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CHAPTER 17
GREAT PLAINS

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FINDINGS

Agriculture in the Great Plains (this study focused on Nebraska, Kansas, Oklahoma, and Texas) is sensitive to climate fluctuations and would be at risk from global warming. Although uncertainties remain regarding the rate and magnitude of global climate change and the models used to estimate impacts, results indicate that climate change would cause reductions in regional agricultural production. Demand for irrigation is likely to increase, and quality of water may diminish. Regional electricity use may increase.

Agriculture

- The effects of a warmer climate alone would generally reduce wheat and corn yields. Yield changes range from + 15 to -90%. The direct effects of CO_2 on crop photosynthesis and water use may mitigate these effects, but the extent to which the beneficial effects of CO_2 on crop yields would be seen with climate change is uncertain.

- Crop yields in Texas and Oklahoma may decline relative to northern areas of the United States. This change in productivity could lead to a 4 to 22% reduction of cultivated acreage in these states.

- Because of increased reliability of yields from irrigated lands relative to dryland yields, and because of potentially higher crop prices, demand for irrigation water on remaining farms would probably increase as global warming proceeds. The number of acres irrigated may increase by 5 to 30%.

Ogallala Aquifer

- Warming and/or drying in the Great Plains may place greater demand on regional groundwater resources. Many of the problems associated with intense groundwater use -- water depletion,soil damage, altered farm and rural economics, and potential reversion to dryland farming – could be exacerbated by global warming.

Water Quality

- It is not clear how climate change would affect water quality in the Great Plains. Groundwater quality may be less at risk than surface water quality because of increased evaporation and less leaching. These results are very sensitive to changes in the amounts and frequency of rainfall, and groundwater impacts will be affected by total acres under production, by application rates, by soil type under cultivation, and by changes in irrigated versus dryland acres.

Electricity Demand

- Climate warming could cause the annual demand for electricity in Kansas, Nebraska, Oklahoma, and West Texas to rise by an additional 5 to 9 billion kilowatthours (kWh) (2 to 4%) by 2010, and by an additional 37 to 73 billion kWh (10 to 14%) by 2055. Summertime use for air-conditioning and irrigation pumping could increase and outpace reductions in winter demand for space heating.

- Approximately 3 to 6 gigawatts (GW) of generating capacity would be needed by 2010 to meet the additional increased demand, and 22 to 45 GW would be needed by 2055 -- a 27 to 39% increase over baseline additions that may be needed without climate change. The cumulative cost of these additions by 2055 would be $24 to $60 billion.

Policy Implications

- Agencies with responsibility for agricultural land use, such as the U.S. Department of Agriculture (USDA) Agricultural Stabilization and Conservation Service and the Soil Conservation Service, should begin to analyze how their missions may be affected by climate change and to consider development of flexible strategies to deal with potential impacts. Water resource managers, such as those on river basin commissions and in state natural resource agencies, may wish to factor the potential effects of climate change into planning of land use, long-term water supply, irrigation, drainage, and water-transfer systems.

CLIMATE-SENSITIVE RESOURCES IN THE GREAT PLAINS

The Great Plains consists of a predominantly treeless region of relatively flat topography between the Rocky Mountains and the Mississippi lowlands of central North America. Although very productive, the region (Figure 17-1) is sensitive to climate fluctuations, a fact that has been made apparent in several major droughts over the last few decades.

Despite this climate sensitivity, dryland agriculture provides the chief economic base for this thinly populated region with few cities. The region was first settled by farmers in the late 1800s under the Homestead Act, w1uch created the family-farm system in place today in the Plains (Bowden et al., 1981).

The Great Plains, including portions of Nebraska, Kansas, Oklahoma, and Texas, constitutes a vital part of the United States' agricultural base and is the focus of this report. Nearly 100,000 farms encompassing over 111 million acres produce an important array of dryland and irrigated crops. Major dryland crops include winter wheat and grain sorghum, and key irrigated grains include corn and rice. In all, the four states have a combined production of over 80, 30, and 25% of the nation's grain sorghum, wheat, and cotton, respectively (Table 17-1).

Exploitation of water from the Ogallala Aquifer has supported significant irrigated agricultural production in the Great Plains during the last two decades. In many areas, irrigated farming of corn, rice, and cotton has replaced dryland wheat production, especially in western Kansas and the Texas Panhandle (Figure 17-1). However, the region's groundwater resources have been overexploited in some areas, leading to some reversion to dryland cropping.

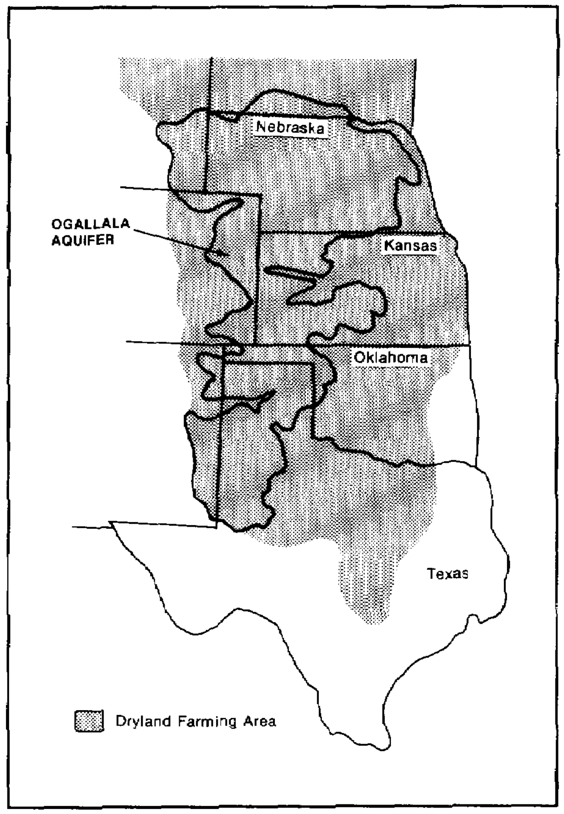


Figure 17-1. Boundaries of the Ogallala Aquifer and dryland wheat production in the Great Plains (Science of Food and Agriculture, 1987, 1988).

Livestock constitute another important agricultural commodity in the region. Almost 50% of all cattle fattened in the country are raised in the four states, accounting for 40% of the total U.S. value of marketed livestock.

In addition to contributing substantially to national food supplies, the four states are also major exporters of agricultural products. Foreign exports of grain and animal products are especially notable (Table 17-2). In total, these four states provide approximately one-fifth of the dollar value of all U.S. agricultural

Table 17-1. U.S. Agricultural Ranking for Great Plains States and Percent of U.S. Total (for the four states combined) for Selected Products, 1982

Product	Kansas	Nebraska	Oklahoma	Texas	U.S. total (all four states) (%)
Sorghum harvested	2	3	5	1	80.5
Cattle fattened on grain and concentrates sold	2	3	9	1	46.7
Value of cattle and calves sold	2	3	7	1	40.7
Wheat harvested	1	9	3	6	31.8
Cotton harvested	--	--	9	2	25.8
Hay harvested	9	2	16	7	15.9
Market value of all agricultural products	6	5	20	3	18.5

Source: USDA (1983).

Table 17-2. Agricultural Exports From Selected Great Plains States, Fiscal Year 1984 (millions of dollars)

Exports	U.S.	Kansas	Nebraska	Oklahoma	Texas	U.S. total (%)
Feed grains and byproducts	7,585	372	903	-	385	22
Wheat and byproducts	4,526	797	150	353	276	35
Live animal and meats	1,161	130	134	18	161	38
All agricultural products	31,187	1,719	1,762	1,471	2,031	19

Source: USDA (1985).

exports. Yet, dependence on foreign markets puts Great Plains farmers at high risk. While large historical fluctuations in grain and livestock production levels are partly related to climatic variability, changing international demand, and its effects on price, play an important role in the region's continuing economic and social instability.

The Great Plains is also a major source of coal and oil, though such extractive industries vary more with international energy markets than with climate. Otherwise, the area exhibits little economic diversity, a pattern that has led to a net outmigration, especially of younger segments of the population. Regional population is growing slowly mostly in the fringe cities (e.g., Omaha), while rural population and the total number of farms are slowly decreasing. The region's economy remains inexorably linked to the fortunes of agriculture and, thus, to the climate.

Dryland Agriculture

The dryland farming area of the Great Plains is one of the most marginally productive agricultural regions in the United States. Some observers have stated that the southern Plains are simply too sensitive to climate swings and that intensive dryland farming should be abandoned (Worster, 1979; Popper and Popper, 1987). Yet in many years, the Plains produce bumper crops of small grains that add significantly to the nation's export trade balance.

Dryland farmers in the Great Plains are particularly vulnerable to climate variability. The Great Plains States of Nebraska, Kansas, Oklahoma, and Texas were the hardest hit during the Dust Bowl of the 1930s (Worster, 1979; Hurt, 1981). Yields of wheat and corn dropped as much as 50% below normal, causing the failure of about 200,000 farms and migration of more than 300,000 people from the region.

The Dust Bowl, other droughts, and the desire for continued expansion and intensification of dryland farming have led to numerous technological and social adjustments to climate and market fluctuations. Especially critical, from a dryland farming perspective, has been the improvement of conservation tillage practices like summer fallowing (Warrick and Bowden, 1981; Riebsame, 1983). These practices are designed to conserve moisture, reduce energy input, and minimize erosion, and thus, to increase yields and profits. Nevertheless, dryland crop yields still fluctuate widely with temperature and precipitation variations between years. The coefficient of variation of wheat yields is close to 50% over much of the region, and approximately 30-40% of the planted acreage is abandoned every year because of poor crops, especially on the western fringes of agriculture where the dominant crop is dryland wheat grown on summer fallow (Michaels, 1985).

In addition to the developments in cropping systems, government policies and programs have also been devised to absorb or mitigate the impacts of climate stresses in the Great Plains and elsewhere. These include federal programs for crop insurance, disaster grants and low-interest loans to farmers, and government-sponsored drought research (Warrick, 1975). Such programs can be costly. For example, the projected cost of the 1988 Drought Relief is about $3.9 billion nationally (Schneider, 1988).

Despite the adoption of conservation tillage techniques, drought-resistant cultivars, and risk management programs, some analysts argue that the region remains particularly vulnerable to climate-induced reductions in crop yields and will be one of the first U.S. agricultural regions to exhibit impacts of climate change (e.g., Lockeretz, 1978; Warrick, 1984). Rapid acreage increases in the 1970s, destruction of windbreaks for larger fields to accommodate bigger machinery, and speculative farm expansion all raise the possibility of renewed land degradation and economic losses similar to those of the Dust Bowl period, if climate change creates an increased frequency of heat waves and droughts in the region. Most climate models indicate that the region would become drier as global warming proceeds, suggesting potentially severe impacts on dryland farming.

Irrigated Agriculture

One response to the semiarid and highly variable climate of the Great Plains has been exploitation of surface and groundwater resources for irrigation to replace dryland farming. In 1982, 19 million acres, or 12% of all Great Plains cropland, mostly in the southern Plains, were irrigated. Groundwater provides most of the water for irrigation: 61 to 86% of the water used in Nebraska, Oklahoma, and Kansas as compared with only 20% nationally. In this respect, irrigation farmers in the Great Plains are less sensitive to climate change relative to dryland farmers. However, the demand for irrigation water throughout the region is very sensitive to climate.

The improvement and application of well drilling and pumping technology after World War 11 permitted the use of water from the immense Ogallala Aquifer (Figure 17-1). Today, the aquifer supplies irrigation for approximately 14 million acres in the Great Plains States of Colorado, Nebraska, Kansas, Oklahoma, New Mexico, and Texas (High Plains Associates, 1982). Use of the aquifer allows the irrigation of terrain too far from surface supplies. The aquifer also provides water for municipal and industrial purposes.

Farmers in Nebraska recently began to use the aquifer to irrigate corn, which is grown mostly for livestock feed. Corn, wheat, and some sugarbeets are irrigated farther south, while in Texas the Ogallala is tapped chiefly for cotton. The aquifer varies in depth from the land surface, in rate of natural discharge, and in saturated thickness across the region. In Nebraska, the aquifer has a higher recharge rate (i.e., the rate at which the aquifer is replenished) than in the other Great Plains States, and significant drawdown problems have not yet occurred. In Texas and other states, high withdrawal and low recharge rates of the aquifer have already resulted in "mining" of the resource (i.e., the rate of water withdrawal is greater than rate of recharge) and in the abandonment of thousands of irrigated acres (see Glantz et al., Volume 7).

Water Quality

Nonpoint pollution (runoff and leaching) is the main contributor to water quality problems in the Great Plains. Many of the groundwater supplies in the region contain elevated levels of fertilizer and pesticide-derived pollutants.

Electricity Demand

Electricity use in the region is sensitive to climate fluctuations in terms of space heating, cooling, and agricultural operations such as irrigation and livestock management (heating, cooling, etc.). Other types of energy are also sensitive to climate, but this study addresses only electricity.

PREVIOUS CLIMATE IMPACT STUDIES

Many studies of climate impacts on agriculture in the Great Plains have been performed using a variety of approaches and models. Dozens of climate impact studies have focused specifically on the 1930s drought (e.g., Lockeretz, 1978; Bowden et al., 1981) and, more generally, on Great Plains droughts (Warrick, 1975). Many recent studies have used crop-climate models to estimate impacts of climate on yields. Warrick (1984) analyzed the vulnerability of the region to a possible recurrence of the 1930s drought by running a dryland crop yield model tuned to 1975 technology with 1934 and 1936 temperature and precipitation conditions. He found that recurrence of 1930s conditions in the region would result in wheat yield reductions of over 50%. Terjung et al. (1984) used a crop water demand and yield model to investigate irrigated corn production sensitivity to differing temperature, precipitation, and solar radiation fluctuations. They found that in the central Great Plains, evapotranspiration and total water applied for irrigation were very sensitive to climate variations. Liverman et al. (1986) continued this modeling and found that the lowest irrigated yields occurred under cloudy, hot, and very dry climate scenarios. Under dryland cropping, minimum yields occurred under sunny-hot and sunny-warm scenarios with very dry conditions.

