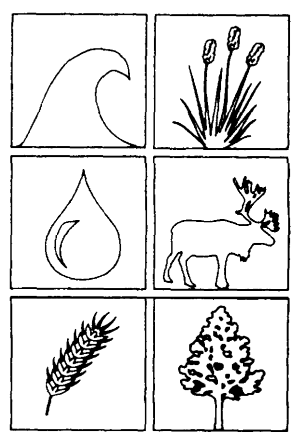
Synthesis, Summary and Policy Options 1

Widespread public attention to the question of whether or not climate is changing intensified during the hot summers of the late 1980s. Since then, during the time the Office of Technology Assessment (OTA) was conducting this assessment, the Nation has experienced major drought in the western and southeastern United States, powerful hurricanes in Florida and Hawaii, a destructive forest fire in Northern California, and substantial flooding in the Midwest. Although none of these events can be clearly linked to climate change, they represent the types of extreme events that may occur with greater frequency if climate warms.

Most scientists believe that the Earth's climate is likely to warm by several degrees during the next few decades. Although our understanding of climate change has progressed a great deal in the past few years, major knowledge gaps remain, and empirical evidence of human-induced climate change is not unequivocal. Many factors important to understanding climate, such as the role of clouds, ocean circulation, and solar cycles and the interactions between living organisms and the environment, cannot yet be reliably incorporated into general circulation models (GCMS), science-based computer models used to predict potential changes in average global surface temperature. Some key information that could guide policy response is likely to remain unknown for another decade or two (69). We cannot predict rates or magnitudes of changes in local or regional temperature and precipitation patterns. Predicting changes in the variability of climate and weather patterns, particularly on small spatial scales, is also beyond current scientific capabilities, Existing ecological, social, and economic models are similarly limited and cannot adequately predict the responses to climate



changes by natural systems (e.g., forests and wetlands) or managed systems (e.g., water resource systems and agriculture). Therefore, most policy decisions made in the near future about how to respond to the specter of climate change will be made in light of great uncertainty about the nature and magnitude of potential effects.

Although climate change has certainly become a public and scientific concern, what to do about it is not clear. Issues now being heatedly debated are the technical feasibility and economic implications of reducing or offsetting emissions of greenhouse gases. Several studies concluded that cutting U.S. emissions of carbon dioxide ($C0_2$), the most important anthropogenic greenhouse gas, below current levels is plausible. OTA'S 1991 report, *Changing by Degrees: Steps to Reduce Greenhouse Gases,* concluded that by adopting a package of low-cost measures, the United States could significantly slow the growth of its $C0_2$ emissions over the next 25 years-but could not easily decrease them to below current levels (172). With aggressive-but potentially expensive-initiatives, OTA found that the United States might be able to decrease its $C0_2$ emissions to 35 percent below today's levels by 2015. Even in this case, U.S. emissions of $C0_2$ are expected to rise again after 2015 unless there are successful programs for developing alternatives to fossil-energy supplies (such as solar and nuclear power)-programs that would lead to substantial increases in market penetration of one or more of these energy alternatives by 2015.

Since the 1992 United Nations Conference on Environment and Development (UNCED) in Brazil, many countries have signed the Climate Convention, seeking to freeze greenhouse gas emissions at 1990 levels in the near future. On Earth Day 1993, President Clinton announced that the United States would participate in this effort. The Climate Convention represents a landmark agreement and recognition that global environmental problems must be addressed on a global scale.

Nonetheless, the bulk of scientific evidence indicates that simply freezing greenhouse gas emissions at 1990 levels will not stop global warming. *Stabilizing emissions* is different from *stabilizing atmospheric concentrations.* Constant annual emissions will still increase the total concentration of greenhouse gases and, thus, the heat-trapping capacity of the atmosphere. The Intergovernm ental Panel on Climate Change (WCC), an international group representing more than 50 countries, concluded that to stabilize the concentrations of greenhouse gases in the atmosphere at today's levels would require up to an 80 percent reduction in world $C0_2$ emission levels immediately, along with significant reductions in other greenhouse gases. Even if such reductions could be achieved, the world would warm about 1 to 4 OF (1 to 2 'C) because of long-lived greenhouse gases emitted over the last century. Given the virtual certainty that energy use (and associated $C0_2$ emissions) in developing countries will rise as they pursue economic growth and given the intense debate in the United States and other industrialized countries about the feasibility of achieving even a freeze in emissions, it seems certain that global atmospheric concentrations of greenhouse gases will continue to rise. Thus, unless the predictive GCMS are seriously flawed, average global temperatures are expected to increase several degrees over the next century, even under the most optimistic emissions scenarios (see box 2-B).[1]

If climate change is inevitable, then so is adaptation to climate change. Society and nature may have to cope with rising sea levels, more frequent drought and periods of temperature extremes, changes in water supplies, disruption of ecosystems, and changes in many other climate-sensitive natural resources (see ch. 2). The term *adaptation, as* used here, means any adjustment to

[1] All chapters, boxes, figures, and tables cited here can be found in volumes 1 and 2 of this report Volume 1 addresses coastal areas, water resources, and agriculture; volume 2 includes wetlands, preserved lands, and forests.

altered conditions; it can be a biological, technical, institutional, regulatory, behavioral, or economic response. It encompasses *passive adjustments (e.g.,* biologically *driven* changes in plant communities or gradual changes in human behavior and tastes), *deliberate reactive responses* (management responses after climate change effects are observed), and *anticipatory actions, (planning,* engineering, or regulatory responses taken in preparation for climate change). Throughout this report, we examine the ability of natural-resource-based systems, both unmanaged and managed, to adapt to climate change and consider means by which adaptation can be enhanced by modifying management, advancing research and technology, disseminating information, and taking legislative actions.

Given the current inability to predict accurately where, when, and how much change will occur, decisionmakers must plan for natural and managed systems in light of considerable uncertainty. It is understandable, under these circumstances, that postponing responses until more is known about climate change is very appealing. Nonetheless, uncertainty does not mean that the Nation cannot position itself better to cope with the broad range of impacts possible under climate change or protect itself against potentially costly future outcomes. In fact, delay in responding may leave the Nation poorly prepared to deal with the changes that do occur and may increase the possibility of impacts that are irreversible or otherwise very costly. Many options that will increase the Nation's ability to cope with the Uncertainties of climate change will also help in dealing with existing threats to natural resource systems, such as those related to climate extremes (e.g., droughts, floods, and fire) and the fragmentation of natural habitat.

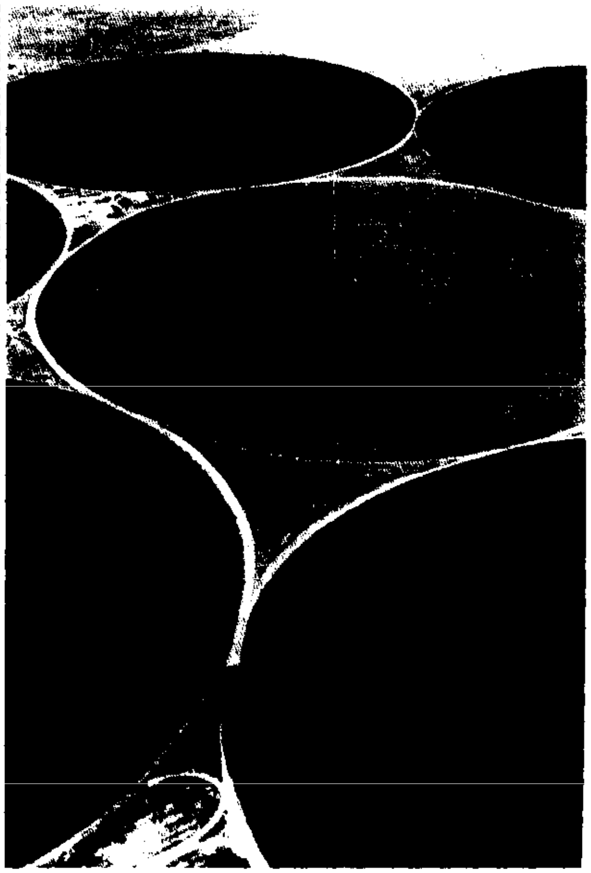
The following sections of this chapter discuss the OTA assessment, general problems posed by climate change, criteria for choosing strategic responses, near-term opportunities for Congressional action, and summaries and first steps for the six resource systems studied in detail.

THE OTA ASSESSMENT

Three Committees of Congress asked OTA to help them think about coping with potential climate change. OTA was asked: How can the United States set prudent policy, given that we do not know for certain what the climate will be? This assessment attempts to answer three key questions:

- What is at risk over what time frames? Which natural ecological systems and managed natural resource systems are at risk from climate change? How do the lead times needed for human interventions in these systems vary?
- How can we best plan for an uncertain climate? When and how should decisionmakers consider the uncertain effects of a changing climate as they plan the future management of natural and managed systems in the United States? What criteria should be used?
- Will we have answers when we need them? Does the current U.S. Global Change Research Program (USGCRP) reflect the short- and long-term needs of decisionmakers? Will it provide information about rates of climate change, the potential for "surprise' effects on different systems, potential strategies for making systems more resilient in the face of uncertain climate change, and adapting to the changes that may occur?

Society depends on natural and managed systems for both basic needs and amenities. These include, for example, food, shelter, clothing, drinking water, energy, and recreation. Many social and economic problems arise when the availability and diversity of goods and services decline. Such disruptions can range from mild to severe, and they include unemployment, famine, migration of workers, and political instability. Climate change heightens the uncertainty about future availability of desired goods and services.



USDA AGRICULTURAL RESEARCH SERVICE

In the West, center-pivot sprinklers irrigate wheat, alfalfa, potatoes, and other crops. Increasingly efficient irrigation techniques maybe critical if regional climates become drier.

Yet, given the potentially long delays until the onset of significant changes, reacting to climate change as it occurs may seem more practical than undertaking anticipatory measures. Why adopt a policy today to adapt to a climate change that may not occur, for which there is significant uncertainty about regional impacts, and for which benefits of the anticipatory measure may not be seen for decades? Effort put into adopting the measure could well be wasted. Furthermore, future generations may have more sophisticated technologies and greater wealth that can be used for adaptation (91).

The Committee on Science, Engineering, and Public Policy (COSEPUP) (27)[2] concluded that it is theoretically possible to put technology and practices into place to adjust to the changing climate as it happens if the change is gradual enough. However, the rate of climate change is, admittedly, unknown. IPCC concluded: "it is uncertain whether these changes-should they come-would be gradual or sudden" (68). Furthermore, "our imperfect understanding of climate processes . . . could make us vulnerable to surprises; just as the human-made ozone hole over Antarctica was entirely unpredicted" (69).

Waiting to react to climate change may be unsatisfactory if it is possible that climate change impacts will be very costly. Of greatest concern may be those systems where there is the possibility of surprise-of facing the potential for high costs without time to react--or where the climate change impacts will be irreversible. Such impacts seem more likely if long-lived structures or slow-to-adapt natural systems are affected, if adaptive measures require time to devise or implement, or if current trends and actions make adaptation less likely to succeed or more costly in the future. In these cases, anticipating climate change by taking steps now to smooth the path of adaptation may be appropriate.

Ideally, a policy-relevant research program could help identify appropriate actions as the current state of knowledge evolves. In response to the potential risks of climate change and the uncertainties surrounding the science, the Federal Government launched a massive, multiagency research effort in 1989 to monitor, understand,

2 COSEPUP's 1992 report, a joint publication of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine, stated: "While inventions and their adoption may occur quickly, we must ask whether the broad spectrum of current capital investments could be changed faat enough to match a change in climate in *50* to 100 years' *(27). The report goes* on to note that half a century should be time enough to allow most major technological systems (and some natural systems) to be transformed and most capital stock to turn over.

and, ultimately, predict global changes and to determine the mechanisms influencing these changes *(25, 26).* Chapter 3 examines the USGCRP and suggests ways to effectively broaden the program to both incorporate natural resource concerns and assessment activities.

Other studies have examined systems at risk from climate change in various ways (see boxes l-A, l-B, and 2-F and refs. 27, 67, and 188). To complement these analyses, OTA focused its examination of adaptation potential on areas where:

- Costs of climate change may be very high. For example, flood and wind damages from more-intense storms could lead to death and extensive property damage.
- Impacts of climate change may be irreversible. For example, species extinction and loss of valuable ecosystems—in wetlands, forests, and wilderness areas-may be permanent.
- The validity of long-term decisions made today will be affected by climate change. For example, trees planted with a life expectancy of many decades may not survive to maturity if climate conditions change. Agricultural and coastal development in climate-sensitive areas may add to the likelihood of future losses to natural disasters.
- Preparing for catastrophic events is already warranted. Reacting to climate change may mean reacting to climate extremes-such as floods, droughts, storms, and fires. Coordinated contingency planning can help avert high costs and reduce risk of loss.
- There is a significant Federal role in the research, planning, or management of these systems.

On the basis of these criteria, OTA selected six systems for further analysis:

1. coastal areas,
2. water resources,
3. agriculture,
4. wetlands,
5. preserves (federally protected natural areas), and
6. forests.

The first three systems are managed natural-resource-based systems with a high degree of government involvement and a complex system of incentives and subsidies in place; these are grouped together in volume 1 of the report. The other three systems include less-managed natural systems and are presented together in volume 2. Both volumes contain this summary chapter, a primer on climate change, and a chapter on the Federal research effort. Box 1-A highlights our overall methodological approach.

Each of the six systems OTA examined is stressed to some degree today, and that may influence how well it can respond to any change in the future. For example, because populations in coastal areas are growing, the exposure to costly natural disasters is increasing. Water scarcity and water-quality concerns are already common in many parts of the United States. Current agricultural support programs often distort and constrain choices about crop and farm management. Wetland loss continues-albeit at a much slower rate than 20 years ago-despite a stated national goal of “no net loss” (see vol. 2, ch. 4). Preserved natural areas serve aesthetic, recreational, and biodiversity functions, but may not be adequate in size or distribution to maintain wildlife and plant species in the face of growing habitat loss and fragmentation. U.S. forest managers are finding it increasingly difficult to meet the sometimes competing demands for recreation, environmental services, and commercial wood products.

Water is an integral element of all of the resource systems discussed in this report. Its abundance, location, and seasonal distribution are closely linked to climate, and this link has had much to do with where cities have flourished, how agriculture has developed, and what flora and fauna inhabit a region. Water quality and quantity will remain key to the economy. Future

Box I-A—The OTA Study in Context

Within the past 5 years, three major studies of the impacts of climate change have been released. The Environmental Protection Agency (EPA) (166) and the Committee on Science, Engineering, and Public Policy (COSEPUP) (27) issued reports on potential effects of global climate change on the United States; Working Group II of the Intergovernmental Panel on Climate Change (IPCC) focused on potential impacts from climate change worldwide (67).

The Sensitivity and Adaptability of Human Activities and Nature

Human activity and nature	Low sensitivity	Sensitive; adaptation at some cost	Sensitive; adaptation problematic
Industry and energy	✓		
Health	✓		
Farming		✓	
Managed forests and grasslands		✓	
Water resources		✓	
Tourism and recreation		✓	
Settlement and coastal structures		✓	
Human migration		✓	
Political tranquility		✓	
Natural landscapes			✓
Marine ecosystems			✓

SOURCE: Redrawn from Committee on Science, Engineering, and Public Policy, Panel on Policy Implications of Greenhouse Warming, National Academy of Sciences, National Academy of Engineering, and Institute for Medicine, Policy Implications of ***Greenhouse Warming: Mitigation, Adaptation, and the Science Base*** (Washington, DC: National Academy Press, 1992).

COSEPUP divided human activities and natural systems into three classes of sensitivity and adaptability to climate change: 1) low sensitivity, 2) sensitive but can adapt at a cost and 3) sensitive with problematic adjustment or adaptation (see table). The report concluded that industry decisionmaking horizons and building schedules are shorter than the time frame within which most climatic changes would emerge, so most industries could be expected to adapt as climate shifts. COSEPUP listed human migration and water resources as “sensitive to climate change,” but adaptable “at some cost.” Finally, it suggested that unmanaged natural ecosystems respond relatively slowly and that their ability to adapt to climate change is more questionable and “problematic” than that of managed cropland or timberland. The EPA report concluded that natural ecosystems have only limited ability to adapt if the climate changes rapidly and suggested that “managed systems may show more resilience.”

The Office of Technology Assessment (OTA) analysis began with the EPA, COSEPUP, and IPCC reports and related literature, but it goes beyond them in several important ways. COSEPUP addressed natural systems primarily in the general terms of “natural landscape” and “marine ecosystems.” However, natural systems are much more numerous and complex than this categorization suggests. We examine some natural systems in the United States at a much finer level of resolution (e.g., wetlands, forests, and preserved areas) and in different regions of the country.

We also consider systems under varying degrees of management intensity-from Iess-managed wilderness areas, wetlands, and some coastal systems, to systems managed for multiple uses, such as forests and rangelands, to intensively managed agricultural and commercial forestry systems. We consider each to be a system for which we can characterize outputs and’ inputs. We focus on the outputs that society cares about whether for economic, recreational, aesthetic, or other reasons-in short, things about which policy is made.

While recognizing the value of climate predictions used in previous assessments, we chose to acknowledge the uncertainties of our changing climate by deliberately avoiding predictions linked to any particular climate change scenario. Instead, we examine the vulnerabilities of natural resource systems to climate change, attempt to elucidate how different climate variables drive natural resource systems, and examine the types of planning and management practices that might help vulnerable systems adapt to a changing climate.

Timing is key to our analyses. In addition to the sensitivity of systems to climate change, the lead time needed for human interventions in these systems also varies, as does the time framefor systems to respond. Continuation of the structure, function, and services of many systems in an uncertain future depends on decisions being made today. In this report, we highlight how today's decisions about long-lived systems (e.g., forests and water resource projects) may determine how those systems respond to tomorrow's unknown climate.

Finally, and perhaps most importantly for Congress, our assessment examines the institutions and legislative framework that surround natural and built systems in the United States today. Whether or not a system can adapt to a changing climate may depend on how adaptable the institutions themselves are. Many systems transcend agency, geographic, or legislative boundaries; such fragmentation can impede adaptation. OTA identifies these rigidities and offers new legislative, coordination, planning, and management options to facilitate adaptation.

water availability is essential for continued services and functions from coasts, water resources, agriculture, preserves, wetlands, and forests. Competition for water, whether for irrigation, recreation, wildlife, or urban use, is likely to heighten in some regions of the country. Throughout the report, we highlight this and other intersecting issues in cross-cutting boxes, indicated by a bar of icons representing the six systems studied (see table l-l).

THE PROBLEM OF CLIMATE CHANGE

Climate change alters the baseline against which future actions are gauged. Our lifestyles, water supplies, and food supplies and other things society values from natural resources rely on a dependable, consistent, and sustainable supply. Our institutions and infrastructure presume that the past is a reasonable surrogate for the future. When designing reservoirs, for example, historic rainfall patterns are assumed to provide a good indication of the range of future patterns. A farmer plants knowing that at times, weather conditions will cause a crop to fail, but with the expectation-based on past climate--that the crop will succeed, in most years.

Climate change poses two potential problems for existing management strategies for resources: 1) increased unpredictability resulting from changing climate averages, and 2) increased risk of surprises or large-scale losses. These, together with the "background" of increasing population, greater future demand, and growing competition for the use of scarce resources, make the need to improve the Nation's ability to deal with an uncertain climate all the more urgent.

Stresses on resources are most acute and visible during extreme events such as floods and droughts. Our response to such events has often proven to be expensive and unsatisfactory. Damages from the Mississippi River flooding in 1993 are expected to range from $5 billion to $10 billion, with Federal disaster payments of about $3 billion. Almost $4 billion in Federal payments went to farmers suffering crop losses during the 1988 drought. Hurricane Hugo cost the Federal Government about $1.6 billion. Hurricane Andrew topped $2 billion in Federal disaster payments, and many complained about the Government's response.[3] Policies that improve the Nation's ability to prepare for and cope more effectively with climate hazards (e.g., floods, fires, and droughts) would be valuable now **and** would help prepare the Nation for a less certain future.

3 Hurricane Andrew's estimated cost to property insurers as of February 1993 is at least $15.5 billion (136). Additional losses involved uninsured property, public utility equipment (e.g., power lines), crop damage, property insured under the National Flood Insurance and the Small Business Administration programs, lost tax revenue, and the costs of emergency services.

Table I-I—List of Boxes in Report[a]

■ What Is at Risk?

As described in chapter 2, climate change predicted by the models includes changes in precipitation patterns, increased temperature, in**creased** evaporation, and sea level rise. The combination of these factors could cause significant impacts on all systems. For example, sea level rise could lead to higher storm surges and

VOLUME 2

[a] Shading indicates boxes that discuss interactions across resource systems

increased erosion of coasts (see vol. 1, ch. 4). Shifts in precipitation patterns could cause more floods, droughts, water-supply disruptions, hydropower reductions, and groundwater overdrafts, especially in the arid West (see vol. 1, ch. 5). The ideal range for agricultural crops might move north as temperatures increase, and drought losses could become more frequent (see vol. 1, ch. 6). Forests could experience more-frequent fire and diebacks driven by drought, insects, and disease (see vol. 2, ch. 6). It could become difficult to retain unique assemblages of plants and animals in preserves as the climate to which they are adapted effectively shifts northward or to higher elevations (see vol. 2, ch. 5). With sea level rise, loss of coastal wetlands maybe accelerated, and regional drying could eliminate some prairie potholes (see vol. 2, ch. 4).

