPITATION SCENARIOS

$2xCO_2$ less $1xCO_2$



CANNOT BE CERTAIN THAT A FOREST WILL BE ABLE TO MIGRATE, WHETHER FISH WILL FIND NEW HABITAT, HOW AGRICULTURAL PESTS WILL PROLIFERATE, OR HOW IMPACTS WILL COMBINE TO CREATE OR REDUCE STRESS.

THE RESULTS ARE ALSO INHERENTLY LIMITED BY OUR IMAGINATIONS. UNTIL A SEVERE EVENT OCCURS SUCH AS THE DROUGHT OF 1988, WE FAIL TO RECOGNIZE THE CLOSE LINKS BETWEEN OUR SOCIETY, THE ENVIRONMENT, AND CLIMATE. FOR EXAMPLE, IN THIS REPORT WE DID NOT ANALYZE OR ANTICIPATE THE REDUCTIONS IN BARGE SHIPMENTS DUE TO LOWER RIVER LEVELS, THE INCREASES IN FOREST FIRES DUE TO DRY CONDITIONS, OR THE IMPACTS ON DUCKS DUE TO DISAPPEARING PRAIRIE POTHOLES; ALL THESE IMPACTS WERE MADE VIVID DURING THE PAST YEAR. THE DROUGHT DRAMATICALLY REMINDED US OF OUR VULNERABILITY AS A NATION, BUT IT CANNOT BE VIEWED AS A PREDICTION OF THINGS TO COME.

MANY OTHER CHANGES WILL ALSO TAKE PLACE IN THE WORLD AT THE SAME TIME THAT GLOBAL CLIMATE CHANGE IS OCCURRING. WE CANNOT ANTICIPATE HOW CHANGING TECHNOLOGY, NEW SCIENTIFIC ADVANCES, URBAN GROWTH, AND CHANGING DEMOGRAPHICS WILL AFFECT THE WORLD OF THE NEXT CENTURY. THESE CHANGES AND MANY OTHERS MAY SINGULARLY OR IN COMBINATION EXACERBATE OR AMELIORATE THE IMPACTS OF GLOBAL CLIMATE CHANGE ON SOCIETY. THE SCIENTISTS, ENGINEERS, ECONOMISTS, URBAN PLANNERS, AND OTHERS WHO CONTRIBUTED TO THIS REPORT RECOGNIZE SOME OF THESE INFLUENCES AND IN A FEW INSTANCES HAVE ATTEMPTED TO INCORPORATE THEM INTO ANALYSES.

THE FINDINGS COLLECTIVELY SUGGEST A WORLD THAT IS DIFFERENT FROM THE WORLD THAT EXISTS TODAY. GLOBAL CLIMATE CHANGE WILL HAVE SIGNIFICANT IMPLICATIONS FOR NATURAL ECOSYSTEMS; FOR WHEN, WHERE, AND HOW WE FARM; FOR THE AVAILABILITY OF WATER TO DRINK AND WATER TO RUN OUR FACTORIES; FOR HOW WE LIVE IN OUR CITIES; FOR THE WETLANDS THAT SPAWN OUR FISH; FOR THE BEACHES WE USE FOR RECREATION; AND FOR ALL LEVELS OF GOVERNMENT AND INDUSTRY.

FOR NATURAL ECOSYSTEMS (FORESTS, WETLANDS, BARRIER ISLANDS, NATIONAL PARKS) THESE CHANGES MAY CONTINUE FOR DECADES ONCE THE PROCESS OF CHANGE IS SET INTO MOTION. AS A RESULT, THE LANDSCAPE OF NORTH AMERICA WILL CHANGE IN WAYS THAT CANNOT BE FULLY PREDICTED. THE ULTIMATE EFFECTS WILL LAST FOR CENTURIES AND WILL BE IRREVERSIBLE. STRATEGIES TO REVERSE SUCH IMPACTS ON NATURAL ECOSYSTEMS ARE NOT CURRENTLY AVAILABLE.

OTHER SYSTEMS MAY SHOW CONSIDERABLE RESILIENCE. FOR EXAMPLE, SEA LEVEL RISE MAY PUT ADDITIONAL STRESSES ON COASTAL CITIES, AND CHANGES IN SEASONAL RAINFALL PATTERNS MAY REQUIRE NEW STRATEGIES FOR MANAGING WATER SUPPLY AND DEMAND; HOWEVER, THESE SYSTEMS CAN BE SUSTAINED BY TECHNOLOGY, IF WE HAVE ENOUGH FINANCIAL RESOURCES. WE WOULD EXPECT THAT BASIC REQUIREMENTS FOR FOOD AND WATER WILL BE MET IN THE UNITED STATES, AND THAT DEVELOPED AREAS WITH HIGH ECONOMIC VALUE WILL BE PROTECTED IN THE FUTURE FROM SEA LEVEL RISE. THE TOTAL COST OF ADAPTING TO GLOBAL CLIMATE CHANGE IS BEYOND THE SCOPE OF THIS REPORT.

IN MANY CASES, THE RESULTS FROM OUR ANALYSIS APPEAR TO BE CONSISTENT AND NOT DEPENDENT ON REGIONAL SCENARIOS, BECAUSE EITHER INCREASING TEMPERATURES OR HIGHER SEA LEVELS DOMINATE THE SYSTEMS THAT WERE STUDIED. IN OTHER CASES, ONLY A RANGE OF VALUES CAN BE PRESENTED BECAUSE UNCERTAINTIES IN A VARIABLE SUCH AS PRECIPITATION AFFECT THE OUTCOME.

THE MAIN FINDINGS AND POLICY IMPLICATIONS OF THIS REPORT ARE PRESENTED IN NATIONAL AND REGIONAL CHAPTERS. THEY ARE SUMMARIZED IN THE FOLLOWING PAGES, BUT THE READER IS URGED TO EXPLORE THE FULL REPORT TO UNDERSTAND THE COMPLETE CONTEXT OF THESE RESULTS.

ECOLOGICAL SYSTEMS

The location and composition of various plants and animals in the natural environment depends, to a great extent, on climate. Trees grow in certain areas and fish exist in streams and lakes because the local climate and other conditions are conducive to reproduction and growth. A major focus of this report was to identify what may happen to plants and animals; whether they would survive in their current locations or be able to migrate to new habitat; and how soon these ecosystems could be affected.

Natural Systems May Be Unable To Adapt Quickly To a Rapid Warming

If current trends continue, it is likely that climate may change too quickly for many natural systems to adapt. In the past, plants and animals adapted to historic climate changes over many centuries. For example, since the last ice age 18,000 years ago, oak trees migrated northward from the southeastern United States as the ice sheet receded. Temperatures warmed about 5°C (9°F) over thousands of years, but they rose slowly enough for forests to migrate at the same rate as climate change. In the future, the greenhouse effect may lead to similar changes in the magnitude of warming, but the changes may take place within a century. Climatic zones may shift hundreds of miles northward, but animals and especially plants may have difficulty migrating northward that quickly.

Forests

Forests occupy one-third of the land area of the United States. Temperature and precipitation ranges are primary determinants of forest distributions. Forests are also sensitive to soils, light intensity, air pollution, pests, disturbances such as fires, and management practices.

This report used several approaches to examine geographic shifts in forests. Potential ranges of forests were estimated for eastern North America using temperature and precipitation correlations from pollen data. Changes in composition and abundance of particular forests were estimated for particular sites in the Great Lakes and Southeast using site-specific models. These regions were chosen to represent a diversity of forest types and uses. Finally, the ability of trees to migrate to new habitat was analyzed using estimates of shifts in climate zones from GCMs and high estimates of the speed of tree migration. This study focused on several species that are widely dispersed across the northeastern United States. The direct effects of CO_2, which could change water use efficiency and the competitive balance between plants, was not modeled.

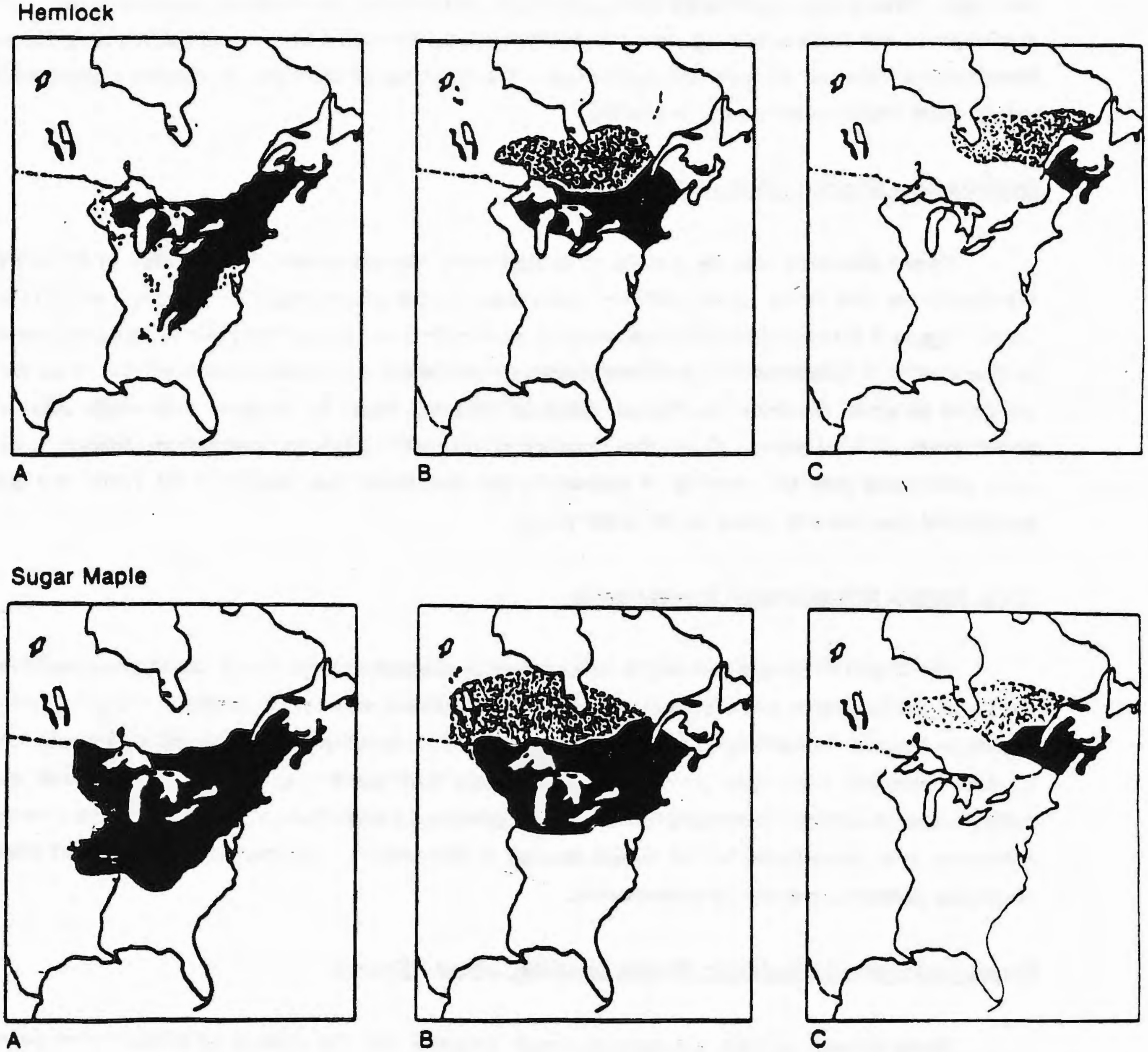
The Range of Trees May Be Reduced

Figure 4 shows, in black, the current geographic range of hemlock and sugar maple in the eastern United States. Climate change could move the southern boundary northward by 600-700 km (approximately 400 miles) for the scenarios studied. The potential northern range, indicated by the stippled area, could also move by the same amount. Historically, forests in this region have only migrated 100 km (60 miles) per century, a much slower rate. As a result, the actual ranges of forests are likely to be reduced for centuries because the southern boundary may advance more quickly than the northern boundary. If elevated CO_2 concentrations increase the water-use efficiency of tree species, the declines of the southern ranges could be partially alleviated.

Changes in Forest Composition Are Likely

Climate change may cause major changes in forest composition and significant reductions in the land area of healthy forests. Higher temperatures may reduce soil moisture levels in many parts of the country. Trees that need wetter soils may die, and their seedlings would have

FIGURE 4. SHIFTS IN RANGE OF HEMLOCK AND SUGAR MAPLE UNDER ALTERNATIVE CLIMATE SCENARIOS



Potential Range

Inhabited Range

A—Present Range

B—Range After 2050 Under GISS Scenario

C—Range After 2050 Under GFDL Scenario

Scale 0 400Km

Source: Zabinski and Davis.

difficulty surviving. A study of forests in northern Mississippi and northern Georgia indicated that seedlings in such areas would not grow because of the dry soil conditions. In central Michigan, forests now dominated by sugar maple and oak may be replaced by grasslands, with some sparse oak trees surviving. In northern Minnesota, the mixed boreal and northern hardwood forest would become all northern hardwood. The process of changes in species composition would most likely continue for centuries.

Declines May Begin in 30 to 80 Years

Forest declines may be visible in as little as a few decades. The studies of forests in the Southeast and Great Lakes indicate that these forests could begin to die back in 30 to 80 years. Figure 5 displays possible reduction in balsam fir trees in northern Minnesota and forests in Mississippi in response to two different scenarios of warming. These forests appear to be very sensitive to small changes in climate, because dieback starts to become noticeable after an approximate 1°C warming. Once this process starts, major dieback may occur rapidly. It has been estimated that the decline of forests in the Southeast may begin in 30 years and that substantial decline will occur in 60 to 80 years.