Using an agroclimatic approach, Rosenzweig (1985) found that lack of cold winter temperatures in the southern Great Plains may necessitate a change from winter to spring wheat cultivars with climate change projected for a doubling of CO_2. Changes in temperature, precipitation, and solar radiation were considered. Decreased water availability may also increase demand for irrigation. In a later study, Rosenzweig (1987) showed that although the combined impact of doubled CO 2 climate change (temperature, precipitation, and solar radiation changes) and the direct effects of elevated CO_2 (increased photosynthesis and improved water use) compensated for the negative effects of climate change in years with adequate rainfall, this compensation did not reduce crop failures in dry years.

Robertson et al. (1987) estimated the combined impact of temperature and precipitation changes due to doubled CO_2 climate change and the direct effects of increased CO_2 on rainfed corn and wheat yields and erosion using the Erosion Productivity Impact Calculator (EPIC). Results showed that modeled wheat yields in Texas decreased and modeled corn yields increased slightly. Such changes in productivity could result in long-term changes in cropping patterns.

Glantz and Ausubel (1984) suggested that the Great Plains' mining of the Ogallala Aquifer and its susceptibility to future incidence of drought projected by global climate models be combined in analyses of the region, since both are critical to the habitability of the area.

GREAT PLAINS STUDIES IN THIS REPORT

The studies for this report examine the implications of climate change for several important activities in the region: agricultural production and economics, demand for irrigation water, and water quality. Climate change impact research on livestock, electricity use, and resource management policy relevant to the Great Plains is also described. The individual studies performed for this report are listed in Table 17-3.

The Great Plains studies explore the sensitivities of regional activities to climate change scenarios. The results are not meant to be predictions of what will happen; rather the studies aim to define the ranges and magnitudes of potential responses of critical regional systems to the predicted climate changes.

GREAT PLAINS REGIONAL CLIMATE CHANGE SCENARIOS

The estimated changes in seasonal and annual temperatures and precipitation for the scenarios are shown in Figure 17-2. For a description of the global climate models, climate scenarios, and a discussion of the likelihood of these changes, see Chapter 2: Climate Change, and Chapter 4: Methodology. All three scenarios show large increases in temperature for the Great Plains States under a doubled CO_2 climate. The GISS scenario has an annual warming of 4.5°C, the GFDL scenario has an annual warming of 5.0°C, and OSU has an annual warming of 3.3°C. In general, winter temperatures increase more than summer temperatures in the GISS model, and summer temperature changes are greater than winter temperature changes in the GFDL and OSU scenarios. The differences between the models range from 0.2 to 1.5°C. The impact studies used only the GISS and GFDL climate change scenarios because of time limitations.

Average annual precipitation decreases by 0.26 millimeters per day (3.7 inches per year) in the GISS scenario, while GFDL and OSU have slight increases. However, these annual values mask a pronounced reduction in rainfall in Nebraska and Kansas in the GFDL scenario (see Figure 17-3). The large temperature increase and pronounced summer drying combine to make the GFDL scenario severe in these states, and the most severe case among the climate change scenarios.

The magnitudes of climate changes in the spring and summer from the GFDL scenario and the climate of the 1930s drought in Nebraska and Kansas are compared in Figure 17-3. While the scenario decreases in growing season precipitation are about the same as those during the most severe drought years (1934 and 1936) in the area, the climate change scenario temperatures are about 3°C higher than the Dust Bowl temperatures.

Table 17-3. Great Plains Studies for EPA Report to Congress on the Effects of Global Climate Change

Analyses Performed for This Case Study

- Potential Effects of Climate Change on Agricultural Production in the Great Plains: A Simulation Study - Rosenzweig, Columbia University, NASA/Goddard Institute for Space Studies (Volume C)
- Effects of Projected CO_2-Induced Climatic Changes on Irrigation Water Requirements in the Great Plains States - Allen and Gichuki, Utah State University (Volume C)

National Studies That Included Great Plains Results

- Economic Effects of Climate Change on U.S. Agriculture: A Preliminary Assessment - Adams, Oregon State University and Glyer and McCarl, Texas A&M University (Volume C)
- Impacts of Climate Change on the Movement of Agricultural Chemicals Across the U.S. Great Plains and Central Prairie -Johnson, Cooter, and Sladewski, Oklahoma Climatological Survey, University of Oklahoma (Volume C)
- Changing Animal Disease Patterns Induced by the Greenhouse Effect - Stem, Mertz, Stryker, and Huppi, Tufts University (Volume C)
- Effect of Climatic Warming on Populations of the Horn Fly, with Associated Impact on Weight Gain and Milk Production in Cattle - Schmidtmann and Miller, U.S. Department of Agriculture, Agricultural Research Service (Volume C)
- The Potential Impacts of Climate Change on Electric Utilities: Regional and National Estimates - Linden and Inglis, ICF Incorporated (Volume H)
- Climate Change and Natural Resources Management in the United States - Riebsame, University of Colorado (Volume J)

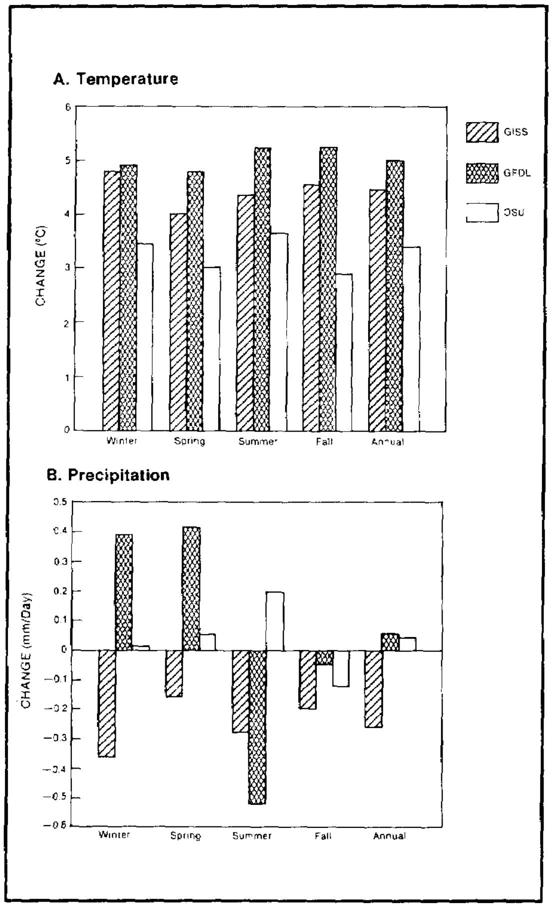


Figure 17-2. Average change in (A) temperature, and (B) precipitation over Great Plains gridpoints in GISS, GFDL, and OSU global climate models (2X CO_2 run less 1X CO_2 run).

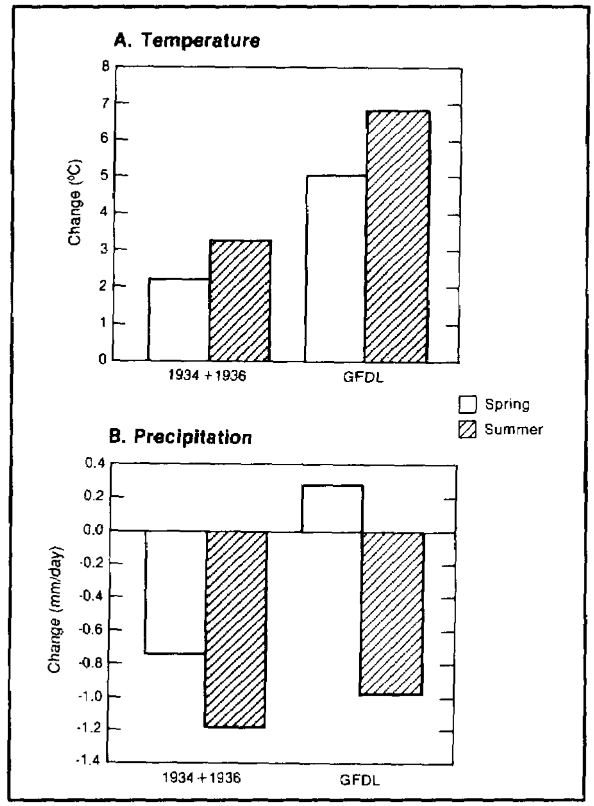


Figure 17-3. Comparison of observed drought (1943 and 1936) and GFDL climate change in Nebraska and Kansas for (A) temperature, and (B) precipitation (Rosenzweig, Volume C).

RESULTS OF THE GREAT PLAINS STUDIES

Crop Production

To better understand the potential physical impact of climate change on crops, Rosenzweig modeled changes in corn and wheat yields in the Great Plains using crop growth models.

<u>Study Design</u>

Two crop growth models, CERES-Wheat (Ritchie and Otter, 1985) and CERES-Maize (Jones and Kiniry, 1986) were used to test the sensitivity of crop yields to the GISS and GFDL climate change scenarios. These models are designed for large-area yield prediction and for farm decisionmaking and have been validated for a wide range of conditions (Otter-Nacke et al., 1986). The CERES models simulate crop responses to the major factors that affect crop yields: climate, soils, and management. The models employ simplified functions to predict crop growth stages; development of vegetative and reproductive structures; growth of leaves and stems; dieback of leaves; biomass production and use; root system dynamics; and the effects of soil-water deficit on photosynthesis and biomass use in the plant.

At each of 14 locations, the crop models were run with three soils present in the region representing low, medium, and high productive capacity. Model results were generated for changes in yield, water used for irrigation (if crop is irrigated), crop evapotranspiration, and planting and maturity dates for both dryland and irrigated cases. The direct effects of CO_2 (i.e., increased photosynthesis and decreased transpiration per unitleaf area) were simulated with the climate change scenarios in another set of runs. A method for approximating the direct effects in the CERES models was developed by computing ratios of daily photosynthesis and evapotranspiration rates for a canopy exposed to elevated (660 ppm) CO_2 to those rates for the same canopy exposed to current (330 ppm) CO_2 conditions (see Peart et al., Volume C). Daily photosynthesis rates of wheat and corn canopies were increased 25 and 10%, respectively, based on published results of controlled environmental experiments with crops growing in air with increased CO_2 levels.

Limitations

This work does not consider changes in frequencies of extreme events, even though extremes of climatic variables, particularly runs of extremes, are critical to crop productivity (see Chapter 3: Variability). Development of the CERES models was based on current climate; the relationships in the models may or may not hold under differing climate conditions, particularly the high temperatures predicted for greenhouse warming.

The direct effects of CO_2 are only approximated in the crop modeling study, because the models do not include a detailed simulation of photosynthesis. Also, experimental results from controlled environments may show more positive effects of CO_2 than would actually occur in variable, windy, and pest-infested (e.g., weeds, insects, and diseases) field conditions; thus, this study probably overestimated the beneficial effects of increased CO_2.

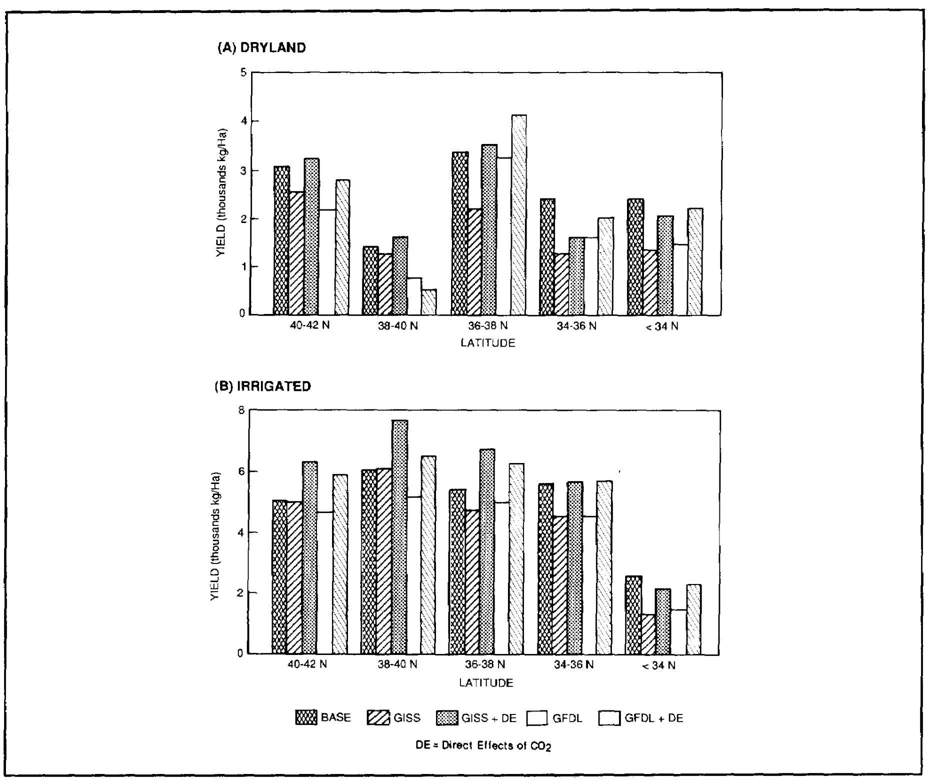


Figure 17-4. CERES-Wheat yields in the Great Plains with GISS and GFDL climate change scenarios with and without the direct effects of CO_2: (A) dryland, (B) irrigated (Rosenzweig, Volume C).

Results

Climate change scenarios cause simulated wheat (Figure 17-4) and corn (Figure 17-5) yields to decrease in the southern and central Great Plains. Results shown are means of modeled yields at study sites grouped by latitude for 30 years of baseline and climate change scenarios. With climate change alone, decreases in modeled yields appear to be caused primarily by increases in temperature, which would shorten the duration of crop life cycle (the period during which a crop grows to maturity). This results in reduced yields. When the direct effects of CO_2 on crop photosynthesis and transpiration are included in the climate change simulations, modeled crop yields overcome the negative effects of climate change in some cases, but not in others. In general, the more severe the climate change scenario, the less compensation provided by direct effects of CO_2.

Corn and wheat yields were estimated to respond differently to dryland and irrigated climate change conditions and to the direct effects of CO_2. Dryland corn yield decreases were very high in the hotter and drier GFDL scenario, particularly at higher latitudes. These decreases were caused by the combined effects of high temperatures shortening the grain-filling period and increased moisture stress. The GFDL scenario has pronounced reductions in summer precipitation (decreases of about 30 mm per month) in the two northern gridboxes of the study area, which occur during critical growth stages of corn. Irrigated corn was more negatively affected than irrigated wheat in the combined climate and direct effects runs because of the lower photosynthetic response of corn to CO_2.

