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Resource Use and Management

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RESOURCE USE AND MANAGEMENT

Preface

The First Report of the Resource Use and Management Subgroup (RUMS) focuses on that subset of natural resources which are of common interest to most nations, i.e., food, water, land, and biological resources. The topics, which were selected at the RUMS initial meetings, were: agriculture, animal husbandry, fisheries, desertification and salinization, forestry, land use, unmanaged ecosystems (including biological diversity), and water resources. Various nations produced papers addressing one or more of these topics. Based upon these contributions, theme papers addressing water resources, biological diversity and food security were commissioned from individuals associated with the American Association for the Advancement of Science's Water Resources and Climate Change Panel, United Nations Environment Programme, and the Food and Agricultural Organization, respectively. In addition, the several papers on each of the abovementioned topics were consolidated.

On October 30–November 1, 1989, RUMS held a workshop in Geneva, Switzerland to discuss the theme and consolidated topic papers, and to solicit additional input from experts from developing nations, academia, and other non-governmental entities. This workshop was scheduled immediately prior to a meeting of the Agriculture, Forestry, and Other Human Activities Subgroup (AFOS) to assure broad participation from that Subgroup because of the potential overlaps on food and forests. As this report was produced in parallel with the IPCC Science and Impacts Working Groups' first report, rather than the more logical series approach, special efforts were made to obtain these groups' interim findings. Accordingly, the workshop also heard reports from Working Groups I and II on their efforts, particularly by participants in those Groups concerned with agriculture and food security. This First Report is a synthesis of all of the above efforts.

Appendix 6.1 lists all the papers contributed to the Subgroup, which form the basis of this report. The Subgroup is grateful for these contributions, and to the IPCC Secretariat for making this report possible.

Executive Summary

This report addresses adaptation responses pertinent to resource use and management in the event of human-induced climate change. These will help societies anticipate and reduce any negative impacts as well as capitalize on any positive consequences. Topics addressed here include food security (i.e., crops, animal husbandry, fisheries, desertification, and salinization), water resources, land use, and managed and unmanaged ecosystems (including forests and consideration of biological diversity).

The impacts of, and responses to, human-induced climate changes on resource use and management must be considered against a backdrop of (a) population growth, which increases the pressures and demands on all resources, (b) technological change, which may alleviate some pressures while creating others, (c) the hoped-for advancements in economic progress that could, on the one hand, increase the per capita demand for some resources but, on the other hand, allow for greater support for resource conservation and environmental protection, and (d) natural climatic variability.

In many instances, the impacts of human-induced climate change could be a relatively small perturbation on the larger effects resulting from increasing populations and other socio-economic factors. In other instances, they could be quite significant. Human-induced climate change may, in some areas, add to these pressures; in others, it may relieve them.

There are several reasons for focusing on adaptation. First, even in the absence of human-induced climate change, we need to deal with the climate's natural variability. Second, if human-induced climate change is significant, because of the time lags between increases in greenhouse gases (GHG) concentration and climate change, and climate change and impacts on natural resources, some degree of adaptation will be necessary even if all anthropogenic GHG emissions were halted. Third, the overall approach toward dealing with climate change must consider both limitations and adaptations as one package. Finally, the potential cost of adaptation will help to assess the costs associated with no action and, therefore, inform decision makers on processes for setting limits on greenhouse gases.

There already exists a large reservoir of experience and knowledge to help formulate and implement adaptation response strategies in the event of climate change:

- Society and living things have a built-in ability to adapt to some degree of climate change because climate is inherently variable at all time scales. Through the ages they have developed the capability, and a suite of responses, to adapt—in many instances, successfully—to extreme events (e.g., floods, droughts).
- As noted in the Scientific Assessment, human activities will alter the climate; however, economic and technological progress will also make it easier to cope with climatic variability and extreme events through earlier warning systems, better infrastructure, and greater financial resources.
- Several climatic zones span the globe, and resource use and management is an ongoing challenge in each of these zones. Therefore, one area could draw upon experiences and practices in those zones that most closely approximate future expected conditions in their area.

This is especially true for activities that are managed intensely (e.g., agriculture, water use, and plantation forests). However, even if there are similarities in the climates, other conditions may be sufficiently different to preclude use of analogues without modifications. In addition, there may be legal, economic, institutional or cultural barriers to translocating adaptation measures from one locale to another. More importantly, the ability to adapt is not uniform: developing nations would have greater difficulty in adapting, especially if that requires substantial financial expenditures and institutional changes, for example those which could occur as a result of loss of cultural and social heritage.