Other Factors Will Influence Forest Health

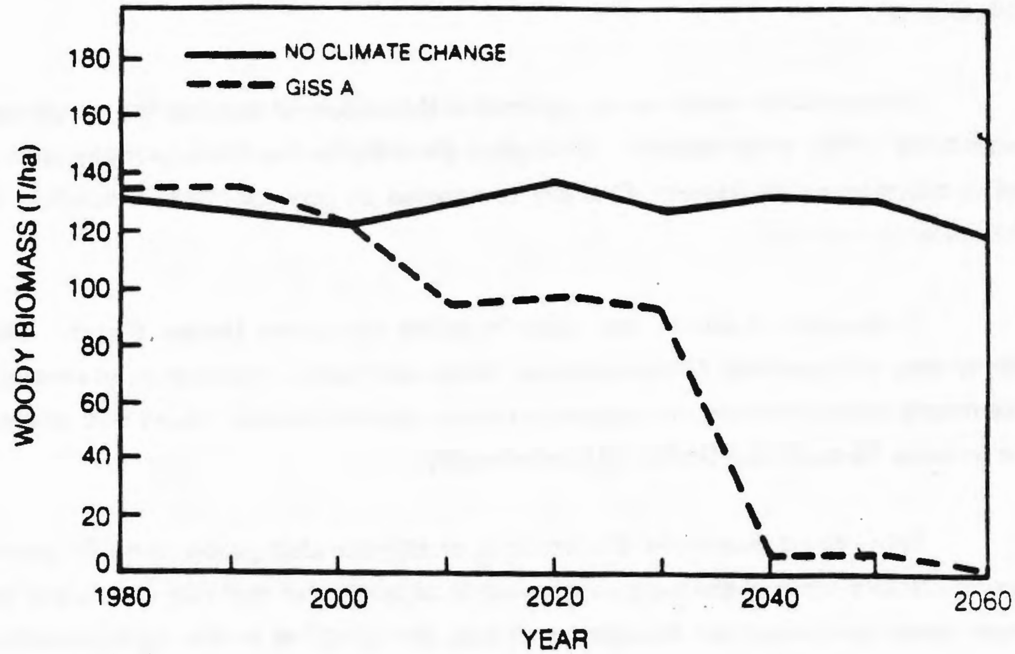
The health of forests will not be determined by climate change alone. Continued depletion of stratospheric ozone, the presence of tropospheric ozone, and acid deposition will place more stress on forests. In addition, the drier soils expected to accompany climate change could lead to more frequent fires, warmer climates may cause northward migration of forest pests, and pathogens and changes in oxidant formation could reduce the resilience of forests. None of these outcomes was considered by the forest studies in this report. The combined effects of these stressors cannot currently be determined.

Forest Management Decisions Should Consider Climate Change

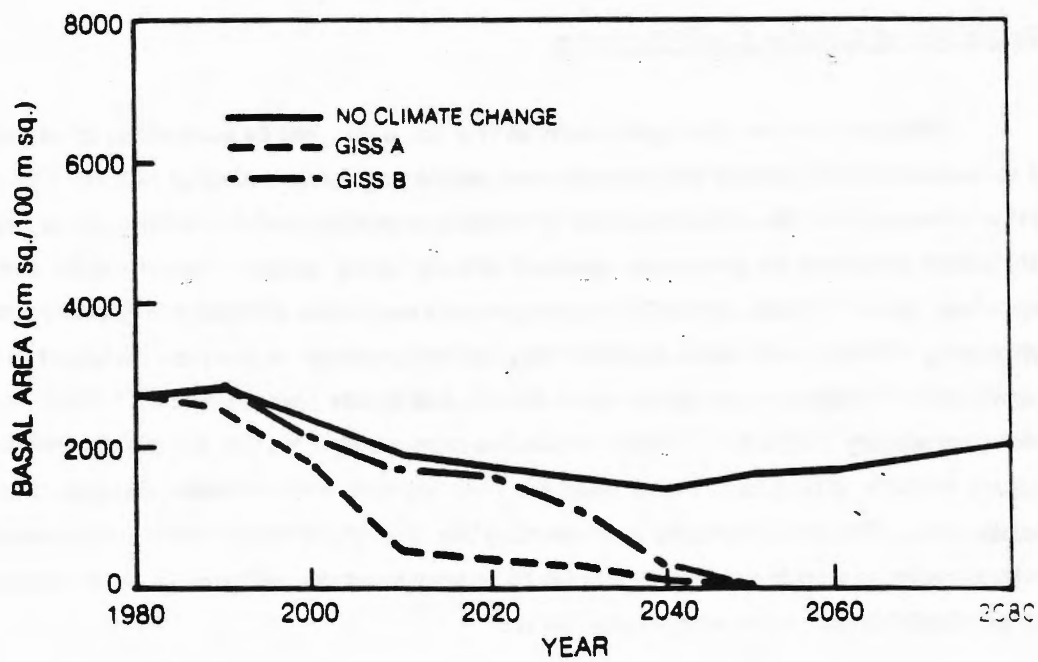
Since forests require decades to reach maturity and the effects of climate change on forests may become evident within a generation or more, public and private forest managers, such as the U.S. Forest Service and State Forest agencies, may wish to consider climate change in their long-term planning. For example, the Forest Service may need to begin considering how to include

FIGURE 5. FOREST DECLINES DUE TO TEMPERATURE INCREASES

MISSISSIPPI FORESTS



MINNESOTA BALSAM FIR



Source: Urban and Shugart; Botkin et al.

climate change as a factor in their 50-year plan. Additional options that forest agencies could consider are modifying restoration practices and developing new forest plantations on a large scale.

Biodiversity

Biological diversity can be defined as the variety of species in ecosystems, and the genetic variability within each species. Biological diversity is declining globally with an increasing rate of species loss. Biological diversity is needed to provide food, medicine, shelter, and other important products.

A diversity of plants and animals exists within the United States. Over 400 species of mammals, 460 reptiles, 660 freshwater fishes, and tens of thousands of invertebrate species can be found in this country, in addition to some 22,000 plants. About 650 species of birds reside in or pass through the United States annually.

This report examines the impacts of climate change on specific plants and animals by using climate change scenarios and models of particular regional species or systems. Analyses have been performed for impacts on finfish and shellfish in the Apalachicola Bay in the Florida panhandle, fish in the Great Lakes, and marine species in the San Francisco Bay. Additional information on potential impacts on biodiversity was gathered from the literature.

Extinction of Species Could Increase

Historic climate changes, such as the ice ages, led to extinction of many species. Thus, it is reasonable to expect the greenhouse effect to lead to a similar result. The differences from prior changes are the expected rate of climate warming and the influence of man, which absent an active program to preserve species, would likely cause a more rapid and greater loss of species. As with trees, other plants and animals may have difficulty migrating along with a rapidly changing climate, and many species may become extinct or may be reduced in population. The presence of urban areas, agricultural lands, and roads has restricted habitat areas and blocked many migratory pathways. These obstacles may make it harder for plants and wildlife to survive future climate changes. Some species may benefit from climate change due to increases in habitat size. The uncertainties surrounding the rate of warming, individual species response, and interspecies dynamics make it difficult to assess impacts, although natural ecosystems are likely to be destabilized in unpredictable ways.

Impacts on Fisheries Will Vary

Freshwater fish populations may experience growth in some areas and losses in others. Fish in some systems such as the Great Lakes may grow faster and may be able to migrate to new habitats. In addition, higher temperatures may lead to more algal blooms and longer stratification of lakes, which will deplete oxygen levels in shallow areas of the Great Lakes and make them less habitable for fish. Increased amounts of plankton, however, could provide more forage for fish. Fish in small lakes and streams may be unable to escape temperatures beyond their tolerances, or their habitat may simply disappear.

Warmer temperatures could exceed the thermal tolerance of many marine finfish and shellfish in some southern locations, although the full impacts on marine species are not known at this time. Many finfish and shellfish may be able to migrate northward along coastlines. The loss of coastal wetlands could lead to reduced populations of fish, especially shellfish. Increased salinity in estuaries could reduce the abundance of freshwater species and increase the presence of marine species.

Effects on Migratory Birds Will Depend on Impacts on Habitats

Migratory birds are likely to experience mixed effects from climate change, with some arctic-nesting herbivores benefiting and continental nesters and shorebirds suffering. The loss of wintering grounds resulting from sea level rise and changing climate could harm many species as would the loss of inland prairie potholes resulting from potentially increased midcontinental dryness.

Climate Change Should Be Considered in Preserving Wildlife and Protecting Endangered Species

Wildlife and fishery managers, such as the U.S. Department of Interior, may wish to consider climate change in refuge siting and to study establishing migratory corridors to enhance species' ability to migrate to new areas as climate changes occur.

Sea Level Rise

A rise in sea level is one of the most certain impacts of climate change. Higher global temperatures will likely lead to thermal expansion of the oceans and melting of glaciers. Published estimates of sea level rise generally range from 0.5 to 2.0 meters by 2100, although some estimates are higher. Rising sea level will drown many coastal wetlands, inundate coastal lowlands, increase coastal flooding, erode beaches, and increase salinity in estuaries.

This study estimates the potential nationwide loss of wetlands, and the cost of defending currently developed areas from a rising sea, for three scenarios (50, 100, and 200 cm) of sea level rise by the year 2100. Wetland loss estimates were based on remote sensing data and topographic maps for a systematic sample of 10% of the U.S. coast. The cost of holding back the sea was based on (1) the quantity of sand necessary to elevate beaches and coastal barrier islands as sea level rises; (2) rebuilding roads and elevating structures; and (3) constructing levees and bulkheads to protect developed lowlands along sheltered waters.

Protecting Developed Areas May Be Expensive

Given the high property values of developed coastlines, measures to hold back the sea would be justified along most developed shores. Preliminary estimates suggest that the cumulative capital cost of protecting currently developed areas would be $73 to 111 billion (in 1988 dollars) through 2100 for a 1-meter rise. Even with these costs, 7,000 square miles of dryland, an area the size of Massachusetts, could be lost (see Table 1).

Most Coastal Wetlands Would Be Lost

Historically, wetlands have kept pace with a slow rate of sea level rise. However, in the future, sea level will probably rise too fast for marshes and swamps to keep pace. Although some wetlands can survive by migrating inland, a study on coastal wetlands estimated that for a 1-meter rise, 26 to 66% of wetlands would be lost even if wetland migration is not blocked. A majority of the wetlands lost would be in the South (see Table 2). Efforts to protect coastal development would increase wetland losses, because bulkheads and levees would prevent new wetlands from forming inland. If all shorelines are protected, wetland losses would be 50 to 82%. The different amounts of dryland lost for different regions and scenarios are shown in Figure 6.

The ability of ecosystems to survive rising sea level will depend greatly on how shorelines are managed. For many species, the fraction of shorelines along which wetlands can be found is more important than the total area of wetlands; this fraction could remain at approximately today's level if people do not erect additional bulkheads and levees. In Louisiana, with 40% of U.S. coastal wetlands, large losses of wetlands are already occurring from relative sea level rise and most could be lost by 2030 if current trends continue. A major fraction of this

Table 1. Nationwide Impacts of Sea Level Rise

	50 cm	100 cm	200 cm
If Densely Developed Areas Are Protected			
Shore protection costs ($ billions)	32-43	73-111	169-309
Dryland lost (mi^2)	2,200-6,100	4,100-9,200	6,400-13,500
Wetlands lost (%)	20-45	29-69	33-80
If No Shores Are Protected			
Dryland lost (mi^2)	3,300-7,300	5,100-10,300	8,200-15,400
Wetlands lost (%)	17-43	26-66	29-76
If All Shores Are Protected			
Wetlands lost (%)	38-61	50-82	66-90

Source: Assembled by Titus and Greene.