In general, the amount of water needed for irrigation in the crop models is estimated to increase in the areas where precipitation decreases and irrigation reduces interannual variability in yields. These results suggest an increased demand for irrigation in the region.

Adjusting the planting date of wheat to later in the fall, one potential farmer adjustment to a warmer climate, was not estimated to significantly ameliorate the effects of the GISS climate change scenario on CERES-Wheat yields. Changing to varieties with lower vernalization requirements (need for a period of cold weather for reproduction) and lower photoperiod sensitivity (sensitivity to daylength), in addition to delaying planting dates, overcomes yield decreases at some sites but not at others.

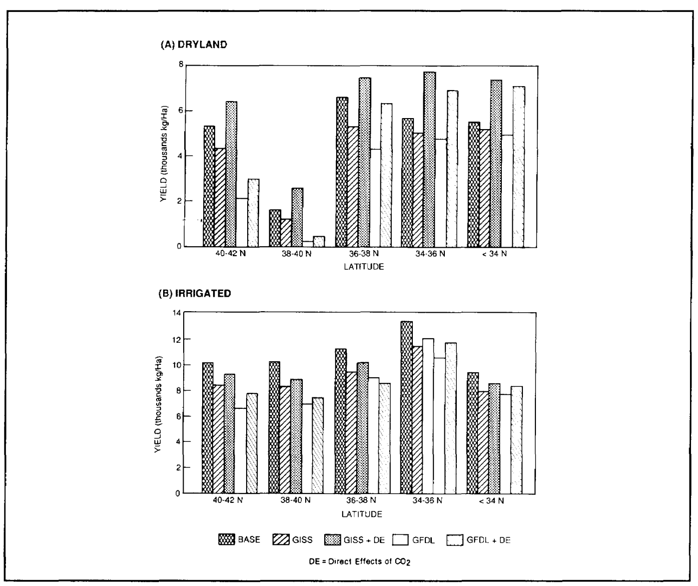


Figure 17-5. CERES-Maize yields in the Great Plains with GISS and GFDL climate change scenarios with and without the direct effects of CO_2: (A) dryland, (B) irrigated (Rosenzweig, Volume C).

Table 17-4. Estimated Changes in Agricultural Land Usage in Oklahoma and Texas (millions of acres)

Usage	Base acreage	GISS			GFDL		
		Acreage	Change	% Change	Acreage	Change	% Change
Agricultural land							
Without direct effects	54.7	42.6	-12.1	-22.1	52.0	-2.7	-4.9
With direct effects	54.7	48.8	-10.9	-19.9	52.7	-2.0	-3.8
Irrigated acreage							
Without direct effects	5.3	6.9	1.6	29.6	5.6	0.3	4.9
With direct effects	5.3	5.8	0.5	9.4	6.1	0.8	15.3

Source: Adams et al. (Volume C).

Implications

There is potential for climate change to cause decreased crop yields in the southern Great Plains. Farmers would need varieties of corn and wheat that are better acclimated to hotter and possibly drier conditions to substitute for present varieties, and adjustment strategies tailored for each crop and location.

Pressure for increased irrigation may grow in the region, particularly with more severe climate changes. This would occur for two reasons: first, crops currently irrigated would require more water where precipitation decreases; and second, more acreage would be irrigated as high temperatures increase the risk of crop failures. Increased irrigation would be needed to ensure acceptable and stable yield levels. However, availability of and competition for water supplies also may change with climate change, and defining the extent to which irrigation can provide an economic buffer against climate change requires further study.

Agricultural Economics

Many economic consequences are likely to result from the physical changes in crop yields and water availability caused by climate change. Decreased yields will further stress farmers already affected by marginal productivity and economic fluctuations. Additional irrigation needs could place greater demand on the Ogallala Aquifer and other water resources in the region. To examine the agricultural implications of climate change more closely, Adams et al. introduced yield changes from the Great Plains and other regional crop modeling studies, and changes in crop water use and water availability from the GISS and GFDL scenarios into an economic model to translate the physical effects of climate change into economic consequences. (For study design and limitations, see Chapter 6: Agriculture.) Analyses were done both for climate change alone and for the combined effects of climate change and enhanced CO_2 concentrations to explore the sensitivity of the agricultural system to the projected changes. The economic study did not address the issues of whether the physical and institutional changes required to accommodate increased demand for irrigated acreage are feasible or whether new crops would be introduced. The study did not consider changes in global agriculture.

Results

The estimates of Adams et al. (see Volume C) for total agricultural and irrigated acreage changes in the southern Great Plains States (Oklahoma and Texas only) are shown in Table 17-4. Agricultural land is estimated to decrease in the southern Great Plains in all scenarios, with and without the direct effects of CO_2. Decreases range from 4 to 22%. Irrigated acreage, on the other hand, increases in all scenarios, from 9 to 30%. This is because of increased stability of irrigated yields relative to dryland yields, and because of a rise in commodity prices that makes expansion of irrigation production economically feasible.

Implications

The results of the agricultural economics study imply that wheat and corn production may shift away from the southern Great Plains. This may weaken the economic base of many rural communities in the region and cause dislocations of rural populations. Uncertainties exist about adaptation in the region, such as substitution of more heat- and drought-tolerant varieties and crops. If irrigated acreage expands as predicted in the economic analysis, changes in capital requirements for agriculture would also occur.

If irrigated acreage does increase in the area, groundwater overdrafts also would be likely, along with associated increases in surface and groundwater pollution and other forms of environmental degradation. The current analysis did not address the issue of whether the physical and institutional changes required to accommodate such an increase in irrigated acreage are feasible.

Irrigation

Higher air temperatures cause increased evaporative demands, which largely govern crop water use and irrigation water requirements. The climate and crop production changes that might be associated with global warming in the southern Great Plains are likely to heighten farmer interest in irrigation, both because evapotranspiration may increase and because irrigated crops might obtain a larger economic advantage in a less favorable climate. Therefore, climate change impacts on irrigation water requirements were analyzed in more detail.

Study Design

Allen and Gichuki (see Volume C) evaluated the effects of climate change and reduced transpiration due to enhanced CO on crop irrigation water requirements in the Great Plains. They used an irrigation water requirement model to calculate daily soil moisture balances, evapotranspiration, and irrigation water requirements for corn, wheat, and alfalfa. The model employed the Penman-Monteith combination method to estimate crop evapotranspiration (Monteith, 1965). Four levels of potential direct effects of CO_2 on transpiration were simulated.

Limitations

Some uncertainty is embedded in the evapotranspiration and irrigation water requirement estimates owing to mismatching of weather profiles and crop characteristics. Also, this study assumed that alfalfa, corn, and wheat all would respond similarly to increased CO_2 (which may reduce transpiration), although published reports of experimental results show different responses among crops (see Rose, Volume C). The majority of results presented in this study assumed that crop varieties would not change, even though farmers may shift to crops more adapted to the changed climate.

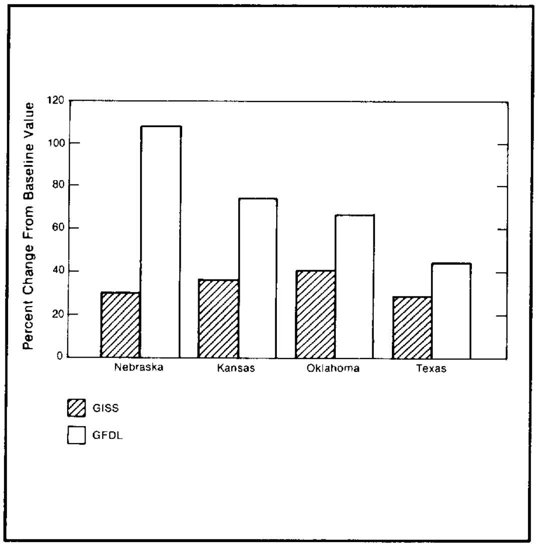
Results

In general, modeled results showed that seasonal irrigation requirements for an area growing alfalfa, corn, and winter wheat in the Great Plains would increase by about 15% under the doubled CO p scenario. These results are based on averages of the two GCM doubled CO 2 scenarios and the likely occurrence of only moderate CO_2 induced decreases in transpiration.

Irrigation requirements were estimated to vary depending on the type of crop, changes in climatic factors, and variations in response to CO_2. The perennial crop alfalfa showed persistent increases in seasonal net irrigation water requirements (see Figure 17-6). These increases are driven primarily by higher temperatures, with less influence from stronger winds, greater solar radiation, and a longer growing season.

On the other hand, decreases in seasonal net irrigation requirements were estimated for the region's two most important crops, winter wheat and corn, in most areas, depending on the projected direct effects of CO_2 on transpiration. These water need decreases would be generally due to shorter crop growing periods caused by higher temperatures, which accelerate crop maturity. When crop varieties appropriate to the longer growing season were modeled, irrigation requirements for winter wheat were estimated to increase. Water requirements during peak irrigation periods (when plant growth and temperatures are greatest) increased in almost all cases (Figure 177). These results are consistent with results from the crop modeling study.

Figure 17-6. Seasonal irrigation water requirement for



alfalfa for GISS and GFDL climate change scenarios and a moderate CO_2 induced decrease in transpiration (Allen and Gtchuki, Volume C).

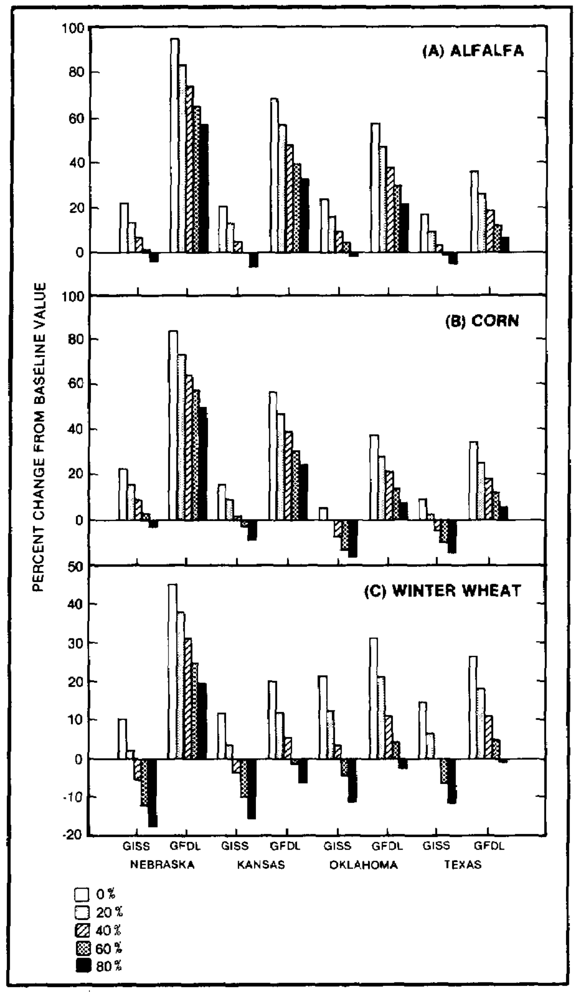
Plant canopy (leaf) temperatures were estimated to increase above current baseline values for all crops and sites studied. Increases in leaf temperatures may reduce photosynthetic activity and crop yields. They also would make crops more sensitive to moisture stress. (See discussion on direct effects of CO_2 in Chapter 6: Agriculture.)

<u>Implications</u>

Any reduction in irrigation requirements for corn and winter wheat would be beneficial in the Great Plains because less water and energy would be required to produce the crops. However, the shortened crop growth periods might allow for double-cropping (planting two crops in one season), thus increasing total irrigation requirements. Farmers may shift to longer-season varieties, which would also increase water needs.

Expanded farm irrigation systems will require increased capital investments and larger peak drafts on groundwater systems and on energy supplies. Increased groundwater extraction could pose environmental and economic problems, especially where "water mining" is currently a major problem. Any action of irrigators to increase irrigation efficiency as an attempt to cope with projected water shortages, while economically beneficial, may lead to increased salinity problems if sufficient water is not applied to meet soil leaching requirements.

Figure 17-7. Percent change in net peak monthly



irrigation requirement from baseline values for alfalfa, corn, and winter wheat for GISS and GFDL climate change scenarios and five levels of CO_2 induced decreases in transpiration (Allen and Gichuki, Volume C).

Water Quality

Agricultural pesticides are a high-priority pollution problem in at least half of the states within the US. Great Plains and Central Prairie. Potentially toxic agricultural chemicals can be removed from farmers' fields through degradation, surface runoff, sediment transport, and downward percolation. An understanding of potential climate change effects on the movements of agricultural chemicals is needed to identify potential changes in drinking water quality.

Study Design

Johnson et al. used the Pesticide Root Zone Model (PRZM) (Carsel et al., 1984) to simulate the partitioning of pesticides between plant uptake, chemical degradation, surface runoff, surface erosion, and soil leaching in the Great Plains under baseline climate and climate change scenarios. The locations modeled were representative of cropping practices for winter wheat and cotton in the region. The interactions among soil, tillage, management systems, pesticide transport, and climate change were studied. (For further discussion of the study's design and limitations, see Chapter 6: Agriculture.)

Results

As Figure 17-8 shows, surface runoff and surface erosion of agricultural pesticides increased under the GISS scenario for the winter wheat regions of the Great Plains. In the southern Great Plains cotton simulations, both the GISS and GFDL scenarios produced increases in surface pesticide losses with runoff and eroded soils.

The quantity of pesticides leached below the crop root zone is estimated to decrease everywhere except on silty soils in the cotton region. This overall decline most likely results from higher evaporative demands in response to temperature increases and to less available moisture for infiltration and deep percolation.

Implications

Results of the modeling imply that water quality in the southern Great Plains may be affected by climate change. However, because these results are highly dependent on the frequency and intensity of precipitation events, directions of change are uncertain. Surface water appears to be vulnerable to deterioration under climate change conditions, although the result does not hold for all cases. Groundwater quality in some areas appears to be less at risk than surface water quality. However, groundwater impacts will depend on total acres under production, application rates, soil type under cultivation, and changes in irrigated versus dryland acres.