The loss of soil moisture that might result from higher evaporation rates at warmer temperatures is likely to present the greatest threat to natural systems. Figure 1-1 shows areas of the United States that may undergo significant changes in soil moisture based on climate changes projected by two GCMS. The Goddard Institute for Space Studies (GISS) scenario suggests that large areas face moderate drying. The Geophysical Fluid Dynamics Laboratory (GFDL) scenario shows more severe drying across much of the eastern and central United States. Figure 1-2 illustrates the

The summer floods of 1993 in the Midwest demonstrate the risks of floodplain development combined with intensive control of river flow. The satellite photograph on the top shows the Mississippi River as it appeared in July of 1988 during the drought; the one on the bottom shows the same area during the floods of July 1993.

extent to which changes in soil moisture could affect U.S. lands in natural cover (e.g., forests and wetlands) or agricultural use. Much of the Nation's natural resource base may face at least moderate drying, which is likely to increase stress on vegetation.

It is impossible to estimate with any confidence the cost of climate change to society. Estimates of the costs to the United States resulting from an average temperature increase of 4 to 5 OF (2 to 3°C)[4] range from 0.3 to 2.0 percent of the gross national product (GNP) (22, 23)-corresponding to tens of billions of dollars per year. Box 1-B highlights a broad range of climate impacts that could be caused by climate change.

Although it is desirable to anticipate climate change, the uncertainties involved make the design of appropriate policies challenging. These uncertainties include: 1) the extent of global and regional climate change, 2) its economic and ecological impacts, and 3) the ability of society to adapt.

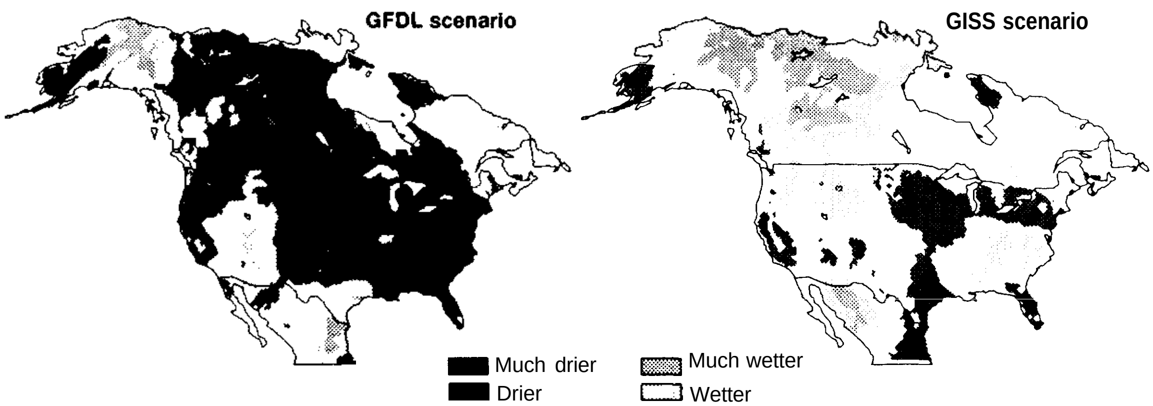
Uncertainties About Global and Regional Climate Change

Atmospheric scientists generally agree about the direction of climate change on a global and latitudinal scale. Global temperatures will likely rise, which would cause an increase in global precipitation and sea levels. Temperature increases are likely to be greater at higher latitudes. Winter precipitation could increase in middle and high latitudes; decreased summer precipitation in midcontinental, midlatitude regions could result in reduced summer soil moisture (69). At finer spatial scales, such as at the regional or State level, uncertainty about climate change increases.

The rate of change is also uncertain. IPCC estimated that global average temperatures will increase at over 0.5 OF (0.3°C) per decade. As average temperatures increase, the entire range of expected temperatures increases as well; thus, both the warmest and coolest temperatures experienced will be warmer than before. This does not preclude late frosts or early freezes if variability increases. Some analyses show that climate variability may increase at the regional level-a series of warm years in a region could be followed by a series of cool years (195). There is, however, significant uncertainty about whether the frequency and intensity of extreme events will change. It is likely that, on average, precipitation worldwide will increase with climate change (69), but the models suggest that the interior of continents will get drier. It is not known whether droughts or floods will increase or decrease.

[4] This temperature increase is the estimated equilibrium warming from an atmosphere containing a greenhouse gas concentration equivalent to a doubling of CO_2 above preindustrial levels. Although the atmospheric concentration of gases leading to this temperature change is expected by about 2030, due to time lags, any resulting temperature effect might not be fully realized until several decades later.

Figure I-I—Potential Sol I-Moisture Changes Under Two GCM Climate Change Scenarios



NOTE: GFDL=Geophysical Fluid Dynamics Laboratory; GISS--Goddard Institute for Space Studies.

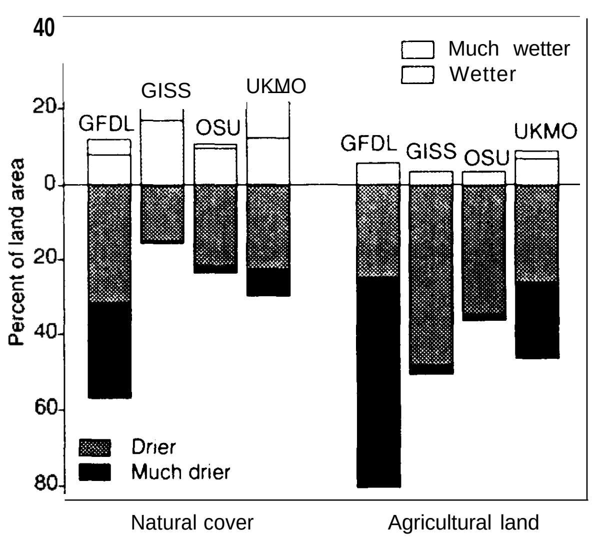
SOURCE: P.N. Halpin, 'Ecosysatems at Risk to Potential Climate Change," contractor report prepared for the Office of Technology Assessment, June 1993.

Some analyses predict that hurricane intensities could increase (43), and drought in lower latitudes could be more severe (144).

Uncertainties About Direct Effects

Even if the regional changes in climate could be predicted, important uncertainties would remain about the physical and biological effects they would have. We do not really know how vegetation,animals, and other natural resources will be affected by climate change. Rising concentrations of atmospheric CO_2 will change the rates at which plants grow, respire, use water, and set seeds. Numerous laboratory experiments on intensively managed agricultural systems suggest that CO_2 will boost plant growth and productivity as long as other nutrients are plentiful (6, 39, 81); this is called the CO_2 *fertilization effect (see* ch. *2). This* effect has not yet been studied in many natural ecosystems (72, 124). Many studies of climate effects have used statistical models that relate natural vegetation or crop productivity to differences in current regional climates in order to estimate impacts under climate change scenarios. These are summarized in chapter 2 and in volume 1, chapter 6. The ability of plants and animals to

Figure 1-2-Soil-Moisture Changes for Agricultural Lands and Areas of Natural Cover, by GCM Climate Change Scenario



NOTE: Bars above the zero axis show the percent of land area becoming wetter; bars below the axis show the percent of land area becoming drier. GFDL--Geophysical fluid Dynamics Laboratory; GISS-Goddard Institute for Space studies; OSU-Oregon State University; and UKMO-United Kingdom Meteorological Office.

SOURCE: P.N. Halpin, "Ecosystems at Risk to Potential Climate Change," contractor report prepared for the Office of Technology Assessment, June 1993.

Box I-B-How Climate Change May Affect Various Systems[1]

Natural ecosystems-These may be the systems most vulnerable to climate change. We are least able to intervene and help with adaptation of natural ecosystems because of limited knowledge about ecological processes (see chs. 2 and 3). The shift in climate zones may far exceed the ability of vegetation, such as forests, to adapt through migration (see fig. 1-7). Climate zones may shift hundreds of miles in a century, whereas natural rates of dispersal and colonization maybe on the order of tens of miles in the same time period (35). In addition, fire and disease could result in rapid dieback of many existing forests and other terrestrial ecosystems (157). Helping plants to migrate through such activities as widespread seed dispersal would be very expensive and have dubious prospects for success (188). These issues are discussed in detail in “Forests” (vol. 2, ch. 6).

Climate change could also lead to a loss of species diversity. Isolated (“island”) species may find themselves in climate zones that are no longer suitable for their survival (132). The potential for migration of plants and animals to new suitable habitats is not known, but barriers such as water bodies or development could impede migration (see fig. 1-6), Species in mountainous terrain could migrate to higher elevations. This creates reduced habitat areas, which are correlated with reductions in species diversity. For example, a study ofa5‘F (3 ‘C) warming in the Great Basin National Park in eastern Nevada concluded that it would cause 20 to 50 percent of species in individual mountain ranges to go extinct (108). The ability for human intervention to maintain species diversity in the face of climate change is currently limited. Selected species could be transplanted to new habitats, but this could be very resource intensive and would only be feasible in certain cases; little research has actually been done on transplantation of multiple-species systems. Migration corridors could be created, but their chances of success are limited because migration rates are slow and the direction of species migration is unknown. In addition, the creation of corridors maybe relatively expensive compared with setting aside new protected areas (154). These issues are discussed further in “Preserves: Federally Protected Natural Areas” (vol. 2, ch. 5).

Climate change can result in the loss of coastal wetlands directly through sea level rise, and indirectly, through interaction with societal response to sea level rise. Many coastal wetlands will likely be inundated because the sea will rise faster than wetland sediments accrue (161). Some wetlands will adapt to climate change by migrating upland with the rising tides. The areas with the greatest risk of wetland loss are along the Gulf and East Coasts of the United States (see fig. 1 -4). This will result in a net loss of wetlands because vast areas of tidal flats, such as in the Mississippi Delta, will be inundated, while inland migration will create new wetlands having only a fraction of the area of today’s wetlands.[2] This net loss of wetlands will be even larger where coastal structures, such as bulkheads or levees, block the inland migration of wetlands (162).

Even if it were feasible to create new coastal wetlands, the costs of this would be so high that large-scale restoration programs would become unattractive. The average cost of creating wetlands has been estimated at roughly $20,000 to $45,000 per acre ($50,000 to $100,000 per hectare),[3] not including land-acquisition costs.[4] This figure, however, can vary from just a few hundred dollars per acre to many hundreds of thousands of dollars per acre. Though technology is improving (see vol. 2, box 4-A), attempts to recreate wetland structure and function fully have been limited. Prohibiting the construction of or removing coastal structures would enable more wetlands to colonize upland areas. It may not be feasible to move some existing coastal structures that impede wetland migration. For example, it is unlikely that areas of dense development would be relocated.

1 This box is a compendium of information drawn from previous studies, recent research, and OTA’S assessment. The back chapters of this report discuss a subset of these issues.

2 S. Leatherman, University of Maryland at College Park, personal communication, November 1992.

3 To convert acres to hectares, multiply by 0.405.

4 D. King, Chesapeake Biological Laboratory, University of Maryland, personal communication, November 1992.

Prairie pothole and riparian wetlands in regions that get drier maybe at greater risk than those in regions that get wetter. For example, in the North central States, increases in temperatures and evaporation rates could cause many prairie potholes to shrink or disappear, leading to further declines in already diminished continental waterfowl populations (9). Tundra may shrink as increased temperatures allow the permafrost to thaw and drain (see box I-G). In addition, wetlands of any type that are already degraded by pollution, water diversions, or fragmentation may also be particularly vulnerable (1 98, 199). The status and vulnerability of coastal, riparian, depressional, and tundra wetlands are discussed in "Wetlands" (vol. 2, ch. 4).

Fisheries-The potential effects of climate change on aquatic ecosystems have been studied very little to date, and could vary significantly. in some cases, marine fish maybe able to migrate to new, more suitable habitats, depending on several factors, if food sources are available (80). Some freshwater fish in open waters, such as the Great Lakes, could benefit from a larger thermal niche (98). Fish in small lakes and streams, however, may suffer from increases in temperature that adversely affect survival, reproduction, or their ability to migrate to cooler locations (101). Changes in water quality will also affect the survival of aquatic organisms. Climate change may alter circulation patterns in many lakes, reducing dissolved-oxygen concentrations. Higher temperatures will also act to reduce dissolved-oxygen concentrations (71). Sea level rise will increase saltwater intrusion of estuaries, potentially benefiting marine fish at the expense of freshwater species (80). However, changes in estuaries could have broad impacts on the U.S. fishery. By far, the greatest portion of commercial catches, with the exception of those from Alaskan fisheries, are composed of estuarine-dependent species (139). Ongoing alterations of critical habitat (such as those caused by geographic fragmentation and pollution) may be exacerbated by climate change. Box 2-C (ch. 2) discusses, by region, the condition and value of fisheries today, current problems, and the potential impacts of climate change.

Agriculture--This system is very sensitive to climate, but climate change impacts maybe offset by intense management over short time frames. High temperatures and drought could reduce crop yields, although this effect could be counteracted by higher atmospheric concentrations of carbon dioxide and longer growing seasons in higher latitudes (129). The potential for agricultural adaptation, particularly at the farm level, is very high (30). Changes in management practices (e.g., changing planting dates or using irrigation or crop-switching) can reduce or eliminate many of the potentially negative impacts of climate change. Shifts in climate zones would result in changes in relative productivity levels, with some areas increasing output, and other areas reducing output due to increased competition (l). See "Agriculture" (vol. 1, ch. 6) for further discussion.

Coastal resources-Cities, roads, airports, and other coastal resources are vulnerable to flooding from sea level rise and hurricanes. The population near the coast is growing faster than populations in any other region of the country, and the construction of buildings and infrastructure to serve this growing population is proceeding rapidly. As a result, protection against and recovery from hazards peculiar to t he coastal zone, such as hurricanes and sea level rise, are becoming ever more costly (11). The combination of popularity and risk in coastal areas has important near-term consequences for the safety of coastal residents, protection of property, maintenance of local economies, and preservation of remaining natural areas. These points are discussed further in "Coasts" (vol. 1, ch. 4).

Water resources-These resources are vulnerable to several climate change impacts. Changes in precipitation and higher levels of evapotranspiration can combine to affect surface-water and groundwater supplies, flood and drought frequency, and hydropower production. Arid basins could experience the largest relative change in water flow from climate change (67). Numerous studies have been conducted on the relative vulnerability of the major US. river basins to flood and drought, supply disruptions, hydropower reductions, groundwater overdrafts, and extreme events (48, 49,88, 188). They conclude that the water resource regions most vulnerable to some or all of these events are the Great Basin, California, Missouri, Arkansas, Texas Gulf, Rio Grande, and Lower Colorado (see fig. 1-5). See "Water" (vol. 1, ch. 5) for more information; Appendix 5.1 lists State-by-State problems.

(Continued on next page)

Box I-B-How Climate Change May Affect Various Systems--(Continued)

Human health-Climate change could affect human health, but there is a great deal of uncertainty about whether mortality and morbidity would actually increase and about the potential for adaptive measures (such as the use of air conditioning) to offset any negative impacts. Several studies have concluded that the potential range of infectious diseases could shift with climate change, but the exact nature of these shifts is uncertain (94). Even if the range of disease-carrying vectors, such as mosquitoes, changes, enhanced pest-control measures could nullify the increased threat of disease. Effects of climate change in other countries could displace some populations. If "environmental refugees" lead to an increase in immigration, there is the potential for increased importation of communicable diseases into the United States (184). Other studies have shown that climate change could lead to increased cases of heat-stress mortality (74). Uncertainties about changes in human physiological and behavioral response make it difficult to draw conclusions about the risks of climate change to human health.

Energy-Higher temperatures will no doubt increase energy demand for cooling and decrease energy demand for heating. This would result in an increase in the demand for electricity (primarily for air conditioning) and for electric-generating capacity (93). This new demand would not be completely offset by reductions in the use of oil and gas for heating (98). The largest capital costs would be associated with increased power plant construction, which could cost as much as $170 to $320 billion, about 12 percent more than the increases in capacity needed to meet population and economic growth through the middle of the next century (93). As with sea level rise, adapting to increased energy demand could involve significant costs.

Transportation-Some forms of transportation could be positively or negatively affected by climate change. inland shipping may be the most sensitive to climate change. On the one hand, warmer winters would likely result in less ice cover and a longer shipping season. For example, ice cover on the Great Lakes could be reduced by 5 to 13 weeks (4), lowering shipping and related costs (78). On the other hand, lower river flow and lake levels could increase shipping costs by reducing shipping tonnage capacity or blocking shipping (143). Some roads near the coast may have to be moved or protected from sea level rise. In many instances, adaptation is highly probable in transportation at some cost to the economy (see vol. 1, box 5-E, "Navigating the Mississippi through Wet and Dry Times").

adapt to changes in climate, either through physiological adjustment or through migration, is uncertain. Historically, trees can disperse and migrate about 60 miles (100 kilometers)[5] per century, but the projected rates of temperature change would require migration rates 5 to 10 times faster for forests to remain in suitable habitats (35, 36). The success with which natural vegetation can migrate will depend on seed dispersal, physical barriers to migration (e.g., mountains and developed land), competition between species, and the availability of fertile soils in areas of suitable climate.

■ Uncertainties About Society's Ability to Adapt

Finally, how society will respond to whatever climate change occurs and the resulting impacts are uncertain. Coping with climate change can take the form of technical, institutional, regulatory, behavioral, and economic adjustments. Future technologies and levels of income are unknown, although they will most likely improve and increase and will aid in adaptation (5). Will population growth or environmental consensus limit or expand adaptation options? Will people

5 To convert miles to kilometers, multiply by 1.609.

Box 1-B-How Climate Change May Affect Various Systems--(Continued)

The table below summarizes potential climate change impacts for these various systems.

Potential Climate Change Impacts for Various Systems

Systems	Potential impacts
Forests/terrestrial vegetation	Migration of vegetation. Reduction in inhabited range. Altered ecosystem composition.
Species diversity	Loss of diversity. Migration of species. Invasion of new species.
Coastal wetlands	Inundation of wetlands. Migration of wetlands.
Aquatic ecosystems	Loss of habitat. Migration to new habitats, Invasion of new species.
Coastal resources	Inundation of coastal development. Increased risk of flooding.
Water resources	Changes in supplies. Changes in drought and floods. Changes in water quality and hydropower production.
Agriculture	Changes in crop yields. Shifts in relative productivity and production,
Human health	Shifts in range of infectious diseases. Changes in heat-stress and cold-weather afflictions,
Energy	Increase in cooling demand. Decrease in heating demand. Changes in hydropower output.
Transportation	Fewer disruptions of winter transportation. Increased risk for summer inland navigation. Risks to coastal roads.

SOURCE: J.B. Smith and J. Mueller-Vollmer, “Setting Priorities for Adapting to Climate Change,” contractor paper prepared for the Office of Technology Assessment, March 1992.

react quickly and efficiently to trends deemed outside the range of normal, or will they assume that conditions will return to-historic no&? Will people overreact to periodic climate extremes that do not actually signal a substantial change in the underlying climate? Responses to recent extreme events, such as the Mississippi River flooding in the summer of 1993, may provide an interesting lesson.

CHOOSING ADAPTATION STRATEGIES

How should” decisionmakers incorporate the uncertainties posed by a changing climate into long-term plans for resource systems? What can be done to minimize vulnerability to climate change? Uncertainty makes acting now difficult, but it also makes preparing for a wide range and intensity of climate impacts essential.

The Grand Teton National Park, along with other national parks and preserves, provides habitat for countless species of birds and wildlife. The parks and preserves also offer extensive recreational opportunities such as hiking, camping, nature study, and photography. These are examples of services at risk from climate change.

Possible responses to the threat of climate change depend on what one wants to save. Do we try to maintain systems in their current form (e.g., the extent of forests and the varieties of crops), or do we maintain the services they provide (e.g., enough food for the population, scenic views, beach recreation facilities)? Do we wish to minimize the economic costs of facing a changing climate? Do we attempt to forestall only catastrophic events? However these interests are balanced, two general primary characteristics of adaptation policies stand out: *flexibility* and *robustness*. By helping to ensure quick and effective response to changing circumstances (flexibility) and by being prepared for the worst (robustness), the potential costs of an uncertain future climate can be reduced.