Natural ecosystems, while having a degree of inherent adaptability, are less able to adjust if the disturbance is large or rapid. Increasing populations and associated demand for land for a variety of human activities including agriculture, human settlements, grazing and plantation forests, and for forest products (e.g., fuelwood, timber); and the use of inland and coastal waters for waste disposal have radically altered some natural ecosystems and made others more vulnerable in many parts of the world. Thus, adaptive policies may be necessary to deal with the impacts on such ecosystems: the faster the rate of climate change—or more importantly, the rate of occurrence of the impacts of climate change—the greater the need for developing, evaluating, and implementing such policies.

A major obstacle to development and analysis of adaptive policy options for resource use is the substantial uncertainty associated with each link in the chain of calculations necessary to undertake such analysis. First, credible *regional* estimates of changes in critical climatic factors (e.g., temperature; soil moisture; diurnal, annual, and seasonal variability; frequencies and magnitudes of extreme events such as droughts, floods, and storms) are simply not available. While temperature, if anything, is likely to increase, the rate and magnitude of temperature change is uncertain. For some of the other critical climatic factors, even the direction of change is uncertain. Second, many processes linking changes in climate and in greenhouse gas concentrations to the effects on the biosphere and other natural resources are not well understood or characterized. Third, there are uncertainties regarding the linkages between natural resource effects and socioeconomic consequences.

Nevertheless, these uncertainties do not preclude planning and taking anticipatory actions, where appropriate. Such action may be indicated in circumstances where the impacts or costs of reacting to climate change could be very high or irreversible; where the lifetime of decisions is long enough to be adversely affected by a change in the climate; or where there are significant technological, informational, cultural, legal, or other barriers to efficient adaptation. Most importantly, many actions that would help societies adapt to any climate change would be worthwhile for other reasons—i.e., they need to be undertaken for wise and sustainable resource use and management whether or not climate changes. As elaborated below, the focus should be on such actions as we further develop scientific and economic understanding.

Temperature increase attributable to atmospheric composition change is expected to be larger at higher latitudes, particularly in the Northern Hemisphere. In the Southern Hemisphere, there may be impacts on agriculture in areas already suffering from environmental problems, e.g., soil degradation. For small island states, sea level rise will expose vulnerabilities. While some semiarid areas may be vulnerable, some in the north may, in fact, benefit, e.g., due to increases in agricultural productivity. Moreover, some sectors are more able to adapt.

In agriculture, and to some extent in forestry, the rate at which technology is introduced is, on the whole, likely to accelerate with the advent of biotechnology and genetic engineering. The efficiency with which many countries have adopted new technology in these sectors, albeit often without adequate environmental assessment, suggests a considerable ability to adapt to new circumstances whatever their cause; however, the closer farming is to subsistence farming the less the likelihood that it would adapt without assistance and "appropriate design."

In recognition of the uncertainties regarding resource use and management, the Subgroup provides a menu of options rather than more specific recommendations. These options need to be analyzed by each nation taking into consideration its specific social, environmental, and economic context. Based on this, a nation can decide on the precise mix of response options that would maximize its net socio-economic (including environmental) well-being. This inevitably must involve achieving the necessary balance between various competing societal objectives (of which dealing with climate change is one) and allocating limited financial, technical and human resources between them. Accordingly, evaluation of each option should be based on the criteria outlined below. An option should be:

- *Flexible*, i.e., adjustable in light of new knowledge, reductions in uncertainties and a variety of climatic conditions, and add to the resilience of resource use and management, i.e., the option should be successful whether or not climate changes.
- *Timely*, considering the time it takes to formulate effective responses, and for any effects on natural resources to be manifested.
- *Feasible*, based on its compatibility with other climate-related responses and socio-economic objectives, and with institutional, economic, legal, and cultural barriers and the degree of difficulty in overcoming them.
- *Economically justifiable*, on grounds other than climate change, while we further develop our scientific and economic understanding. This includes ensuring cost-effectiveness and economic efficiency, and consideration of opportunity costs—aspects that are likely to be met if it provides other non-climate-related benefits. Such analysis should also consider the broad range of social and environmental factors.

In some instances, options may have to be analyzed at the subnational levels, because they may make sense in one area but not in another. In other instances, such options analysis may be done on a national or even on a bi- or multi-national basis (e.g., for rivers crossing international boundaries). To assist in this, national, regional, and international institutions may have to be strengthened (or, where appropriate, new ones established). Such actions could also help implement several of the options mentioned below, e.g., inventorying, monitoring, assessments and information and technology transfer.