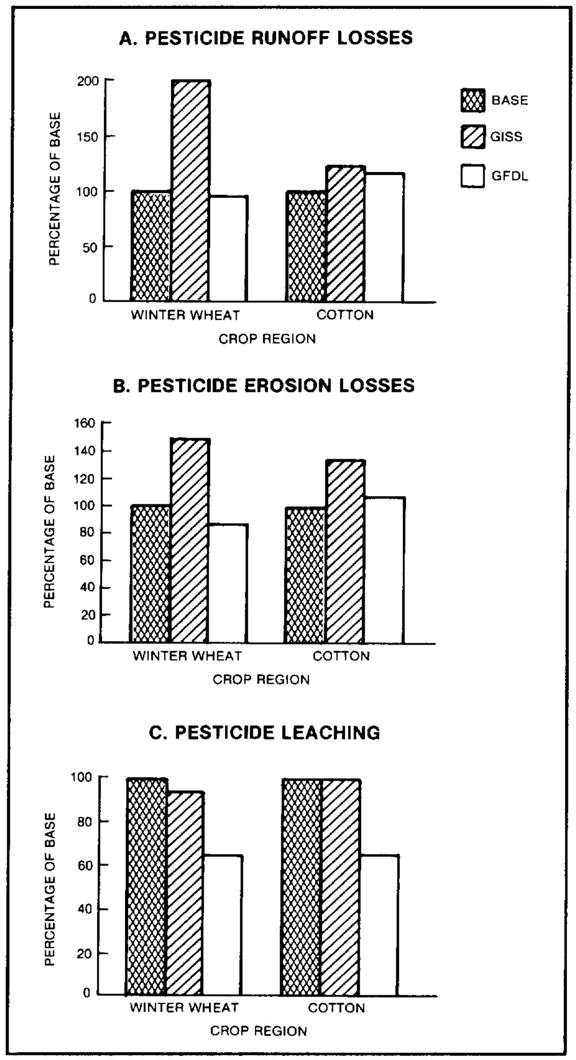


Figure 17-8. Regional summary of surface and subsurface pesticide loss as a percentage of the base climate scenario losses (Johnson et al., Volume C).

From a water quality perspective, decreased pesticide leaching may be advantageous. From a water quantity perspective, these results could be cause for concern. Less leaching can imply less water movement through soil profiles and less water availability for aquifer recharge. If water demands were to increase (as suggested by the crop production, economic, and irrigation analyses) at the same time that recharge rate decreased, competition for scarce water resources could increase dramatically in the region.

Livestock

Livestock production is a critical agricultural activity in the Great Plains and may be sensitive to climate fluctuations in several ways. The warming in the climate change scenarios may alleviate cold stress conditions in the winter but would exacerbate heat stress in the summer. Warmer summers are likely to necessitate more hours of indoor cooling. Reproductive capabilities have been shown to decline as a result of higher temperatures. Higher temperatures also may enable tropical diseases and pests to extend their ranges northward into the southern Great Plains. High temperatures also may reduce insect pest activities in some locations and increase them in others. (For a discussion of livestock issues, see Chapter 6: Agriculture.)

Schmidtmann and Miller (see Volume C) modeled the effect of climate warming on the horn fly, a common pest of pastured cattle that causes reductions in weight gain and milk production. (For a description of study design and limitations, see Chapter 6: Agriculture.) This study used only the GFDL scenario; since it had the highest temperatures, results should be considered as an extreme case. In Texas, horn fly populations were estimated to become lower in summer than they are currently because high temperatures are lethal to the insects when they are immature. Thus, weight gains of calves and feeder/stocker cattle could increase relative to current rates in Texas. In Nebraska, however, temperatures in the GFDL scenario would not reach lethal levels, and increases of 225 to 250 horn flies per head were estimated. This would result in greater weight reductions than those currently observed. These results suggest that greater stress may occur in livestock production in the northern part of the Great Plains, and that stress may be alleviated in Texas.

Stem et al. (see Volume C) studied the effects of climate change on animal disease patterns. (For study design and limitations, see Chapter 6: Agriculture.) The ranges of some diseases may be extended as habitats of disease vectors enlarge or as warmer environments permit longer seasonality of diseases currently present. Stem et al. calculated that the ranges of bluetongue and Rift Valley fever (both serious or potentially serious diseases of cattle) could be extended northward from Texas to Kansas and Nebraska with climate warming. Climate change thus has the potential to cause increased incidence of animal disease and to increase stress on livestock production in the Great Plains.

Electricity Demand

Linder and Inglis (see Volume H) estimated the changes in demand for electricity for the years 2010 and 2055. (For a description of the study's design and methodology, see Chapter 10: Electricity Demand.) In each case, they first estimated the change in electricity demand due to projected regional economic and population growth, and then factored in changes in demand based on the GISS transient climate change scenarios A and B. The results for the southern and central Great Plains are discussed here.

Results

Estimates of changes in peak demand, capacity requirements, and cumulative and annual costs projected for the climate change scenarios in the Great Plains are shown in Table 17-5. The results are driven by seasonal changes in weather-sensitive demands for electricity: summertime use for airconditioning and irrigation-pumping increases and outpaces reductions in demand for space heating in the winter. Electricity demand grows by 2 to 4% by 2010, and new capacity requirements are estimated to increase by 15 to 28% by 2010 for the climate change scenarios as compared with the base case (i.e., economic growth without climate change). By 2010, additional cumulative capital costs induced by climate change may be $3.7 to $6.7 billion, and annual costs of generating power may rise by 3 to 6%.

In 2055, new capacity generating requirements are estimated to increase by 22 to 45 gigawatts or 27 to 39%. Annual electricity demand in the region increased an additional 10 to 14% by 2055 under the climate

Table 17-5. Estimated Change in Peak Demand and Annual Energy Requirements Induced by Climate Change (%)

Utility area	2010				2055	
	GISS A		GISS B		GISS A	
	Ann.	Peak	Ann.	Peak	Ann.	Peak
Kansas/Nebraska	1.7	6.8	1.3	5.2	5.7	22.1
Oklahoma	3.0	7.9	2.8	6.6	11.3	25.3
Texas, east	3.0	7.9	2.8	6.6	11.3	25.3
Texas, south	3.3	10.0	1.7	5.1	10.6	24.6
Texas, west	3.1	8.6	2.4	6.1	11.1	25.1

Source: Linder and Inglis (Volume C).

change scenarios. New capacity requirements without climate change are estimated to be 20 GW by 2010 and 112 to 134 GW by 2055.

Linder and Inglis calculated that cumulative capital costs for electricity in the region would increase from $20 to $53 billion by 2055 with climate change. The estimated changes in annual costs induced by climate change range from $5 to $10 billion.

Implications

Increased electrical capacity requirements and the need to maintain the reliability of utility systems could place additional stress on the Great Plains. This is especially important if climate change increases the demand for irrigation, which is an important consumer of electricity in the region. Also, the potential exists for conflicts between power production and agriculture over the use of scarce resources such as water. Powerplants may take the cooling water they need from rivers or from the already overused Ogallala Aquifer, and increased coal and oil production in the region would utilize land that might be farmed. However, energy production may provide alternative income sources in an area whose economy is poorly diversified.

CLIMATE CHANGE AND THE OGALLALA AQUIFER

Warming and/or drying in the Great Plains may place greater demand on regional groundwater resources. Although the Ogallala Aquifer has come under close scrutiny in the past, it is important to note that previous studies have not addressed potential climate change impacts on this resource. Many of the problems associated with intense groundwater use (water depletion, soil damage, altered rural and farm economics, and potential reversion to dryland farming) could be exacerbated by global warming. This study shows that irrigated acreage in the Great Plains could increase and that the demand on the aquifer could rise by up to 15%. These potential adjustments to climate change should be studied to understand their implications for land use, resource conservation, regional economics, and community issues in the Ogallala area.

POLICY IMPLICATIONS

The policy options for responding, either in anticipation or in reaction, to climate change in the Great Plains range from noninterference, in which agricultural, water, and other resource systems are left to adjust without assistance, to a more active approach in which federal, state, and local government agencies plan for and assist in the process of adaptation.

Given the historical government involvement in agriculture, especially in this marginal region where support programs may mean the difference between farm survival and failure, it is likely that an active adjustment process will be called for. PoGcymakers in the Great Plains may have to respond to decreased agricultural production in the area, increased demand for water and electricity, poorer water quality, and changes in livestock production. The major issues that policymakers should address include land-use management, water resource management, and agricultural risk management (see Riebsame, Volume J). Regional utility planners and policymakers should also begin to consider climate change as a factor -- along with other uncertainties -- affecting their resource availability analyses and planning decisions.

Of course, uncertain and limited impact assessments such as those described above cannot be used to create and implement detailed policy. Rather, they should be viewed as scenarios that suggest the types of policies and the range of policy mechanisms and flexibilities that could alleviate potentially disruptive impacts from climate change. The eventual problem for the policymaker, of course, is deciding when to switch from scenario analysis to actual policy formulation and implementation. The last few sections of this chapter suggest some of the policy implications raised by the impacts described earlier.

Land-Use Management

Land managers should analyze how their missions and holdings may be affected by climate change and should develop flexible strategies to deal with potential impacts. Federal agencies, such as the Department of Agriculture, the Forest Service, the Fish and Wildlife Service, and the Department of Interior, should work with state agriculture, forest, and park agencies on such plans.

Climate change may cause agriculture and other land uses to become more environmentally and economically marginal in the Great Plains. Consequently, land uses may shift in intensity, type, and location. Indeed, locational shifts may involve several states or multiple regions. This adjustment process can be made more efficient and less disruptive if individual jurisdictions, such as municipalities, states, and federal regions, respond in a coordinated manner. Decisions made by managers of agriculture will affect forests, wildlife, and water resources. Decisionmakers should begin now to work together to develop a sound and flexible repertoire of anticipatory strategies; new institutional arrangements may be needed.

Some programs already in place can help to lessen the negative effects of climate change on the Great Plains. Federal legislation such as the "SodBuster Bill" and programs such as the Conservation Reserve Program are examples of new policies designed to reduce the use of marginal lands for agriculture. The basic goals of these laws are to protect the most erodible farmlands by removing them from crop production, and to use conservation as a tool for reducing overproduction. Such programs are prudent now for reducing erosion and may become even more important for protecting soil and water quality in a changing climate. However, protection of marginal lands may have to be weighed against the need for greater crop production if climate change lowers yields. For example, the government's response to the 1988 drought was to release some conservation land for cropping in 1989. This would help replenish food stocks but also would place a greater amount of marginal land at risk of erosion.

Water Resource Management

If GCM projections of climate change are qualitatively correct, parts of the Great Plains are likely to suffer increasing aridity. Farmers may demand more water for irrigation, although groundwater sources are already taxed. Competition for water resources between agricultural and nonagricultural demands may be exacerbated. Water managers need to factor the potential effects of climate change into their decisions on irrigation, drainage, and water transfer systems, and they should consider potential climate change as they formulate supply allocation rules, reservoir operating criteria, safety protocols, and plans for long-term water development. Water conservation techniques, water reallocation between competing uses, water transfers and marketing, and land-use adjustments should be evaluated for their ability to absorb the effects of a range of future climate changes. The goal at this point may not be to formulate detailed policy, but rather to test the climate sensitivity and feasibility of alternative water management policies and practices.

Decisionmakers should also consider the potential effects of climate change on water quality and the use of pesticides. They should examine alternative pest control strategies, such as Integrated Pest Management, which use biological control, genetic resistance, and innovative cropping systems to reduce pesticide applications.

Risk Management

Several government, semiprivate, and private institutions have a large financial stake in Great Plains agriculture through land credit, commodity and equipment loans, and insurance. Additionally, the federal government provides disaster relief for climate extremes affecting regional agriculture. Climate warming poses a potential long-term risk to the financial institutions supporting agriculture, to the resources available for emergency relief, and to individual farmers. This possibility should be carefully assessed, and plans should be made now to monitor risk as climate changes.

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CHAPTER 18
RESEARCH NEEDS

by Anthony Janetos

This report has suggested that concerns over the adaptability and fate of both natural and managed ecosystems in a changed climate are well founded. Natural forested ecosystems, aquatic and marine biota, wildlife in refuges, water quality in small lakes, and other resources may be vulnerable to rapid climate change. Strategies for mitigating changes in these systems are likely to be complex and difficult to implement. While it may be difficult to quantify the consequences, climate change may have large effects on biodiversity, primary productivity, and cycling of nutrients, and it may be difficult, if not impossible, to reverse these impacts.

This report has also shown that while intensively managed ecosystems, especially agroecosystems, may also be affected by a climate change, there seem to be more opportunities for human intervention to mitigate or adapt to their responses. Thus, the critically important question is whether the capacity for human intervention can keep pace with the rate of change induced by changing climate. Areas of major concern are the interactive effects of climate change and carbon dioxide increases on crop yields, and the adaptation rate of management practices.

Although it is clearly not possible to study all the potential effects of a change in the climate system, or to consider all the possible social or political ramifications of responding to climate change, there will be a continuing need to understand better the possible consequences of climate change because adaptation to different climates will be a necessary part of any complete societal strategies to cope with the greenhouse effect. Therefore, it is important to have in place a research framework for both the natural and the social sciences that will provide the information required to allow societies to respond to the challenge of large-scale, rapid changes in the climate system. This research should be undertaken simultaneously and in coordination with programs directed at establishing a broad consensus for governmental actions, both domestic and international, that address energy, land use, and other social policies that might lead to reduced emissions of greenhouse gases.

Research in the natural and social sciences must have an important role in developing wellreasoned adaptation strategies because it will provide the data and understanding of processes necessary to design efficient responses to a new climate, and better management techniques for the resources that must be conserved.

The needs of U.S. and international policymakers for information on the possible environmental effects of climate change and the processes that control them should not be underestimated, especially since the task of attempting to mitigate emissions of greenhouse gases is so large and complex. This chapter identifies some of the major topics for research in the natural and social sciences that should be pursued to help policy analysis and development in t1us area.

The scope of this chapter is necessarily broad. It addresses both the research proposed by EPA and the research recommendations of the scientific research community from a perspective that the development of sound environmental policy, both for mitigation and adaptation, depends on the capability of the scientific research community to respond to increasingly specific demands for information from policymakers.

RELATIONSHIP BETWEEN POLICY AND SCIENCE

Secretary of State James Baker and EPA Administrator William Reilly recently set forward four principles to guide policy development:

> The first is that we can probably not afford to wait until all of the uncertainties have been resolved before we do act. Time will not make the problem go away.