Just how much effort should be expended to avoid future risks will ultimately depend on the perceived costs of the effort compared with the likelihood and scale of future damages that will be avoided. In some cases, the same strategies that help protect against climate risks might also provide some immediate and certain benefits: enhanced services from natural systems, improved productivity in managed systems, better means for dealing with existing climate variability and weather extremes, or reduced environmental damages from managed systems. The costs of these *low-regrets* strategies or activities may be relatively easy to defend. Other activities, however, would be most useful only in the event of severe climate change. The costs of such activities may be considered in the same light in which we consider the purchase of insurance--it may be better to pay a relatively small premium now than to be uninsured against the threat of severe and more costly ecological and economic damage.

Enhancing Flexibility

Any policies that improve the chances of adapting more smoothly and painlessly provide a buffer against the negative impacts of climate change. Flexible systems and policies are those that allow self-adjustments or midcourse corrections as needed without major economic or social disruption. For example, flexible systems can be fine-tuned to cope with hot and dry weather as well as more-intense rainstorms. The system should work now, under current climate conditions. Flexibility would not preclude potentially desirable actions or lock policy makers into expensive, irreversible decisions. For example, in some cases, building a dam is a less flexible policy than is water conservation. If new information becomes available that suggests that the dam is not needed in that location or is the wrong size, fine-tuning is difficult. Efforts to conserve water can (within limits) be used to supply quantities of water without building new, expensive infrastructure with 50- to 100-year lifetimes; the policy is also reversible in times when water is plentiful (see vol. 1, boxes 5-G, 5-H, 5-I, and 5-J).

Advancing the knowledge base will enhance flexibility. In agriculture, the development of new crops suited to a wide variety of climates, improved understanding of the performance of crops under a changing climate, and continuing education and extension programs to provide better-informed decisionmaking by farmers will all help smooth the path of adaptation (see vol. 1, ch. 6). In general, research that clarifies how systems respond to climate change will help identify and expand the range of possible adaptive actions and will speed their successful implementation.

Removing legislative or administrative constraints that now limit our ability to change would also promote flexibility. For example, the complicated programs of price supports in agriculture now penalize farmers who choose to change planting or management practices significantly. Given the importance of agriculture in the United States, large economic costs could be associated with even brief delays in agricultural adjustment to a changing climate. Other subsidies, such as those for irrigation and those implicit in the support for infrastructure in coastal zones, add to our inflexibility by encouraging the development of built systems in areas that maybe increasingly at risk to natural disasters. Resolving conflicts over the use of natural resources, through the creation of organizational structures or market incentives, should also help with our ability to implement change.

Enhancing Robustness

Policies can also minimize the risk of adverse effects from climate change by making systems less sensitive to climate. Robust systems are those that can tolerate a wide range of climate conditions and are, therefore, less vulnerable to climate change extremes. Actions that increase robustness in a system are those that help protect against the threat of large-scale losses or climate surprises. The robustness of a system can be increased in several ways. One is to take actions that make the system itself inherently more tolerant of a variety of climate conditions. For example, developing and planting crops that perform reasonably well under a wide range of climates may be wise no matter how the climate changes. Adding capacity to dams or other structures can make them more "robust, ' that is, able to accommodate greater variability in precipitation. Another way to increase robustness is to put a variety of mechanisms in place to protect against possible losses, hoping that some mechanisms will succeed even if others fail. For example, a mix of management strategies for forests and natural areas could be used to protect against climate change.

Improving the robustness of a system will often require an *insurance strategy something* must be initiated now in order to avoid extremely high costs under a much warmer climate. The idea is that paying a small amount now will reduce the risks of a major loss in the future. For example, establishing gene banks or learning how to undertake ecosystem restoration may be an "investment' that would reduce the risks of catastrophic forest or ecosystem loss in the future.

Efforts that enhance the general health, productivity, or quality of a system can also enhance robustness by making the system more resilient, or able to tolerate some climate-related stresses. Actions promoting robustness include improving the quality and protection of wetlands, minimizing existing threats to natural areas, and establishing new preserves (see vol. 2, chs. 4 and 5). Planning and management measures that avert trends that make adaptation more difficult in the future are also robust strategies.

It is not immediately obvious that natural systems, such as forests or wetlands, are less robust (more vulnerable) in the short term than are managed systems such as agriculture and water-supply systems. Natural systems do have some inherent buffering to protect themselves against existing climate variability. However, what may put natural systems at greater risk than systems that are actively managed is continued stress from climate change over a long time period. Once a natural system declines, it may take many years to recover. Of particular concern is the possibility that losses to natural systems may be irreversible, such as the loss of species. In managed systems, it is much more likely that there would be intervention to reduce the losses because the economic value at stake is often very high.

■ Applying the Criteria

Federal agencies are currently making many decisions about the management of natural resources that could be significantly affected by climate change. What the Federal Government decides now about the management of water supplies, forests, wetlands, fish, wildlife, and other issues could limit or foreclose the ability of these resources and their managers to adapt to the future effects of climate change, or could help make us better prepared to deal with an uncertain climate future.

Given the broad criteria of flexibility and robustness, we identified a large class of policy options that could remove inefficiencies, address existing problems, and help insure against the uncertainties posed by climate change to resource systems. Many studies term such options no *regrets* or *low regrets* because they make sense to pursue now, even assuming no climate change. The question that arises is: Why are actions that are supposed to be prudent, anyway, even without the added impetus of climate change, being pursued in such a limited way (5)? Actions that appear reasonable for protecting resources cannot be considered in a vacuum. In reality, there are barriers of many sorts-in information, institutions, and process-even to options that appear to be low regrets. OTA'S policy analysis focused on these barriers and tried to identify ways to overcome them.

Another large class of policy options calls for us to be prepared for the worst. Whether these options will still be seen as no-regrets once climate does change may depend on the rapidity and magnitude of that climate change, and the future response of decisionmakers. If, in the face of significant climate change, the no-regrets options prove inadequate, there could indeed be regrets that substantially more aggressive measures were not taken earlier. OTA has also looked at some of the more aggressive measures that would be appropriate if the likelihood of climate change is considered high.

The policy options presented in this report to enhance the flexibility and robustness of the various resource systems represent a gradation from "learn more about the natural resource system" to "improve the technology or know-how required for adaptation" to "relax the institutional constraints that tend to inhibit the ability or incentive to respond. " This gradation depends on whether the ability to respond to climate change is limited by information, by available technologies, or by the institutions that govern the system.

Coastal systems and water resources (discussed in vol. 1, chs. 4 and 5, respectively) face many institutional factors that may limit adaptation. Theoretically, there is enough water to supply needs throughout the United States, even under climate change. We know how to move water from one place to another and have technologies to save water or even to make fresh water from salt water. However, the complex system of water rights, lack of incentives to conserve water, and limits on the transferability of water result in daunting institutional constraints and inflexibility. In coastal systems, the infrastructure of roads and bridges and subsidized flood insurance encourage a degree of development in high-risk zones that maybe economically unwise even under current climate conditions and sea levels.

In agriculture, market incentives and annual planting cycles make the system quite responsive, or flexible, to change. As long as there are continued efforts in research, technology, and innovation that expand the base on which adaptation can proceed, coping with climate change should be relatively easy for agriculture-barring catastrophic changes (vol. 1, ch. 6). Yet, whether adaptation is optimal may depend greatly on our ability to remove certain institutional incentives that may encourage uneconomic farming of areas where climatic risks are high. In this regard, farm subsidies and disaster-assistance programs need review and, likely, adjustment.

For less-managed systems, our ability to facilitate natural adaptation is limited by inadequate information or understanding of natural processes and by the narrow range of available and suitable technologies for adaptation. In wetlands (vol. 2, ch. 4), sea level rise and changes in the timing and amount of precipitation will exacerbate ongoing habitat loss. Efforts to reduce current loss will make the system more robust and improve chances for adaptation to climate change. Actions to minimize the possibility of irreversible damage should receive high priority. For forests and natural preserves (vol. 2, chs. 5 and 6), climate change may make the continued existence of unique assemblages of plants and animals questionable. Natural areas have become the repository of biodiversity in the United States. Yet little is known about maintaining, changing, restoring, or transplanting natural ecosystems. There is no systematic effort to document what is currently preserved and how that can be augmented or protected under climate change. Enhancing these areas through strategic acquisitions of land or land easements and through innovative coordination of management with adjacent landowners offers great promise as an approach for maximizing protection of biodiversity. Filling in gaps in our knowledge through research would allow us to better manage and protect these areas and to reduce the risk of decline under climate change.

OVERARCHING POLICY THEMES

As we developed and evaluated policy options, using the criteria described above, for the six different resource sectors examined in this report, many sector-specific policy options appeared to coalesce into several broad themes, or problems. Four particular themes were found to be shared by several or all of the sectors:

- geographic and institutional fragmentation,
- inadequate *communication of climate risk,*
- the need for *contingency planning,* and
- an ongoing Federal research effort-the U.S. Global Change Research Progrogram--that will not fill many key *research and information gaps.*

Each chapter addresses these themes within the context of the appropriate resource sector, but the common threads are highlighted here. Below, we describe the overarching themes more fully and illustrate some possible directions Congress could take to begin addressing these broader policy challenges. Box 1-C examines some specific options from the resource chapters, and relates them to these common themes.

Fragmentation

A key problem in natural resource management is that the most sensible management units from a resource perspective—watersheds or ecosystems-rarely correspond to the boundaries within which resources are actually managed. Furthermore, resources are usually owned and managed for multiple purposes. Many different government agencies and private owners may have some responsibility for the management of a given resource, with differing incentives motivating its management and use. As a result, resources may be fragmented geographically and jurisdictionally.

One aspect of fragmentation is the geographical division of landscapes and ecosystems that results from uncoordinated development and the encroachment of human activity. Such activity has left few ecosystems intact in the lower 48 States (the Greater Yellowstone Ecosystem is often cited as the most important remaining example). Inmost parts of the country, remaining natural areas have become “islands’ of habitat, surrounded by developed or altered landscapes and vulnerable to a variety of human stresses (see vol. 2, box 5-E). This fragmentation of former large ecosystems has led to greater stress on the natural resources within the remaining fragments. Many natural areas, including the federally pro-

Box I-C-Solutions from General to Specific: Addressing the Overarching Problems

During the course of developing policy options for coping with climate change, OTA heard repeatedly from many experts that climate change alone is not necessarily the most worrisome threat to natural resources. Rather, climate change is likely to exacerbate various trends and problems that already plague natural resource management. Current management policies and practices for coasts, water resources, agriculture, wetlands, natural areas, and forests are perceived in many quarters as being inadequate in ways that not only hinder management today, but could impose greater constraints under a changing climate. Four particular problems were found to be common to several or all of the sectors: 1) institutional and geographical fragmentation; 2) Inadequate communication of information that would improve response to climatic risks; 3) lack of contingency planning and other measures to prepare for extreme events or weather surprises; and 4) information gaps in various key scientific and policy areas.

Addressing these overarching problems will pose numerous challenges for Congress and Federal agencies. All four problems have been recognized to varying degrees in the past, but progress toward solving them has been slow. Attempting to solve any of them could require far-reaching policy changes, but small piecemeal actions could be undertaken for individual resource sectors by many different government agencies or by congressional appropriations, legislation, and oversight committees. Big, bold policy changes could accomplish the job more uniformly or effectively, but reaching agreement on solutions and then garnering sufficient support to implement them could prove impossible. Incremental changes do not require such widespread support and may accomplish specific goals, but such policies can also detract from needed larger changes by leaving the impression that no further action is necessary.

In the resource and research chapters of this report (vols. 1 and 2, chs. 3 through 6), we suggest numerous policy options that address parts of the four overarching problems in ways that are specific to each resource sector. In many cases these resource-specific options could be formulated in broader terms to attempt across-the-board solutions to the overarching problems identified above. Furthermore, many of the sector-specific options are interconnected, and could be more effective if enacted in a coordinated way. In some cases, any of several different resource-specific policy options could forma first step toward solving an overarching problem. A few of these options are described below.

Fragmentation

Options to help reduce institutional fragmentation include:

- Promoting the reestablishment and strengthening of Federal-State river basin commissions to improve coordination among agencies. (Vol. 1, option 5-11—''Water.")
- Promoting integrated resource management at the watershed level, (Vol. 2, option 4-22-''Wetlands.")
- Creating a Federal coordinating council for ecosystem management. (Vol. 2, option 5-12–''Preserves.")
- Amending the Science Policy Act of 1976 (P.L. 94-282) to strengthen the ability of the Office of Science and Technology Policy (OSTP) and the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET) to coordinate research and ecosystem management across agencies. (Vols. 1 and 2, option 3-1-''Research.")

Although these options seem varied, all four address, in some way, the problem of institutional fragmentation and the need for greater coordination and integrated management. If enacted individually, these policies could focus on specific problems in the management of water resources, wetlands, and preserves. However, any of the four could also serve as part of a larger effort to coordinate the management of all three resources. Reinstated river basin commissions could form a local base for watershed management that could be broadened to include attention to wetlands and other natural areas within the watershed. Similarly, a Federal coordinating council for ecosystem management could use watershed units as one level of coordination and examine the interaction of water resources with other natural resources in that unit. The problem in trying to expand any of these individual options to cover the overarching concerns would be in how best to assign authority and enforcement capabilities for any coordinating agency without interfering with the jurisdiction of the agencies to be coordinated.

Options to help reduce geographic fragmentation include:

- Identifying and assigning priorities to the wetlands that are most important to protect and restore. (vol. 2, Option 4-19-- "Wetlands.")
- Directing agencies to modify their criteria for land acquisition to include underrepresented ecosystems and long-term survivability. (Vol. 2, option 5-9-'' Preserve")")
- Using current conservation incentive programs administered by the Secretaries of Agriculture and Interior to enhance the Federal effort to protect natural areas. (Vol. 2, option 5-16-'' Preserve")")
- Protecting highly valued forest sites. (Vol. 2, option 6-4-''Forests.")
- Providing incentives to reduce fragmentation of private forestland. (Vol. 2, option 6-5-''Forests.")

Several of the policy options for wetlands, preserves, and forests either explicitly address the problem of geographic fragmentation or could be used to do so. The options listed above would promote priority setting for land acquisition or restoration of valuable natural areas, including wetlands, forests, and other typesof preserves. Reducing landscape fragmentation could be viewed as a high-priority goal. Furthermore, existing conservation incentive programs of various types could be required to focus on the lands most valuable for preventing or ameliorating fragmentation.

Communication of climate risk

Options to communicate risk through modifying subsidies include:

- Raising premium rates for the National flood Insurance Program (NFIP) policyholders who receive subsidized flood insurance. (Vol. 1, option 4-1-''Coasts.")
- Reducing the Federal share of public disaster assistance. (Vol. 1, option 4-7-'' Coast")")
- Reforming pricing in Federal water projects. (Vol. 1, option 5-5--"Water.")
- Defining disasters formally, with assistance provided only for unusual losses. (Vol. 1, option 6-3--''Agriculture.")
- Improving participation in the crop-insurance program. (Vol. 1, option 6-5--''Agriculture.")
- Eliminating incentives to destroy wetlands. (Vol. 2, option 4-8-"Wetlands.")
- Reducing Federal subsidies, such as Coastal Zone Management funds and flood insurance, in areas that have not established setback or "planned retreat" policies. (Vol. 2, option 4-16-' 'Wetland")")

One of the major ways the Federal Government affects the responsiveness to climate risk is in the distribution of public money for disaster assistance and insurance subsidies. Subsidized and regulated prices distort the perception of changing risks and could slow the response to growing water scarcity and to increases in the frequency of droughts, floods, and storms. The options listed above suggest that policies to reduce or eliminate such subsidies could be beneficial in encouraging greater precautions and faster responses to changing climate risk in nearly every individual resource sector-as well as in reducing Federal spending in an era of constrained budgets. If enacted together, these options could go a long way toward addressing the overarching problem of misperception of risk.

Options to communicate risk through tax signals include:

- Eliminating or reducing tax benefits for coastal development (such as the casualty-loss deduction). (Vol. 1, option 4-16--"Coasts.")
- Reforming tax provisions to promote conservation investments. (Vol. 1, option 5-4--"Water.")
- Using current conservation incentive programs administered by the Secretaries of Agriculture and Interior to enhance the Federal effort to protect natural areas. (Vol. 2, option 5-9--'' Preserves.")

(Continued on next page)

Box I-C-Solutions from General to Specific: Addressing the Overarching Problems--(Continued)

The U.S. Tax Code can provide both incentives and disincentives for financial risks. Tax incentives can be used to encourage behavior that might reduce risks to humans and the environment, including investments in water conservation and in protecting natural areas. Tax disincentives could be used to help prevent unproductive behavior, such as coastal development in high-risk zones or where development leads to the destruction of wetlands or creates barriers against their movement inland as the sea level rises.

Other options to communicate risk include:

- Improving the research and extension process (develop a database on successful practices; expand farmer involvement; provide support for on-farm experimentation). (Vol. 1, option 6-11—''Agriculture.")
- Incorporating climate change scenarios into forest plans and assessments. (Vol. 2, option 6-11—''Forests.")
- Eliminating the even-flow-harvest requirement of the National Forest Management Act (P.L. 94-566), which falsely implies that future timber supplies will be stable). (Vol. 2, option 6-12–''Forests.")
- Incorporating sea level rise into National Flood insurance Program mapping. (Vol. 2, option 4-5--''Coasts.")

The Government is the source of considerable information that can serve to improve private sector response to a changing climate. Outreach and extension services will be valuable in communicating changes in the effectiveness of farm management techniques and crop choices, speeding t he process of adaptation. Inventories, monitoring, climate data, and resource-status assessments will indicate trends in natural resource conditions and signal changes in the future supply of products and service from natural resource systems. Better understanding of these trends will help businesses and individuals to anticipate and adjust more effectively to changing future conditions. Inappropriate signals about climate risk that create an unrealistic expectation of stable conditions may encourage unwise financial investments in resource-dependent communities that are at risk of decline. The public generally is not well-informed about the risks associated with living in coastal areas, and this lack of awareness has led and will continue to lead to large public and private expenditures. Educating people now about the risk of a rising sea level could greatly reduce future damages.

Contingency planning

Options to formalize contingency planning include:

- Creating an interagency drought task force to develop a national drought policy and plan. (Vol. 1, option 5-I&' 'Water.")
- Creating a national flood-assessment board. (Vol. 1, option 5-17--''Water.")
- Establishing criteria for intervention in order to protect or restore forest health through a forest health bill. (Vol. 2, option 6-7—''Forests.")

Droughts, forest fires, floods, and hurricanes have all become the focus of public attention in recent years after events such as the nationwide drought in 1968, the 5-year California drought of 1968-1992, the Mississippi floods in the summer of 1993, and Hurricanes Hugo and Andrew in 1968 and 1992. In many cases, contingency plans set up to deal with such disasters were either inadequate or nonexistent. Policy options for water resources and forests suggest different types of contingency planning that may help address future disasters as the climate changes. Because the presence of forests and wetlands moderates how water moves through the landscape, both should be considered in flood planning and development.

Options that add a measure of "insurance" against catastrophic events include:

- Increasing support for the development of new commercial crops. (Vol. 1, option 6-14--"Agriculture.")
- Conducting research on natural resources to prepare for climate change (restoration ecology, preservation of biodiversity, effective preserve design). (Vol. 2, option 5-2—''Preserves.")
- Directing agencies to modify their criteria for land acquisition to include underrepresented ecosystems and long-term survivability. (Vol. 2, option 5-9—''Preserve")")

- Enhancing forest seed banks and genetics research programs. (Vol. 2, option 6-1—''Forests.")

Preparing for extreme future climate conditions through the development of technologies or institutions will assist in recovery and can help reduce the threat of future damage. The development of crops well-suited to harsher future climate may provide some insurance against a steep decline in our agricultural sector. Contingency preparations for forests and preserves must consider the potential need for active restoration or protection if natural processes become excessively disturbed. Seed banks may provide the material to rebuild a forest in the event of severe decline and loss of species or populations from their natural range.

Information gaps

Options to help decrease these gaps include:

- Supporting long-term research and monitoring on the impacts of climate change on wetlands. (Vol. 2, option 4-24--''Wetlands.")
- Increasing funding for ecological research in the U.S. Global Change Research Program (USGCRP). (Vol. 2, option 5-1--''Preserves.")
- Supporting coordinated research in federally protected natural areas. (Vol. 2, option 5-4--''Preserves.")
- Creating a national program for inventorying and monitoring. (Vol. 2, option 5-5-'' Preserve")")
- Using the Experimental Forests for research on adaptation to climate change. (Vol. 2, option 6-2—''Forests.")
- Using existing monitoring and inventorying efforts to identify causes and effects of forest decline. (Vol. 2,option 6-6--''Forests.")
- Creating an Integrated Assessment program within or outside USGCRP positioned above the agency level, (Vols. 1 and 2, option 3-8-''Research.")
- Creating an adaptation and mitigation research program either within USGCRP or separate but parallel to it. (Vols. 1 and 2, option 3-+'' Research.")