Table 2. Loss of Coastal Wetlands for One-Meter Rise in Sea Level

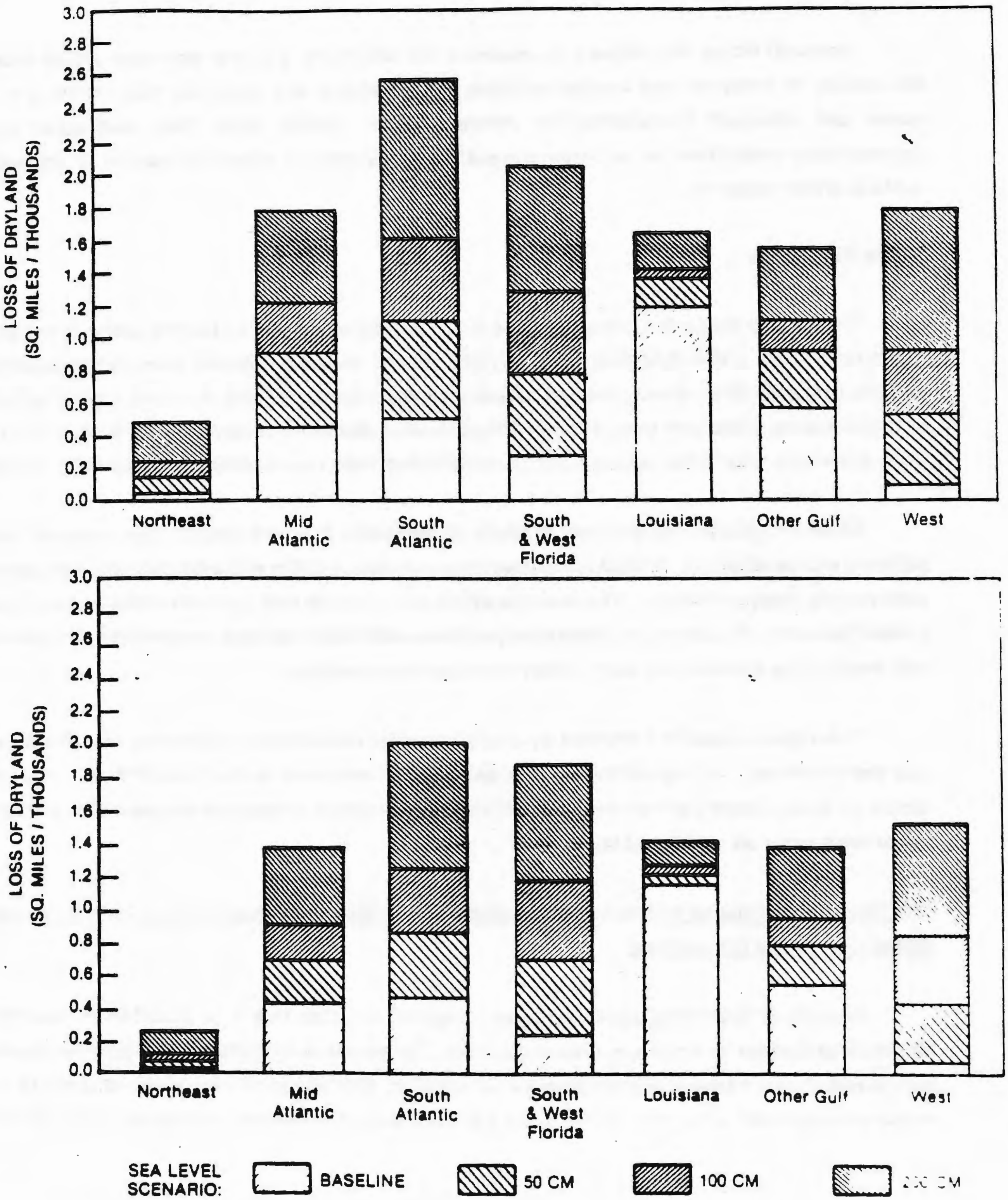
	Current Wetlands Area (mi²)	All Dryland Protected (%)	Current Development Protected (%)	No Protection (%)
Northeast	600	16	10	2
Mid-Atlantic	746	70	46	38
South Atlantic	3,813	64	44	39
S/W Florida	1,869	44	8	7
Louisiana*	4,835	77	77	77
Other Gulf	1,218	85	76	75
West	64	56	gain**	gain**
USA	13,145	50-82	29-69	26-66

*Louisiana projections do not consider potential benefits of restoring flow of sediment and freshwater.

**Potential gain in wetland acreage not shown because principal author suggested that no confidence could be attributed to those estimates. West coast sites constituted less than 0.5% of wetlands in study sample.

Source: Adapted from Park et al.

FIGURE 6. LOSS OF DRYLAND BY 2100 (A) IF NO SHORES ARE PROTECTED AND (B) IF DEVELOPED AREAS ARE PROTECTED FOR SEA LEVEL RISE



Source: Titus and Greene, adapted from Park et al.

ecosystem could survive a rapidly rising sea level if human activities would stop preventing the sediment from reaching the wetlands; this would also take several decades to accomplish.

Estuaries May Become More Saline

Although future riverflows into estuaries are uncertain, a rise in sea level would increase the salinity of estuaries and coastal aquifers. For example, sea level rise may result in a more saline and enlarged Sacramento-San Joaquin Delta. Miami, New York, and other coastal communities would have to increase current efforts to combat salinity increases in ground and surface water supplies.

Water Resources

The United States is endowed with a bountiful supply of water, but the water is not always in the right place at the right time or of the right quality. In some regions, such as the Great Basin and the Colorado River Basin, the gap between demand for water and available supply is narrow. In these basins, offstream uses such as irrigation and domestic consumption often conflict with each other and with other needs such as maintaining flow to preserve environmental quality.

Although global precipitation is likely to increase, it is not known how regional rainfall patterns will be affected. Annual rainfall levels could rise or fall in different regions, and seasonal patterns are likely to change. Whatever the effect, it is unlikely that current rainfall patterns would remain the same. Furthermore, higher temperatures will likely increase evaporation. The changes will create new stresses for many water management systems.

This report examined impacts by studying water resources in California, the Great Lakes, and the Southeast, and by estimating the demand for irrigation in the Great Plains. The report draws on these studies and on information from the literature to discuss the potential impacts on water resources on a national level.

The Direction of Change in Some Water Bodies Can Be Estimated, but Total Impacts in the United States Cannot Be Determined

Results of hydrology studies in some regions indicate that it is possible to specify the direction of change in water supplies and quality. For example, in California, higher temperatures would reduce the snowpack and cause earlier melting. Earlier runoff from mountains could upset water management systems. In the Great Lakes, reduced snowpack combined with potentially higher evaporation could lower lake levels. In other areas, such as the South, little snowcover currently exists, so riverflow and lake levels depend more on rainfall patterns. Without better rainfall estimates, we cannot determine whether riverflow and lake levels in the South would rise or fall.

Water Quality in Many Basins Could Change

Changes in water supply could significantly affect water quality. Where riverflow and lake levels decline, there will be less water to dilute pollutants. On the other hand, where there is more water, water quality may improve. Higher temperatures may enhance thermal stratification of lakes and increase algal production, degrading water quality. Changes in runoff and leaching from farms and potential increases in the use of irrigation for agriculture could affect surface and groundwater quality in many areas.

Water Use Conflicts May Increase

In some regions, decreased water availability and increased demand for water, such as for irrigation, may intensify conflicts among offstream uses, such as agricultural and urban uses. Conflicts between these offstream uses and instream uses such as flood control and wildlife habitat also may be intensified.

Water Resource Managers Should Consider Climate Change

Climate change may reduce the performance of many water management systems for flood control, water supply, and water quality protection that were designed based on historical climate and hydrologic conditions. Water resource managers should consider ways to improve the flexibility and efficiency of water management systems to handle climate change and variability. These include modifications to existing structures, coordinated regional operation of structures and systems, and incorporation of climate uncertainty in system planning. In addition, measures to reduce demand by improving the efficiency of water use should be considered. Lower demand improves the flexibility of systems to meet needs during low flow conditions. The possibility of reduced water quality in some areas should be considered by pollution control agencies as they develop long-range strategies.

Agriculture

The temperate climate and rich soils in the United States, especially in the Midwest, have made this country the world's leading agricultural producer. Agriculture, a critical component of the U.S. economy, contributed 17.5% the gross national product in 1985, with farm assets totaling $771 billion. Crop production is sensitive to climate, soils, management methods, and many other factors. During the Dust Bowl years of the 1930s, wheat and corn yields dropped by up to 50%, and during the drought of 1988, estimates of corn yields show a decline of about 37%. Global warming will likely affect agriculture directly through changes in the length of the growing season, the frequency of heat waves, and rainfall, and indirectly through changes in topsoil management.

The agriculture analyses in this report examined potential impacts on crop yields and productivity from changes in climate and direct effects of CO_2. (Higher CO_2 concentrations may increase plant growth and increase water use efficiency.) Corn, wheat, and soybean yields, and irrigation demand changes were estimated for the Southeast, Great Plains, and Great Lakes regions using widely validated crop growth models. In addition, crop yield changes were estimated for California using a simple agroclimatic index. Changes in yields of specialty crops such as citrus were not examined. The impacts of more rapid weed growth caused by higher CO_2 concentrations also were not examined.

The estimated yield and irrigation changes from the crop modeling studies were used in a nationwide agricultural economic model to estimate regional and national changes in crop production, land use, and demand for irrigation. The model did not consider changes in Government policies on agriculture and assumed that demand for U.S. crop exports did not change. Both a modeling study and a literature review were used to estimate changes in plant-pest interactions. An agricultural runoff and leaching model was used to estimate potential changes in water quality in the Great Plains. Some farm level adjustments were investigated in various studies, including the effects of improved agricultural technology. Potential national implications on livestock were analyzed using modeling studies and a literature review.

The Combined Effects of Climate and CO_2 Are Uncertain

In most regions of the country, climate change alone could reduce site to site dryland yields of corn, wheat, and soybeans, with losses ranging from negligible amounts to 80%. These decreases are primarily the result of higher temperatures, which shorten a crop's life cycle. In very northern areas, such as Minnesota, dryland yields of corn and soybeans could double as warmer temperatures extend the frost-free growing season. The combined effects of climate change and CO_2 resulted in net increases in yields in some cases, especially in northern areas or areas where rainfall is abundant. In southern areas, however, where heat stress is already a problem, and in cases where there were reductions in rainfall, crop yields declined.

<u>On a National Scale, the Supply of Agricultural Commodities Does Not Appear To Be Threatened by Climate Change</u>

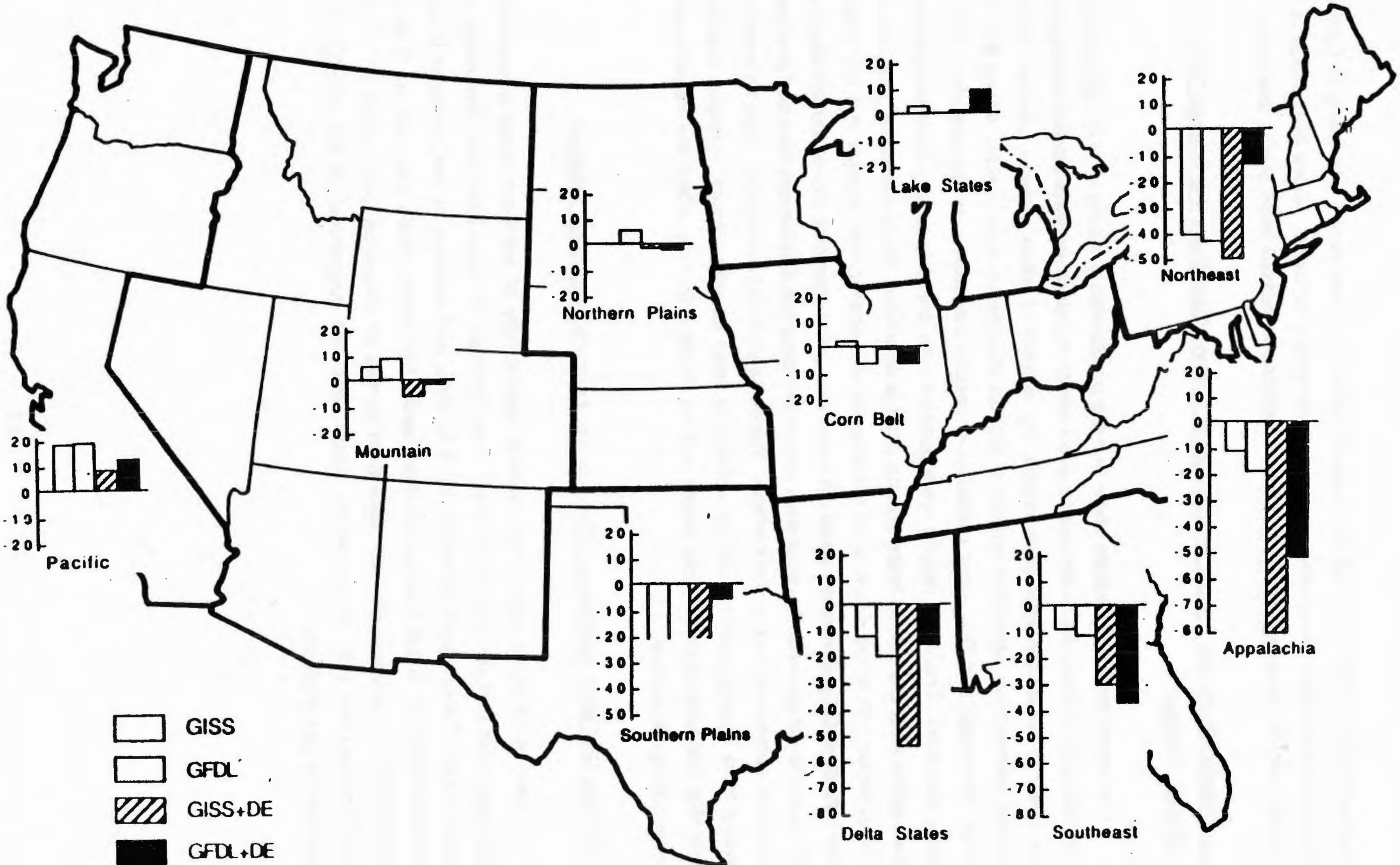
Economic modeling results show that the production capacity of U.S. agriculture appears to be adequate to meet domestic needs, even under the more extreme climate change scenarios. Only small to moderate economic losses are estimated when climate change scenarios are modeled without the beneficial effects of carbon dioxide on crop yields. When the combined effects of climate and CO_2 were considered, results depended on the severity of the climate change scenario. Economic results were positive with the less severe climate change scenario and negative with the hotter, drier climate change scenario. Thus, the severity of the economic consequences will likely depend on the degree of warming that occurs and the ability of the direct effects of CO_2 to enhance yields. If crop production declines, the reduction may negatively affect exports. In general, the economic model showed that consumers lose and producers gain because of somewhat higher food prices. Technological improvements, such as improved crop varieties from bioengineering, will be needed to keep up with climate change. Continued and substantial improvements in crop yields will be needed to fully offset the negative effects, if climate change is severe.

<u>Productivity May Shift Northward, Affecting the Economies of Many Regions</u>

Under all of these cases, the relative productivity of northern areas generally rose in comparison with that of southern areas. Crop acreage in Appalachia, the Southeast, and the southern Great Plains could decrease by 5 to 25%, and acreage in the northern Great Lakes States, the northern Great Plains, and the Pacific Northwest could increase by 5 to 17%. A northward shift in productivity was consistent across all scenarios (see Figure 7). Changes in foreign demand for U.S. crops, which could alter the magnitude of the results, were not considered in this analysis.

FIGURE 7.

REGIONAL AGRICULTURAL LAND USE CHANGE
(PERCENTAGE OF CHANGE)



DE = Direct Effect of CO_2

Source: Adams et al.