> The second is that while scientists refine the state of our knowledge, we should focus immediately on prudent steps that are already justified on grounds other than climate change. These include reducing CFC emissions, greater energy efficiency, and reforestation.
>
> The third is that whatever global solutions to global climate change are considered, they should be as specific and cost-effective as they can possibly be.
>
> The fourth is that those solutions will be most effective if they transcend the great fault line of our times, the need to reconcile the transcendent requirements for both economic development and a safe environment.

These four principles establish a framework within which both domestic and international programs will develop. They balance the needs for both scientific research and policy development, while clearly recognizing the international scope of the issue. In doing so, these four principles will act as the basis for U.S. participation in international assessment activities, as well as for domestic policy development.

The Global Climate Protection Act of 1987 directs EPA and the State Department to coordinate the development of national policy for global climate change. This coordination involves many other agencies with essential policy roles, such as the Department of Energy.

In addition, the Global Climate Protection Act directs EPA, in cooperation with other agencies, to prepare a scientific assessment of climate change. This assessment is now being coordinated through the Intergovernmental Panel on Climate Change, an organization created under the joint auspices of the United Nations Environment Programme and the World Meteorological Organization (WMO). It will be developed by a work group with extensive U.S. participation coordinated through the Federal Coordinating Committee on Science and Engineering Technology Committee on Earth Sciences. A second work group will analyze climate change impacts, and a third work group is responsible for examining response strategies. Each work group has approximately 18 months to develop an interim report. Reports from these three work groups will be critical to the development of international scientific and policy consensus on greenhouse issues.

EPA's domestic responsibilities, and the research reported on in this document, have led us to formulate several important questions that should be thought of as overriding themes, rather than as a list of all the potential issues:

- How rapidly might climate change as a result of future manmade emissions?
- What are the likely regional atmospheric manifestations of such global atmospheric changes?
- What are the likely extent and magnitude of ecological, environmental, and societal changes associated with a given change in regional atmospheres?
- What technologies and policy options exist to reduce the rate of growth in greenhouse gas emissions, and how much would they cost?
- What are the cultural and institutional barriers that might limit the implementation of such options?
- What are the likely consequences of proposed mitigative or adaptive policies?

These questions are viewed as the foundation for analyzing possible environmental changes due to climate change, and eventually for analyzing possible approaches to managing risks. They begin to match needs for policy development with scientific needs for understanding the functioning of the Earth as an integrated system. By doing so, they define the specific areas in which scientific research is necessary: biogeochemical dynamics, physical climate and the hydrologic cycle, ecosystem dynamics, Earth system history, and human interactions with the geosphere-biosphere. Indeed, they justify an overall program of research, with one of the main goals being to "establish the scientific basis for national and international policymaking related to natural and human-induced changes in the global earth system" (Federal Coordinating Committee on Science and Engineering Technology).

RESEARCH AND ASSESSMENT NEEDS IN THE SOCIAL SCIENCES

This report has identified many important issues that policy analysts and decisionmakers must begin or have begun to address. It is apparent that even for the heavily managed environmental resources such as agriculture and water supply, an existing range of concerns makes the response of resource managers to climate change difficult to predict. Even current climate variability is not always accounted for in resource management. Yet it is the response of resource managers and environmental policymakers to climate change that will ultimately determine how society responds to a changed climate both for managed and natural resources. The inadequacy of our current knowledge regarding how their decisions are made demands closer attention from the social science research community.

Institutional Response to Climate Variability and Climate Change

One of the major issues identified in t1us report is how institutions respond to current variability in climate. It is well known that current climate variability, represented by such episodes as the recurrence of the El Nino and periodic droughts, can have catastrophic effects on major regional industries, that in turn have larger, sometimes global consequences on supply and processing of resources. It is also well known that in both the relatively distant and relatively recent past, variability in climate has led to severe regional economic dislocation and subsequent migration of large numbers of people, even in industrialized societies such as the United States. What is not as well known is how the U.S. institutions responsible for managing agriculture, forestry, and water resources will be able to respond to future climate variability, especially if that variability increases. The drought of the summer of 1988 clearly illustrates that U.S. farms are still susceptible to severe weather conditions; it does not, however, answer the question of whether a succession of such droughts, as might be expected in future scenarios of a warmer, drier Grain Belt, could be accommodated by the existing government programs.

Water resource managers face similar problems. In California, all the scenarios indicated that large changes in the management of water might need to be considered if the snowpack were smaller and melted earlier. In the Great Lakes, lower water levels may necessitate changes in management. While changes in precipitation remain the most uncertain of the outputs from GCMs, the lessons for research in water management are relatively clear. We need to understand the degree to which there is flexibility in water allocation decisions, and to develop the information needed by water managers to evaluate possible changes in allocation under climate change.

In each of these cases, both the institutional and historical factors that affect the decisionmaking process must be analyzed and understood, as must local, regional, and national political influences. In particular, the problems of designing resource management systems for flexible response need to be addressed as institutional and investment questions. While the need for flexible resource management is clear, the reality of maintaining flexibility while still making decisions regarding large capital expenditures, such as building powerplants and dams, may be quite difficult. There will be a continued need to conduct targeted case studies of how resource managers currently consider climate variability and to address potential future changes in variability (see Chapter 19: Preparing for Climate Change).

In addition, while climate change may ultimately be one of the most important variables that managers must consider in the decisionmaking process, it may not be the most immediate. Research is necessary to show how devoting attention and resources to a developing issue such as climate change makes sense from a management and policy standpoint. Research is also necessary to examine the differences in how a wealthy, highly industrialized society, such as the United States, makes decisions about responding to climate variability and change and how other societies, especially lesser developed countries, make such decisions. Since climate change is intrinsically a global issue, such studies will be necessary to form a consensus regarding the need for coordinated responses and management strategies.

RESEARCH AND ASSESSMENT NEEDS IN THE NATURAL SCIENCES

As reviewed by the National Academy of Sciences Committee on Global Change (NRC, 1988), in order to be responsive to policy concerns, the primary scientific research needs are in those phenomena and processes that occur on global scales, or that occur on regional scales but will have global consequences over the next few decades to a few centuries. Therefore, research and assessment activities must examine global scale questions of emissions and atmospheric chemistry as well as the regional consequences of global atmospheric change. The transition from traditional disciplinary investigations of processes to interdisciplinary investigations of the links between processes on such large spatial scales will demand new approaches from the scientific research community.

Figure 18-1 represents in schematic fashion the information flow that must occur among scientific disciplines while explicitly taking into account the transitions between spatial scales. It indicates that the purpose of conducting research in emissions of trace gases, inventorying and evaluating the emission factors of anthropogenic and biogenic sources of trace gases, evaluating possible technological controls, investigating the possibility of positive feedbacks, and attempting to realistically simulate the emissions of trace gases is to provide information for understanding the composition of the atmosphere. Models can then be used to create estimates of atmospheric composition on approximately the same temporal and spatial scales.

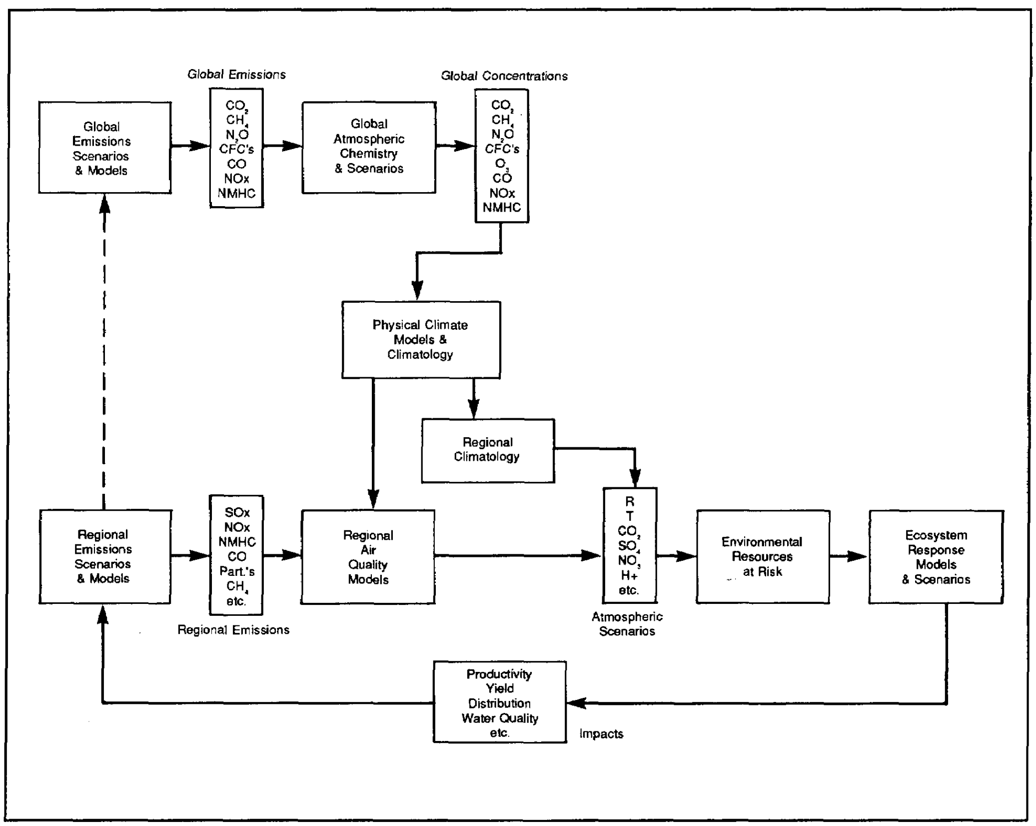


Figure 18-1. Relationship between global and regional information flow.

Climate System

The scientific research community should fully investigate the dynamic consequences of different compositions of the atmosphere, including the dynamics of the ocean as it influences both atmospheric composition and heat transfer. The derivation of regional climate scenarios from either modeling output or analog methods and scientific understanding are then necessary to link the processes on global scales with environmental and ecological research questions on regional and local scales. The climate system modeling community, as well as the statistical climatology community, must devote significant effort to improving the ability of the atmospheric sciences to make predictions on relatively small regional scales, so that policymakers can begin to have some quantitative confidence in the results from environmental and ecological modeling.

Research Scales

A further critical link identified in Figure 18-1 is that estimates of environmental changes will be needed on spatial scales that are larger than ecologists and environmental scientists have traditionally used in their research (e.g., ecoregions to biomes). While initially qualitative, as in much of this report, these estimates will be used both as input for assessments and as a way to formulate series of testable hypotheses concerning the processes that control projected ecological changes.

The ecological and environmental research community must, therefore, define those atmospheric variables that control the growth and distribution of major vegetation types, including crops, and must explore the physical and biological processes that control the distribution of water and nutrients in natural and managed landscapes. These definitions and processes must be those that affect the characteristics and dynamics of ecosystems on spatial scales commensurate with the atmospheric scales dermed above.

Socioeconomic Impacts

The final major link is between the ecological and environmental consequences of climate change and emissions of greenhouse gases. This link must include the interaction between societal impacts, such as changes in energy demand and end-use, and changes in emissions. It will be critical to establish interdisciplinary communication because of feedbacks between the biosphere and the atmosphere. Clearly, changes in the growth and distribution of major terrestrial vegetation types, as well as changes in ocean chemistry and biology, will alter biogenic emissions of trace gases. Of critical importance is the possibility that these biogenic emission changes may lead to even greater temperature changes (positive feedbacks), as has been hypothesized for methane. How climate change will affect anthropogenic emissions, and whether changes would be positive or negative feedbacks, is largely unexplored.

Data

Underlying all these concerns for the interaction among processes in the natural world is a critical need for long time-series of data on Earth system processes, and the information systems necessary to manage the data. No amount of modeling or experimentation of processes will replace actual observations of how the Earth system responds to changes in climate forcing and the degree and characteristics of its natural variability.

Objectives of Federal Global Change Program

Both the NAS (NRC, 1988) and the Federal Global Change Program (CES,1989) have identified the scientific elements intrinsic to understanding the Earth's behavior as an integrated system, and especially its response to global atmospheric change. The section below summarizes the scientific elements and their rationale, and presents the broad scientific objectives of the research to be sponsored in the Federal Global Change Program. These scientific elements refer directly back to the needs for information identified in Figure 18-1, as shown in Figure 18-2.

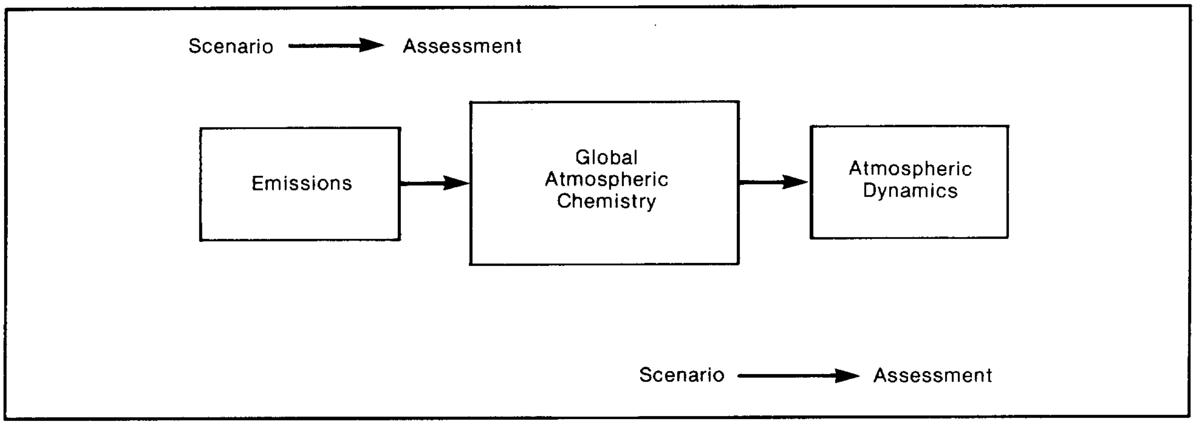


Figure 18-2. Two-stage scenario approach to integration.

- Biogeochemical dynamics include (1) the sources, sinks, fluxes, and interactions between biogeochemical constituents within the Earth system; (2) the cycling of biogeochemical elements in the atmosphere, oceans, terrestrial regions, biota, and sediments over Earth's history; and (3) the influence of biogeochemical elements on the regulation of ecological systems and contribution to potential greenhouse constituents (CO_2, CH_4, N_2O, CFCs) that have a direct influence on mate.