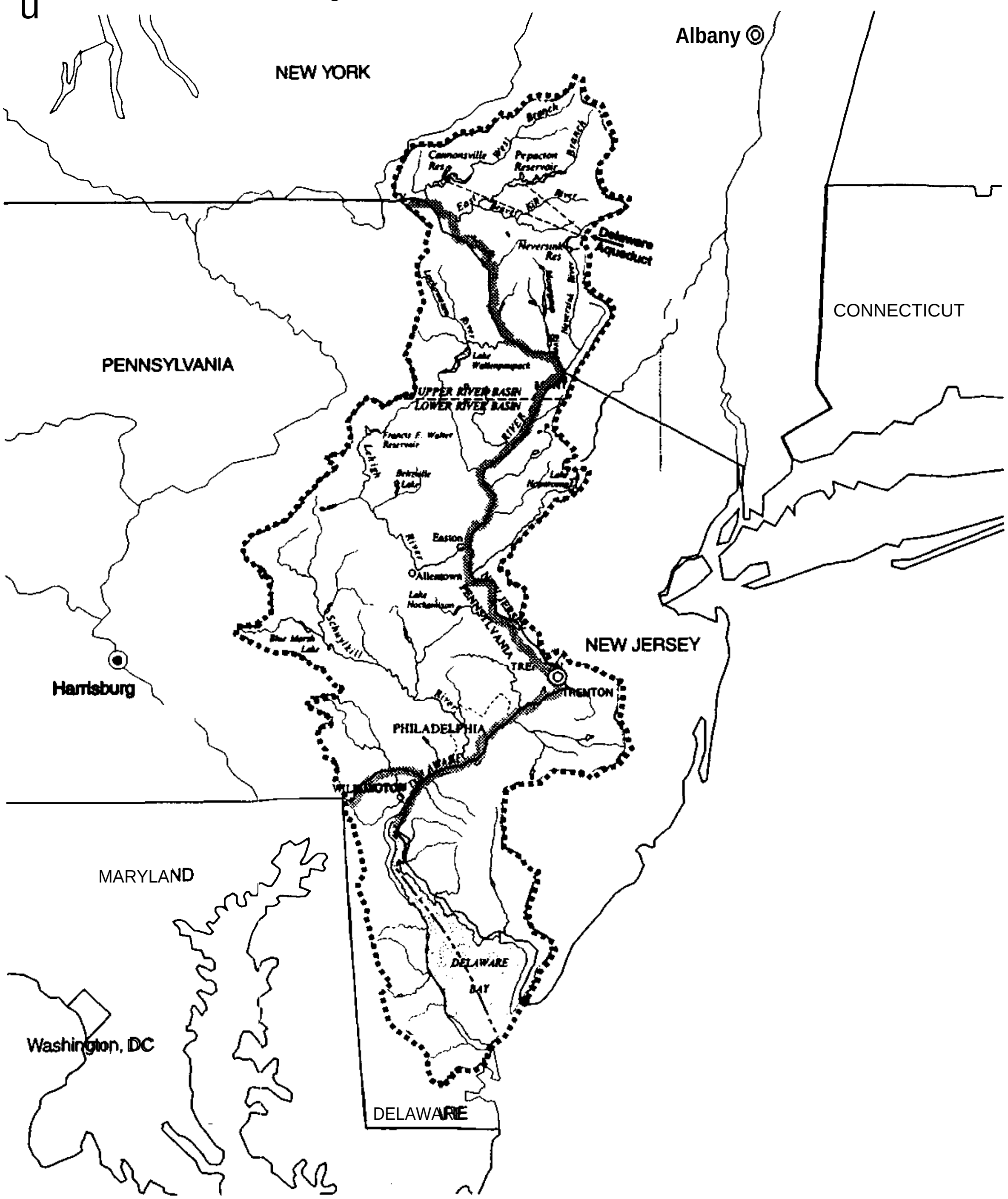
Many policy options suggest particular research questions or promote the use of specific existing programs to address some of the information gaps regarding climate change. Coordinating these different research efforts and ensuring that each considers some of the related concerns of others might yield synergistic results. For example, while the Experimental Forests should be useful sites for examining how forests may adapt to climate change, research could be focused more broadly to consider issues that affect natural areas (including questions of how to maintain biodiversity and how to restore damaged ecosystems) and forested wetlands.

While these research programs in individual areas are forming useful building blocks toward solving the overarching problem of Iack of knowledge, a broader program of coordinated research across-the-board could also be attempted. Some of the research listed could be coordinated under the Ecological Systems and Processes priority group in the USGCRP. However, the USGCRP goals and purview need to be broadened to include ecosystem research, adaptation and mitigation research, and an iterative integrated assessment in order to be more useful to policy-making.

tected natural areas, may not be large enough to withstand future stresses such as climate change. Managing smaller areas as individual parcels in an uncoordinated manner and without larger needs in mind has become part of the problem.

A second aspect of fragmentation is the inefficiency that results from a lack of coordination in management across government agencies. It is not uncommon in even relatively small watersheds, for example, for dozens of Federal, State, and local agencies to share jurisdiction overwater and other natural resources. For instance, the Delaware River Basin is divided among four States (fig. 1-3). Responsibility for water resources alone in this basin is divided among at least 10 agencies in each of the four States and among more than 20 Federal agencies. In most basins, responsibility for groundwater manage-

Figure 1-3-The Delaware River Basin



NOTE: As is typical of many watersheds, the boundaries of the Delaware River Basin do not coincide with legislated boundaries. The multiple jurisdictions make management more difficult.

SOURCE: W.E. Harkness, H.F. Uris, and W.M. Alley, "Drought in the Delaware River Basin, 1984-85," in: National Water Summary 1985-Hydrological *Events and Surface Water Resources,* U.S. Geological Survey Water Supply Paper 2300 (Washington, DC: U.S. Government Printing Off be, 1986).

ment is separate from that for surface-water management (see also vol. 1, box 5-D). Water quality and water quantity are usually treated separately. And jurisdiction over navigation, recreation, flood control, and wetlands may also be split, although all these aspects of water resource management are related and may affect one another. Problems are encountered in managing a single reservoir as if its operation does not affect how others within a basin are operated, or in managing to control floods without considering the role of wetlands. The result of this jurisdictional fragmentation is often seen in conflicting efforts, high management costs, and foregone opportunities to provide better overall service. These inefficiencies may be of increasing concern if climate changes threaten the supply and services of natural resources. Box 1-D describes the complexities of trying to manage a growing urban center, agricultural areas, and the Everglades of South Florida (see also vol. 1, box 5-B).

More effective management for coping with current and potential future stresses on natural resources and built systems is possible and needed. Today's agency-by-agency, owner-by-owner, and system-by-system management approach leaves much to be desired. Many improvements can be made by going beyond our customary fragmented style of management to consider more comprehensively the services of watersheds, ecosystems, and landscapes (see vol. 2, box 5-F). Within most sectors or systems examined in this report, we have identified options that can begin moving toward more integrated management and reduced geographical fragmentation: breaking down institutional barriers among agencies, acquiring and consolidating natural areas, and providing private owners with incentives to maintain the environmental services of a landscape. Regional priorities could be used to direct activities in regulatory, acquisition, and incentive programs. We also consider some more fundamental changes, such as creating major new programs and reorganizing agency responsibilities, which can be pursued if the political will exists. However, neither breaking down institutional barriers nor altering private incentives will be easy. Watershed management, for example, has been discussed for many years, but established styles of management have changed little to date. Nevertheless, watershed management seems to be a concept whose time has come: the Environmental Protection Agency (EPA), backed by the current Administration, has strongly advocated the approach, and watershed management is being considered in current legislation to reauthorize the Clean Water Act (P.L. 92-500) (see vol. 1, box 5-c).

More integrated planning and management along watershed and ecosystem lines is likely to be one of the best ways for the Nation to promote the flexibility, robustness, and efficiency that is desirable in coping with the uncertain impacts of climate change.

Communication of Climate Risk

If climate changes as predicted, resource managers and individuals will find it necessary to adjust to new circumstances. Certain parts of the country are likely to become much less desirable

NOAA

Hurricanes and other tropical storms cause millions of dollars' worth of damage each year as homes, boats, and businesses are destroyed by high winds and water. Some Federal programs and regulations encourage redevelopment in high-risk areas without requiring appropriate safety measures.

places to live and work. Even where climate changes are less harsh, current management practices and lifestyles may not continue to be appropriate. The speed with which resource managers and individuals can recognize and respond effectively to new climate conditions will largely determine the economic and social costs of climate change. Adaptation to change is likely to be delayed by the inherent difficulties in recognizing climate change against the background of normal climate variability. Responsiveness to changing climate risks maybe further impeded by existing Federal programs designed to protect individuals from the financial risks of climatic extremes. It maybe enhanced by providing information about the nature of climate change risks, the changing resource situation, and the likely success of particular adjustments in resource-management techniques. Effective communication of the nature of climate-related risks can be promoted through formal educational efforts or through appropriate incentives.

The Government could better communicate climate risk by reducing the various public subsidies for developments in areas of high risk. The public has come to depend heavily on government disaster assistance and subsidized insurance programs, which helps reduce exposure to the financial risks from climate extremes. Such programs have been valuable in allowing the productive use of resources in areas of highly variable climate. Problems may arise, however, if the financial buffer provided by these Federal programs unintentionally encourages people to move into environments where they may be exposed to greater risk in the future, or reduces incentives to take adequate precautions against climate risk. Because development decisions are not easily reversible, and the consequences of decisions taken now are, in some cases, likely to be with us for many decades, it seems prudent to begin reexaminingg policies that may encourage development in climate-sensitive areas. Private citizens should recognize the true costs of extending farms into economically marginal areas, building structures in areas of high forest-fire risk, or locating buildings in coastal erosion zones.

We assessed two systems in which a reexamination of current risk protection policies may be especially important in the face of climate change: coastal areas and agriculture (see vol. 1, chs. 4 and 6). Flooding and erosion are of particular concern in coastal areas, and these hazards could increase in a warmer climate. We discuss options in the coastal and agriculture chapters that could help owners respond more effectively to climate change and that would decrease potential future exposure to climate risk. For example, the National Flood Insurance Program has been only partially successful in reducing the need for taxpayer-funded disaster assistance and in encouraging local mitigation efforts. In agriculture, Federal Crop Insurance, various disaster-assistance programs, and irrigation subsidies all tend to distort the manner in which farmers respond to climate risks. (See box 1-Eon water allocation in the Sacramento-San Joaquin River System and box 1-F on agriculture in the prairie-pothole region.) Improvements can and should be made in these program to ensure that in the future, individuals, communities, and the Federal Government are not exposed to excessive costs.

Equally important may be quickly communicating the detection of any change in key climate variables and other information that will assist in the responses to changing climates. Farmers and foresters, for example, may be reluctant to alter practices until they are convinced climate has actually changed. The potential role of the Extension Services in tracking the changing success of farming and forestry practices and spreading this information to managers may prove important in reducing the costs of adaptation.

Contingency Planning

The goal of contingency plarnning is to minimize losses from natural disasters or accidents by preparing in advance to take appropriate actions.

Contingency plarming is important where the threat of significant losses is high in the absence of preparation and prompt response--as is the case with floods, forest fires, droughts, and hurricanes (see vol. 1, chs. 4 and 5 and box 4-C; vol. 2, box 5-I). Climate change could affect the intensity or number of extreme climate events, making preparedness perhaps even more important than it is now. However, adequate contingency plans do not exist for all parts of the country that are vulnerable to extreme events. For example, only 23 States have drought-management plans (197). The States that do have them, however, have generally adapted better to droughts than those without plans (197). We identified options that could help mitigate damages, including the ecological harm caused by natural disasters. Improvements in contingency planning would be helpful both to minimize near-term damages and to prepare for potentially greater damages caused by climate change.

States have a key role in planning for most extreme events and must continue to do so. States should be encouraged to develop contingency plans or to refine them with climate change in mind. The Federal Government also has a role in planning for natural disasters, with many agencies involved in some way in this activity (see cartoon on page 34). However, the Federal Government could do better at defining the respective roles of the agencies that have responsibilities for extreme events. It could also promote stronger coordination among Federal agencies and among the various levels of government in establishing requirements for assistance and in providing such assistance in a more timely, consistent, and equitable manner.

Contingency planning is also important when emergency measures are likely to be controversial; it allows potential responses to be considered in advance when there can be rational debate. Such controversies are very likely to be associated with any efforts to restore the health of natural ecosystems that have been severely harmed by climate-related stresses. This is well-illustrated by difficulties now faced in responding to "massively destructive forest health problems" in the Blue Mountain forests of Eastern Oregon (176; see vol. 2, ch. 6 and box 6-E). Although there is general agreement that major changes in management are needed in those forests, the response has been slow, and agreement about how to proceed has been hard to achieve. Procedures for responding to ecosystem health emergencies should be established.

Research and Information Gaps

The individual resource chapters outline the important research gaps that need to be addressed for coasts, water resources, agriculture, wetlands, preserves, and forests. Overall, we found that various strategies for coping with climate change can be identified for managed natural-resource-based systems (including the coastal zone, water resources, and agriculture-see vol. 1, chs. 4-6). Some of these strategies may require continued support for research on new technologies or management practices that will enhance the potential for adaptation. For natural systems, however (e.g., wetlands, unmanaged forests, and nature preserves-see vol. 2, chs. 4-6), the informational gaps in our understanding of these systems are so large that realistic response strategies are difficult or impossible to identify now (see also vol. 2, box 5-K).

Although an estimated $900 million is spent annually on what can be considered research in "environmental life sciences" (54) or "environmental biology,"[6] there is currently very little research directed specifically at protecting natural areas under climate change and helping land managers modify management strategies to re-

[6] J. Gosz, Executive *Secretary,* Subcommittee on Environmental Biology, Committee on Life Sciences and Health, Federal Coordinating Council for Science, Engineering, and Technology, personal communication, Sept. 14, 1993, Only 11 percent of these expenditures overlaps with the Federal Global Change Research Program budget.

Box I-D–Climate Change, South Florida, and the Everglades

Lying dose to sea level and in the preferred path of a sizable percentage of Atlantic hurricanes, South Florida is potentially one of the most vulnerable areas of the United States to climate change. It is also one of the most distinctive. South Florida's famed Everglades, a vast subtropical wetland of which about one-seventh is preserved in Everglades National Park, is seen by many as one of the crown jewels of the U.S. National Park System. Miami, Palm Beach, and other coastal communities in South Florida makeup one of the most popular seaside vacation destinations in the world. Despite hurricane and flood hazards, these cities have experienced phenomenal growth in recent years. In addition, varieties of crops can be grown in the warm, subtropical climate that grow nowhere else in the United States. And Miami has become a gateway between North and South America, transforming South Florida into an important international crossroads.

Despite, or perhaps because of, its distinctiveness and popularity, South Florida is under stress and, like a few other heavily developed parts of the United States, beginning to bump up against limits to growth. The critical factor is water. Although the region receives an annual average of 60 inches (152 centimeters) of rain, annual evaporation can sometimes exceed this amount, and rainfall variability y from year to year is quite high, resulting in periodic droughts and floods. In the past century, moreover, South Florida has been transformed from a virtual wilderness into a complex, interconnected system of developed and undeveloped land. The main elements of this system-the growing urban sector, agricultural areas, and the Everglades and other remaining natural areas-must all compete for the limited supply of water, and the competition is increasing with every new resident.

Much of the growth of South Florida has occurred since 1870. Then, fewer than 100 people lived in what are now Dade, Broward, and Palm Beach Counties. Now, about 5.2 million people occupy the same area. The vast unaltered Everglades, which originally extended from Lake Okeechobee to Florida Bay, were seen by early settlers as hostile to human welfare and completely without value. Encouraged by a grant from the U.S. Congress, the State of Florida began draining these "useless" wetlands for agriculture, and by the early 20th century, the natural character of the Everglades had begun to change. Farmers planted sugar cane and a variety of vegetables in the drained area south of Lake Okeechobee now known as the Everglades Agricultural Area (EAA).

The initial drainage system worked well enough during normal years but was stressed during occasional abnormal events and failed completely during a major hurricane in 1928. At that time, 2,000 people died in the EAA when the protective dike around Lake Okeechobee burst. This incident prompted the initiation of a massive public works project, as attention shifted from drainage of wetlands to flood control. Eventually, an 85-mile (137-kilometer)[1] earthen dike was built around Lake Okeechobee, and the meandering 98-mile Kissimmee River, which fed the lake from the north, was transformed into a canal 48 miles long and 33 feet (10 meters) deep. Flooding problems diminished, but the former broad, riverlike system north of Everglades National Park has been greatly altered into a series of canals and pools. The former sheet-like flow of water to the park, necessary to its health, has been blocked. Today, the area has more than 1,395 miles of canals and levees and 143 water-control structures.

Projects to expand the supply of water to growing urban centers proceeded in tandem with flood-control projects. To accommodate demands for agricultural and urban expansion, diking and draining of wetlands continued, and as the expansion progressed, more water was diverted for these purposes. Today, additional water is diverted for sewage dilution, pest control, and frost protection. Some water is used to recharge aquifers that supply cities east of the Everglades and the populated areas of the Florida Keys. Large quantities of water that could be recycled or used to recharge urban aquifers are dumped into the Atlantic Ocean (see vol. 1, ch. 5, and vol. 2, ch. 4, for complete discussions of water and wetland issues).

A major effect of this decades-long restructuring of the natural hydrological system has been to drastically reduce the supply of water from the Kissimmee River watershed that reaches the much-diminished-in-size

1 To convert miles to kilometers, multiply by 1.609.

Everglades. The natural system has suffered in several ways as a result: 1) the abundance of species characteristic of Everglades habitats (e.g., wood storks, white ibis, tri-colored herons, and snowy egrets) has declined dramatically in the past 50 years, 2) more than a dozen native species have been listed as endangered or threatened (e.g., the Florida panther, snail kite, Cape Sable seaside sparrow, American alligator, and American crocodile), 3) nonnative and nuisance species have invaded the area (e.g., Melaleuca quinquinervia and the Brazilian pepper tree), 4) sizable land subsidence and water-level declines have occurred throughout the region, 5) water quality has been degraded by agricultural runoff containing excessive nutrients, such as phosphorus, 6) saltwater intrusion of coastal aquifers has occurred, 7) vulnerability to fire has increased, and 8) massive algal blooms have appeared in Florida Bay, accompanied by die-offs of shrimp, lobster, sponge beds, and many fish.

The impacts of development have not been limited to natural areas. As water use in the region has grown, susceptibility to periodic droughts has increased. A 1981 drought, for example, led to mandatory water restrictions for half the counties of South Florida and water rationing in the EAA. Pollution from cities, as well as from agricultural areas, has added to water-quality problems. Saltwater intrusion threatens aquifers used for urban water supplies.

Everglades National Park was created in 1947, the culmination of efforts that began in the 1920s. The transition of the Everglades from being perceived as “worthless land” to an important preserve worthy of designation as an International Biosphere Reserve and World Heritage Site took decades, but preservation of this area and restoration of other degraded wetlands are now considered high priority by a broad spectrum of people and organizations. Although there is broad agreement that the hydrology of the Everglades should be restored to a pattern similar to that found in the original system, it will not be easy to balance the needs of the Everglades for water with the similar needs of other users.

South Florida’s Everglades and coastal areas, dearly already under stress, face an unusually difficult problem in the light of global climate change. Both are already vulnerable to sea level rise and intense tropical storms (see vol. 1, ch. 4). (Damage from Hurricane Andrew, for example, was not confined to urban areas-coastal mangrove forests were heavily damaged, as were trees in many densely forested hammocks.) Climate change could increase the current vulnerability to these events. Climate change may also result in a hotter and drier climate for South Florida, although predictions from general circulation models (GCMs) are not consistent on this point. Whatever occurs, the future is likely to be increasingly stressful for South Florida. Cities are likely to continue to grow and will almost certainly be protected from sea level rise, but the expense of protecting them could be immense. The Everglades, once deemed worthless, is now considered a valuable natural resource. As valuable as it is, however, the Everglades will probably not receive the same attention as cities threatened by rising seas will. Farmers are likely to resist attempts to hinder or reduce long-established patterns of agriculture in favor of other uses for water. In short, South Florida is a system increasingly “close to the edge.” The flexibility to satisfy competing interests for water and land has been reduced by actions taken since the turn of the century, and climate change may further reduce flexibility.

In recent years, some efforts have been made to offset some of the damage to the Everglades and restore some of the lost flexibility to the natural system. In 1970, for example, Congress directed that not less than 315,000 acre-feet (389 million cubic meters) of water be delivered annually to Everglades National Park. In 1989, Congress enacted the Everglades National Park Protection and Expansion Act (P.L. 101-229), one purpose of which was to enable more natural flow of water through a portion of the park. More recently, the Federal Government sued the Florida Department of Environmental Regulation for not upholding its own water-quality laws, thereby allowing degradation of the Everglades to continue. As a result, the State has agreed to design and construct treatment areas in the EAA where drainage could be filtered before it is discharged to the park. The State has also directed the South Florida Water Management District to implement an Everglades Surface Water Improvement and Management Plan. Finally, as authorized in the 1992 Water Resources Development Act (P.L. 101-640), the U.S. Army Corps of Engineers will soon begin a long-term project to restore the Kissimmee River to an approximation

(Continued on next page)

Box 1-D—Climate Change, South Florida, and the Everglades—(Continued)

of its original meandering route, thereby increasing wetlands north of Lake Okeechobee, helping to improve water quality in the lake, and increasing the water-storage capacity of the entire Everglades system.