Farmers Would Likely Change Many of Their Practices

Farm practices will likely change in response to different climatic conditions. Most significantly, in many regions, the demand for irrigation is likely to increase, because (1) irrigated yields would be more stable than dry land yields under conditions of increased heat stress; and (2) if national productivity is reduced, crop prices may rise, making irrigation more economical (see Figure 8). Irrigation equipment may be installed in many areas that are currently dry land farms, and farmers already irrigating may extract more water from surface and groundwater sources. Farmers may also switch to more heat- and drought-resistant crop varieties, plant two crops during a growing season, and plant and harvest earlier. Whether these adjustments would compensate for climate change depends on a number of factors including the severity of the climate change.

The Range of Agricultural Pests May Extend Northward

A northward extension of crop pest ranges and increased pest populations may reduce yields and affect livestock. Climate change could cause increased heat stress for livestock, although cold stress would be reduced. Warmer temperatures may result in northward extension of the range of diseases and pests that now afflict livestock in the South, and could make conditions more favorable for introduction of new livestock diseases into the southern United States.

Shifts in Agriculture May Cause Environmental Changes

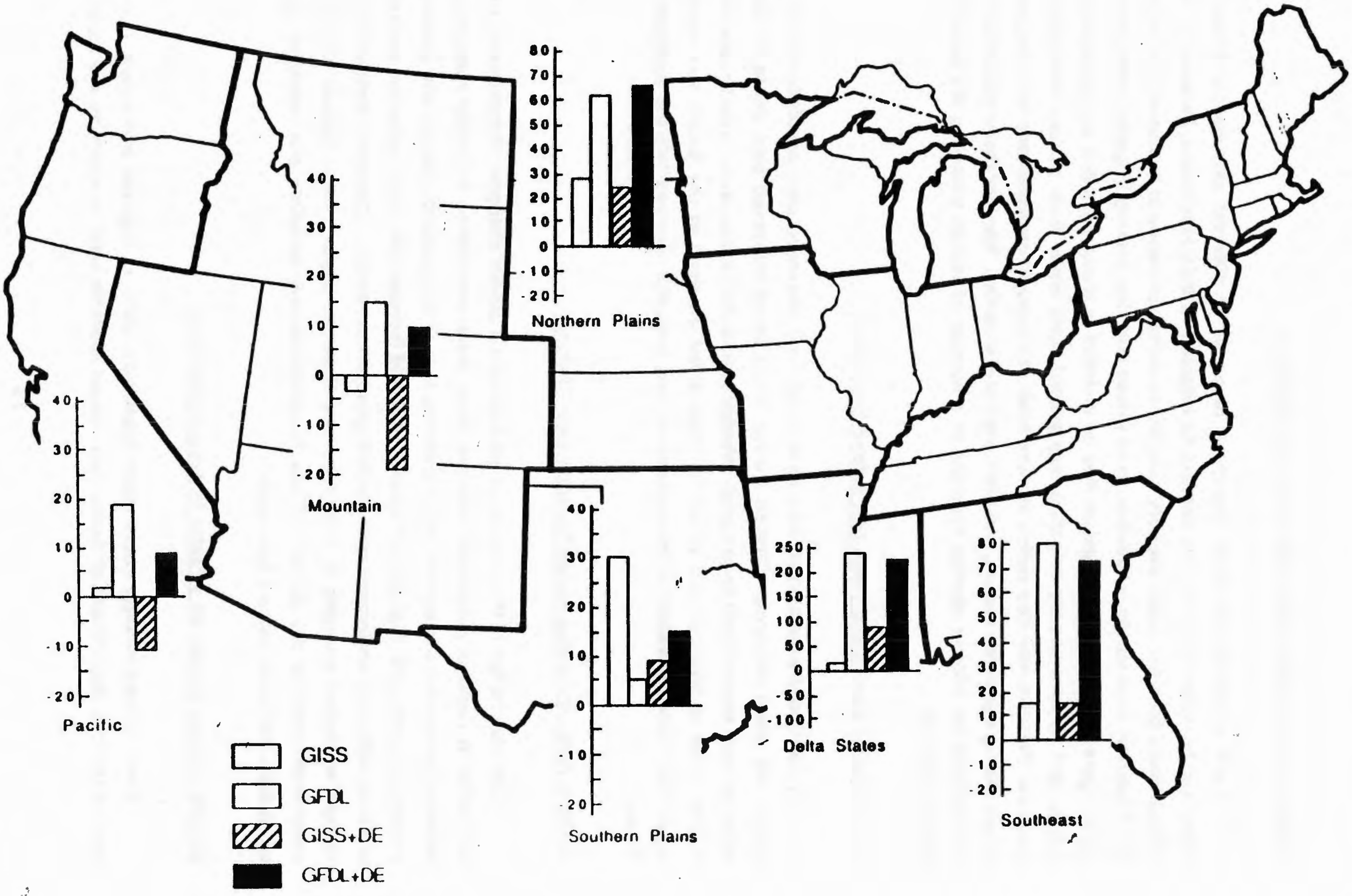
Climate change is likely to cause environmental quality changes. Expansion of irrigation and shifts in regional production patterns imply more competition for water resources, great potential for ground and surface water pollution, loss of some wildlife habitat, and increased soil erosion. A northward migration of agriculture would increase the use of irrigation and fertilizers on sandy soils, thus endangering underlying groundwater quality. Chemical pesticide usage may change to control changes in both crop and livestock pests. Thus, climate change could exacerbate many of the current trends in environmental pollution and resource use from agriculture and could initiate new ones.

Climate Change Should Be a Factor in Agriculture Policy

Since climate change could cause significant shifts in regional agriculture, institutions such as the U.S. Department of Agriculture should consider ways to minimize any adverse

FIGURE 8.

REGIONAL IRRIGATED ACREAGE CHANGE
(MILLIONS OF ACRES)



DE = Direct Effect of CO_2

Source: Adams et al.

impacts and facilitate adjustments to those shifts. Current agricultural policies and laws should be examined to assess the flexibility of agriculture to adapt to global warming by shifting the types of crops and locations of farming, while reducing soil erosion and maintaining water quality over the time period of global warming. Furthermore, agencies such as the U.S. Department of Agriculture, the Department of Commerce, the State Department, and the U.S. Trade Representative, may wish to consider the implications of potential long-term changes in crop production on the level of U.S. exports and for the U.S. balance of trade. Current USDA research on heat- and drought-resistant crops and practices should be sustained to limit vulnerability to climate change.

Electricity Demand

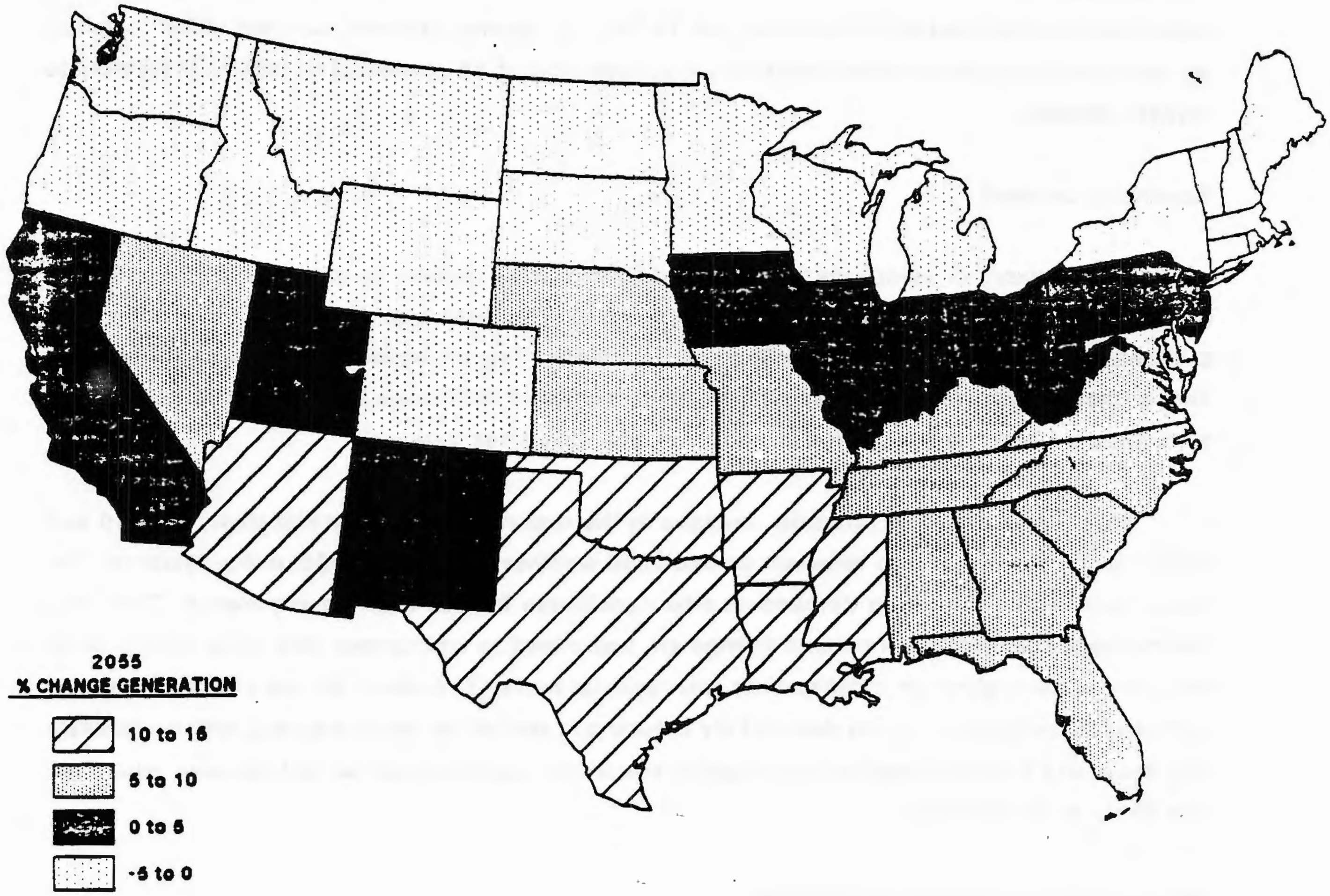
The demand for electricity is influenced by economic growth, by changes in industrial and residential/commercial technologies, and by weather. The principal climate-sensitive electricity end uses are space heating and cooling and, to a lesser degree, water heating and refrigeration. These uses of electricity may account for up to a third of total sales for some utilities and may contribute an even larger portion of seasonal and daily peak demands.

This report analyzed potential changes in the national demand for electricity in 2010 and 2055, using the relationship between demand and weather for several major utility systems. The study estimated changes in demand due to nonclimate factors such as population, GNP, and technology. The impacts of climate change are expressed as an increase over base case growth, and results were given on a nationwide and regional basis. The study did not consider impacts of higher temperatures on the demand for natural gas and oil for home heating, which will likely decrease, and it did not estimate changes in electricity supplies such as hydropower, which are also likely to be affected.

National Electricity Demand Will Rise

Global warming would cause an increase in the demand for electricity and generating capacity requirements in the United States. The demand for electricity for summer cooling would increase, and the demand for electricity for winter heating would decrease; annual electricity generation in 2055 was estimated under the scenarios to be 4 to 6% greater than without climate change. The annual costs of meeting this demand would be $33-73 billion (in 1986 dollars). These results differ on a regional basis and are shown in Figure 9. States along the northern tier of the United States might have net reductions in annual demand of up to 5%. Decreased heating demand would exceed increased demand for air-conditioning. In the

FIGURE 9.
CHANGES IN ELECTRICITY GENERATION BY STATE INDUCED BY CLIMATE CHANGE TO 2055



Source: Linder and Inglis.

South, where heating needs are already low, net demand was estimated to rise by 7 to 11% by 2055.

More Power Plants Will Be Needed To Meet Peak Demands

Generating capacity is determined by peak demand, which occurs in the summer in most areas of the country. By 2010, generating requirements to meet increased demand could rise by 25 to 55 gigawatts (GW) or by 9 to 19% above new capacity requirements, assuming no climate change. By 2055, generating requirements could be up by 200 to 400 GW or 14 to 23% above non-climate-related growth. The cumulative cost of such an increase in capacity would be between $175 and 325 billion. The South would have a greater need than the North for additional capacity, as shown in Figure 10. Additional capacity requirements would range from 0 to 10% in the North to 20 to 30% in the South and Southwest. U.S. emissions of greenhouse gases such as CO_2 could increase substantially if these powerplants are built, and especially if they burn coal.