- Ecological systems and dynamics would involve the responses of ecological systems, both aquatic and terrestrial, to changes in global environmental conditions and of the influence of biological systems on the atmospheric, climatic, and oceanic systems. This includes studies of plant succession, terrestrial and aquatic biodiversity, extinctions, and relationships with geological substrate. Monitoring and specific ecosystem experiments can provide information on stresses influencing the biota and on the biotic response to natural and societal environmental stresses. Such information is needed to achieve the basic understanding required for the development of models. Identification and study of particularly sensitive ecosystems will be especially informative.

- Climatic and hydrologic systems would involve the study of the physical processes that govern the atmosphere, hydrosphere (oceans, surface and groundwaters, etc.), cryosphere (i.e., glaciers, snow), land surface, and biosphere.

These are clearly central to the description, understanding, and prediction of global climate change, particularly in terms of impacts on global climate conditions and the hydrologic system.

- Human interactions has been defined as the study of the impacts of changing global conditions on human activities. The global environment is a crucial determinant of humanity's capacity for continued and sustained development. Research should focus on the interface between human activities and natural processes.

- Earth system history is the study of the natural record of environmental change that is contained in the rocks, terrestrial and marine sediments, glaciers and ground ice, tree rings, eumorphic features (including the record of eustatic changes in sea level), and other direct or proxy documentation of past environmental conditions. These archive the Earth's history and document the evolution of life, past ecosystems, and human societies. Past ecological epochs with warmer or cooler climates relative to the present climate are of particular scientific interest.

- Solid-earth processes include the study of certain processes that affect the lifesupporting characteristics of the global environment, and especially the processes that take place at the interfaces between the Earth's surface and the atmosphere, hydrosphere, cryosphere, and biosphere. Solid-earth processes that directly affect the environment are of primary interest; processes that have only indirect effects are excluded.

- The solar influence is the study of the variability in solar radiation and its impact on atmospheric density, chemistry, dynamics, ionization, and climate. Research on the effects of solar variability on biogeochemical cycles as well as the impact of ultraviolet light on biology and chemistry would be particularly important here.

Of these scientific elements, studies of biogeochemical dynamics, climate and hydrologic systems, ecosystem dynamics, Earth system history, human interactions, and to a lesser extent, solar influences, are the most important from the standpoint of developing a policy-oriented research program. The degree to which the solid-earth processes are important depends entirely on their contribution to global change over the time-scale of a few decades to a few centuries. A better understanding of these processes remains an important scientific aspect of a Federal Global Change Program but can be anticipated to have less value from a public policy perspective.

Three Major Scientific Objectives

The scientific elements relevant to the development of well-informed public policy must be structured in a way that permits the overall objectives of the U.S. program to contribute to both scientific and policy communities. To accomplish this, the Federal Global Change Program has outlined three major objectives in its Strategy Document (CES, 1989).

1. Establish an integrated, comprehensive program for Earth system measurements on a global scale.

2. Conduct a program of focused studies to improve our understanding of the physical, chemical, and biological processes that influence Earth system changes and trends on global and regional scales.

3. Develop integrated conceptual and predictive Earth system models.

Each of these objectives simultaneously leads toward improving the monitoring, understanding, and predicting of global change. They aim to provide, by the year 2000, detailed assessments of the state of the knowledge of natural and humaninduced changes in the global Earth system and appropriate predictions on time scales 20 to 40 years into the future. Assessments of uncertainties in model outputs will be an integral part of these predictions.

THE ROLE OF EPA IN POLICY AND SCIENTIFIC RESEARCH

EPA's own activities have been structured to provide leadership in both policy analysis and development, as required by the Global Climate Protection Act, and in scientific research, especially on the consequences of changes in the climate system. The development of a broad-based, interdisciplinary scientific research program that responds to the policy-oriented questions identified earlier in this chapter has depended strongly on concurrent scientific planning efforts by the National Academy of Sciences and the Federal Global Climate Change Program.

Specifically, the goals and objectives of the EPA Global Climate Change Research Program have been structured to respond both to the policyoriented questions, and to the scientific needs identified by NAS in the U.S. proposal for the International Geosphere Biosphere Program and as adopted by the Federal Global Change Program. The program is designed to provide information on the biosphere and its response to climate change and technical information to develop policy options to limit and adapt to climate change. EPA's proposed research has two goals:

1. To assess the probability and magnitude of changes in the composition of the global atmosphere, the anthropogenic contributions to those changes, and the magnitude of subsequent impacts on the environment and

society.

2. To assess the likely extent, magnitude, and rate of regional environmental effects as a function of changes and variability in climate, for the purpose of evaluating the risks associated with changes in the climate system.

Eight associated scientific and institutional objectives have been identified:

1. To develop improved estimates for both anthropogenic and natural sources of radiatively important trace gases, and to investigate the feedback processes by which climate variability influences the sources of these gases.

2. To develop techniques for estimating current and future emissions of radiatively important trace gases.

3. To improve understanding of global atmospheric chemistry in order to project future concentrations of trace gases, including tropospheric ozone.

4. To relate global changes in climate to regional changes by constructing a series of regional atmospheric scenarios.

5. To predict ecosystems' responses to climate change and to test the processes that control those responses.

6. To document the spatial covariation of regional climate change with regional ecological change in order to establish comprehensive ecological monitoring in selected locations, cooperatively with EPA and other federal programs.

7. To develop information on technologies and practices that could limit greenhouse gases and to adapt to climate change.

8. To produce periodic scientific assessments in conjunction with other federal agencies and international research organizations, and to perform research to evaluate the consequences of adaptation and mitigation policies.

While defining the framework for EPA's own scientific research, these goals and objectives also assume that all federal agencies with significant policy responsibilities in issues of global climate change are going to be able to take advantage of developments in all areas previously discussed. Many of the developmental needs in the atmospheric and space sciences, and many of the global monitoring needs, will be beyond the capability of any one federal agency and will require the cooperation of all.

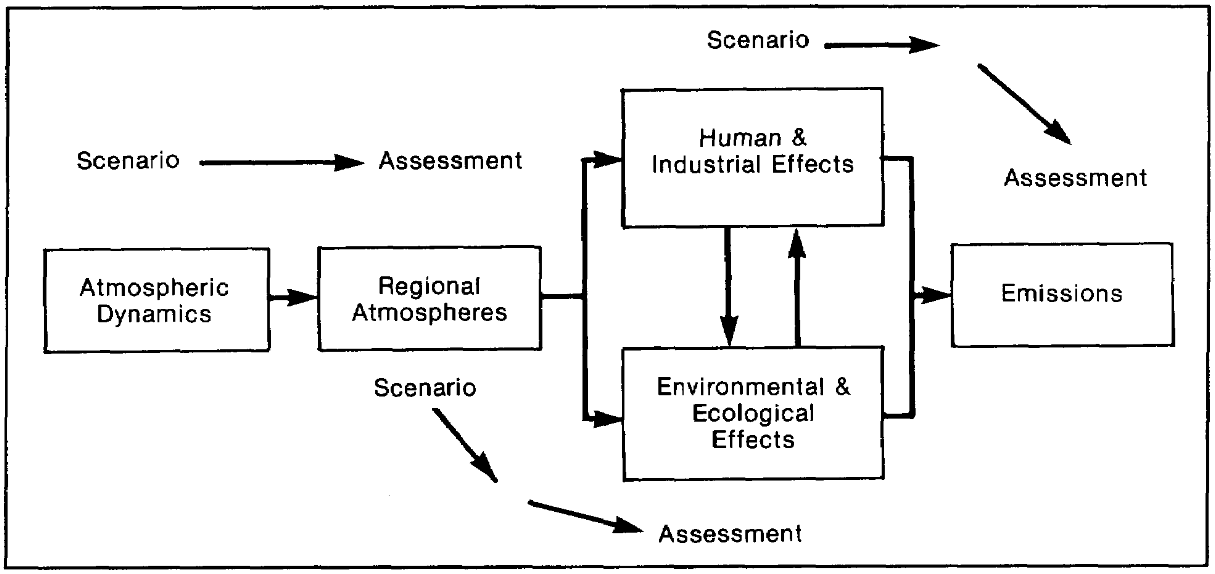
The goals and objectives of proposed policy research and activities in EPA closely follow the previously listed recommendations. The main foci will be on the development and coordination of a national policy, as called for in the Global Climate Protection Act, and the coordination and implementation of the International Response Strategies Assessment of the IPCC. Both mitigation and adaptation policies will be investigated, as outlined in the following chapter.

IMPACT ASSESSMENT METHODOLOGY

Continued efforts at assessing the causes and consequences of climate change are clearly needed. This report has illustrated one potentially valuable method for conducting such an assessment. However, because the need will continue, there is a corresponding need to consider how best to do assessments in a way that preserves both the understanding of what may happen and the certainty with which we know it. This section outlines the approach that will be taken in future impact assessment efforts led by EPA.

Integrated modeling of large-scale environmental issues has been attempted many times before and may be useful for policy analysis or for heuristic purposes. However, there is general agreement within the scientific community that a model adequate to simulate the dynamics of geophysical, chemical, and biological processes on global scales will be developed only after decades of research (ESSC, 1988).

Although achieving such a goal lies so far in the future, the question of how to deal with integrating diverse aspects of science in global climate change and its potential effects in the nearer term remains. One promising approach for integrating research results is to



treat the entire cycle of information flow (Figure 18-1) as a series of two-stage processes (Figures 18-2 and 18-3).

Figure 18-3. Three-stage approach to integration.

Within each two-stage process, research results should be treated as follows: The first part of the process is the creation of a set of scenarios, where a scenario is defined as a plausible combination of variables derived from a set of internally consistent assumptions. The second part of the process will evaluate the range of changes that are potentially attributable to each scenario and will evaluate the sensitivity of the underlying systems to different aspects of the scenarios. Thus, scenarios of changes in land use could be used to evaluate possible changes in emissions; scenarios of emissions could be used to evaluate the possible changes in atmospheric composition; scenarios of atmospheric composition could be used to evaluate changes in climate; climate scenarios could be used to evaluate the possible changes in ecosystems; and scenarios of ecosystem and land-use changes can in turn be used to evaluate possible changes in emissions.

The use of a scenario-assessment approach for impact assessments has several advantages. It could provide clear priorities for research on the sensitivities of important environmental processes in each scientific area. It maintains a realistically holistic view of the problems of global change, and it preserves information on the uncertainty of model results and data, in both qualitative and potentially quantitative fashion.

Each pair of scenario-response steps is explicitly decoupled from other pairs, while remaining consistent with them. Thus, such an approach can indicate both ranges and sensitivities of responses in potentially verifiable fashion within each pair, but does not attempt the premature task of modeling uncertainty all the way through the global system.

The use of scenarios as assessment and integrative tools is not part of the traditional scientific approach toward prediction and validation. Nevertheless, it is important from three standpoints:

- For scientific information to be of use to policymakers, a continued iterative process of evaluating the state of knowledge in the suite of sciences relevant to global change must be maintained. An iterative process of using and analyzing scenario-based assessments can provide such information in a usable and informative way.

- To achieve the multidisciplinary syntheses needed to make scientific advances in problems of global climate change, evaluation of the methods by which predictions are made and by which scenarios of change can be composed, and evaluation of the sensitivities of affected processes must continue. The scenario-based assessment approach provides a ready-made integrating framework for such continual evaluations.

- Because of the importance of this proposed research in public policy arenas, it is critical not to lose sight of what is and is not predictable. By distinguishing between a set of scenarios and actual verifiable predictions, the scenario-based approach can best illustrate the difference without becoming a morass of hedged bets.

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CHAPTER 19
PREPARING FOR CLIMATE CHANGE

by James G. Titus

The preceding chapters suggest that a global warming could have significant impacts on farms and forests, rivers and lakes, fish and wildlife, and many practical aspects of everyday life. This issue is very different from other environmental problems. It is global in scope: all nations emit greenhouse gases and all will experience the impacts. Moreover, the changes are likely to last for centuries and could shape the very nature of society. Although many of the possible consequences may not occur for decades, it is important that we begin now to examine how we might respond.

The potential responses fall broadly into two categories: (1) limiting the change in climate; and (2) adapting to it. These two responses are complementary, not mutually exclusive. Because past emissions of greenhouse gases may eventually warm the Earth one degree Celsius, some adaptation will be necessary, and efforts to prepare for global warming can contribute information to the process of deciding whether, when, and how to limit it. On the other hand, slowing the rate of global warming would make it easier for humans and other species to adapt.

Although limiting climate change would require worldwide cooperation, responding to its consequences would not. Private citizens and companies can relocate or modify their operations. Communities and states can undertake public works or enact planning measures. Charitable foundations and profit-making corporations can support research to develop better response strategies. National governments can support all of these activities.

Preparing for global warming raises three challenges. First, the uncertainties make it difficult to be sure that we are employing the correct response: the climate may change more (or less) than anticipated; in the case of precipitation, we do not even know the direction of change. Second, the long-term nature increases the difficulty of forecasting the impacts and gaining the attention of decisionmakers more accustomed to focusing on near-term problems. Finally, adaptation would require thousands, perhaps millions, of decisionmakers to consciously consider global warming as they plan their activities.

These differences need not thwart the process of preparing for global warming. First, many types of institutions already cope with equally long-term and uncertain trends; transportation planners, for example, routinely consider economic growth over 30- to 50-year periods when picking routes for highways and urban rail systems. Second, reaching a consensus on what is fair would be easiest when no one feels immediately threatened. Finally, the decentralized nature of adaptation would enable the communities and corporations most sensitive to climate change to respond quickly, rather than having to await a national consensus on the most appropriate response.

Because a companion report ("Policy Options for Stabilizing Global Climate") examines options for limiting future global warming, this chapter focuses on adaptation strategies. We briefly discuss the process of choosing such strategies, then present several examples.

WHEN IS A RESPONSE WARRANTED?

Strategic Assessments

One of the most fundamental issues facing decisionmakers is whether to implement responses today or to defer preparation until the timing and magnitude of future climate change are more certain and the potential impacts are more imminent. Although global warming might eventually require particular actions, such actions need not necessarily be taken today. On the other hand, the likelihood of at least some global warming is sufficiently well established and the time required to develop a response sufficiently long that deferring all preparation could lead us to miss opportunities to substantially reduce the eventual economic and environmental costs of the greenhouse effect.