Although important steps are being taken to restore the Everglades, some major obstacles are stymieing the more comprehensive ecosystem planning that will be required to address the full range of South Florida's current and climate-change-related problems. One of the most vexing, and one encountered many times in OTA's study, is the lack of coordination among the responsible State and Federal agencies. Part of the problem is a result of a lack of shared values among agencies and among the constituencies they represent. Furthermore, each agency has a different mandate, and agencies' jurisdictional boundaries seldom coincide with boundaries of natural systems. One might expect that the preservation mandate of the U.S. Fish and Wildlife Service and the Florida Department of Environmental Regulation would often clash with the flood-control mandate of the Corps of Engineers and with the interests of EAA farmers, and such has been the case in South Florida. However, lack of coordination has extended even to agencies with similar mandates; a prominent example has been the difficulty of reconciling the National Park Service's ecosystem-wide approach to restoring the Everglades with the Fish and Wildlife Service's mandate under the Endangered Species Act (P.L. 100-707) to focus on protection of individual species.

Recently, Interior Secretary Bruce Babbitt expressed a strong interest in Everglades National Park and has made clear his intention to get the National Park Service and the Fish and Wildlife Service to work more closely together to develop a common policy. Babbitt has also announced plans to form a Federal task force in an attempt to overcome some of the coordination problems.

The broader challenge for the region is to manage this complex system in an integrated fashion to maximize the health of all its diverse elements. This is no small challenge because it may be very difficult to sustain agriculture without environmental costs, for example, or for urban areas to continue to grow indefinitely without some restraints. The effort to sort through these problems must take place with some understanding of what climate change may mean.

SOURCES: S. Light, L. Gunderson, and C. Holling, "The Everglades: Evolution of Management in a Turbulent Ecosystem," University of Florida, Arthur C. Marshall Laboratory, unpublished manuscript, 1993; National Audubon Society, *Report of the Advisory Panel on the Everglades and Endangered Species* (New York: National Audubon Society, 1992); J. de Golia, *Everglades: The Story Behind the Scenery* (Las Vegas, NV: KC Publications, Inc., 1978); K. Kemezis, "Babbitt To Test Ecosystem Policy in the Everglades," *Environment Week*, Feb. 25, 1993.

spend to climate change. In 1992, only $8 million was spent on research focused on adaptation to climate change.[7]

The U.S. Global Change Research Program (USGCRP) is a $1.4 billion research program. However, as currently designed, it will not provide either the practical technologies that might make us more prepared for climate change or the ecological information that would be helpful in providing policy guidance and adaptation options for natural systems. Overall, USGCRP is more focused on understanding the causes for and rates of climate change[8] than on examining the ecological and human impacts of change (see ch. 3 for a more complete explanation of USGCRP). The agencies primarily responsible

[7] 'I&Working Group on Mitigation and Adaptation Research Strategies (disbanded in 1992) of the Committee on Earth and Environmental Sciences of FCCSET identified Federal research that focuses on or contributes to adaptation to global change (24).

[8] USGCRP is designed to produce a predictive understanding of the Earth system and focuses on three interrelated streams of activity: documenting global change (observations), enhancing understanding of key processes (process march), and predicting global and regional environmental change (integrated modeling and prediction). For FY 1994, a fourth activity stream, assessment, was added.

Box I-E—Water Allocation and the Sacramento-San Joaquin River System

The complexity and divisiveness of western water problems-and the potential for climate change to exacerbate those probleme--is well-illustrated in the continuing battle over allocation of water in California. The Sacramento-San Joaquin River System, and especially the Delta area where the two rivers come together in Northern California, is the focal point of this conflict. Before western water development began, about 40 percent of California's runoff converged into the Sacramento-San Joaquin Delta on its way to San Francisco Bay and, eventually, the Pacific Ocean. However, about half of this water is now diverted to Southern California, the San Joaquin Valley, and parts of the Bay Area the the massive State Water Project (SWP) and central Valley Project (CVP). The water delivered through these huge "plumbing" systems has enabled California's semiarid Central Valley to become one of the Nation's prime agricultural areas and has been partly responsible for the phenomenal population growth of Southern California's mild coastal areas.

Agriculture is now firmly established in the Central Valley, and about 16 million people--over 70 percent of the State's population-now live in Southern California. Water supply is crucial to California: it has been the basis for most agricultural, industrial, and economic development. However, the transfer of water from Northern to Southern California has not come without a cost to the river system and the State. Water supply and allocation issues directly conflict with water-quality and ecosystem concerns, and they pit interests of Southern Californians against those of Northern Californians. Three issues are of special concern.

Delta fisheries-The Delta and extended Sacramento-San Joaquin River System provide important habitat for over 40 species of fish. Coho and chinook salmon, steelhead trout, and striped bass all reside in the river system atone point in their lives and have been especially important to the recreational and commercial fishing industries. Yet these species of fish have declined 50 percent or more since the early 1960s. Fewer than 500 winter run salmon have returned to spawn each year in the Upper Sacramento in recent years, compared with the 60,000 per year that returned 20 years ago. Only 432 steelhead returned in 1966 compared with over 17,000 in 1967 (16). The Delta smelt is dose to extinction. Causes of these dramatic declines include loss of habitat; water pollution; dam, levee, and diversion-facility obstructions; and drought. When conditions are poor in the Delta-when flows are low and water temperatures and exports are high-losses of young, ocean-bound salmon can be very high.

Fishermen, as well as fish, have suffered. Fish losses have cost the local economy over $15 million per year in recent years. In effect, the benefits to people who receive water diverted from the Delta have come partially at the expense of both fish and fishing interests. in March 1993, the U.S. Fish and Wildlife Service and the National Marine Fisheries Service invoked the Endangered Species Act (P.L. 100-707) to protect winter run chinook **salmon** and Delta smelt, setting limits on t he operations of the Central Valley Project and intensifying a dispute between State and Federal officials on how best to protect the Delta.

Delta farmland and levees--The Delta, once a natural marshland, was developed for farming around the turn of the century and now contains almost 550,000 acres (223,000 hectares)[1] of rich farmland. The marshland was converted to a mosaic of over 70 islands by building over 1,100 miles (1 ,600 Kilometers)[2] of levees. The levee system is fragile, however. The peat soils of the Delta have been gradually compacting, requiring that levees constantly be raised or repaired. Many of the levee-surrounded Delta islands are now wel below sea level. Maintenance of the levee system is important for protecting life, property, and infrastructure from flooding on Delta islands. Permanently flooded islands would also have major adverse effects on both water quality in the Delta and freshwater supplies. Since 1960,24 levees have failed, and with each year, the fate of these islands becomes more uncertain.

1 To convert acres to hectares, multiply by 0.405.

2 To convert miles to kilometers, multiply by 1.609.

(Continued on next page)

Box I-E–Water Allocation and the Sacramento-San Joaquin River System--(Continued)

Water quality-Water quality in the Delta is of concern because of possible salinity intrusion into the western Delta from San Francisco Bay, wastewater discharges that contain chemical pollutants, and the inflow of agricultural drainage water that may contain pesticide residues and other toxic agents (18). Maintaining water quality and ecological health in the Delta (by, among other things, ensuring that an adequate amount of fresh water reaches the Delta) is legally required by the State but may conflict with water transfers and local consumptive uses. This is especially true during drought, when there may not be enough water to fulfill all demands. Drought poses another problem as well: during low-flow periods, water temperature in system rivers increases, and this has contributed significantly to the decline of cold-water anadromous fish spades in recent years.

In sum, Californians are making heavy demands on the Sacramento-San Joaquin River System. They recognize that the means of transferring water from the Delta must be improved to maintain water quality and to enable more efficient transfer of supplies to the southern part of the State, but the issue has proved to be one of the most controversial water problems in the West. In 1982, for example, California voters defeated a referendum to build the so-called Peripheral Canal around the Delta to improve the system'sufficiency. Northern Californians overwhelmingly rejected the proposal, for fear that the Delta's environment would not be adequately protected and because they perceived that populous Southern California was attempting yet another "water grab." Although there was more support in Southern California, many in that part of the State feared the project's high cost.

Studies of the potential impact of climate change in California suggest-but have by no means proven-that the regional effects of climate change could be reduced mountain snowpack, a shift in runoff patterns (i.e., in timing, amount, or duration of precipitation), and large decreases in summer soil moisture. Specifically, a possible result of warming temperatures is that more winter precipitation will fall as rain and a reduced mountain snowpack will start melting earlier in the spring. As a result, reservoirs would fill faster. Because a portion of reservoir space must be reserved for flood-control purposes, the additional water would have to be spilled. Although California's total water budget might remain the same, less would be available during the summer, when water demand is highest. The reduced snowpack in effect represents the loss of one or more storage reservoirs. Maintaining adequate freshwater flow to San Francisco Bay would be more difficult in summer and could increasingly conflict with water needed for consumptive purposes. Summer temperatures would also likely increase in the Sacramento and other rivers and represent a threat to fish.

A further complication could be sea level rise. The Intergovernmental Panel on Climate Change predicts a total sea level rise of 26 inches (65 centimeters)[3] by 2100. Such a rise would inundate the entire Delta area and have devastating effects on Delta islands and water quality. A sea level rise of more than 2 feet would transform the current 100-year high-tide peak at Antioch, a western Delta location, into a 1 in 10 event-making such rare occurrences more common. Levees would be even more expensive, or even impossible, to maintain. Because the Delta islands are developed for farming and valued for helping preserve water quality, the initial response to incremental sea level rise is likely be to try to preserve the islands. In the long run, a phased retreat from the Delta may have to be considered (142), Choosing between preservation at any price and abandonment would not be easy.

if the above impacts occur (or worse, if California's water budget actually decreases), maintaining California's water supplies for consumptive purposes and maintaining the health of the Delta will be a great challenge. This would be especially true during droughts, which, if more common than--and as extreme as-the current drought in California, could have devastating impacts. A suite of demand-and-supply management and supply-augmentation responses to the State's water problems is being considered. No one response will be sufficient. Conservation and water marketing could significantly ease California's water problems, but building new reservoirs and even some desalination plants and other responses may be needed as well.

3 To convert inches to centimeters, multiply by 2.540.

SOURCE: Office of Technology Assessment, 1993.

Box I-F-Changes in Agriculture and the Fate of Prairie Potholes: The Impacts of Drought and Climate Change

The prairies comprise millionsof acres over a vast geographical area that includes parts of Canada, and the states of Montana, North Dakota, South Dakota Minnesota, and lowa.The region is characterized by a glaciated, depressed topography with poorly defined drainage that results In numerous small lakes and wetlands known as prairie potholes.[1] Millions of potholes dot the landscape, providing an impermanent water source for the region's agricultural operations and diverse wildlife, including migratory waterfowl. Since the early 1960s, a general shift in the structure of the agricultural economy has occurred in the prairie region, involving a move toward more-intensive farming practices (80). The drainage of prairie potholes has been accelerated in order to bring more land into production and to increase yields on existing cropland. However, drought conditions in recent years have evoked concerns about the sustainability of the regional agriculture and wildlife and have raised questions about impacts that may result from climate change.

The drying effects of climate change are certain to affect the prairie-pothde region by altering aquatic conditions. Agricultural operations and wildlife rely on prairie potholes for water. An increase In temperature, which would influence aridity in continental interior areas, would reduce available volumes, thereby putting both farming and waterfowl at risk. In addition to changes in the availability of surface water, water storage in the soil is likely to decrease (134). Temperature changes may also mean an extended growing season, which could alter the nesting and feeding habits of wildlife. In total, climate change will affect the region by increasing existing stress on the prairie-pothole ecosystems and agriculture.

Agriculture operations in the prairie region have long provided the bulk of the Nation's wheat supply. Wheat is well-suited to the region's dryland agriculture, with the majority of precipitation falling during the growing season and with relatively cod temperatures keeping evapotranspiration rates down. Farming in the region has become more and more intensive as agriculture has become increasingly mechanized. These developments have had a considerable effect on the fate of prairie potholes, which have decreased from 20 million to 7 million acres (8 to 3 million hectares)[2] leaving only 35 percent of the original pothole acreage intact (179). A poor farm economy in the 1980s coupled with mechanization caused prairie farmers to push every possible acre into production. North Dakota's potholes were being drained at an estimated rate of 20,000 acres per year to support conversion to agriculture (179). And drainage rates became similarly high in other prairie States, as farmers recognized the potential value of new farmland.

Now, although 20 percent of all remaining prairie potholes are protected? prairie potholes are among the most threatened ecosystems in the United States. They provide prime nesting grounds and habitat for a multitude of waterfowl and other wildlife. Since the 1970s, populations of three common duck species (the mallard, the pintail, and the blue-winged teal) have declined dramatically. Populations of some other spades of duck less dependent on potholes in agricultural regions have increased. The mallard, pintail, and blue-winged teal nest in the drought-prone zone of intensive agriculture (1 19). These migratory waterfowl have lost not only extensive areas of breeding habitat, but also adjacent vegetated areas once used for food and cover. Here, the detrimental effects of the loss of wetlands cleared for agricultural use are dramatic; wildlife populations have likely been cut in half (80).

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1 Prairie-pothole ***wetlands are*** relatively shallow, water-holding depressions that vary in size, water permanence, and water chemistry. They are located in the glaciated portion of the North American Great Plains and are the single most important breeding area for waterfowl on this continent (63). They also support a variety of other Wildlife.

2 To convert acres to hectares, multiply by 0.405.

3 Protection includes, but IS not limited to: ownership by Federal or State governments, short-and long-term government easements, and ownership by private conservation groups.

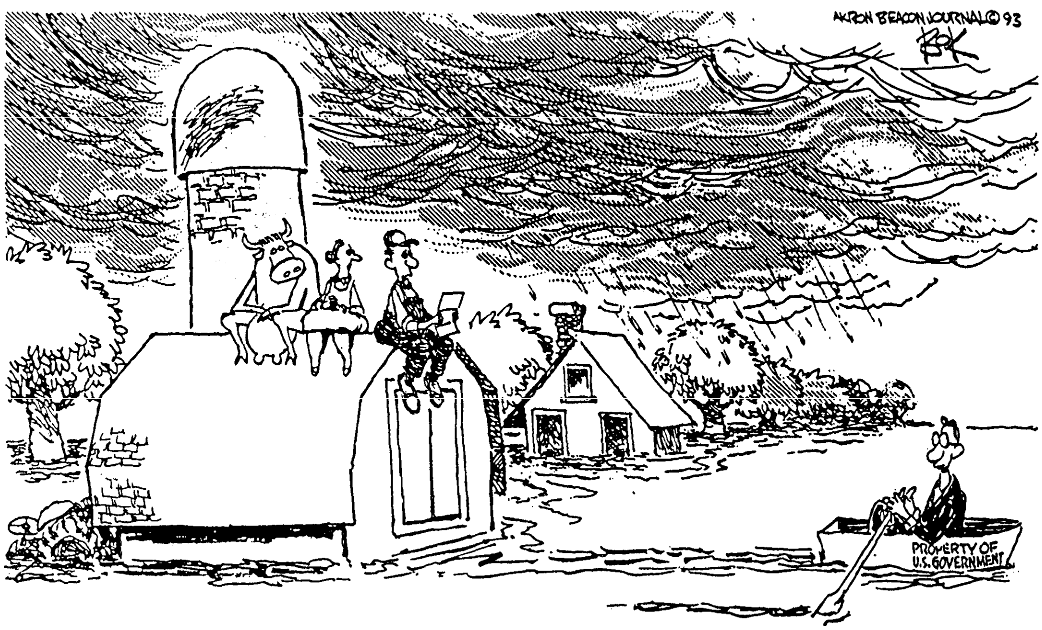
(Continued on next page)

Box I-F-Changes in Agriculture and the Fate of Prairie Potholes: The Impacts of Drought and Climate Change-(Continued)

Though these changes have been occurring over along period of time, effects were most dramatic during recent drought conditions in the region. Severe drought marked both the 1988 and the 1989 growing seasons in North Dakota the heart of the country's spring wheat production area (143). This dry spell was the second to occur during the 1980s and the fourth serious drought in the past three decades (143). The lack of precipitation and subsequent loss of soil moisture resulted in dramatic decreases in agricultural yields and in abandonment of some cropland. Despite the grain crop losses (some more than 70 percent), net farm income and farmed acreage did not suffer. This was basically due to government drought assistance, in the form of insurance and direct aid. The combination of insurance, aid, and the higher grain prices resulting from the drought helped farmers avoid losses that might ultimately have led to extensive farm failure and abandonment.

Climate change may significantly alter growing conditions in the prairie region. Changes resulting from global warming may decrease both water depth and the number of ponds holding water in t he spring and summer. This aspect is likely to further influence the degradation of waterfowl and wildlife habitat and to upset populations. Waterfowl may respond by migrating to other areas, relying heavily on the semipermanent prairie-pothole wetlands, remaining on permanent wetlands but not breeding, or failing to renest as they currently do during drought (160). On the other hand, drier conditions in these shallow, temporary, seasonal wetlands will make land-use conversion to agriculture much more reasonable in terms of expense and ease. Long-term changes in agricultural activity in the region, caused by economics and climate change, are sure to affect the fate of prairie potholes and the waterfowl and wildlife they support, placing them at further risk.

SOURCE: Office of Technology Assessment, 1993.



BOK, 1993; REPRINTED WITH PERMISSION FROM THE AKRON BEACON JOURNAL

"LOOKS LIKE A DISASTER RELIEF CHECK, CROP LOSS COMPENSATION, AND A FINE FOR DISTURBING A WETLAND' for research and management of public lands (the Department of the Interior (DOI), the U.S. Department of Agriculture, the National Science Foundation and EPA) combined receive less than 30 percent of the total funding for Ecological Systems and Dynamics (less than 5 percent of the total USGCRP budget). Given that such research on ecological and human impacts may take years or decades to produce results, the slow process may cost us the ability to respond to global change in areas that are especially at risk to irreversible damage. In addition to understanding climate impacts and effects, it is important to know how to minimize socioeconomic impacts. Ultimately, to be useful in planning for an uncertain climate, USGCRP must include ecosystem research that can feed into management, socioeconomic analysis, and adaptation research. An assessment process that incorporates all these categories and permits inputs from stakeholders and policy makers is necessary to make USGCRP truly policy relevant. This is a much broader definition of "assessment" than USGCRP can accommodate given its current research program and structure.

NEAR-TERM CONGRESSIONAL ACTION

In the resource chapters (vol. 1, chs. 4-6, and vol. 2, chs. 4-6) of this report, a series of "first steps' ' is outlined to illustrate ways to begin incorporating climate change considerations into statutes, policies, and programs relating to various natural resource--coasts, water, agriculture, wetlands, preserved lands, and forests. The first steps for the resource chapters are summarized briefly in the last section of this chapter. Several of the first steps focus on actions that offer important and immediate benefits, even without climate change as an additional factor justifying them. Several targets of opportunity in the near-term congressional agenda, in the announced and potential initiatives of the new Administration, and in the programs of the various agencies can be capitalized upon now.

Likewise, the USGRP offers annual opportunities for changes. Chapter 3 discusses several directions the program could take; many of these options are included below as possible near-term congressional actions. The process of policy development in government is not so orderly that one can lay out and follow a detailed plan of logical first steps, followed by logical second steps, and so on. Regular congressional reauthorization cycles for major natural resource programs, the annual budget cycle, election cycles, the fragmentation of responsibilities among congressional committees, and still other policy-making realities provide the context in which decisions about climate change will be made. Seen in this light, the choice of frost steps is significantly influenced by an assessment of where the opportunities lie.

Annual Appropriations

Even if Congress did nothing else, each year it would enact legislation appropriating money for carrying out governmental programs. Thus, an immediate and recurrent annual opportunity to address many of the issues considered in this report is through the appropriation process. Most simply and directly, to narrow the breadth of uncertainties that exist today, Congress can ensure adequate levels of funding for existing climate-change-related research programs. Through the appropriation process, Congress can also encourage natural resource management agencies to carry out their monitoring and research programs in ways that meet their intended objectives while simultaneously producing data that could be useful to their own or other agencies' climate change research efforts.

The annual appropriation process is also the means by which Congress makes major long-term investments-for example, in land acquired for National Parks and wildlife refuges and in dams and other water resource projects. Until now, climate change considerations have not been a factor in deciding whether any of these investments were prudent. One could justify inclusion of such considerations now because climate change has the potential to lessen the value of such investments. Thus, Congress could require that the land-acquisition, water-resource-development, and other similar proposals brought before it be accompanied by explicit evaluations of how climate change may affect the long-term viability of the investment. Alternatively, in the case of lands proposed to be acquired for conservation purposes, Congress could direct that the criteria by which agencies rank their acquisition priorities include some consideration of potential climate change impacts on those lands or their resources. Building up the Nation's reserve of protected land would help stem some climate change impacts by reducing fragmentation and, possibly, reducing other threats to natural area resources. Increased protection and reduced fragmentation of these areas could help build more resiliency into some natural systems (see vol. 2, chs. 4 and 5).