Utility Planners Should Consider the Possibility of Increased Demand Resulting From Climate Change

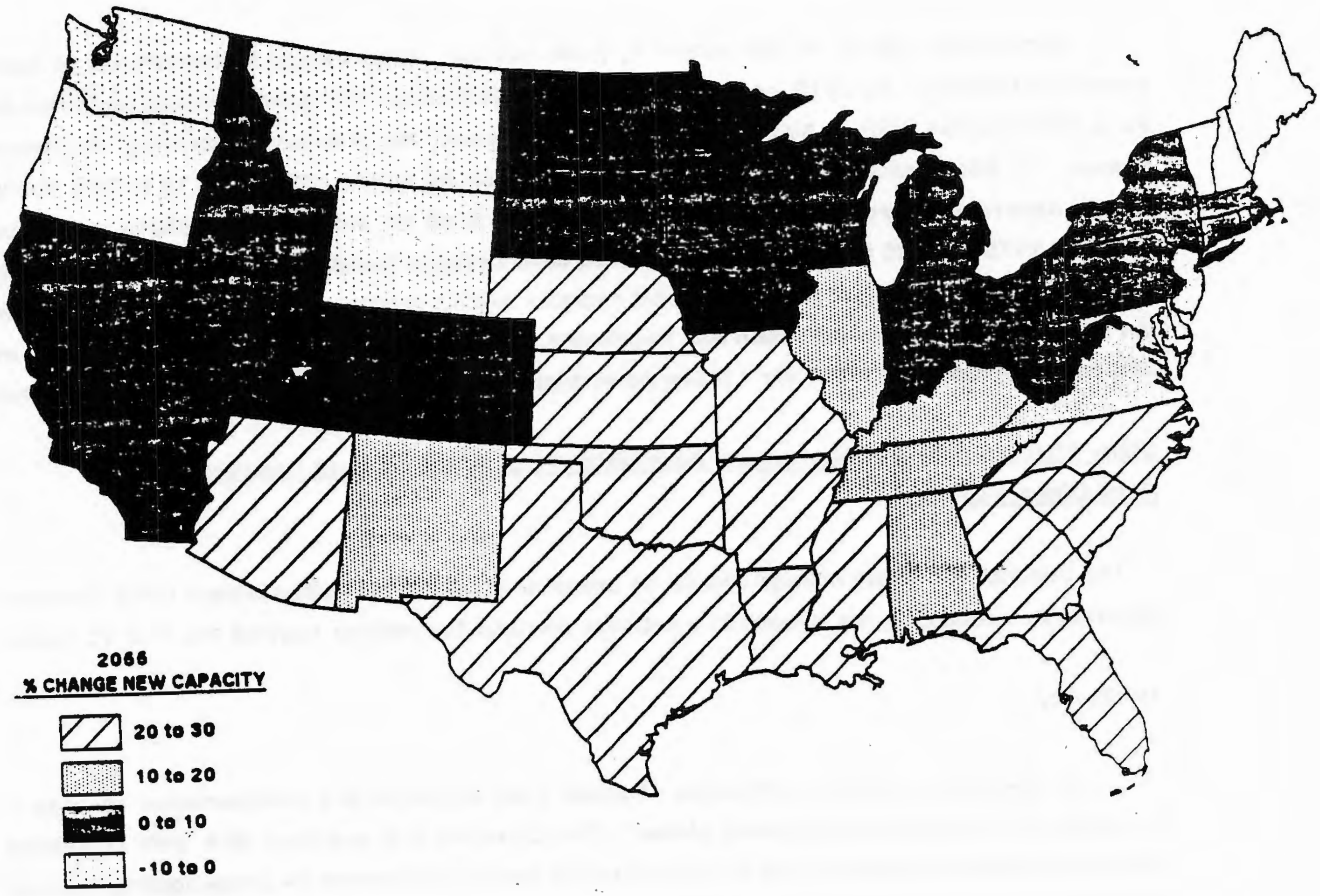
The impacts of climate change should be considered, along with other factors utility planners address, in forecasting the growth in electricity demand for periods beyond the next 20 years.

Air Quality

Air pollution caused by emissions of gases from industrial and transportation sources is a subject of concern in the United States. The Clean Air Act provides EPA with regulatory authority to reduce emissions and to protect public health and welfare by promulgating National Ambient Air Quality Standards (NAAQS). Over the last 10 years, considerable progress has been made in improving air quality by reducing emissions. But air quality is also directly affected by weather variables such as windspeed and direction, temperature, precipitation patterns, cloud cover, atmospheric water vapor, and global circulation patterns. A literature review of the relationship between climate and air pollution was conducted for this report. In addition, air quality models were used to conduct preliminary analyses of the changes in ozone levels in several regions.

FIGURE 10.

CHANGES IN ELECTRIC UTILITY CAPACITY ADDITIONS BY STATE INDUCED BY CLIMATE CHANGE IN 2055



Source: Linder and Inglis.

Climate Changes Will Increase Air Pollution in the Future, but the Severity of the Impacts is Uncertain

Global temperature increases would increase manmade and natural emissions of hydrocarbons and manmade emissions of sulfur and nitrogen oxides. Natural emissions of sulfur would also change, but the direction is uncertain. Because no estimate of the impact of temperature on future emissions exists, the potential magnitude of the impacts on air quality is uncertain.

Global temperature increases would speed the reaction rates among chemical species in the atmosphere, causing increased ozone pollution in many urban areas. It would also increase the length of the summer season, usually a time of high air pollution levels. Preliminary analyses, shown in Figure 11, of a 4°C temperature increase in the San Francisco Bay area suggest that ozone concentrations would increase 20% and that the area in exceedence of the NAAQS would almost double, even if emissions did not increase from present levels. Studies of the Southeast also show changes in areas, but they show smaller changes in levels. Analyses of the impacts on acid rain were not conducted, but it is likely that increased temperatures would cause sulfur and nitrogen to oxidize more rapidly. The ultimate effect on acid deposition is difficult to assess because changes in clouds, winds, and precipitation patterns are uncertain.

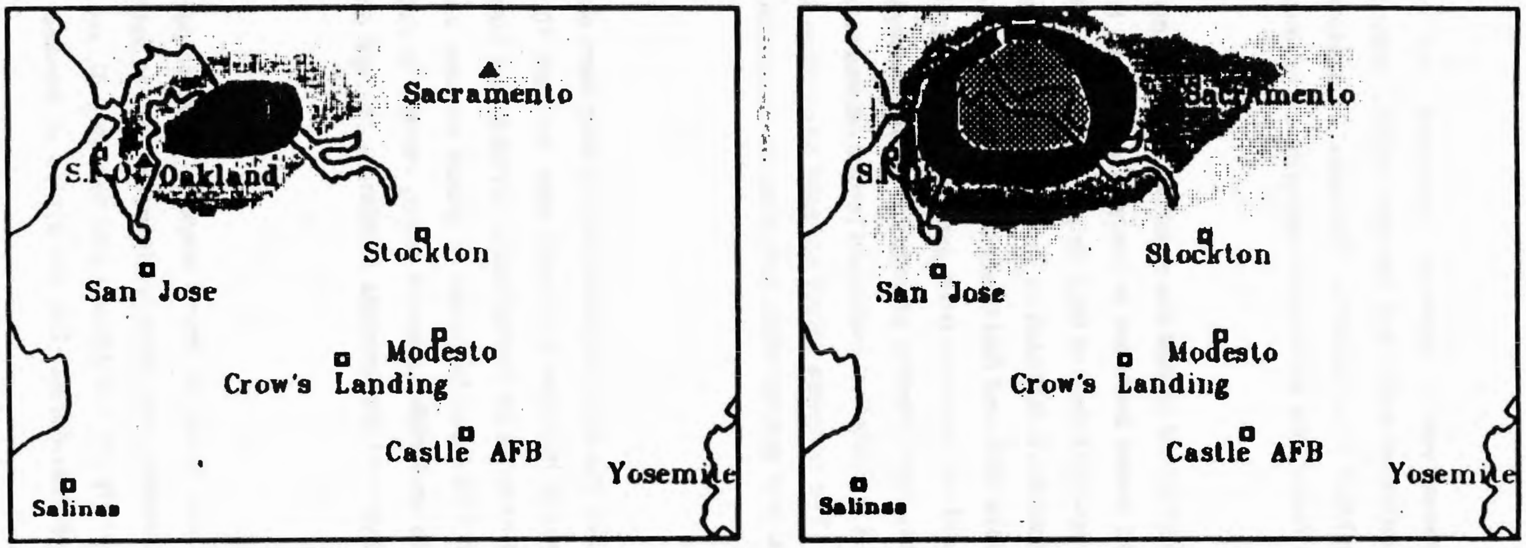
Policy Implications

Global climate change will have important implications for long-term air pollution problems in the United States. Current actions to improve air quality over the next 10 to 20 years through State Implementation Plans do not need to be immediately revised, but long-term strategies to reduce ozone and acid rain levels may need to factor in global climate change in the future. Agencies such as EPA may need to undertake a broad policy review to assess the impacts of current air policies on climate change and the impacts of climate change on air policies.

Health Effects

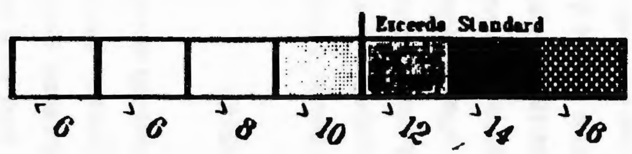
Human illness and mortality are linked in many ways to weather patterns. Contagious diseases such as influenza and pneumonia, and allergic diseases such as asthma, are influenced by weather. Mortality rates, particularly for the elderly and the very ill, are influenced by the frequency and severity of extreme temperatures. The life cycles of disease-

FIGURE 11. CHANGES IN MAXIMUM OZONE DAILY OZONE CONCENTRATIONS IN CALIFORNIA



August 6, 1981

4°C Temperature Increase



Source: Morris et al.

carrying insects, such as mosquitoes and ticks, are affected by changes in temperature and rainfall, as well as by habitat, which is itself sensitive to climate. Finally, air pollution, which is related to weather patterns, can increase the incidence and severity of respiratory diseases such as emphysema and asthma.

Both expert judgment and modeling were used to study the potential impacts of climate change on human health. A literature review and workshop were conducted to identify potential changes in vector-borne diseases caused by ticks, fleas, and mosquitoes (such as dengue and malaria). Models were used to estimate potential geographic shifts in the prevalence of Rocky Mountain spotted fever and malaria. Potential changes in mortality from heat and cold stress were quantitatively estimated, although such estimates did not consider the combined effect of changes in air pollution. The total impacts of climate change on human health are difficult to assess; these analyses only looked at a limited number of potential effects and are only indicative of possible changes in mortality and morbidity.

Summer Mortality Could Increase

Global warming may lead to changes in morbidity and increases in mortality, particularly for the elderly during the summers. These effects may be more pronounced in some regions than in others, with the North and the Midwest more susceptible to higher temperature episodes than the South. There may be offsetting decreases in morbidity and mortality because of milder winters, although net mortality may increase. An increase in the frequency or intensity of climate extremes is likely to be associated with an increase in mortality. If people acclimatize by using air-conditioning, changing workplace habits, and altering the construction of homes and cities, the impact on summer mortality rates may be substantially reduced.

The relationship between pollution episodes and weather events on mortality is unknown. Further investigations currently under way may provide additional insights into these causes of death.

Regional Morbidity Patterns Could Change

The regional prevalence of vector-borne diseases could change. This would be the result of changes in climate as well as in habitat. For example, some forests may become grasslands, thereby modifying the incidence of vector-borne diseases. Changes in summer rainfall could alter the amount of ragweed growing on cultivated land. Changes in humidity may change the incidence and severity of skin infections and infestations such as ringworm, candidiasis and scabies. Increases in the persistence and level of air pollution episodes associated with climate change will have other adverse health effects.

A Strong Health Research and Public Health System Must Be Preserved

More research is needed on the potential effects of climate change on human health. Global climate change will create new challenges for public health over the next century, which should be analyzed in detail by the health community. A strong research base, coupled with a vigorous public health system capable of monitoring and responding to new health threats, may be necessary to anticipate climate change.

REGIONAL IMPACTS

Studying the national impacts of climate change may disguise important regional effects. The effects of climate change will be quite different across the country. Furthermore, changes in one system such as water supply may affect other systems such as irrigation for agriculture. Shifting demands for economic and natural resources may cause stresses that cannot be seen at a national level. These combined effects may be most evident on a regional scale, some of which are discussed below. The design of regional studies on agriculture, forests, and electricity were described above.

The regional studies discussed below only track the surface of the potential impacts on a regional scale. Many potential impacts were not considered, for example demographic shifts into or out of the Southeast, recreational impacts in the Great Lakes, direct effects on aquifers such as the Ogallala in the Great Plains, and many specialty crops in California. The discussion that follows should not be viewed as comprehensive, but rather as examples of important issues for each region.

California

California contains a highly managed water resource system and one of the most productive agricultural regions of its size in the world. The State produces 10% of the nation's cash receipts for agriculture. California's water resources are poorly distributed with relation to needs. Rainfall is abundant in the north, with the highest levels in the winter, and water is needed in the south for agriculture and domestic consumption. The Central Valley Project (CVP) and State Water Project (SWP) were built basically to capture runoff from the north and deliver it to uses in the south. These projects also provide flood protection, hydroelectric power, and freshwater flows to repel salinity in the Sacramento-San Joaquin River Delta (known as carriage water). Islands in the delta are highly productive farmlands and are protected by levees.

The California case study focused on the Central Valley. Runoff in the valley was quantitatively estimated. These results were then used to estimate changes in the performance of the CVP and SWP. Sea level rise estimates were used to model how the salinity and shape of the San Francisco Bay estuary may change and how the demand for carriage water may be affected. The estimated changes in salinity and sea level rise were used to examine impacts on wetlands and fish in the bay. Changes in ozone levels in central California were also quantitatively derived, as were changes in electricity demand (see Figure 12).

Water Management in California Will Face Sizable Challenges

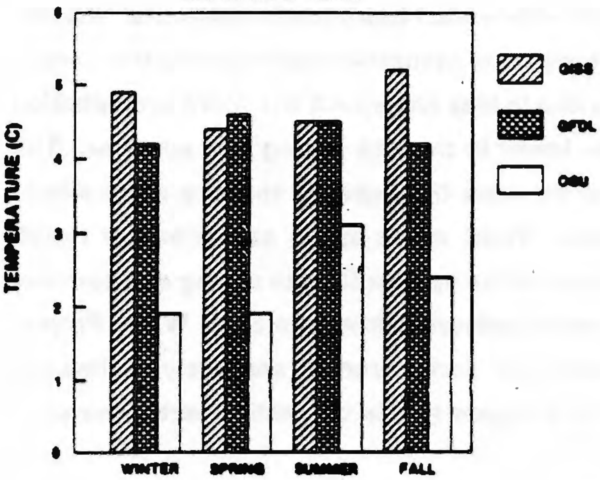
Climate change may lead to particular problems with water resources in California. Warmer temperatures would change the seasonality of runoff from the mountains surrounding the Central Valley. Runoff would be higher in the winter months due to less snowpack and more precipitation in the form of rain. Consequently, runoff would be lower in the late spring and summer. The current reservoir system in the Central Valley does not have the capacity to store more winter runoff and to still provide adequate flood protection. Thus, much of the earlier winter runoff would have to be released. This would leave less water in the system for late spring and summer deliveries, when runoff would be lower. Annual water deliveries from the State Water Project would decrease by 7 to 16%. Reduced snowpack and earlier runoff are likely to happen throughout the West, affecting water management in a region that is currently short of water.