The options in this document have been classified into three categories, as described below.

CATEGORY A

Category A consists of options that would augment our knowledge base to make reasoned judgment on response strategies dealing with climate change, and should be undertaken in advance of accurate predictions of climate change impacts. This category includes:

- Developing inventories and data bases of the current state of resources.
- Documenting, cataloguing, and making more accessible the information on resource use and management practices under the widely divergent, existing climatic conditions since many of the response strategies identified here already exist and are in current use around the world.
- Improving our scientific understanding of, and the methodological tools for predicting changes in, critical climatic factors, their impacts on natural resources and their socio-economic consequences.
- Developing estimates of the costs and benefits for both adaptation and limitation measures to help determine the optimal mix of responses that would maximize social well-being.
- Undertaking studies and assessments to gauge the resilience of resources and their vulnerability to climate change which may help establish priorities regarding which areas—and, within areas, which resources—authorities should focus upon.
- Establishing systems that monitor the status of climate, resources, and rates of change in status to give early warning of further potential changes and trends.
- Encouraging research and development by both public and private enterprises directed toward more efficient forestry, agricultural, land and water use practices, and biotechnological innovation with adequate safeguards for public health and safety, and environmental protection. This may require developing new or modified institutional, legal, and financial measures that (i) would allow innovators to benefit from their R&D, and (ii) encourage individuals and communities to develop an economic stake in conservation and in efficient and sustainable resource use and management.
- Continuing existing research and development

on methods to cope with the potentially worst consequences (e.g., developing more drought- or salinity-resistant cultivars) and, in conjunction with improvements in feed, developing more efficient livestock strains and/or breeds using classical and modern breeding techniques such as genetic engineering, which would help keep farming and forestry options open, and research on agrometeorology or agroclimatology.

Other measures in Category A pertinent to food security and land use include new food products that can be more easily stored and improvement of storage facilities where yields tend to be unstable; development of baseline information on and monitoring changes in climate, crop production, pest and disease incidence, livestock fecundity and quality, and fisheries at local, regional, and global levels; protection of germ plasm resources and biodiversity (including increased research on the preservation of biological resources *in situ* and *ex situ*); investigations into the size and location of protected natural areas and conservation corridors; increased R&D to enable fuller utilization of felled trees, and to increase sustainable yields for traditional and new uses of forests and associated products (e.g., for fuel wood, chemicals, materials, fruits, and nuts).

Category B

Category B consists of responses that are probably economically justified under present-day conditions and could be undertaken for sound resource management reasons, even in the absence of any climate change, to meet increasing demands on these resources in a sustainable manner. In general, this would mean improving the efficiency of the use of natural resources by increased productivity and fuller utilization of the "harvested" component of resources and by waste reduction. Measures that could be implemented in the short-term include:

- Increased emphasis on the development and adoption of technologies which may increase the productivity or efficiency (per unit of land and water) of crops, forests, livestock, fisheries, and human settlements consistent with the principles of sustainable growth and development. Such efficiencies reduce the demand for land for a variety of human activities including agriculture, plantation forests, grazing and human settlements, which is the major cause of conversion of natural ecosystems and loss of biological diversity. In addition to alleviating pressures on land, such measures would also help reduce emissions of greenhouse gases. On the other hand, in areas where carrying capacities are strained or extended, appropriate measures to expand carrying capacities should be considered, e.g., by implementing pollution control measures, improving access to potable water or transportation infrastructure. Examples of options to increase efficiency include more efficient milk and meat production per unit product; improved food storage and distribution; and better irrigation water management practices and drainage, which would allow water supplies to serve greater areas, and limit salinization.
- Increased promotion and strengthening of resource conservation and sustainable resource use—especially in highly vulnerable areas. Climate change may or may not exacerbate conditions in marginal and endangered ecological and agricultural systems and overused water basins. Assessments of the potential impacts of climate change might help clarify this point. In areas that are likely to be further stressed, various initiatives could be explored for conserving the most sensitive and valuable resources including strengthening conservation measures, managing development of highly vulnerable resources, and promoting reforestation and afforestation. Identification of the most sensitive and valuable resources would necessarily be based upon each society's consideration of relevant social, cultural, environmental, and economic factors.
- Acceleration of economic development efforts in developing countries. Because these countries have largely resource-based economies, efforts improving agriculture and natural resource use would be beneficial. Such efforts would help formation of such capital as may be necessary to adapt to climate change, and generally make sustainable growth and development more feasible.
- Developing methods whereby local populations and resource users gain a stake in conservation and sustainable resource use, e.g., by investing

resource users with clear property rights and long-term tenure, and allowing voluntary water transfer or other market mechanisms.