Congress has increasingly linked policy direction to agency funding during the appropriation process. Congress could include requirements in its various appropriation bills that each of the agencies managing natural resources potentially affected by climate change provide Congress with its own evaluation of the agencies' preparedness to cope with a range of climate futures. The appropriation process may also be especially well-suited to encouraging agencies that implement climate-sensitive programs (e.g., agricultural disaster assistance, crop subsidies, and flood insurance) to develop long-term budget projections for those programs based on several future climate scenarios. In this way, a budget-conscious Congress can better inform itself early on about the potential costs of climate change for those programs.

Reauthorization Cycle

In addition to the annual appropriation cycle, congressional action is heavily influenced by the reauthorization cycles of major Federal programs. Congressional attention is not focused on all issues at once. Rather, at any given time, its attention is disproportionately focused, through its committees, on the major Federal programs for which current authorization is about to expire. The process of extending that authorization provides an opportunity to evaluate the workings of a program closely and to provide legislative direction for that program for a period of many years. Thus, at least with respect to changes in existing Federal natural resource programs, the best opportunities to implement the first steps recommended here are in the context of laws and programs that are about to be reauthorized.

Among these, the Clean Water Act is a high-priority target of opportunity (see vol. 1, box 5-C). Comprehensive revisions of that law have been proposed, and the act's wetland provisions are undergoing particular scrutiny. The reauthorization of the Clean Water Act provides a key opportunity to address one of the more important needs identified in this report-the need to achieve more effective integration of resource-management efforts across political jurisdictions. Comprehensive watershed planning (see vol. 1, ch. 5), which integrates wetland protection and restoration goals (see vol. 2, box 4-A), water-use-efficiency goals, strategies for controlling point-source and non-point-source pollution, and both water-quantity and water-quality concerns generally, could create the institutional capability and flexibility to anticipate and plan for climate change. Such planning could be especially valuable for finding creative ways to resolve current conflicts in which landowner and development interests chafe at restrictions on use of wetlands, while environmental interests decry the continued loss of wetlands (see vol. 2, ch. 4 and box 4-B).

Another major target of opportunity is the upcoming reauthorization of farm programs in the 1995 Farm Bill. The next reauthorization cycle could provide a forum for considering how to enhance farmers' flexibility and effectiveness in responding to a changing climate and how climate change may affect Federal expenditures on disaster assistance and farm commodity programs (see vol. 1, ch. 6).

New Targets of Opportunity

In addition to the reauthorization of existing laws, Congress regularly considers altogether new legislation creating programs for existing or new agencies of Government. A program of potentially great significance on the horizon is Interior Secretary Babbitt's proposal to create a National Biological Survey (see vol. 2, box 5-L). Legislation to establish the Survey has been introduced in both the House and Senate, and a National Research Council committee has been asked to offer advice on the formation and role of the Survey. The nature, mandate, resources, and overall purposes of the National Biological Survey, however, are still very much in the process of development. The bills introduced in Congress thus far to establish the Survey give only a very general description of its functions. Thus, there exists an opportunity to shape the content and direction of this new institution in ways that wouId be useful to the management of natural resource systems in a changing climate.

The rationale frequently offered by Secretary Babbitt for creating a National Biological Survey is its potential, by cataloging the biological resources of the Nation and monitoring their status and trends, to avert future "train wrecks,' that is, the disruptive and wrenching conflicts between conservation and development goals. A "train wreck' of another sort could take the form of severe adverse impacts on our natural resources from climate change for which we were unprepared. A National Biological Survey could help detect, evaluate, and prepare for that climate change. Thus, an important opportunity exists to structure the mission and capabilities of the Survey so that it can contribute to the early detection of indicators of climate change, a better understanding of the ability of organisms and natural communities to respond to climate changes, and the design and management of a system of preserves best able to achieve the purposes for which they were established. Careful congressional attention now to these details in the design of a National Biological Survey could yield major returns in the future (see vol. 2, ch. 5).

Existing Statutory Language

Of the many Federal statutes pretaining to the management of the natural resource systems discussed in this report, only one-the Coastal Zone Management Act (CZMA; P.L. 92-583)--explicitly addresses climate change and its potential consequences. The 1990 amendments to that law required that possible sea level rise resulting from climate change be anticipated and addressed in State coastal zone management plans (see vol. 1, ch. 4). Congress could extend this legislative precedent to other statutory arenas; here, we attempt to identify which statutes may be most appropriate for this.

None of the statutes governing the various natural resource systems discussed throughout the full report precludes the agencies responsible for their management from fully considering climate change. Existing grants of authority are sufficiently general and open-ended to allow an agency, on its own initiative, to examine the implications of climate change for the natural resources under its jurisdiction and to tailor its management of those resources accordingly. The question, therefore, is whether Congress wishes to supplement the existing legislative framework with explicit directives pertaining to climate change.

Several categories of legislation maybe especially appropriate for considering possible climate-change-related amendments. First among these are statutes, such as CZMA, that require long-range planning for the management of natural resources. For example, the Rangeland and Renewable Resources Planning Act of 1974 (RPA; P.L. 93-378) requires the preparation of a forest 'resource planning assessment' that looks

50 years into the future. Similarly, the Clean Water Act requires preparation of area-wide waste treatment plans that look two decades into the future, a planning horizon also found in the Pacfic Northwest Electric: Power Planning and Conservation Act (P.L. 96-501). In general, the longer the time frame over which management is to be planned, the greater the likelihood that climate change may affect the resources being managed. Thus, mechanisms to ensure that climate change is taken into) account when long-range plans are being developed and to ensure that plans can be revised as new information about the direction and magnitude of climate change becomes available are clearly desirable.

A second statutory area where it is especially important to ensure that potential climate change is considered is long-term public or private investments affecting natural resources. Examples include public land acquisition for parks, wildlife refuges, and the like (see vol. 2, box 5-C). Historically, such public land acquisitions have been viewed as permanent investments, with the intention of keeping the areas acquired in public ownership in perpetuity. The expectation implicitly accompanying these investments has been that the areas acquired would, with appropriate management, continue to provide the environmental and recreational benefits for which they were acquired indefinitely into the future. Climate change introduces a new uncertainty about the validity of this expectation. At the very least, it suggests the need for a more careful examination of whether particular acquisitions are, in fact, likely to continue to provide the environmental benefits that they provide today.

Somewhat similar are public or private investments in dams and other water-resource-development projects. Public projects are governed by the Water Resources Planning Act (P.L. 89-80) and private ones are licensed pursuant to the Federal Power Act (P.L. 102486). The implicit assumption underlying both has always been that hydrological models based on past climate will accurately predict future conditions as well. The possibility of climate change casts doubt on the continuing validity of that assumption and may warrant statutory revisions explicitly requiring water resource planning agencies and Federal regulators to factor climate change into their decisionmaking.

A third statutory arena relevant here includes those laws that require an evaluation of the expected environmental impacts of planned actions. Foremost among these laws is the National Environmental Policy Act (NEPA; P.L. 91-190); similar, though less far-reaching, laws include the Fish and Wildlife Coordination Act (P.L. 85-624) and the Endangered Species Act (P.L. 100-7O7). Under these and similar laws, expectations of the environmental impacts of planned actions may vary, depending on whether a constant or changing climate is anticipated. Legislative direction could provide useful guidance to agencies with respect to their duties to consider climate change possibilities in implementing their responsibilities (see, for example, vol. 2, box 5-D).

A fourth set of laws that warrant discussion consists of those that authorize research programs. The Clean Water Act and the Rangeland and Renewable Resources Planning Act are examples. As this report makes abundantly clear, there are many uncertainties about climate change, including its magnitude, its direction, and its impact on natural resource systems. Natural resource management will require research aimed at resolving many of today's uncertainties. Reflecting that need in the legislative description of the various research missions may serve o underscore the importance of this area of inquiry. Each resource chapter highlights important research options to consider.

Finally, the Science Policy Act of 1976 (P.L. 94-282), which established the Office of Science and Technology Policy (OSTP) and the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET), could be amended to strengthen the ability of these offices to coordinate science and ecosystem management across agencies.[9] These offices have the authority to develop and implement coherent, government-wide science policy and have been the mechanism for coordinating several multi-agency programs. However, OSTP has not always been an active or influential player in the executive branch, and FCCSET lacks the authority to set priorities, direct policy, and fully participate in the budget process (17, 51). FCCSET acts largely as a fulcrum for coordination. Agency participation in FCCSET projects is voluntary, and FCCSET has no authority over how participating agencies spend their funds. Congress could amend P.L. 94-282 to change this. Similarly, the U.S. Global Change Research Act of 1990 (P.L. 101-606) could be amended to require periodic integrated assessment reports to be presented to Congress and to specify key participants in the assessment process.

SUMMARIES AND FIRST STEPS FOR EACH RESOURCE CHAPTER

▮ The Coastal Zone

The coastal zone is a complicated area that includes both human-made and relatively ‘undisturbed” features, ranging from densely settled urban areas to cypress swamps (see vol. 1, ch. 4). Populations in coastal areas are growing faster than in any other region in the United States, and the construction of buildings and infrastructure to serve this growing population is proceeding rapidly. Consequently, protection against and recovery from hazards peculiar to the coastal zone, such as hurricanes and sea level rise, are becoming ever more costly (163). The combination of popularity and risk in coastal areas has important near-term consequences for the safety of coastal residents, the protection of property, the maintenance of local economies, and the preservation of remaining natural areas (see fig. 1-4).

The expected climate change impacts are likely to exacerbate problems that already plague the coastal zone (66). Sea level rise will substantially increase flooding and erosion in areas already vulnerable. Coastal storms-whether or not they increase in intensity or frequency under a changing climate-will have increasingly greater effects as sea level rises.

The coastal areas most vulnerable to the effects of climate change are those with low relief and easily eroded shorelines-such as those in the Southeast and Gulf Coasts-and those where the coastline is already subsiding, such as in Louisiana (52). Structures close to the ocean in low-lying areas are also vulnerable.

U.S. FISH AND WILDLIFE SERVICE

Barrier islands provide protection for coastal ecosystems and help stem erosion. In some cases, such as this barrier island near Tampa, Florida, these islands have been heavily developed, exposing many communities to the risks of serious damage from storms and high seas.

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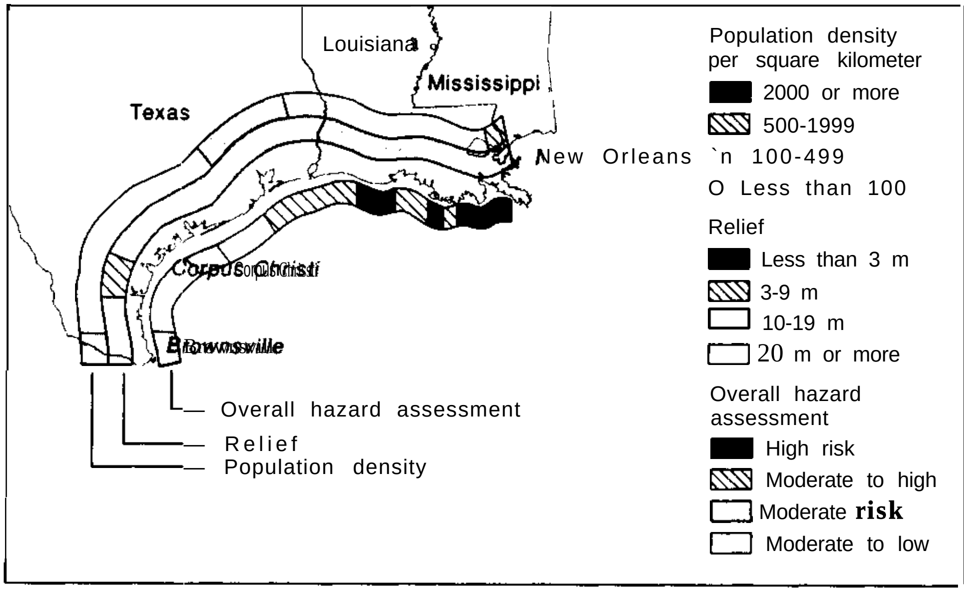
9 OSTP was established to “define coherent approaches for applying science and technology to critical and emerging national and international problems and for promoting coordination of the scientific and technological responsibilities and programs of the Federal -rots and agencies in the resolution of such problems,” and FCCSET was established to “provide more effective planning and administration of Federal scientific, engineering, and technological programs”(P.L. 94-282, the Science Policy Act of 1976).

Figure f-4-An Assessment of Coastal Hazards: Texas and Louisiana



NOTE: To convert square kilometers to square miles, multiply by 0.624. To convert meters to feet, multiply by 3.280.
SOURCE: U.S. Geological Survey (USGS), "Coastal Hazards," In: National Atlas *of the United States of America* (Reston, VA: USGS, 1985).

Although development pressures in coastal areas are driven by many social and economic trends, government policies can influence the appropriateness, rate, quality, and location of development. The current system of allocating the costs of preventing or repairing climate-related damage in the coastal zone among Federal, State, and local governments and private entities encourages certain types of+ development, or at least does not discourage them (11). Climate change will likely add to the risks and costs of living in the coastal zone. It is essential that all stakeholders, such as property owners, understand them and that coastal development and preservation are guided by this understanding. The sooner policies are in place that encourage an adequate appreciation of risk, that offer sufficient incentives to take adequate precautions, and that attempt to overcome the organizational fragmentation that makes a unified approach to coastal climate change issues impossible, the easier and less costly adaptation to a changing climate is likely to be.

The Federal Government has an interest in promoting sound planning and public safety in an effective and efficient manner. Federal coastal zone policies can be improved in many ways to better guide the decisions of those living in coastal areas, and a suite of options for doing so is presented in volume 1, chapter 4. We focus on five general categories in that chapter: revamping the National Flood Insurance Program (NFIP), improving diaaster-assistance policies, revising the Coastal Barrier Resources Act (P.L. 97-348) and the Coastal Zone Management Act, changing beach-renourishment guidelines, and altering the U.S. Tax Code.

To help focus on where to start with responses to climate change in the coastal zone, some first steps that could be taken are listed below.

- **Revamp the National Flood Insurance Program.** The National Flood Insurance Program could be revised to provide stronger incentives to reduce the potential costs associated with high-risk development in coastal areas. Congress has been considering revising the NFIP for several years, and bills to do this have been introduced in both the House and Senate. H.R. 62, the "National Flood Insurance Compliance, Mitigation, and Erosion Management Act of 1993, " contains provisions that partially address some of the NFIP improvements that maybe desirable. Most pressing is the need to adequately address erosion along the coast. Erosion losses will increase with rising sea levels. The Federal Emergency Management Agency does not now have the authority to map erosion risks or to reflect such risks in insurance premiums, and as a consequence, information and incentives to avoid development in eroding areas are inadequate. Also, it seems especially desirable to increase insurance premiums after multiple claims are made on properties in high-risk areas subject to repeated flooding.
- **Improve disaster assistance.** Several bills have also been introduced in the 103d Congress to revise disaster-assistance policies and regulations. More stringent disaster mitigation by States and localities could be required, which could hold down future costs to the Federal Government. This could be accomplished by more strongly tying disaster assistance to adoption of mitigation measures. H.R. 935, the "Earthquake, Volcanic Eruption, and Hurricane Hazards Insurance Act of 1993, " for example, would establish minimum criteria for reducing losses, recommends such measures as fiscal incentives to reduce losses, provides for low-interest loans or grants to retrofit facilities vulnerable to hurricanes, and provides guidelines for establishing actuarial premium rates for disaster insurance. S. 995, the "Federal Disaster Preparedness and Response Act of 1993,' would establish, among other things, a grant program and accompanying performance standards to help States prepare for, respond to, and recover from major disasters.
- **Strengthen coastal zone management.** The Coastal Zone Management Act will be up for reauthorization in 1995, and this provides an opportunity to require stronger State controls on risky development. Such controls could include, for example, an erosion-setback program (already adopted by several States), re-restrictions on construction of immovable buildings, a relocation-assistance program, restrictions on rebuilding damaged or destroyed structures in high-risk locations, and adoption of minimum coastal-construction standards. All of these controls would add some degree of protection against sea level rise and flood or storm damage. Another possibility for reducing risks of living on the coasts would be to encourage States to adopt coastal-hazards-management programs. These could be overseen jointly by the National Oceanic and Atmospheric Administration and the Federal Emergency Management Agency.
- **Promote public education.** The public generally is not well-informed about the risks associated with living in coastal areas, and this lack of awareness has led and will continue to lead to large public and private expenditures. H.R. 935 provides one possibility for expanding public education. The act authorizes education programs and provides funds to States to implement them through a self-sustaining mitigation fund. The private sector, particularly the private insurance industry, could also play an important role in increasing awareness of coastal hazards.
- **Require increased State and local contributions to beach-nourishment operations.**

Most benefits of the U.S. Army Corps of Engineer's beach norishment and shoreline-protection projects are realized at the local or regional level, yet these projects are often heavily subsidized. In most instances, the Federal share is 65 percent. Greater State and local contributions could be required, both for initial construction and for maintenance, and Federal funding could be made conditional on adoption of stronger mitigation measures. These adjustments would tend to increase the interest of local governments in acting to limit community exposure to coastal hazards.

■ Water Resources

Many factors are straining the Nation's water resources and leading to increased competition among a wide variety of different uses and users of water (see vol. 1, ch. 5), Human demands for water are increasingly in conflict with the needs of natural ecosystems, and this has led to significant water-quality and water-quantity problems (see vol. 1, box 5-B). In addition, water infrastructure in many urban areas is aging.

Although it is unclear exactly how climate change will affect water resources, climate change has emerged as another important factor to consider in water resource planning. Changes in water availability as a result of climate change could further affect already overburdened systems, and changes could occur in the frequency, duration, and intensity of floods and droughts (105). The areas that are most vulnerable to climate change are, not surprisingly, places that are already experiencing stressed water resources (see fig. 1-5), such as many parts of the Southwest and South Florida; the central part of the country, which most models predict will become hotter and drier; and areas where competition for water is expected to increase.

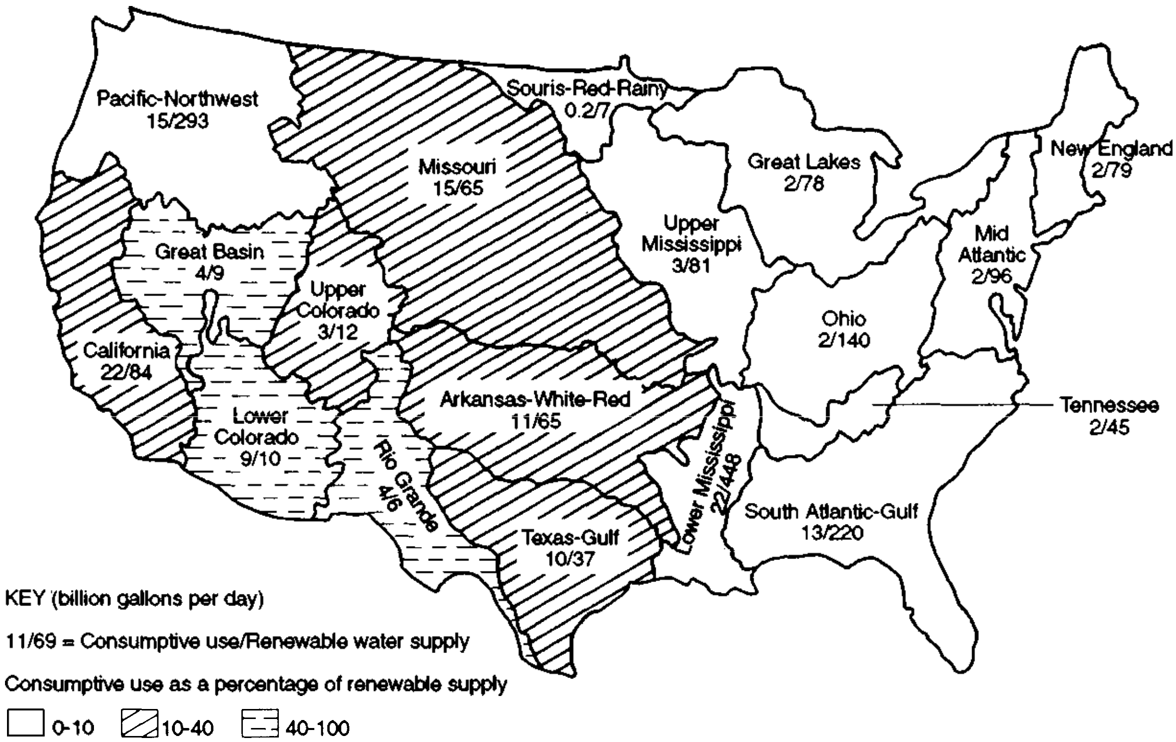
The country faces a huge challenge in adapting its water resource systems to the many current and potential stresses. The numerous impediments to this adaptation include the fact that traditional engineering solutions for developing additional water supplies-such as dam construction-have become prohibitively expensive and politically less acceptable because the best sites have already been developed. Federal agencies' responsibilities for water often overlap or conflict, and coordination among different levels of government on water issues is often inadequate (166) (see vol. 1, box 5-F). Many institutional arrangements for the management and allocation of water resources are rigid and inefficient, making them ill-equipped to cope well with water scarcity. And there are very few incentives to conserve water.