Climate Change Is Likely To Increase Water Demand

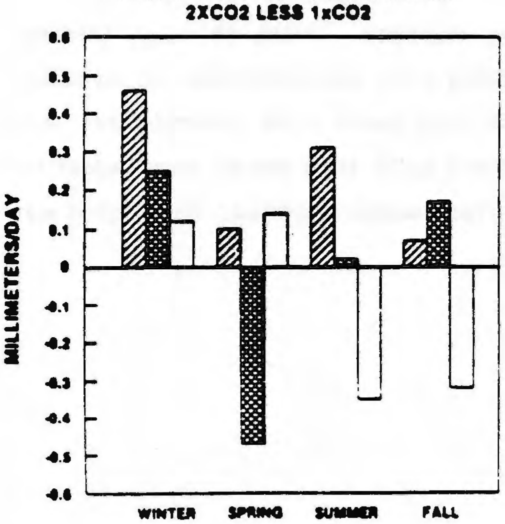
On the whole, California's water demand could also increase. Twice as much carriage water may be needed to repel higher salinity levels resulting from sea level rise. In addition, consumptive uses may also rise slightly. Irrigation, which may come from groundwater, may increase in some parts of the State. If new powerplants were built, they would need water for cooling, which depending on location, could come from surface water supplies. Although it was not studied, municipal demand for water may also rise.

FIGURE 12. CALIFORNIA

TEMPERATURE SCENARIOS
2xCO2 LESS 1xCO2



PRECIPITATION SCENARIOS
2XCO2 LESS 1xCO2



Water Resources
Regional warming could cause:
- **higher winter, lower summer runoff**
- **decreased deliveries from Central Valley Project and State Water Project**
- **decreased water quality in subalpine lakes**

Wetlands and Fisheries
Sea level rise could cause:
- **gradual inundation of wetlands**
- **increased salinity and size of in the San Francisco Bay**
- **shift from brackish and freshwater species to more salt-tolerant plants**
- **alteration of waterfowl habitat and shifts to marine fish species**

Agriculture
Increases in temperature and CO_2 concentrations could cause:
- **uncertain crop responses**
- **increased irrigation demand resulting in groundwater extraction and decreased water quality**
- **an increase in crop acreage**

Air Quality
- **increased temperatures will cause an increase in ambient ozone levels**

Electricity
- **higher temperatures could increase electricity demand**

Sea Level Rise Will Affect the Size and Environment of San Francisco Bay

A sea level rise would change the salt concentrations of San Francisco Bay. It is estimated that a 1-meter rise would cause the salt front in the Sacramento-San Joaquin River Delta to migrate upstream 4 to 10 km (2.5 to 6 miles).

Sea level rise would also make it harder to maintain the Sacramento-San Joaquin Delta islands. A 1-meter sea level rise would increase the volume of the San Francisco Bay estuary by 15% and the area by 30%, if the levees around the delta islands are strengthened and raised. If the levees are not maintained, there would be a doubling and tripling, respectively, of the volume and area of the bay. As a result of these changes, wetlands would be affected and species would shift to marine aquatic species.

Climate Change Will Affect Air Quality

Air quality is currently a major concern in California. For example, ozone levels in central California will increase in intensity and change in location due to higher temperatures. As a result, the number of people-hours of exposure to elevated ozone levels in excess of the EPA standard of 0.12 ppm would triple under one climate scenario, with a 4°C rise and current emission levels. Air pollution control agencies may have to re-evaluate the effectiveness of strategies to deal with air pollution on a long-term basis.

Natural Resource Management Agencies in California May Need To Examine the Long-Term Implication of Global Climate Change

Water management institutions, such as the U.S. Bureau of Reclamation and the California Department of Water Resources, may need to consider whether and how to modify the Central Valley Project and State Water Project to meet changing supplies and increasing demands resulting from climate change. They may also wish to determine whether water allocation rules should be changed to encourage more efficient use of water.

Southeast

The Southeast is distinguished from the other regions in this study by its warm temperatures, abundant rainfall, large coastal plain, and productive marine fisheries. The region supplies about half of the nation's softwood and hardwood timber, and tobacco, corn, and soybeans are among its major crops. Over 85% of the nation's coastal wetlands are in the Southeast, and over 43% of the finfish and 70% of the shellfish harvested in the United States are caught in the region.

This report focused on two regions within the Southeast: the Tennessee Valley and the Chattahoochee and Apalachicola Rivers. The Tennessee Valley Authority examined the potential vulnerability of its water management system to high and low riverflow scenarios. Flow in the Chattahoochee River Basin was estimated to analyze impacts on the management of Lake Lanier, which supplies water to Atlanta. The estimates of outflow from the lake, along with estimates of the flow in the Apalachicola River, were combined with potential wetland losses attributable to sea level rise to identify impacts on finfish and shellfish in Apalachicola Bay. Sea level rise impacts were derived from the national studies (see Figure 13).

Changes in Farms and Forests Could Hurt the Entire Region

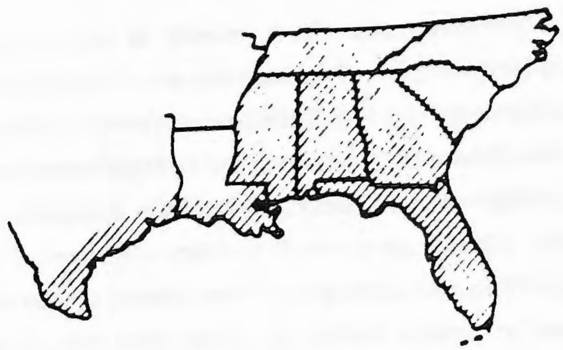
Shifts in the relative productivity of agriculture may lead to the abandonment of 10 to 50% of agricultural acreage in the region. The decline in cultivated acreage may tend to be concentrated in areas where farming is currently marginally profitable.

Significant dieback may occur in the southern forests, one of the major forest production regions. Areas in the Deep South such as Georgia and Mississippi may have particularly large reductions in biomass. The combined effects of reduced agriculture and forest industry could lead to important economic impacts in the South.

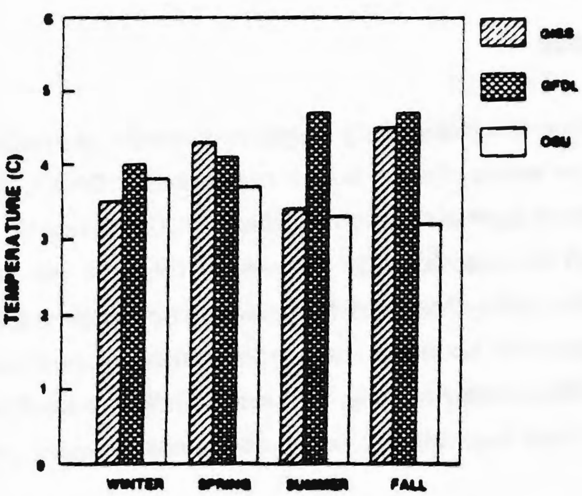
Coastal Fisheries Will Be Threatened by Higher Water Temperatures and Loss of Wetlands From Sea Level Rise

The coastal fishing industry could be adversely affected by the combination of higher temperatures and sea level rise. Sea level rise could inundate most of the coastal wetlands and cause higher salinity levels, which could adversely affect gulf coast fisheries. In addition, higher temperatures may exceed the thermal tolerances of many species of shellfish in gulf coast estuaries (see Figure 13).

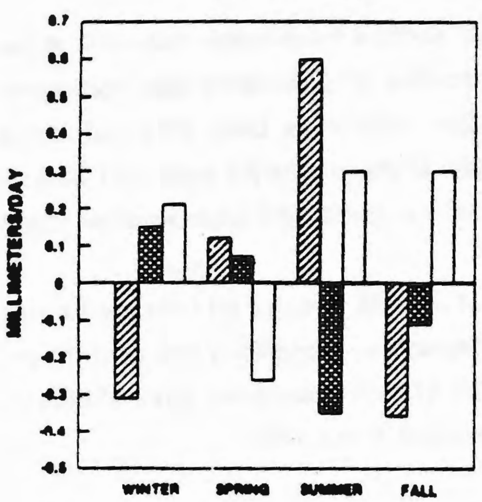
FIGURE 13. THE SOUTHEAST



TEMPERATURE SCENARIOS
2xCO2 LESS 1xCO2



PRECIPITATION SCENARIOS
2xCO2 LESS 1xCO2



Agriculture
Climate change could:
- decrease in corn and soybean yields in warmer areas; mixed results elsewhere
- decrease cultivated acreage
- increase need for irrigation, if rainfall declines
- increase pest infestations

Forests
Higher temperatures could result in:
- significant dieback of southern forests in 30 to 80 years
- regeneration of species becoming difficult
- conversion of some forests to grassland
- forest declines evident in 30 to 80 years

Water Resources
Increased temperature and changes in precipitation:
- produce uncertain effects for water resource availability
- could affect water quality and flood risks
- cause levels in some recreational lakes to drop

Sea Level Rise
Rising sea level could result in:
- inundation of a significant proportion of the region's coastal wetlands
- flooding of some dry land areas
- significant costs for protecting coastal resources

Fisheries
- higher water temperatures and rising sea level could reduce fish and shellfish populations

Electricity
- higher temperatures will increase the demand for electricity

Impacts on Water Resources Cannot Be Determined

The Southeast currently has little winter snowcover; therefore, runoff is much more dependent on changes in rainfall than on changes in temperature. The impacts of climate change on rainfall are uncertain. Analysis of the rivers managed by the Tennessee Valley Authority showed that increased rainfall could lead to higher riverflow and increased flood probabilities, and less rainfall could lead to lower riverflow and problems maintaining adequate supplies for industrial use, powerplants, and dilution of effluent. Similar uncertainties exist concerning the direction of flow in the Chattahoochee River; a study of the management of Lake Lanier concluded that changes in operating rules would be sufficient to handle higher or lower flow situations, although some uses would be restricted. The uncertainty concerning the volume of flow is likely to apply to most rivers in the region.

Policymakers in the Southeast Face New Challenges

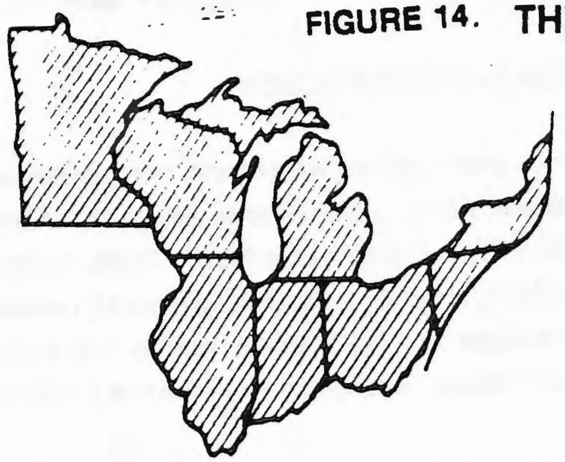
Policymakers in the Southeast should consider the potentially negative impacts of climate change on agriculture, forestry, wetlands, and, in some cases, water resources. Given the potentially important impacts on forests, agricultural agencies such as the U.S. Department of Agriculture and related State agencies may wish to examine the long-term impacts on the economy of the South. Federal laws constrain the Army Corps of Engineers and other water resource managers from rigorously considering tradeoffs between many nonstatutory objectives of Federal dams in the southeast, including recreation, water supply, and environmental quality. Increased flexibility would improve the ability of these agencies to respond to and prepare for climate change.

Great Lakes

The Great Lakes contain 18% of the world's supply of surface freshwater and 95% of the U.S. surface freshwater supply, and they are an important source of commerce and recreation for the region. In recent years, the quality of such water bodies as Lake Erie has been significantly improved. The Great Lakes States produce most of the country's corn and 40% of its soybeans, and their forests have important commercial, recreational, and conservation uses.