Individual organizations must decide for themselves whether or not to prepare for the greenhouse effect. The first question is whether global warming is likely to alter the success of current activities or projects now being planned. If not, preparing for the impacts of climate change usually would be unnecessary; if so, the next question is whether doing something today would be worthwhile.

We use the term "strategic assessment" to refer to the process by which people and organizations examine whether, when, and how to respond to global warming, based on what people know today. In some cases, these assessments formally consider the costs and benefits of alternative responses; in others, a qualitative analysis is sufficient to reach a conclusion.

Strategic assessments would be good investments for almost any organization whose activities are sensitive to climate or sea level and whose decisions have outcomes stretching over periods of 30 years or longer. In many cases, these studies can use existing analytical tools and consequently be relatively inexpensive. If they reveal that action today is worthwhile, the savings from such action may be orders of magnitude greater than the cost of the studies. Even if they show that no action is necessary, many organizations will find it useful to know that their projects are not vulnerable, and the studies would contribute to society's understanding of the impacts of global warming.

These assessments can be conducted as decision-oriented analyses (e.g., supplements to ongoing evaluations of proposed projects) or as special studies focusing on particular programs or particular problems; Table 19-1 lists examples of each type.

<u>Decision-Oriented Assessments</u>

The most cost-effective strategic assessments are those conducted as a routine part of the evaluation of ongoing projects. Because they are oriented toward a specific near-term decision, they are not likely to be ignored. Moreover, their cost is often minimal because they supplement existing studies and therefore have little overhead. For example, once a consultant has developed a hydrologic model for a levee or dam, examining the potential implications of climate change may require little more than a few additional computer simulations.

The Council on Environmental Quality has held public meetings on the possibility of requiring federal agencies to consider climate change in environmental impact statements. The rationale is that (1) if climate changes, the environmental impact of some federal projects may be different than the impact if the climate does not change; and (2) these assessments are an inexpensive way to increase our understanding of the potential implications of global warming. The Corps of Engineers has recently announced that it intends to estimate the impacts of sea level rise in future feasibility studies and environmental impact statements for coastal projects. (Baldwin, Volume J, discusses including climate change as a consideration in environmental impact statements.)

<u>Program-Oriented Assessments</u>

Agencies with many potentially vulnerable activities may need programwide assessments. In some cases, the combined impact of climate change can be summarized by a single variable, such as flood insurance claims. On the other hand, many agencies, such as the TVA, the Corps of Engineers, and EPA, have programs that face several impacts, each of which must be examined separately.

<u>Problem-Oriented Assessments</u>

These studies are sometimes necessary because project-oriented studies lack a mandate to examine broader implications. Utility companies, for example, may want to consider the implications of increased demand due to warmer temperatures. Moreover, problems that are explicitly the responsibility of no one while implicitly the responsibility of several different groups could be beyond the scope of program-oriented assessments. For example, the combined impact of farm closures and forest dieback raises land-use questions that would be outside the responsibility of any single organization.

Criteria for Choosing a Strategy

Strategic assessments can objectively identify the implications of climate change and possible responses, but picking the "best" response will sometimes be a subjective decision based on a number of criteria:

Table 19-1. Examples of Strategic Assessments

Decisionmaker	Question
<u>Decision-Oriented</u>	
Home buyers	Is the buyer willing to accept long-term risk of erosion and flooding?
Forestry companies	Are the appropriate species being planted? If so, when would a shift be necessary?
Utility companies	Is the size of a proposed powerplant optimal given projected climate change?
City engineers	Should new drainage facilities be designed with extra margin for sea level rise and possibly increased rainfall?
Water resources agencies	Is the dam designed properly? Would its benefits be different?
Federal agencies developing environmental impact statements	Would sea level rise or climate change significantly alter the environmental impacts of a project?
<u>Program-Oriented</u>	
Research directors	For which impacts can we develop a solution? What would be the costs of the research and the potential benefits of anticipated solutions?
Utility companies	Does system capacity need to be expanded? If not, when would expansion be necessary?
Flood insurance programs	By how much would insurance claims increase? Does expanding the program to include erosion increase the impact of climate change?
Agricultural planners	Do current farm programs help or hinder the adjustments climate change might require?
Public health agencies	Would climate change increase the incidence of malaria and other tropical diseases in the United States?
Air pollution regulatory agencies	Should current regulatory approaches be supplemented with incentive systems, new chemicals, or relocation policies?
<u>Problem-Oriented</u>	
Natural resource agencies	Do we need a program to aid the survival of forests and other terrestrial ecosystems?
Federal and state agencies	Which options would ensure long-term survival of Louisiana's coastal wetlands?
Wetland protection agencies	How do we ensure that wetlands can migrate at sea level?
Canada and the United States	How do we manage changes in levels of the Mississippi River and Great Lakes?
State coastal zone agencies and barrier island communities	Would the state provide necessary funds to hold back the sea on barrier islands? If not, would the town bear the cost of retreat? Are current erosion and flood programs consistent with long-term response?
Water resource agencies	What should be done to address increased salinity in estuaries?
Air pollution agencies	Will climate change alter the results of current air-pollution strategies?
Public utility commissions	Should power companies be building extra capacity for increased demand?

Flexibility: Is the strategy reasonable for the entire range of possible changes (including no change) in temperature, precipitation, and sea level?

Urgency: Would the strategy be successful if implemented today but fail if implementation were delayed 10 or 20 years?

Low Cost: Can the strategy be implemented with a negligible investment today?

Irreversibility: Would failure to adopt a strategy result in irreversible loss of a resource?

Consistency: Does the policy support other national, state, community, or private goals?

Economic Efficiency: Are the benefits greater than the costs?

Profitability: Does the investment provide a return greater than alternative investments, i.e., greater than the "discount rate"?

Political Feasibility: Is the strategy acceptable to the public?

Health and Safety: Would the proposed strategy increase or decrease the risk of disease or injury?

Legal and Administrative Feasibility: Can existing organizations implement the strategy under existing law?

Equity: Would implementing (or failing to implement) the strategy impose unfair costs on some regions or on a future generation?

Environmental Quality: Would the strategy maintain clean air and water or help natural systems survive?

Private versus Public Sector: Does the strategy minimize governmental interference with decisions best made by the private sector?

Unique or Critical Resources: Would the strategy protect against the risk of losing unique environmental or cultural resources?

The highest priorities would generally be actions that meet the criteria of flexibility, urgency, irreversibility, and low cost, because they inherently address the major obstacles encountered in preparing for global warming: (1) flexible policies meet the challenge of uncertainty because they are appropriate regardless of how the climate eventually changes; (2) although analytical techniques substantially discount the benefits of taking action sooner rather than later, delaying action is not a viable option when the urgency criterion is met; (3) irreversible losses can be avoided only by anticipating a problem; and (4) low-cost options are always easiest to implement.

Nevertheless, these responses would not always be sufficient to address the implications of climate change. More comprehensive solutions would often involve measures with more significant costs that might prove, in retrospect, to have been unnecessary if climate does not change as projected. The costs of not acting may still be great enough to justify such actions, but decisionmakers would have to carefully weigh the various tradeoffs.

To a large degree, the procedures for doing so have already been developed and applied. Most corporations and many government agencies conduct profitability or cost-benefit analyses. If the principal costs and benefits of a strategy can be quantified in monetary terms, economic theory provides a rigorous procedure for making tradeoffs between present and future costs, and for considering uncertainty, profitability, and most of the other criteria.

Nevertheless, subjective assessments are necessary when the impacts cannot be readily valued in monetary terms. Many decisionmakers do not feel comfortable with economic estimates of the value of a lost human life, unique cultural resource, or endangered species. Although economic theory provides a procedure (discounting) for comparing present and future costs, it provides less guidance on how much wealth and how many unsolved problems one generation should pass along to future generations. Although it provides tools for assessing risk and uncertainty, economic theory does not specify the extent to which society should be riskaverse. Because there is no objective formula for addressing these types of issues, responses are more likely to be based on intuitive judgment and on what is broadly acceptable to the public.

EXAMPLE RESPONSES FOR ADAPTING TO GLOBAL WARMING

This chapter presents a variety of example responses rather than a single integrated strategy because the process of adapting to climate change would be relatively decentralized. Although the various impacts would not be completely independent of each other, responses to one type of impact in one region generally could be implemented regardless of whether strategies are implemented to address other types of impacts in other regions. The need to protect California's water supplies, for example, would be largely independent of the impact of global warming on southeastern forests, midwestern agriculture, mid-Atlantic barrier islands, and the level of the Great Lakes.

For purposes of this discussion, approaches for adapting to global warming can be broadly divided into four categories, three of which require a response before the climate changes:

- No immediate action is necessary if least-cost solutions could be implemented using existing technology and institutions as the problem emerges.

- Anticipatory action is appropriate where taking concrete actions today would avert irreversible and expensive costs.

- Planning is appropriate where we do not need to physically change what we are doing immediately, but where we need to change the "rules of the game" now, so that people can respond to new information in a way that furthers social goals.

- Research and education are appropriate in cases where decades would be required to develop solutions and to train people to implement them, or where uncertainties must be reduced before the appropriate action can be identified.

We discuss each of these categories in turn.

No Immediate Action

The urgency of responding to climate change depends not only on the severity of a potential impact but also on the extent to which taking action today would diminish the ultimate cost of adaptation or allow us to avoid problems that would be unavoidable if we waited before taking action. Even where the impacts of climate change would be severe, if the solution to a problem is well defined and can be implemented quickly, or if no known solution would substantially mitigate the problem, immediate action is not necessary (although in the latter case, research may be appropriate). Two examples follow.

Reservoir Operation Rules

The decision rules that govern the timing and magnitudes of water releases are generally based on historic climate variability. For example, if the flood season is March to May and droughts are from July to September, reservoir managers typically lower the water levels by the end of February to ensure adequate flood control capacity, and they allow the levels to rise in June to ensure adequate water in case of a drought. If global warming advanced the flood season by one month, managers could eventually shift the schedule of water releases. But since such modifications could be implemented quickly, there is no advantage in modifying the schedule until the climate changes.

Choice of Crops

The differences among crops grown in various regions of the country result largely from differences in temperature and water availability. If the climate of one state gradually comes to resemble the climate currently experienced in another state, farmers in the former state may gradually begin to plant the crops currently grown in the latter. But there is no advantage in switclung crops today.

Anticipatory Action

Although many responses will not be necessary for a few decades, studies have identified a number of instances in which physical responses to global warming are appropriate even today. These circumstances fall broadly into two categories: (1) incorporating awareness of global warming into long-term projects that are already under way, where climate change must be addressed either now or not at all; and (2) taking actions today that, without climate change, would not be necessary until later, if at all.

Modifying Ongoing Projects to Consider Climate Change

The rationale for incorporating global warming into current decisions is that the outcome of projects initiated today will be altered by changes in temperature, rainfall, sea level, or other impacts of global warming. For many long-term projects, factoring climate change into the initial design is economically efficient because the failure to do so would risk premature failure of the project, while the cost of doing so would be only a few percent of the total project cost. Because consideration of global warming would also ensure that projects are adequate to address current climate variability and trends in sea level, such modifications may prove to be worthwhile investments even if the anticipated climate change does not occur, as described in the following examples. Thus, these actions can satisfy the criteria of flexibility, urgency, irreversibility, and low cost.

Street Drains

Consider the replacement of a century-old street drain. If designed for the current 5-year storm, such a system might be insufficient with a 10% increase in the severity of the design storm or a 1-foot rise in sea level, necessitating a completely new system long before the end of the project's useful life. On the other hand, installing slightly larger pipes to accommodate climate change might cost only an additional 5%. In such a case, designing for changes in climate might prove to be worthwhile if these changes occurred; even if they did not occur, benefits would be realized because the system would provide additional protection during the more severe 10-year storm. (For additional examples, see Chapter 7: Sea Level Rise, and Chapter 13: Urban Infrastructure.)

Commercial Forests

Because some commercial tree species live as long as 70 years before being harvested, consideration should be given to modifying the locations of commercial forests and types of species planted to account for global warming. For example, some types of Douglas-firs need at least a few weeks of cold winter temperatures to produce seeds. Forestry companies currently concentrate planting efforts at the mountain bases, from which logs can be most readily transported. However, if temperatures rise, the forests there may no longer produce young firs to replace the old. Thus, it might be reasonable to begin planting farther up the mountain or in a colder region of the country.

A shift from long-lived species vulnerable to climate change to species having less vulnerability or shorter growing cycles may also be appropriate. If two species are equally profitable today but one would fare much better if climate changed, shifting to the latter species would involve little risk and might substantially help long-term profits. Shifting to a species whose life cycle is only 20 years would enable harvests to take place before the climate changes enough to adversely affect growth, and would make it easier to respond to climate change as it occurs (see Chapter 5: Forests).

Undertaking New Projects Primarily Because of Future Climate Change

In a few cases, where authorities are already contemplating public works for which the economic justification is marginal, the prospect of climate change might encourage decisionmakers to proceed today with such projects. For example, a storm surge that almost flooded London during the 1950s led the Greater London Council to develop plans to build a movable barrier across the Thames River. Although many questioned whether the barrier was worth building, steadily rising flood levels (1 foot every 50 years for the past 5 centuries) convinced the technical advisory panel that the barrier would become necessary; once that eventuality was generally recognized, the consensus was that the project should go forward.

Constructing a project today solely because of the greenhouse effect requires more certainty than incorporating climate change into the design of a project that would be undertaken anyway, primarily for two reasons: (1) undertaking a new project requires the legislature or the board of directors to initiate major appropriations rather than approve small increases in the cost of a project already approved; and (2) because it is not motivated by the need to address current problems, the project can be delayed until there is more certainty. Even if decisionmakers are sufficiently certain of future impacts, they do not have to initiate the project today unless the time expected to pass before the impacts occur is not much greater than the time required to design, approve, and build the project intended to prevent those impacts. Thus, only nearterm impacts of global warming and those whose solution would take several decades to implement require remedial action today. Two examples follow.

River Deltas

The loss of wet and dry land in the Mississippi River Delta in coastal Louisiana is one example of how global warming could alter the timing of a project (see Chapter 16: Southeast). If current trends continue, most of the delta will be lost by 2100. But if sea level rise accelerates, this can occur as soon as 2050. The immediacy of the problem is greater than these years suggest, because the loss of land is steady. Assuming the additional loss of land to be proportional to sea level rise, half the delta could be lost by 2030, with some population centers threatened before then.