Water resource planning is a complex political, economic, sociological, scientific, and technological endeavor, so adaptation to change will not be straightforward. In encouraging adaptation to changes in water resources caused by climate change, the Federal Govenrnent, in cooperation with State and local agencies, should focus on encouraging five types of activity: improving demand management (e.g., through pricing reform and conservation); improving supply management (e.g., through improving coordination, jointly managing ground- and surface-water supplies, and improving the management of reservoirs and reservoir systems); facilitating water marketing and related types of water transfers; improving planning for floods and droughts; and promoting the use of new analytical tools that enable more efficient operations.

The following first steps toward improving water resources planning and management—selected from a longer suite of options presented in volume 1, chapter 5-are intended to both relieve existing stresses and make sense for climate change.

- Improve extreme-events management. Despite all efforts to date, both floods and droughts continue to cause significant losses to human and natural systems (143, 200). Greater coordination of the many agencies with flood- or drought-related re-

Figure 1-5-Water Withdrawals and Consumption in the Coterminus United States, 1985



NOTE: To convert gallons to liters, multiply by 3.785.

SOURCE: Adapted from W. Solley, R. Pierce, and H. Perlman, Estimated Use of Water the *United States* in *1990,* USGS Survey Circular 1081 (Washington, DC: U.S. Geological Survey, 1993),

sponsibilities is needed. Congress could direct the executive branch to create high-level coordinating bodies, such as an inter-agency drought task force and a national flood-assessment board. Such bodies could be given the responsibility to develop a national drought policy and to establish national goals for floodplain management. The "National Flood Insurance Compliance, Mitigation, and Erosion Management Act of 1993" (H.R. 62) calls for establishment of a flood-insurance task force. This bill could also be broadened to create a more comprehensive flood-assessment board.

- Make it easier to manage reservoirs on a basin-wide level. Operating reservoirs within the same basin as a single system rather than individually (as is often the case) could greatly improve the efficiency and flexibility of water-quantity management. New legislation, perhaps as part of the next omnibus water bill, could grant the Army Corps of Engineers and the Department of the Interior's Bureau of Reclamation greater flexibility to manage their reservoirs basin-wide and thus encourage development of a more integrated approach to water-quality, wetland, flood, and drought management.
- Support water marketing. As long as adequate attention is given to protecting all affected parties, water markets could provide an efficient and flexible way to adapt to various stresses, including a changing climate. It would be very useful for Congress to clarify reclamation law on trades and transfers and define the Federal

Government's interest in facilitating the creation of markets (193). Congress could urge the Department of the Interior to provide stronger leadership to assist with water transfers, and water marketing could be thoroughly evaluated as part of the Western Water Policy Review, authorized in late 1992.

- Promote the use of new analytical tools. Further development dissemination, and use of new modeling and forecasting tools could greatly enhance water resource management. Some current analytical efforts have not been adequately funded, and the most advanced tools now available are not yet being used by many States or water utilities. Small investments in promoting dissemination and use of these tools today could save substantial sums later. Section 22 of the Water Resources Development Act of 1974 (P.L. 93-251) authorizes funding for training and technical assistance to States and could be used to promote the adoption of the new tools. Congress could also consider providing funds to develop or refine tools that incorporate climate uncertainty into traditional hydrologic analyses.
- Promote demand management. The upcoming reauthorization of the Clean Water Act is one potential target of opportunity for improving water-use efficiency (see vol. 1, box 5-C). Congress could consider making conservation projects eligible for the State revolving-fund loans created under the act to fund wastewater treatment plants. The Federal Government could set an example by adopting efficient water-use practices in its own facilities. The Energy Policy Act of 1992 (P.L. 102-486) requires that Federal facilities adopt conservation practices to the extent practicable, but it concentrates primarily on energy conservation. A technical-adjustment bill to the Energy Policy Act could be considered in the 103d Congress and would provide a way to clarify and underline congressional intent toward water conservation in Federal facilities.
- Expand the scope of the Western Water Policy Review. With the enactment of Title 30 of the Reclamation Projects Authorization and Adjustment Act of 1992 (P.L. 102-575), Congress authorized the Resident to oversee a major water-policy study. Title 30 directs the President to undertake a comprehensive review of Federal activities that affect the allocation and use of water resources in the 19 western States and to report findings to appropriate congressional committees by the end of October 1995 (190). Climate change is not mentioned as a factor motivating the Western Water Policy Review, but the study could provide an opportunity to assess more fully how climate change may affect water resources and to evaluate policy options that might help with adaptation to a warmer climate. Congress could expand the scope of the Review beyond the West, or it could authorize a similar follow-on study of eastern water issues. The Review could also provide an opportunity to explicitly consider land-use practices and water resource issues jointly. The relationship between the two is close, and there appear to be significant opportunities to improve both water-quantity and water-quality management by improving land-use practices.

Agriculture

Agriculture in the United States is an intensively managed, market-based natural resource. Throughout the world, agriculture has adapted continuously to the risks associated with normal climate variability, just as it has adapted to changes in economic conditions. The American agricultural sector will undoubtedly make further adaptations in response to climate changes, with market forces rewarding and encouraging the rapid spread of successful adaptation (30, 41, 148). Just what these adaptations will be and what public actions could be taken to encourage them are addressed in detail in volume 1, chapter 6, of this report.

The possible effects of climate change on agriculture are difficult to predict. Agricultural productivity is likely to be affected worldwide, which would lead to alterations in the regional distribution and intensity of farming (1, 188). The range over which major U.S. crops are planted could eventually shift hundreds of miles to the north (13, 150) (see vol. 1, box 6-C). For American farmers, already facing increasingly competitive and growing world markets, any relative decline in productivity compared with the rest of the world would mean lost markets (40). A significant warming and drying of the world's climate might lead to an overall decline in agricultural yields (75, 150). Consumers would bear much of the cost through higher food prices or scarcities. Some individual farmers might still benefit through locally improved yields or higher prices; others might suffer because of relatively severe local climate changes. Rapid geographical shifts in the agricultural land base could disrupt rural communities and their associated infrastructures.

If the United States wants to ensure its competitive position in the world market and meet the growing demands for food without higher prices, public efforts to support the continued growth in agricultural yields remains necessary. Climate change adds to the importance of efforts to improve the knowledge and skills of farmers, to remove impediments to farmer adaptability and innovation, and to expand the array of options available to farmers (157). Efforts to expand the diversity of crops and the array of farm technologies insure against a future in which existing crop varieties or farming systems fail (137) (see vol. 1, box 6-H). Efforts to enhance the adaptability of farmers--to speed the rate at which appropriate farming systems can be adopted-lower the potentially high costs of adjustment to climate change.

USDA AGRICULTURAL RESEARCH SERVICE

This soybean field shows the devastating effects of droughts. The farmer indicates how tall soybean plants would normally be. Warmer climates could lead to an increase in both nurnber and severity of droughts.

Impediments to adjusting to climate change are numerous (see vol. 1, box 6-I). Water shortages will probably limit the potential for compensating adjustments in certain regions. The uncertainty of climate change makes effective response difficult, as do limitations on the availability of suitable crops and agricultural practices. The decline in the Federal Government's interest in agricultural research and extension is also a problem (138, 174); more-vibrant research and extension programs could enhance adaptability.

Certain agricultural programs may increase the costs associated with a changing climate (90). Because the commodity programs link support payment to maintaining production of a particular crop, they could inadvertently discourage adjustments in farming. Disaster-assistance programs may become increasingly costly under a harsher climate, and, if not well designed, may tend to discourage farmers from taking appropriate cautionary actions to reduce exposure to climate risks. Restriction on the marketing of conserved water may limit the incentive for efficient use of scarce water resources.

The most pressing tasks concerning agriculture and climate change that the Federal Government should undertake are: improving technology and information transfer to farmers in order to speed adaptation and innovation in farm practice; removing the impediments to adaptation created unnecessarily by features of commodity support and disaster-assistance programs; and supporting research and technology that will ensure that the agricultural sector can deal successfully with the various challenges of the next century.

The Government could organize its approach around the following first steps, which should increase the ability of the farm sector to adjust successfully to a changing climate.

- Revise the commodity support programs. Congress addresses farm issues every 5 years in omnibus farm bills, with the next one likely to be debated for passage in 1995. The annual budget-reconciliation process and agricultural appropriations bills offer intermediate opportunities for revisions in commodity support programs. commodity support payments are linked to the continued production of a single crop. If a farmer significantly changes crops, support payments will be reduced. This link discourages the responsiveness of farmers to changing market and climate conditions. The cumulative economic costs of even temporary delays in adjusting to climate change might prove to be large. Congress should consider breaking the link between farm support and the production of a single crop. A further increase in flex acreage (an amount of land that can be shifted to new crops with little penalty) or other more substantial revisions in the commodity support programs that would allow greater flexibility in crop choice (42) could be considered in the 1995 reauthorization of the Farm Bill. These changes would increase the ability of farmers to adapt to climate change.
- Encourage research and development in computerized farm-management systems. The competitiveness of the farm sector will increasingly depend on advances that improve the efficiency of U.S. farmers-rather than on further increases in intensity of input use. Computerized farm-management systems include land-based or remote sensors, robotics and controls, image analysis, geographical information systems, and telecommunications linkages packaged into decision-support systems or embodied in intelligent farm equipment. Such systems will be increasingly important to the farmer's ability to increase yields, control costs, and respond to environmental concerns. The U.S. Department of Agriculture's Agricultural Research Service already provides leadership in this area and has proposed an "Integrated Farm Management Systems Research' program that would provide for the development and broader use of technologies that have the potential to greatly enhance the efficiency of farming and to increase the flexibility with which farmers can respond to climate conditions.
- Use the 1995 Farm Bill to modify disaster-assistance programs. Since the late 1970s, Congress has been considering how to best structure the crop-insurance and disaster-payment programs (20, 21). After a flurry of proposals and studies before the passage of the 1990 Farm Bill, the programs were left essentially unchanged. Major revisions are likely to be considered in the 1995 Farm Bill. The best option for revising these programs remain unclear. For the purpose of preparing for climate change, any program that provides a greater incentive for farmers or local communities to reduce their exposure to risk should lessen the potential for large-scale future losses and encourage adaptation to changing climate risks. Features of a restructured system might include: defining disasters formally,

with assistance provided only for statistically unusual losses; eliminating either crop insurance or disaster payments (or merging the two programs) so that one does not undercut the incentives to participate in the other; limiting the number of times a farmer could collect disaster payments; and requiring farmers or farm communities to contribute to a disaster-payment fund, thus providing a greater incentive to reduce exposure to risks.

Wetlands

More than half of the Nation's wetlands have been destroyed by activities ranging from agriculture to flood-control projects to urban development. Roughly 5 percent of the lower 48 States is currently covered by wetlands (see vol. 2, ch. 4). They provide diverse products of considerable commercial value, playing a key role in the production of goods such as finfish, shellfish, fur, waterfowl, timber, blueberries, cranberries, wild rice, and peat. Wetlands also nurture biological productivity, slow surface-water flows, and transform nutrients and toxic chemicals. Wetlands are key to the harvest of 75 percent of the Nation's fish and shellfish and harbor about one-third of the Nation's threatened and endangered species (83).

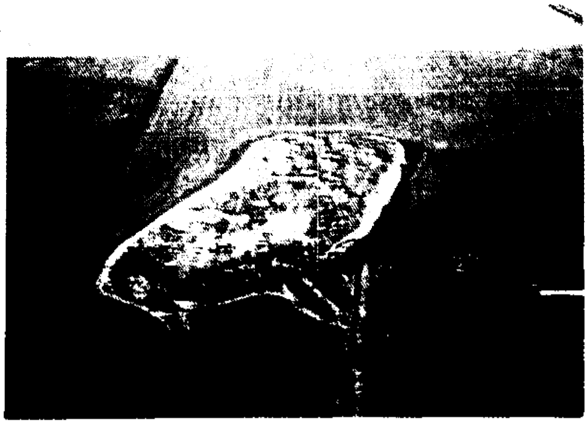
As a result, in 1989, the Federal Government embraced the policy goal of no net loss of wetlands-any destruction of wetlands should be offset by an equivalent restoration or creation of wetlands (28, 184). Steps to achieve this goal, however, have not been fully implemented. Part of the problem is that no single Federal statute is directed at protecting, restoring, and acquiring wetlands, and there is no coordinated effort to monitor and evaluate wetlands. Different authorities with different goals are scattered across many Federal and State agencies, and the criteria they use for decisionmaking are somewhat inconsistent. Federal policies have sometimes failed to discourage--and sometimes have encouraged—wetland destruction (179). Few programs for wetland acquisition and restoration address the possibility of climate-induced alteration of wetlands.

Climate change is likely to accelerate the loss of wetlands, especially of the following highly vulnerable types: coastal wetlands, depressional wetlands in arid areas (i.e., inland freshwater marshes and prairie potholes), riparian wetlands in the arid West and Southwest, and tundra wetlands. Coastal wetlands may be drowned by a rising sea or altered by changing salinity (123, 194, 198). Depressional wetlands are susceptible to the lowered water tables that will likely result from the higher temperatures, increased evaporation, and decreased summertime precipitation predicted for these already dry areas. Riparian wetlands in the arid West, which rely on water flowing through rivers and streams, could also be threatened by drier conditions. Tundra areas in Alaska may shrink as increased temperatures allow the permafrost to thaw and drain.

Whether or not a no-net-loss goal can be achieved as the effects of climate change become more pronounced, the goal remains a useful focal point for policy makers (114). Wetlands are a diminishing resource, and the Federal Government could play a lead role in ensuring that wetlands survive climate change by adopting the following objectives: protect existing wetlands, restore degraded or converted wetlands, facilitate migration (e.g., the upslope movement of coastal wetlands as sea level rises), and improve coordinated management and monitoring.

Given the available policy levers (regulation and acquisition, incentives and disincentives, and research), limited money to fund programs, and the level of scientific understanding of the impacts of climate change on wetlands, we identified the following strategies as first steps to use in responding to climate change and the threats it poses to wetlands. Additional options are assessed in volume 2, chapter 4.

U.S. FISH AND WILDLIFE SERVICE



Prairie potholes, like these in North Dakota, serve valuable storm-water-retention functions and provide breeding and stopover habitat for migratory waterfowl. Agricultural development, encouraged in part by Federal subsidies, has eliminated many of these wetlands. Climate change rnay pose further risks if moisture declines or if farming intensifies with a warming in these northern lands.

- **Revise the Clean Water Act. The act is up now for reauthorization, and it could be revised to improve wetland protection (169). This could be done through minor revisions or through transforming the act into a broad wetland-protection and watershed-management act. For example, the mitigation requirements could be clarified to ensure that lands set aside for protection or restoration more than compensate for wetlands that are destroyed. Congress could establish uniform standards for mitigation activities and require that restoration projects be monitored and evaluated for success in meeting these standards. At a broader level, Congress could devise a mechanism for coordinated management of water quality and wetland resources at a regional or watershed level. For example, regulations covering non-point-source water pollution might be linked to wetland protection, allowing wetland restoration or protection in exchange for relaxation in pollution-control requirements (127).**
- **Develop and implement a priority plan to coordinate wetland protection across agencies. Direct Federal agencies to develop and implement uniform regional plans guiding wetland protection, acquisition, mitigation, and restoration and to coordinate the designation of wetlands deemed high priority for protection or restoration. These priority plans could be built on existing plans under various agencies (e.g., the Army Corps of Engineers, the Environmental Protection Agency, DOI'S Fish and Wildlife Service, and the U.S. Department of Agriculture) that now set priorities for wetland management and acquisition. With better coordination and guidance and a watershed-management focus, existing programs could accomplish wetland protection more efficiently.**
- **Ensure that all Federal policies and incentives are consistent with wetland protection. Congress could ensure that all Federal policies and incentives are consistent with wetland protection, reviewing Federal programs to find and eliminate those that offer incentives to destroy wetlands and to perhaps bolster programs that encourage wetland protection. For example, the Coastal Barrier Resources Act (P.L. 97-348, as amended) might be extended to include coastal wetlands; funding for the Wetlands Reserve Program might be restored to at least authorized levels and targeted to wetlands in high-priority areas. The Fish and Wildlife Service could be required to complete and issue the report on the impact of Federal programs on wetlands that was mandated in the Emergency Wetlands Resources Act of 1986 (P.L. 99-645).**
- **Conduct research, development, monitoring, and evaluation in key areas. A new National Biological Survey at the Department of the Interior could incorporate wetland monitoring as part of its mission (see vol. 2, ch. 5). Relevant agencies should be encouraged to include wetland research in**

their component of the U.S. Global Change Research Program (USGCRP).

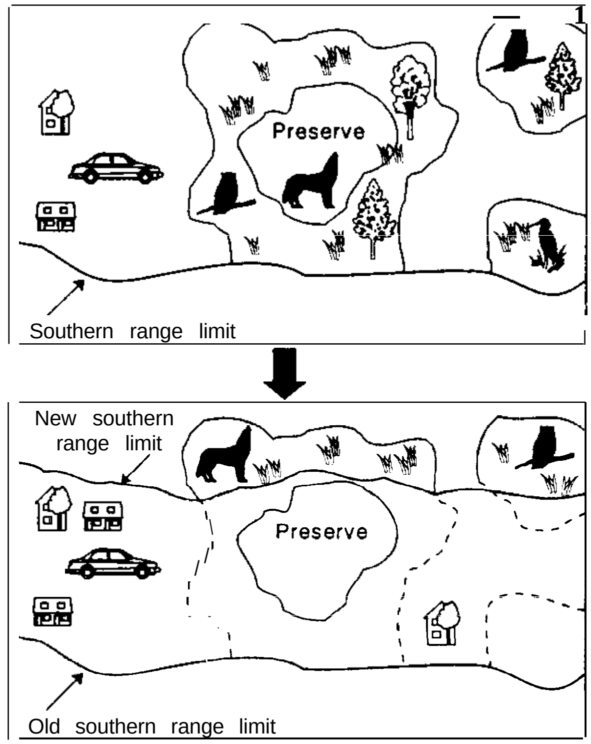
Federally Protected Natural Areas

Over 240 million acres of land have been set aside by the Federal Government to protect some part of nature for generations to come. These lands represent and protect the best of the Nation's natural heritage and have become a source of national pride. Chapter 5 of volume 2 focuses on National Parks, Wilderness Areas, and National Wildlife Refuges, which comprise the bulk of the Federal lands held primarily for nature conservation.

Because a variety of human activities has altered or degraded the habitat for many species, federally protected natural areas have become repositories for the Nation's rarest species and sites for conserving biological diversity (181, 185). Protected natural areas are also subject to increased stress from activities that occur both within and outside their boundaries. Natural areas are being effectively dissected into smaller and smaller parts in some places--especially in the East-leaving them more vulnerable to other stresses that could degrade habitat quality and ecosystem health (103).

Under climate change, the climate "map' that has helped to shape natural areas will shift while the boundaries that define the management and degree of protection for natural areas will remain fixed (see fig. 1-6). As a result the biological makeup of the protected natural areas will change. Some may become incapable of providing the benefits or serving the functions for which they were originally established, such as maintaining their unique or distinctive character, providing protection for rare species and other biological resources, and maintaining the quality or availability of other services, such as nature study or certain kinds of recreation (see vol. 2, box 5-B).

Figure l-S-Preserves and Climate Change



NOTE: As climate changes, the preferred range of many species may shift, leaving preserves dramatically changed.
SOURCE: Office of Technology Assessment, 1993.

Certain general characteristics of protected natural areas may make them more vulnerable to climate change, such as being small, isolated, fragmented, or already under considerable stress, and containing sensitive species or ecosystems, such as coastal, alpine, or Arctic ecosystems or midcontinent wetlands (67, 133, 188). If climate change leads to accelerated habitat loss or proceeds so quickly that some species cannot adapt quickly enough, species loss may accelerate, and overall biodiversity will decline (29, 196).

Even if species can move fast enough, adaptation by migration may be difficult because in many places, the landscape has been sectioned off into small pieces. Some natural areas are islands in the middle of extensively developed areas. Geographic fragmentation may limit the ability of

Box I-G-Climate Change in Alaska: A Special Case

Nowhere in the United States does there remain such a vast expanse of land so undisturbed by human activity as in Alaska. Because of its distinctive character, pristine conditions, and abundant natural resources, Alaska has become a national treasure. Nearly 66 percent of Alaska's land base is protected in wilderness areas, National Wildlife Refuges, National Forests, or public lands administered by the Bureau of Land Management (BLM). Alaska contains some 170 million acres (69 million hectares)[1] of wetlands (over 60 percent of the Nation's total) and 330 million acres of boreal forest. Alaskan plants and animals withstand some of the harshest environmental conditions in the world and many are unique to polar climates. Although human activities are to some extent adversely affecting this remote environment, it remains the most wild place in the United States and is rightly referred to as our "last frontier."