Models were used to estimate the potential impacts of climate change on lake levels and ice cover. Results from these studies were used to analyze impacts on navigation and shorelines. Changes in the thermal structure of the Central Basin of Lake Erie and southern Lake Michigan were quantitatively derived. Output from these studies was used along with

FIGURE 14. THE GREAT LAKES



Lakes
Climate change could:
- cause average lake levels to fall 0.5 to 2.5 meters
- reduce ice cover duration by 1 to 3 months

Adjustments may be required, including:
- increased dredging of harbors and channels; or
- lower cargo capacities on ships

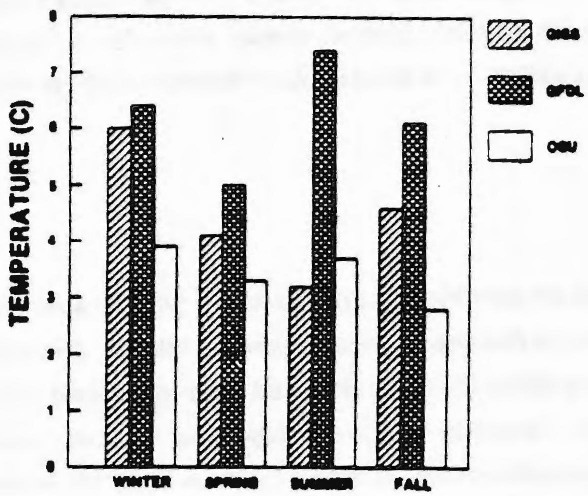
Water Quality
Changes in temperatures and precipitation could cause:
- greater stratification in lakes and increased growth of algae; causing:
- lower dissolved oxygen levels in shallow areas
- an increase in pollutants resulting from more dredging

Wetlands and Fisheries
Increased temperature could cause:
- mixed effects on fisheries overall
- an increase in fish habitats in fall, winter and spring; decrease in summer
- accelerated growth for some fish species
- potential invasion by new species

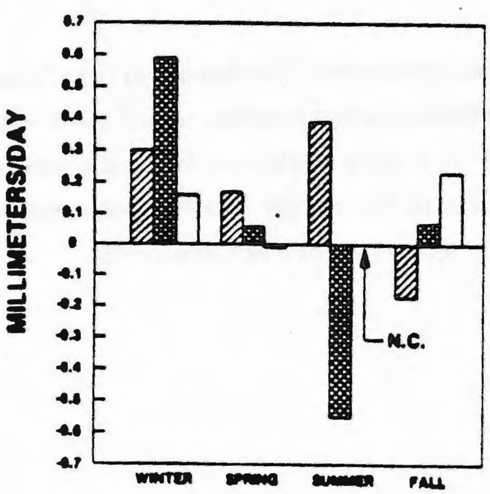
Forests
Changes in climate could result in:
- shifts from mixed northern hardwood and oak to oak savannas and grass-land
- shifts of mixed northern hardwood and boreal forests to all northern hardwood
- forest declines evident in 30 to 60 years

Agriculture
Increased temperature could cause:
- corn and soybean yields to increase in north, decline in cornbelt; mixed results for cornbelt under climate and CO_2
- production to expand in the North, decline elsewhere
- increase erosion and runoff in North

TEMPERATURE SCENARIOS
$2xCO2$ LESS $1xCO2$



PRECIPITATION SCENARIOS
$2xCO2$ LESS $1xCO2$



scenario temperatures to analyze potential impacts on fishes in the lakes (see Figure 14).

Lake Levels Are Likely To Drop and Duration of Ice Cover Will Decrease

Higher temperatures would likely reduce snowpack and increase evaporation, which would lower lake levels. The level of Lake Superior was estimated to be reduced by 0.4 to 0.5 meters (1.2 to 1.5 feet) and that of Lake Michigan by 0.9 to 2.5 meters (3 to 8 feet). These results are very sensitive to assumptions made about evaporation. Higher temperatures would reduce ice cover on the lakes, cutting ice duration by 1 to 3 months on Lake Superior and by 2 to 3 months on Lake Erie. However, ice would still form on both lakes. Changes in windspeed could affect the reduction in duration of ice cover.

Lower lake levels may lead to expensive adjustments such as dredging of ports and channels. In response to lower lake levels, either ships would have to sail with reduced cargoes or ports and channels would have to be dredged. Disposal of contaminated dredge spoils could increase water pollution. On the other hand, a shorter ice season would allow for a longer shipping season. Diversions out of the lakes for irrigation or to supply other basins would further lower lake levels.

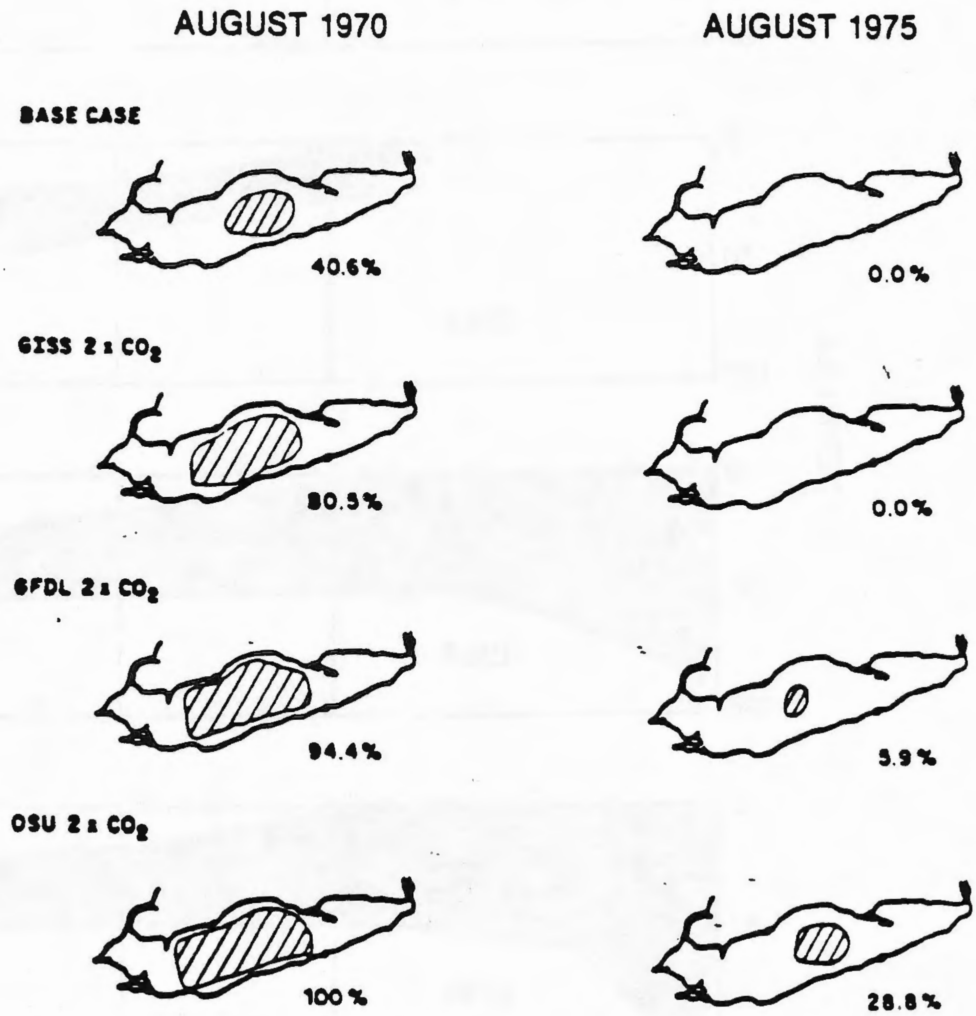
Water Quality May Be Degraded in Some Areas

Higher temperatures are also likely to lengthen stratification of the lakes (where summer temperatures warm the upper part of lakes and isolate the cooler lower layers of lakes). Analysis of the Central Basin of Lake Erie showed that longer stratification combined with increased algal productivity would likely reduce dissolved oxygen levels in the lower layers of the lake (see Figure 15). One study raised the possibility that annual turnover in lakes such as Lake Michigan may be disrupted.

Some Fish Species May Increase in Productivity

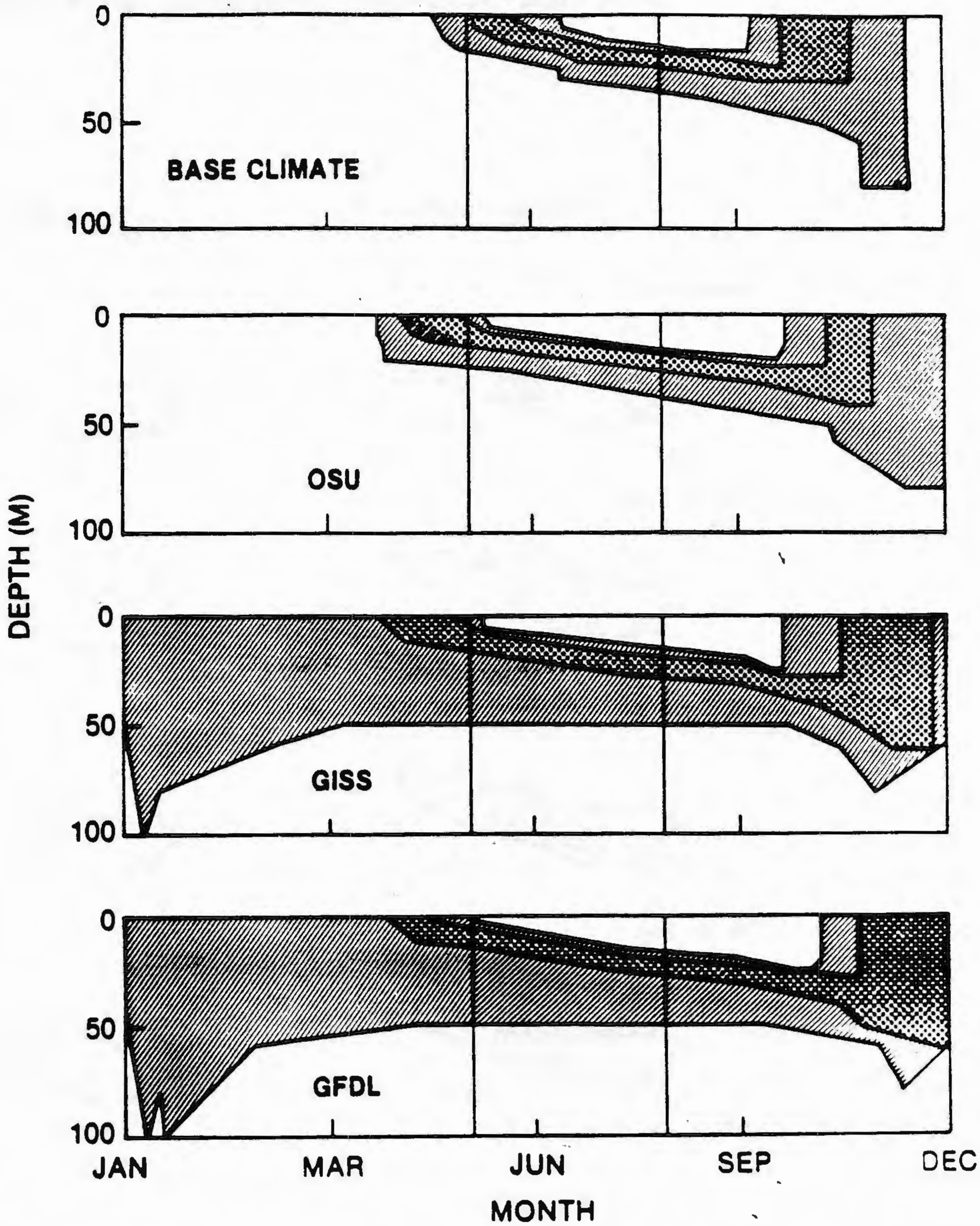
If anoxic conditions are not present, growth rates and productivity for bass and lake trout in open areas of large lakes may increase because of expanded thermal habitats (see Figure 16). Higher temperatures, reduced ice cover, and decreased water quality in shallow lakes and rivers could have negative impacts on some species. The effects of increased species interaction, changes in spawning areas, and possible invasion of exotic species were not analyzed.

FIGURE 15. CHANGES IN ANOXIC CONDITIONS IN THE CENTRAL BASIN OF LAKE ERIE UNDER ALTERNATIVE CLIMATE SCENARIOS



Source: Blumberg and DiToro.

FIGURE 16. INCREASES IN THERMAL HABITAT FOR LAKE TROUT IN SOUTHERN LAKE MICHIGAN UNDER ALTERNATIVE CLIMATE SCENARIOS



Habitat: ± 2°C of optimum temperature

± 5°C of optimum temperature

Source: Magnuson et al.

Northern Agriculture May Benefit

Agriculture could be enhanced in Minnesota, Wisconsin, and northern Michigan, although the presence of glaciated soils could limit agricultural growth. Increased cultivation in the North combined with reduced forest productivity could increase erosion and runoff, with negative impacts on surface and groundwater quality.

Forests Could Change in Abundance and Composition

The composition and abundance of forests in the Great Lakes region will change. Northern hardwood forests in Michigan may be reduced to oak savannas or grasslands, and mixed boreal and northern hardwood forests in northern Minnesota may become all northern hardwoods. Commercially important softwood species would be replaced by hardwoods used for different purposes. Declines in forests could be evident in 30 to 60 years.

Long-Range Management Plans for the Great Lakes May Need To Be Reevaluated

Water and fisheries management strategies and the implications for land use may need to be assessed in response to climate change. The water regulation plans for Lake Ontario and, possibly, for Lake Superior may have to be re-evaluated by U.S. and Canadian policymakers to accommodate lower lake levels. In addition, there may be increased demands for diversion of Great Lakes water for uses outside the basin, although current law prohibits the Federal Government from studying the feasibility of diversions without the consent of Great Lakes Governors. Water pollution control agencies such as EPA should examine the implications for long-term point and nonpoint pollution control strategies. Forest and State natural resource management agencies could consider the potential shifts in northern forests, planting and land purchase decisions, and wetland policies.

The Great Plains

Agriculture is one of the main sources of income in the Great Plains. The States of Kansas, Nebraska, Oklahoma, and Texas produced 80% of the nation's sorghum and 40% of the wheat crop. In recent years, increased use of water from the Ogallala Aquifer has reduced groundwater levels in the region, with potential long-term consequences for agriculture and the economy.

This report focused on Nebraska, Kansas, Oklahoma, and Texas. The studies focused on agriculture issues. The studies estimated changes in corn, wheat, and soybean yields, and in the demand for irrigation. Changes in runoff and leaching of chemicals from farms were also examined (see Figure 17).

Crop Acreage Could Decline

The crop yield and economic adjustment studies indicate that crop acreage could be reduced in the region. The direction of changes in wheat and corn yields depends on the direct effects of CO_2 on crop growth and the severity of climate change (if climate change is hot and relatively dry, yields will decrease). Either way , relative productivity may decline. As a result, crop acreage was estimated to drop by 4 to 22%. A reduction in agriculture could affect the economy of this region.