Whether or not sea level rise accelerates, the majority of the delta can survive in the long run only if society restores the natural process by which the Mississippi River once deposited almost all of its sediment in the wetlands. Because billions of dollars have been invested over the last 50 years in flood-control and navigation-maintenance projects that could be rendered ineffective, restoring natural sedimentation would cost billions of dollars and could take 20 years or longer. Because of the wide variety of interests that would be affected and the large number of options from which to choose, another 10 to 20 years could pass from the time the project was authorized until construction began.

Thus, if sea level rise accelerates according to current projections and a project were initiated today, about half of the delta would remain when the project was complete; however, if the project were authorized in the year 2000, 60 to 70% might be lost before it was complete. By contrast, if sea level rise does not accelerate, the two implementation dates might imply 25% and 35% losses of coastal wetlands.

Undertaking a project today satisfies the flexibility criterion, because even current trends imply that something eventually must be done. Because a failure to act soon could result in an irreversible loss of much of the delta, it also satisfies the urgency criterion.

Purchase of Land

Purchasing land could keep options open for water resource management and wetlands protection. In regions where climate becomes drier, additional reservoirs may become necessary. However, because accurate forecasts of regional climate change are not yet possible, water managers in most areas cannot yet be certain that they will need more dams. Even in areas such as California where dams will probably be required, these will not have to be built for decades. Nevertheless, it may make sense to purchase the necessary land today. Otherwise, the most suitable sites may be developed, making future reservoir construction more expensive and perhaps infeasible. A number of potential reservoir sites have been protected by creation of parks and recreation areas, such as Tocks Island National Park on the Delaware River.

Federal, state, and local governments often purchase land to prevent development from encroaching on important ecosystems. Particularly in cases where ecosystem slufts are predictable, such as the landward migration of coastal wetlands, it may be worthwhile to purchase today the land onto which threatened ecosystems are likely to migrate. Even where the shifts are not predictable, expanding the size of refuges could limit their vulnerability (see Chapter 8: Biodiversity).

Land purchases for protecting ecosystems have two important limitations. First, they would almost certainly be inadequate to address all the species migration that might be required by climate change: protecting coastal wetlands would require purchasing most of the nation's coastal lowlands, and many types of terrestrial species would have to shift by hundreds of miles. Second, land purchases do not handle uncertainty well: if temperatures, rainfall, or sea level change more than anticipated, the land purchased will eventually prove to be insufficient.

Planning: Changing the Rules of the Game

Although concrete action in response to climate change is necessary today for only a few types of problems, defining the "rules of the game" may now be appropriate for a much wider class of problems. Doing so increases flexibility: if climate changes, we are better prepared; if it does not change, preparation has cost us nothing. Another advantage of this type of long-range planning is that reaching a consensus on what is fair is easier when no one is immediately threatened. Moreover, such planning reduces risk to investors: although they still face uncertainty regarding the timing and magnitude of climate change, planning can prevent that uncertainty from being compounded by uncertainty regarding how the government will respond. Two examples in which changing the rules of the game might be appropriate follow.

Land Use

The potential consequences of global warming suggest that it may already be appropriate to guide development away from areas where it could conflict with future environmental quality or public safety. This can be done through master plans, laws and regulations, and revisions of ownership rights. Land use is generally regulated by local governments and planning commissions, with state governments also playing a role in some areas.

A primary rationale for most local land-use planning is that by themselves, real-estate markets do not always produce economically efficient or socially desirable outcomes, because people do not bear all the costs or reap all the benefits from their actions. The uses to which people put their property often can have significant impacts on other property owners and the environment. Because zoning and other land-use restrictions are usually implemented long before anyone would want to undertake the prohibited activities, people have time to plan their activities around the constraints. If people know the rules of the game well in advance, those who want the option of subdividing their property or clearing a forest buy land where these activities are permissible, and those who want property in an area where such activities will not take place buy land where the activities are prohibited. Thus, in the long run, planning helps maintain environmental quality while imposing few costs that individuals could not avoid by buying property elsewhere.

The institutional capabilities of planning are well suited for addressing environmental impacts of climate change when the direction of the impact is known. The example of coastal wetland loss (outside Louisiana) has been extensively examined in the literature; many of the same principles would also apply to shifts in forests, interior wetlands, changing water levels in the Great Lakes, and keeping land vacant for reservoirs.

A possible goal of land-use planning would be to ensure that development does not block migration of ecosystems or preclude construction of a dam. Without planning, the land could be vacated only by requiring abandonment with relatively little advance notice, which would require compensation (except for the case of coastal wetlands in states where property owners do not currently have the right to erect shore-protection structures). Planning measures can either prevent development through zoning (or purchase of land, discussed above), or set the basic social constraint that ecosystems will be able to migrate, while allowing the market to decide whether or not development should proceed given this constfaint.

Preventing Development: Zoning

The most common tools for directing land use are master plans and the zoning that results from them. Zoning to ensure that land is available for a dam would be similar to zoning to keep land available for a freeway. For protecting ecosystems, however, zoning has the same problem as land purchases: it has to be based on a particular assumption regarding how far the ecosystem will need to migrate; if temperature, rainfall, or sea level change more than expected, zoning provides only temporary protection.

Flexible Planning: Allowing the Market to Decide

The rationale for these mechanisms is that preventing development is inefficient; in some cases developing a property might be worthwhile even if it would subsequently have to be abandoned. Flexible planning has the desirable feature of minimizing governmental interference with private decisions. For example, the overall constraint of keeping natural shorelines is set by the government, but the market decides whether nearby property is still worth developing given that constraint. If the effects of climate change do not materialize, the government has not unnecessarily prevented development (satisfying the low-cost criterion). Most importantly, these measures do not require a precise determination of how much climate will change, and thus satisfy the flexibility criterion.

With this situation in mind, the State of Maine has recently issued regulations stating that structures would have to be removed to allow wetlands to migrate inland in response to sea level rise. South Carolina has recently enacted legislation to substantially curtail construction of bulkheads. Because these rules do not interfere with the use of property for the next several decades, they have a minimal impact on property values, and thus do not deprive people of their property. The major limitation of this approach is that it may be too flexible: if sea level rise begins to require a large-scale abandonment, a state or local government may find it difficult to resist pressure to repeal the rule.

An alternative that avoids the risk of backsliding is to modify conventions of property ownership. One example would be long-term leases that expire 50 to 100 years hence or when high tide rises above a property's elevation. This approach, which has been applied to Long Island, allows the market to explicitly incorporate its assessment of sea level rise into its valuation of the leases. Although leaseholders have requested no-cost extensions on their leases when they expire, local governments generally have found enforcing the provisions of leases easier than enforcing regulations requiring people to abandon property. Moreover, this approach can be implemented by the private sector; for example, a conservancy willing to lease the land back to developers for 99 years might be able to buy lowlands inexpensively (see Chapter 7: Sea Level Rise).

<u>Water Allocation</u>

Particularly in the Southwest, the nation's water supply infrastructure is guided by policies embedded in contracts and laws that prescribe who gets how much water. Many of these rules are not economically efficient; water is wasted because of rules that do not allow people with too much water to sell it to people with too little. The equity of these formulas is often sensitive to climate; during wet periods, everyone may receive plenty, but in dry periods some get enough while others get none.

To a large degree, the means by which the impact of climate change might be reduced are already being advocated to address current climate variability and potential supply shortages due to population growth. These measures include legalizing water markets; curtailing federal subsidies, which lead to waste by keeping prices artificially low; and modifying allocation formulas (see Chapter 9: Water Resources).

Nevertheless, the changes required by global warming maybe different in one crucial aspect: the effective date of any rule changes. Because the most severe changes in rainfall from the greenhouse effect may still be decades in the future, the problem can be addressed even if the effective date is not until 2020. This situation, however, may enhance the political feasibility of instituting a rational response today, since no one need be immediately threatened. By contrast, if planning is deferred another 20 years, the impacts of climate change may become too imminent for potential losers to agree to the necessary changes.

Research and Education: Increasing Our Understanding

Although a particular problem may not require solutions for a few decades, society should begin preparing now. In some cases, we are decades away from having viable solutions or the public awareness necessary to reach a consensus. We now examine two vehicles for expanding our knowledge: research and education.

<u>Research and Development</u>

Research and development expenditures can often be economically justified in cases where other responses cannot. Most of the impacts of climate change at least theoretically could be mitigated, but in many cases, effective solutions have not yet been developed. Like strategic assessments, research is as valuable as the savings it makes possible.

Research is also one of the major vehicles by which one generation improves life for succeeding generations. Even if the economic efficiency of taking action to mitigate impacts of climate change cannot be demonstrated, some policymakers might find it equitable for this generation to provide solutions to accompany the problems we pass on to the next generation.

Table 19-2lists a number of research questions and applications that would assist adaptation. However, for the most part, strategic assessments have not been undertaken to determine the cost and probability of developing solutions or the magnitude of potential

Table 19-2. Example Research Problems and Applications

Research problem	Application
Synergistic impacts of CO_2, climate change, and air pollution on plants	Shifts in mix of trees and crops, drought-tolerant crops
Shifts in habitats of birds, fish, and land animals	Restoration ecology: rebuilding ecosystems that are lost
Ability of wetlands and coral reefs to keep up with sea level changes	Mechanisms to accelerate vertical growth
Erosion of beaches due to climatology and sea level change	More efficient placement of sand when beaches are restored
Ability of alternative plant strains to tolerate harsh climate	Development of heat- and drought-resistant crops
Magnitude of changes in global sea level and regional climate	Development of integrated pest management programs and better background data for groundwater protection policies
Shifts in microorganisms that currently diminish water quality in tropical areas	Long-term water supply planning

savings that might result, so it is difficult to be certain that the research would benefit society. The most notable exception is improvement in estimates of future climate change; for virtually every impact examined in this report, the relevant decisionmakers have told EPA that improved climate projections are critical for developing responses. (For more details on necessary research, see Chapter 18: Research Needs.)

Education

Efforts to prepare for climate change can be only as enlightened as the people who must carry them out. Education will be a critical component of any effort to address the greenhouse effect because (1) decisiorunakers in various professions will need to routinely consider the implications of global warming; and (2) an informed citizenry will be necessary for the public to support the public policy and institutional changes that may be required. Governments will almost certainly have a major role.

To factor global warming into their decision processes, people will need information about changes in climate variables, the resulting effects, and techniques for mitigating the impacts. Federal and state agencies have already sponsored large conferences on sea level rise each year since 1983; coastal engineers and policymakers are increasingly considering accelerated sea level rise in land-use decisions and the design of public works. This process is now beginning to unfold in the fields of utility planning and water-resource management, and may emerge in other areas.

Because climate change could require major public policy initiatives, governments must explain the issue to the public at large so that the various options can be fully considered. To a large degree, the news media and school systems will be responsible for explaining the issue to people. Nevertheless, governments can support these institutions by sponsoring public meetings, issuing press releases, and perhaps most important, translating the results of its technical studies into brochures and reports that are accessible to reporters, teachers, and the general public.

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United States Senate

COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS

WASHINGTON, DC 20510

September 12, 1986

Mr. Lee Thomas
Administrator
Environmental Protection Agency
Washington, D.C. 20460

Dear Mr. Thomas:

The purpose of this letter is to formally request that EPA undertake two studies on climate change due to the greenhouse effect and submit them to Congress no later than March 31, 1988.

At the outset, we want to thank you for appearing before the Subcommittee on Environmental Pollution at hearings last June on the problems of global climate change and stratospheric ozone depletion. Your testimony showed a refreshing appreciation for the magnitude of the environmental risks presented by these problems and the need to be exploring incremental actions that can be taken to reduce these risks.

As summarized at those hearings and elsewhere, the scientific community appears to have reached agreement that substantial ozone depletion may result from continued use of chlorofluorcarbons (CFC's) and that increases in CFC's and other greenhouse gases are like to produce global climate changes greater than any in man's history. There is a very real possibility that man - through ignorance or indifference, or both - is irreversibly altering the ability of our atmosphere to perform basic life support functions.

What is urgently needed now is for us to begin to deal with these issues. They can no longer be treated solely as important scientific questions. First, some actions including limits on CFC's appear warranted in the near term. Second, we need to expand efforts to more fully understand the effects that atmospheric pollution has on the environment and to develop an extensive range of policy options for dealing with the serious global problem of climate change due to the greenhouse effect. This second need has led to our request for two EPA studies.

One of the studies we are requesting should examine the health and environmental effects of climate change. This study should include, but not be limited to, the potential impacts on agriculture, forests, wetlands, human health, rivers, lakes and estuaries as well as other ecosystems and societal impacts. This

Mr. Lee Thomas
September 9, 1986
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study should be designed to include original analyses to identify and fill in where important research gaps exist, and to solicit the opinions of knowledgeable people throughout the country through a process of public hearings and meetings.

The other study should include an examination of the policy options that, if implemented, would stabilize current levels of atmospheric greenhouse gas emissions. This study should address: the need for and implications of significant changes in energy policy, including energy efficiency and development of alternatives to fossil fuel; reductions in the use of CFC's; ways to reduce other greenhouse gases such as methane and nitrous oxides; as well as the potential for and effects of reducing deforestation and increasing reforestation efforts. It should include a series of policy options and recommendations for concrete steps to be taken along with a discussion of the potential effectiveness of each for limiting climate change. Since the United States must take a leadership role in addressing these global problems, the policy options that you develop should include a specific plan for what the United States can do to stabilize its share of greenhouse gas emissions as well as a plan for helping other nations to achieve comparable levels of control.

We realize that undertaking this project will be a significant challenge and will require substantial resources. We therefore urge you to immediately direct the necessary funds in both FY-87 and FY-88 to assure that you can comply with our request to promptly conduct these studies.

Many of us believe that these are among the most important environmental problems of the next decade. The sooner you can provide recommendations to Congress, the sooner we will be able to provide leadership throughout the world to prevent a pending environmental disaster.

Your personal attention and prompt reply to this request will be greatly appreciated. We look forward to working with you on these important environmental problems. Please do not hesitate to contact us for additional guidance and assistance.

Sincerely,

George J. Mitchell

John H. Chafee

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