The unique characteristics of Alaska-the natural resources, the wildlife, and the pristine, harsh environment-affect nearly every aspect of life, including the culture and industry of those who live here. For example, traditions of the indigenous communities are deeply rooted in t he distinctive wildlife and vegetation of Alaska. Many indigenous communities, such as the Inupiat Eskimos of Alaska's North Slope, still rely on wildlife and natural vegetation for subsistence. The bowhead whale is central to their culture. The whales are a major food source and the hunts are a community tradition. Caribou and fish are other staples for Inupiats. Athapaskan Indians, who reside mostly in the boreal forest of interior Alaska, rely heavily on the plant life there for food, housing materials, and heating fuels (120). Fish such as salmon and whitefish are primary elements of Athapaskan subsistence, and caribou and moose are important sources of food anddothing(120).

Alaska's economy is also deeply rooted in its abundant natural resources, with oil and gas, fishing, and tourism providing the base for the economy. Nearly 65 percent of the State's revenue comes from oil and gas exploration or development. Two of the largest oil fields in North America (Prudhoe Bay and Kuparuk fields) are located near Alaska's North Slope and provide the economic base for much of that region. Alaskan waters are also sites of some of the world's most productive fisheries. The Bering Sea has the biggest fishery in the United States; it is among the biggest in the world. In 1990, Alaska's fish harvest (mostly salmon, king crab, halibut, shrimp, and scallops) surpassed any other State's, with more than 5.4 billion pounds (2.4 billion kilograms)[2] of seafood harvested-half of all seafood harvested in the Nation. The seafood industry is also Alaska's largest private-sector employer, employing 23 percent of the State's work force. In addition, Alaska's vast expanse of rugged land and abundant wildlife have made tourism a growing and important industry there. Visitors to Alaska spent almost $1 billion in 1989, the third largest source of income in the State. With 13,500 workers in tourist-related industries, tourism is second only to fisheries as a source of employment?

Because climate changes resulting from rising atmospheric carbon dioxide (CO_2) are expected to be especially pronounced in Alaska and other high-latitude regions, Alaska may provide an "early warning" of initial climate effects. In very general terms, Alaska can expect to see increased average temperatures, increased precipitation, and melting of sea ice. The rate and ultimate severity of the climate changes is at present unknown (67). In addition, little is known about the sensitivities of wildlife, vegetation, ecosystems, indigenous cultures, or the economy to any potential climate changes.

Warmer temperatures in polar regions are expected to lead to some melting of sea ice. A recent study of climate change effects on the Canadian Beaufort Sea determined that, based on a doubling of atmospheric CO_2 the open-water season could increase from an average of 2 months to 5 months, the extent of open water could increase from about 100 miles (160 kilometers)[4] to 300-500 miles, and maximum ice thickness could decrease

1 To convert acres to hectares, multiply by 0.405.

2 To convert pounds to kilograms, multiply by 0.454.

3 P. Carlson, Alaska Division of Toursim, personal communication, September 1993.

4 To convert miles to kilometers, multiply by 1.609.

by 50-75 percent (102). Shoreline erosion could increase significantly with a longer open-water season. Overall biological productivity is also expected to increase in parts of the Bering Sea with an increase in temperature and change in ice cover. Because of the drying effects of warmer temperatures, there could be an increase in the frequency and extent of fires. Over the past three decades, fires in Alaska have increased due to warmer and drier conditions. More fires under climate change could expand the extent of early successional vegetation favored by moose, beavers, Arctic hares, sharptailed grouse, and other wildlife species. However, fire may adversely affect the lichen supply in spruce forests--an important food for caribou in winter.

The most profound consequence of warming in Alaska and other polar regions maybe the exacerbation of global climate change through the release of carbon from the permafrost of the Alaskan tundra and boreal forests. Worldwide, tundra and boreal forests contain nearly a third of the world's soil carbon. Thawing of the permafrost, and the resulting decomposition of organic material, could release huge quantities of methane (CH_4) and $C0_2$ into the atmosphere and contribute to accelerated warming (67).[5] Climate warming may also be exacerbated by melting of the vast expanse of ice and snow that now reflects away considerable incoming heat. Little can be done to stem the thaw and resulting secondary climate impacts, except to slow warming by reducing human-made greenhouse gas emissions.

Potential Losers

Indigenous cultures--Alaska's indigenous, subsistence communities could be at risk under climate change. Thawing of the permafrost is likely to affect supported structures such as pipelines and bridges, and roads may be threatened if thawing weakens the soil. Many indigenous peoples use the permafrost for food-storage cellars, so warming may threaten their ability to preserve food during summer months. Hunting the bowhead whale, an ancient and sacred tradition for many indigenous communities on the North Slope, is linked to the extent of sea ice. Melting of the sea ice will likely change the whale's migration and affect access to the whales by indigenous hunters.

Plants and animals--early half of the world's peatlands (tundra) are in North America, with nearly a third of these in Alaska. Evena2'F (1 ºC) warming could lead to forests replacing alpine tundra on many mountains and islands (122). Some tundra species unable to adapt to climate change might decline. Caribou populations depend on lichens for food. The distribution of lichens is sensitive to the amount and extent of snow cover, which will change under a warming climate. Furthermore, because caribou calving is linked to vegetation produced during early snow melt, changes in the timing of the melt could disrupt calving.

Some 25 species of marine mammals regularly use Alaskan waters. The marine mammals most likely to be adversely affected by climate change are pinnipeds (seals and walruses) that winter primarily in t he Bering Sea have regular contact with ice, and are closely associated with the continental shelf or shelf edge. These include spotted and ribbon seals, which may suffer from increased competition with other species and reduced habitat, and Pacific walruses and bearded seals, which are ice-associated bottom feeders and are therefore tied to the seasonally ice-covered continental shelves. Both the beluga and bowhead whales are associated with sea ice, but they may not be significantly affected by melting because they do not depend on ice cover to protect and nurture their newborn.

Perhaps the biggest unknown impact of climate change is how it will affect fish populations and the fishing industry. Variations in stock size and species abundance appear to be correlated wit h periodic variability of ocean temperature, but are not completely understood. For example, huge fluctuations in groundfish stocks occur now.[6] Many scientists believe that overfishing will remain the primary concern for Alaskan fisheries (122). However,

5 Recent measurements Indicate that the tundra of the North Slope of Alaska has in fact Changed from a "sink" to a "source" of $C0_2$ with the warming trend seen in Alaska over the past few decades (125).

6 V. Alexander, Dean, School of Fisheries and Ocean Science, University of Alaska at Fairbanks, personal communication, May *27, 1993.*

(Continued on next page)

Box 1-G--Climate Change in Alaska: A Special Case-(Continued)

considering the importance of fishing to the Alaskan economy, the potential for loss under climate change is significant

Potential Winners

0il and gas industry-Reduction of the sea ice could allow the use of less expensive offshore structures and would reduce the costs of marine transportation. Some speculate that the opening up of the Northwest Passage would offer a shortcut for shipping from Europe to the Pacific Rim, but Alaskan ports probably would not participate significantly in this traffic.

Plants and animals-in general, plant life is likely to benefit from an increase in temperature, though the composition of forests and other vegetated areas will likely change. Some boreal forest species, such as white spruce and birch, are likely to expand northward. Others, such as red and yellow cedar, may be less able to migrate because of the rugged terrain, low genetic variability, and slow dispersing ability. Some migration is already happening--white spruce ranges have been expanding over the past 40 years. Expansion of white spruce into boreal forests may eventually be important for timber harvests.

Most wildlife species, including polar bears, moose, muskoxen, mountain sheep, most marine mammals, and many birds (e.g., grouse, raptors, owls, and migratory birds), will likely benefit from increased temperatures and increased productivity in vegetation. These benefits might be stemmed by losses of tundra wetlands, increases in disease spread, or changes in species assemblages that would result in changed predation patterns. Most birds will likely benefit from having more forage, more insects, and a longer season during which to rear their young. Omnivores such as bears should respond favorable to a changing climate because of the longer availability of green vegetation in the spring. Other forbearers and carnivores should increase in response to larger prey populations unless they are controlled by hunting, trapping, or other human activities.

Tourism-Higher temperatures are likely to benefit the tourism industry, although vigorous advertising by the State has almost certainly had more impact on the industry in recent years than has its climate. Increased wildlife populations will probably attract more hunters, hikers, and campers. However, increased tourism could also mean more impacts on the environment that is so important to indigenous, subsistence communities.

species to find new habitat-they may have no place to go (34).

Natural areas in the West are currently much larger and much less fragmented than they are in the East. However, the institutions that manage these lands are designed to manage only their own parcels-in isolation—and are not encouraged to consider the often more extensive natural ecological system. This compartmental approach to management, or *institutional fragmentation,* may prevent effective solutions to problems that transcend individual management parcels, such as those posed by climate change (64, 92).

The main challenge for policy is to maintain the high value of the system of natural areas while realizing that climate change may affect the very factors that make natural areas valuable: character, species protection, and environmental services. The ideal response to this challenge might be some combination of three general management approaches: 1) maintain species where they are today, 2) help species migrate through more intensive management, and 3) acquire lands that will be valuable under a changed climate. However, the lack of adequate knowledge and information precludes the full implementation of either approach now.

It is difficult to predict how climate change will affect natural areas and how they will respond. This lack of knowledge limits the ability to help natural areas adapt. We do not know which species are most sensitive to climate change, which could be saved, or how to recreate habitats or entire ecosystems elsewhere. The limited success with restoring populations of endangered species illustrates how little is known about restoring species and their natural habitat. In addition, we do not know what lands will be most valuable as preserves under climate change. We do not even know all of the species and kinds of ecosystems currently under formal protection in preserves today.

The most useful approaches that the Federal Government could take to facilitate adaptations to climate change in natural areas fall into two categories: information gathering (including research, inventory, and monitoring options) (115, 171), and managing natural areas now to minimize the impediments to adaptation and to increase their resiliency. The second category includes taking direct Federal action to influence the management of natural areas, establishing incentives to private landowners to encourage conservation under uncertainty, and promoting larger-scale management through more partnerships among agencies, communities, and governments. A variety of options that address these needs are assessed in volume 2, chapter 5.

Because money to implement every policy option and the scientific understanding of how climate change will affect natural areas are limited, we have identifed some strategies that represent inexpensive or useful frost steps for facilitating adaptation to climate change in natural areas. These options meet at least one of several criteria: they will take a long time to complete; they address "front-line," or urgent, issues that need attention before informed policy decisions can be made; they can be approached through mechanisms that are already in place or through efforts already under way; and/or they have benefits in addition to those that help prepare for climate change. In some cases, a near-term legislative action will provide a target of opportunity to pursue these options.

- Use the National Biological Survey (NBS) to assess ecological inventory and monitoring needs. Future strategies to protect natural areas and their resources will require a national picture of current biological resources and the extent of the protection of-or the threat to-these resources. A national inventory and monitoring program would be particularly beneficial in supporting efforts to protect endangered species and biodiversity. DOI'S proposed new National Biological Survey presents an opportunity to implement some of these activities (131, 132, 188). Congress could ask NBS to initiate a nationwide inventory and monitoring program, synthesize ecological and biological information for managers and planners, establish a mechanism for facilitating regional-level research and management, and develop a priority plan for expanding protection of natural areas.
- Support basic research on key gaps in our understanding of ecosystems. This research would include work on species sensitivity to climate change, restoration and translocation ecology, the design and effectiveness of migratory corridors or protective buffer zones, the development of ecological models, and the effect of elevated CO_2 concentrations on plants and animals. Basic research in these areas is needed now to determin e how species might respond to climate change and how best to provide for their protection in the future.
- Conduct a review of ecological research within USGCRP and across Federal agencies. Such a review would evaluate how much ecosystem research relevant to climate change and other long-term ecological problems (e.g., loss of biodiversity) is being done, and would identify important gaps. A review of all research on 'natural resources' has not yet been conducted across the Federal agencies. Existing analyses suggest that a great deal of money is spent on

research relevant to the environment, but how much is useful to understanding long-term ecological problems is not known. Further, there is currently no mechanism for consolidating results from disparate research efforts into "general patterns and principles that advance the science and are useful for environmental decisionmaking. Without such synthesis studies, it will be impossible for ecology to become the predictive science required by current and future environmental problems' (97). An effort to characterize and synthesize ongoing research could help bridge the gap between basic research and natural resource planning. Such a review could be conducted by the Office of Science and Technology Policy, the National Academy of Sciences, or an independent commission.

- Provide funding for the Fish and Wildlife Conservation Act of 1980 (P.L. 96-366). This law establishes a Federal cost-share program for "nongame" species conservation. It has already been enacted, but has never been funded. Many States have prepared initial plans that could qualify for Federal matching funds, making it a target of opportunity to promote natural area conservation at the State level. With some amendments to promote multispecies, or "ecosystem," protection at the State level and adequate funding., the Fish and Wildlife Conservation Act could be used to encourage natural area protection and conservation on State and private lands.
- Use acquisition strategies to enhance protection. Federal land-management agencies should be directed to consider whether all future land acquisitions and exchanges: 1) augment underrepresented ecosystems in the Federal natural area holdings, 2) buffer or connect other preserved land parcels, and 3) provide habitat or services likely to persist over the long term despite anticipated stresses. Setting aside a given amount of land within the modern fragmented landscape does not alone ensure that the ecological features for which it is valued will be preserved. To best conserve species, natural areas should include an array of ecosystems and transition zones between them to allow for the many complex interactions that rely on links between different parts of the landscape. By asking agencies to incorporate such concerns into future acquisitions, Congress could minimize future geographic fragmentation and use limited monies to maximize the range of protected ecosystems.

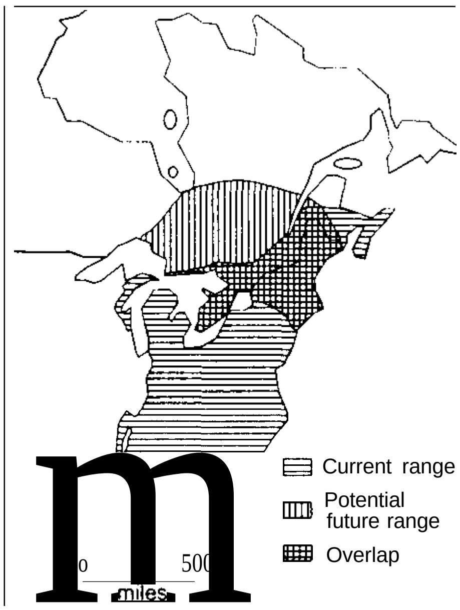
Forests

Forests cover roughly one-third of the U.S. land area, shaping much of the natural environment and providing the basis for a substantial forest-products industry. These forests are enormously variable, ranging from the sparse scrub of the arid interior West to the lush forests of the coastal Pacific Northwest and the South. The Nation's forests provide essential fish and wildlife habitat, livestock forage, watershed protection, attractive vistas, and an array of recreational opportunities. Timber is one of the Nation's most important agricultural crops.

Climate change may pose a significant threat to forests, particularly forests that are not actively managed for timber production. Within a century, climate change might shift the ideal range for some North American forest species more than 300 miles to the north (see fig. 1-7). Such a shift would almost certainly exceed the ability of natural forests to migrate (35, 36, 146). Forests stranded outside their ideal climatic range could suffer from declining growth and increased mortality from climate-related stresses such as insects, disease, and fires (2, 58, 100, 157). Some forests may collapse, and species and unique populations may be lost from isolated ranges if climate change is too rapid.

The most vulnerable forest resources are those in regions subject to increased moisture stress, as

Figure 1-7-Current and Projected Range of Beech Under Climate Change



NOTE: Based on climate projections from the Goddard Institute for Space Studies GCM under the assumption of a doubling of atmospheric CO_2. To convert miles to kilometers, multiply by 1.609.

SOURCE: Office of Technology Assessment, 1993, adapted from M.B. Davies and C. Zabinski, "Changes in Geographical Range Resulting from Greenhouse Warming: Effects on Biodiversity in Forests," in: Global Warming and Biological Diversity, R.L. Peters and T.E. Lovejoy (eds.) (New Haven, CT: Yale University Press, 1992).

in the dry continental interiors (14, 15, 159, 191). Forests in coastal regions may be at risk from rising sea levels, with the threat of flooding and saltwater intrusion, or from increases in damaging wind storms (61, 106). Forests with small or highly fragmented ranges may be lost, such as those at the upper elevations of mountains with nowhere to migrate (89). Forests in locations already subject to droughts, fire, and wind damage will be at high risk if the frequency or intensity of these stressors is increased (157).

The extent to which intervention to facilitate adaptation may be practical or desirable is limited. Even timber-industry forests are not intensively managed by the standards of annual agricultural crops. On large areas of public forest lands, even a minimal management response might be viewed as incompatible with the goals for which the forest is held. The challenge is to find unobtrusive and cost-effective means to help ensure that the health and primary services of the Nation's forest resource will not be lost if climate change proves to be as serious a threat to forests as some believe it will be.

The Federal Government can prepare itself to respond to the threats that climate change poses to forests in several ways: 1) by better understanding which forests are at risk (e.g., by supporting research on species sensitivity to climate and monitoring changes in forests); 2) by acting to avoid the potential loss of forest species (e.g., by promoting and improving forest seed banks, mass propagation techniques, and forest-restoration techniques); 3) by being ready to react promptly to the threat of large-scale forest mortality (e.g., by preventing fires, managing pests, or thinning to promote drought tolerance—in forests where such activities are determined *to* be appropriate); 4) by redirecting incentive programs to encourage improvement in the health of private forests; and 5) by increasing the adaptability of the forest industry and forest-dependent communities to climate change through forest-product research and incentives for diversification.

Given the existing policy levers, the limited money to fund programs, and the poor level of scientific understanding of impacts of climate change on forests, the following subset of policies, discussed in volume 1, chapter 6, are first steps that Congress could take. Each would help the Nation begin to position itself to respond to the effects of climate change on both timber and nontimber forests. These options are justified now either because of existing problems (such as fire, pests, and drought) that will be exacerbated by climate change, or because of the time required to complete the process.

- **Establish an expanded forest seed-bank program.** A rapid climate change could threaten the genetic diversity of U.S. forests. A national effort in the conservation of forest seeds would provide an opportunity to respond to the potential for loss of genetic diversity in the forest resource under climate change. An appropriate goal for such a program would be to maintain sufficient seed variety, or other genetic material, so that much of the original diversity of the Nation's forests could eventually be restored (86, 87). (Current forest seed-collection activities are uncoordinated and focused on only a small number of species (113).) To accomplish this goal., Congress could authorize and fund a National Forest Genetic Resources Program within the Forest Service, providing funds for the construction and operation of seed-storage facilities, for the establishment of associated plantations to be used for continuing seed production, and for a forest genetics research program that would address climate tolerance of trees and means for large-scale propagation. Such a program could be partially supported through fees for private access to the seed collection.

- **Develop strategic plans for responding to major forest declines.** Increased risk of fires and insect damage may result under a warmer climate. The relative value of prevention activities to reduce risk is likely to be increased. The need for aggressive intervention to protect forest resources may also be increased. Because of the need for prompt action and because of the contentiousness that often accompanies forest management, policy rules for pest-control activities and silvicultural management to reduce forest health risks are best established before they are needed. Congress could enact a forest-health bill that would establish criteria that would allow prompt action to protect against threats of catastrophic mortality or restore forests after large-scale mortality and decline. Such a bill might allow for the declaration of temporary forest-health emergencies, under which accelerated actions to protect or restore forest health would be authorized-as long as these actions were consistent with established standards for protection of all forest values. A policy-review group made up of academics, representatives of interest groups, and Federal forestry personnel could develop criteria for undertaking actions to stem forest decline.
- **Prepare for a forest-management response to climate change.** A changing climate may eventually require innovations in forest-management and planting practices. Experimental efforts will be important in establishing a scientific basis for any necessary changes to future management practices that might later be applied to public multiple-use forests. Congress could support a program of research on the Forest Service's Experimental Forests, or other research facilities, to address adaptation to climate change. The Experimental Forests are already designated as outdoor laboratories for evaluating forestry practices. The research could be directed toward finding practical and environmentally appropriate techniques for managing the public forests that will help buffer them or help them adapt to a changing climate.
- **Improve incentives for private management of forest lands.** The Federal Government controls only about one-quarter of the Nation's forestland. In the East especially, where Federal holdings are limited, efforts to support the protection of private forestland may take on increased importance. The Federal Government may use incentives, disincentives, and cooperative approaches to promote the health and productivity of this forestland. Existing subsidy programs under the Cooperative Forestry Assistance Act of 1978 (P.L. 95-313), as amended by the 1990 Farm Bill, provide cost-sharing assistance to owners of small, private forests. Traditional