Demand for Irrigated Acreage Would Increase

Other impacts of climate change could change ground and surface water supplies and possibly, surface water quality. The demand for irrigation on the farms that remain could increase. Irrigated acreage, which currently makes up about 10% of the total acreage, could increase by 5 to 30%. This report did not examine how this demand would be satisfied, although the Ogallala Aquifer would be a candidate. If precipitation changes, there could be changes in leaching of pesticides into groundwater and runoff to surface waters in some cases. Changes in runoff and leaching of pesticides and soils are very sensitive to changes in rainfall variability.

Climate Change Should Be a Consideration in Planning for the Region

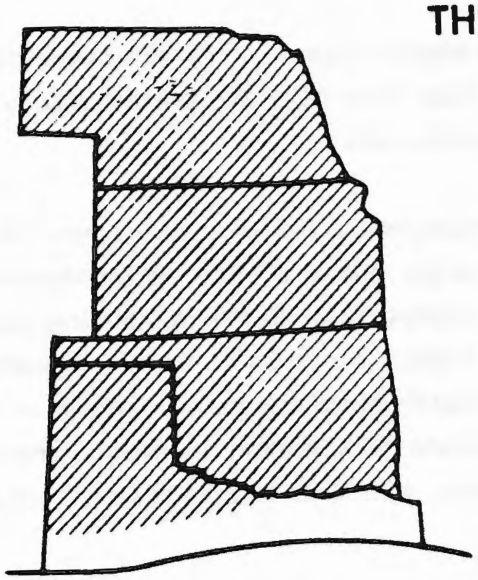
State and other agencies may wish to consider potential shifts in crop acreage. Water resource managers may wish to factor in the potential effects of climate change on the development of long-term irrigation, drainage, and water-transfer systems.

Urban Infrastructure

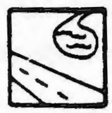
The value of municipal infrastructure in the United States, excluding buildings and electric power production, probably approaches one trillion dollars. The majority of the nation's investments are in water supply, wastewater transport and treatment facilities, drainage, roadways, airports, and mass transit facilities. Like the regions studied for this

FIGURE 17.

THE GREAT PLAINS

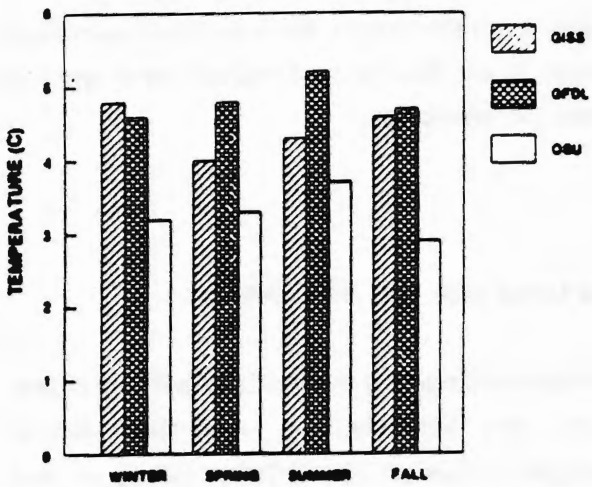


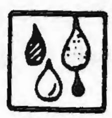
Agriculture
Increases in temperature could result in:
- **reduced corn and wheat yields (due to climate change alone); mixed effects on yields when considering climate and CO_2**
- **reduced crop acreage**



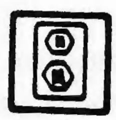
Irrigation Demand
Changes in agriculture are likely to result in:
- **increased irrigation demand**
- **an increase in irrigated acreage**

TEMPERATURE SCENARIOS
2xCO2 LESS 1xCO2



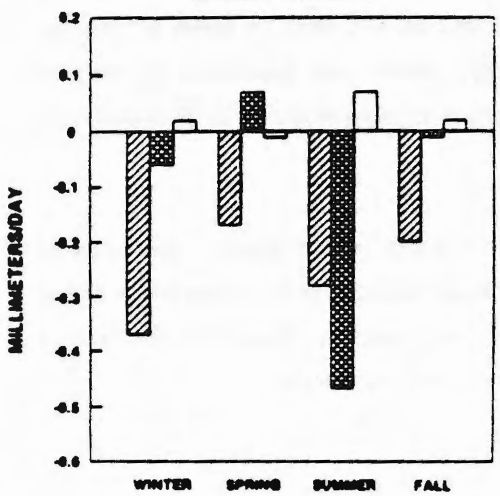


Water Quality
- **changes in rainfall, runoff, pesticide loadings, erosion and irrigation will affect water quality**



Electricity
- **increased temperature will increase demand for electricity**

PRECIPITATION SCENARIOS
2xCO2 LESS 1xCO2



report, urban areas will feel a variety of impacts from climate change. This report examined the potential impacts of climate change on Cleveland, New York City, and Miami. These areas encompass a diversity of climates and uses of natural resources.

Much of the current inventory in urban infrastructure will turn over in the next 35 to 50 years, but the locations of the nation's cities will not change. Global climate will require changes in the capital investment patterns of cities for water supplies, peak electric generating capacity, and storm sewer capacity. Urbanized coastal areas might have to invest additional billions of dollars into coastal protection to defend developed areas from a rising sea. Generally, northern cities such as Cleveland may fare better, since reductions in the operating and maintenance costs associated with heating public buildings, snow removal, and road maintenance should offset increasing costs for air-conditioning (see Table 3).

<u>Investments in Long-Lived Infrastructure Should Consider Climate Change</u>

Federal institutions involved in planning for urban infrastructure, such as the Department of Housing and Urban Development and the National Flood Insurance Program, may wish to consider the implications of climate change for urban infrastructure.

SUMMARY COMMENTS

Effects Dominated by Higher Temperatures and Sea Level Rise Can Be Estimated

Despite the uncertainties about the regional climate changes, it is possible, in many cases, to specify the direction of many regional effects. For example, we know that warmer temperatures will lead to earlier snowmelt and a larger amount of precipitation falling as rain rather than as snow. Based on that, we can determine that water management systems such as those in California would be unlikely to maintain current yields. Only a large increase in spring and summer rainfall could reverse this effect. Higher temperatures will lead to such effects as longer stratification of lakes and increased biological activity, which will combine to reduce dissolved oxygen levels. Only a large increase in summer storms strong enough to overturn the lakes would reverse such an effect.

Higher temperatures across the country will shift relative agricultural productivity northward. Whatever adjustments are made or whatever the direct effects of CO_2, northern areas that now have a short frost-free season would have a longer growing season. Southern areas may have more problems with heat stress. Relative crop yields may be enhanced in the

Table 3. Estimated Impacts of a Doubling of CO_2 on Cleveland's Annual Infrastructure Costs (millions of 1987 dollars)

Cost Category	Annual Operating Costs
Heating	-$2.3
Air-conditioning	+$6.6-9.3
Snow and ice control	-$4.5
Frost damage to roads	-$0.7
Road maintenance	-$0.5
Road reconstruction	-$0.2
Mass transit	summer increase offsets winter savings
River dredging	less than $0.5
Water supply	negligible
Storm water system	negligible
Total	-$1.6 to +$1.1

Source: Walker et al.

North. Higher temperatures will also lead to a northward shift in forests and could lead to a reduction in the area of healthy forests.

Sea level is almost certain to rise under global warming, and the resulting changes are fairly changes. Many wetlands are likely to be lost, which would adversely affect fisheries. Higher sea level will increase salinity and the volume of bays and estuaries, thus affecting fisheries, wildlife, and freshwater supplies.

Rate of Change and Adaptation

The ability of society and nature to adapt to a global warming depends on the rate of climate change as well as the magnitude. If change is slow enough, nature can adapt through migration, and society can adjust through incremental investments in infrastructure improvements and the application of new technologies. A rapid climate change, however, may overwhelm the ability of systems to adapt.

It appears that a rapid rate of global warming may cause irreversible impacts on many natural systems. The inhabited range of many species may shrink considerably as a result of the rapid movement of climate zones. It is likely that many species would become extinct, and wetlands would be lost due to rapid warming.

Society can probably adapt more quickly to changing conditions. Powerplants, dams, and dikes may have to be built, northern agriculture expanded, and rivers and ports dredged, but the full cost of these changes cannot be estimated. If change is slow enough, these expenses may be manageable. However, a sudden or rapid change in climate may even make societal adaptation problematic.

International Impacts of Climate Change

This report did not analyze the impacts of climate change on other countries. Compared to the United States, it may be much more difficult for poorer and less mobile societies to respond to climate change. In those countries, the low standard of living and overstrained resources may make responses to global climate change difficult. It is not unreasonable to assume that climate change could have important geopolitical consequences. It is important for other countries to examine potential impacts of global warming on their natural resources. The UNEP and WMO will need to play an important role in this area in the future.

- THE UNIQUENESS OF THE ECOSYSTEMS OR MANMADE STRUCTURES THAT MAY NEED PROTECTION;
- WHETHER THE IMPACTS WOULD BE GREATER IF NO ANTICIPATORY ACTION WERE TAKEN; AND
- THE IMPACTS ON OTHER NATIONAL AND STATE POLICIES.

THE FEDERAL GOVERNMENT CAN TAKE THE LEAD IN PURSUING PRUDENT POLICIES IN ANTICIPATION OF CLIMATE CHANGE, AND MANY AGENCIES CAN PLAY A ROLE IN PREPARING THE COUNTRY FOR THE IMPACTS. THESE INCLUDE THE DEPARTMENTS OF THE INTERIOR, ENERGY, HEALTH AND HUMAN SERVICES, AND AGRICULTURE; THE U.S. ENVIRONMENTAL PROTECTION AGENCY; THE ARMY CORPS OF ENGINEERS; AND THE TENNESSEE VALLEY AUTHORITY. HOWEVER, ADAPTATION SHOULD NOT OCCUR JUST AT THE FEDERAL LEVEL; HENCE, THERE WILL BE A NEED TO INVOLVE STATE AND LOCAL GOVERNMENTS, INDUSTRY, AND EVEN INDIVIDUALS. THE REGIONAL STUDIES IN THIS REPORT DEMONSTRATE THAT CLIMATE CHANGE CUTS ACROSS MANMADE AND NATURAL SYSTEMS, GEOGRAPHIC BOUNDARIES, AND GOVERNMENT AGENCIES. RESEARCH, TECHNICAL GUIDANCE, AND PLANNING WILL BE NEEDED IN THE FUTURE TO PREPARE FOR THE IMPACTS OF CLIMATE CHANGE ON THE UNITED STATES.

FINAL THOUGHTS

THIS IS THE MOST COMPREHENSIVE STUDY TO ADDRESS THE ISSUE OF THE ENVIRONMENTAL EFFECTS OF CLIMATE CHANGE IN THE UNITED STATES. AS A RESULT, IT IS ANTICIPATED THAT A SIZABLE DEBATE WILL FOLLOW ITS PUBLICATION. CONSIDERABLE ADDITIONAL RESEARCH AND ANALYSES ARE LIKELY TO AMPLIFY, IMPROVE, AND CHALLENGE THESE FINDINGS. WE EXPECT FURTHER RESEARCH TO DEVELOP NEW INSIGHTS INTO THE ROLE OF CLIMATE, BUT PRECISE FORECASTS WILL AWAIT MORE ADVANCED CLIMATE MODELS, WHICH MAY REQUIRE MANY YEARS TO DEVELOP. FOR SOME TIME TO COME, OUR ABILITY TO PROVIDE NATIONAL AND LOCAL OFFICIALS WITH GUIDANCE MAY BE LIMITED TO EFFECTS DRIVEN PRIMARILY BY TEMPERATURE AND SEA LEVEL CHANGES.

APART FROM STRATEGIES TO LIMIT EMISSIONS OF GREENHOUSE GASES (DISCUSSED IN THE COMPANION REPORT), POLICYMAKERS WILL HAVE TO CONSIDER POLICY OPTIONS FOR ADAPTING TO GLOBAL WARMING. CONSIDERATION OF THESE OPTIONS IS COMPLICATED BY THE UNCERTAINTIES IDENTIFIED IN THIS REPORT AND BY THE PRESSURE TO SOLVE TODAY'S PROBLEMS. MANY ADAPTATIONS WILL UNDOUBTEDLY OCCUR AS CLIMATE CHANGES, BUT SOME DECISIONS BEING MADE TODAY HAVE A LONG ENOUGH LIFETIME AND SUFFICIENT RISK TO SUPPORT CONSIDERATION OF THE IMPACTS OF THE GREENHOUSE EFFECT. THESE DECISIONS SHOULD BE MADE IF THEY MAKE ECONOMIC SENSE FOR TODAY'S CONDITIONS AND ARE SUFFICIENTLY FLEXIBLE TO HANDLE CHANGING CLIMATE. THE MOST PLAUSIBLE "ADAPTIVE" RESPONSES AT THE CURRENT TIME ARE INCREASED RESEARCH, IMPROVED LONG-RANGE PLANNING, DEVELOPMENT OF GUIDANCE WHEN THE DIRECTION OF IMPACTS IS CLEAR, AND TAKING NO ACTION WHEN IT IS NOT OBVIOUS THAT THE TIMING OF CLIMATE CHANGE WILL AFFECT THE RESOURCE DECISION. THE CRITERIA TO GUIDE DECISIONS SHOULD INCLUDE CONSIDERATION OF THE FOLLOWING:

- THE UNCERTAINTIES IN THE MAGNITUDE AND TIMING OF EFFECTS;
- WHETHER THE LIFETIME OF THE PLAN, PROJECT, OR POLICY IS LONG ENOUGH TO BE AFFECTED BY CLIMATE CHANGE;
- WHETHER OR NOT A POLICY OR ACTION MAKES ECONOMIC SENSE, EVEN WITHOUT CLIMATE CHANGE;
- WHETHER THE POLICY OR PROJECT WILL INCREASE FLEXIBILITY AND RESILIENCE OR RESTRICT FUTURE OPTIONS;