Other options in this category include: maintaining flexibility in resource use to the extent practicable; decentralizing, as practicable, decision making on resource use and management, while assuring coordination with adjacent jurisdictions and incorporating mechanisms whereby interests of the broader society are also considered; strengthening existing flood management measures; continuing and improving national and international agricultural and natural resource research/extension institutions; strengthening mechanisms for technology transfer and development; and reviewing subsidies for natural resource use.

CATEGORY C

Category C are responses that, because they are costly, should be considered in the longer-term once uncertainties regarding climate change impacts are reduced. Options in this category include, as and where appropriate: building large capital structures (e.g., dams); examining the feasibility of and, if appropriate, strengthening and enlarging protected natural areas; establishing conservation corridors; as appropriate, reviewing and eliminating direct and indirect subsidies and incentives for and institutional barriers to inefficient resource use; and developing alternatives to current resource-based livelihoods. Many of these options may have to be taken in anticipation of the effects of climate change.

In recognition of the importance and special situation of developing nations, the issues of technology transfer and financial assistance are deferred to the Response Strategy Working Group's Task B report.

In summary, development and analysis of limitation and adaptation strategies must be harmonized. There is a relationship between the timing and costs of limitation and adaptation: the slower the rate of climate change, the easier it would be to adapt, and vice versa. Limitation measures should be consistent with adaptation goals, where possible. Thus, analysis of monoculture plantations to absorb CO_2 should consider their potential negative impact on biological diversity. Moreover, analysis of the relative merits of various limitations strategies should consider other non-warming consequences of controlling the various gases (either individually or together) including, e.g., direct effects of CO_2 and CFCs on the biosphere. Thus a truly comprehensive approach toward human-induced climate change should recognize that controlling the different gases might have different effects on the adaptive capacity of natural resources.

There is a range of adaptive measures that could be used to implement response strategies tailored to national situations. These strategies should focus primarily on addressing current problems that seem likely to be intensified by climate change. In considering the above three categories of options, particular attention and support should be given to those developing nations which appear to be most vulnerable to the impact of climate change but the least able—in financial and human capital terms—of responding to them.

6.1 INTRODUCTION

6.1.1 THE IMPORTANCE OF CLIMATE FOR SOCIO-ECONOMIC AND ENVIRONMENTAL WELL-BEING

The climate affects all living things, and in turn, they affect the climate. It influences where and how human beings live, the kind of shelter we build, the quantity and quality of food and water we ingest, what we wear each day, as well as how and where we spend our leisure time.

Resources and their use and management depend upon the climate. It is a major determinant of agricultural and biological productivity in managed and natural lands, water supply and demand, and the distribution, types, and composition of the flora and fauna. Clearly, a significant climate change could affect, for better or worse, the very resources upon which life itself depends and, through that, the social, environmental, and economic well-being of this planet.

6.1.2 STRUCTURE AND CONTENT OF REPORT

This report offers a menu of options that could help societies adapt resource use and management to any effects of human-induced climate changes (hereafter referred to as "climate change" unless otherwise qualified). Such adaptation will be necessary whether it is desired to reduce negative impacts or capitalize on any positive aspects. The options presented here could (a) reduce the uncertainties regarding the effects of climate change on resource use and management, and (b) improve the ability of nations/regions to adapt to the effects of climate change in both the short and long term, should that be necessary. Short-term adaptation options identified here may be economically justified under present-day conditions and might be beneficial even if climate were not to change, whereas long-term options would generally be costlier and should be considered after uncertainties regarding climate change and its impacts are reduced.

It is expected that some options would be desirable for some nations but not others. Furthermore, within nations, an option may be suitable in one area, but not in another. It is hoped that nations will evaluate the desirability and suitability of each option, taking into consideration the particular situation(s) within their jurisdiction.

This report generally avoids narrowing the menu by eschewing recommendations of specific options because such recommendations should be based upon evaluations of their social, environmental, and economic consequences (including cost-effectiveness, economic efficiency and suitability for a given area); however, such evaluations cannot currently be undertaken with sufficient confidence—especially at the regional scale, which is the scale at which the status of resources usually has to be assessed.

6.1.3 POSSIBLE AND LIKELY CHANGES IN CRITICAL CLIMATIC FACTORS

Scientists agree that an increase in greenhouse gas concentrations will eventually be followed by an increase in the globally averaged temperature. However, there are significant scientific uncertainties regarding the magnitude, rate, and timing of such change due to any specified level (e.g., a doubling) of greenhouse gas concentrations.

Temperature, moreover, is only one aspect of the climate. There are other climatic factors that are just as, if not more, critical to sustaining life on this planet and to the status of resource use and management. These include precipitation, soil moisture, wind speed, the frequencies and magnitudes of extreme events such as floods, droughts, hot and cold waves, hurricanes, cyclones, and other storms, and climatic variability on diurnal, seasonal, and annual scales. With respect to many of these critical climatic aspects, scientists are uncertain regarding the direction of change as well as their rates, magnitudes, and timings.

These uncertainties multiply further as one attempts to estimate changes on spatial scales which are less-than-global (e.g., regions or watersheds) or temporal scales that are less than annual (e.g., seasonal, weekly, daily). However, it is at these scales that assessments regarding the status of, and impacts on, resource use and management have to be made to be credible. Yet a wide range of plausible climate change scenarios can be devised to test sensitivities of systems.

6.1.4 POSSIBLE AND LIKELY EFFECTS ON RESOURCES AND SOCIO-ECONOMIC WELL-BEING

Resources will be affected directly because of changes in critical climatic factors and in greenhouse gas concentrations, and indirectly because of sea level rise (see the report of the Coastal Zone Management Subgroup). In turn, these impacts on resources will be translated into socio-economic (including environmental) consequences.

The impacts of human-induced climate changes on resource use and management must be considered against a backdrop of population growth that will increase the pressures and demands on all resources, and technological change which may alleviate some pressures while creating others. Moreover, the hoped-for improvement in each individual's economic status will have a complicated effect on resources. On the one hand, economic growth could increase the per capita demand for some resources and may increase greenhouse gas emissions; on the other, it also allows for greater support for resource conservation and environmental protection.

In many instances, the impacts of climate change could be a relatively small perturbation on the larger effects resulting from increasing populations and other socio-economic factors. Human-induced climate change will, in some areas, add to these pressures; in others, it may actually relieve them. In addition to the scientific uncertainties associated with estimates of various critical climatic factors (noted in Section 6.1.3) which themselves serve as inputs to estimates of resource use and socio-economic consequences, there are other uncertainties regarding the impacts of climate change:

- There are uncertainties regarding the relationships between climate, resources and socio-economic consequences.
- There are interconnections (feedbacks) between estimates of atmospheric greenhouse gas concentrations, the various critical climatic factors, resource use, and socio-economic consequences that are not well understood.

While recognizing the uncertainties in all the above steps, the following general statements can be made regarding resource use and management in the event of climate change:

- The ability to match water supply with demand will vary from area to area; temporal and spatial precipitation patterns will change as well as frequencies and magnitudes of floods and droughts. All this will occur in ways that are not for the most part determinable now, though some aspects, such as earlier snowmelt, would be more likely, as would changes in demand for water. The net effect in some areas would be positive; and in others, negative.
- Food production at the global level could, in the face of estimated climate changes, be sustained at levels sufficient to meet world demand. However, there might be substantial dislocations in some areas in the agricultural sector: some would become more productive, others less. Agroclimatic zones in the mid- and higher-latitudes would shift poleward. In addition, there will probably have to be significant adjustments in types of crops raised and in management practices to optimize farm incomes, and to avoid localized food shortages in some areas where poor economic conditions may not allow food requirements to be otherwise met (via domestic and international markets/trade).

However, because agriculture is a heavily managed system with substantial flexibility, such adjustments (either in absolute terms or in their rate) may be within the bounds of human experience and likely technological progress—at least for the next several decades.

- Whether or not fisheries become more or less productive, the spatial and temporal distribution of commercial marine fisheries may be changed. Some fishing communities (and/or nations) may gain at the expense of others.
- Impacts on unmanaged or natural ecosystems could be critical. If the rate of climate change is more rapid than their rate of adaptation, species composition and biodiversity may be affected. However, established growth may persist for decades or longer, and, in some cases, degenerate. Nevertheless shifts in climatic zones could, over the span of several decades or centuries, shift species poleward or to higher altitudes or lead to cases of extinction. Moreover, if the rate of climate change is sufficiently rapid, ensembles of species may end up trapped in climatic regimes for which they are not generally suitable and some species may not adapt quickly enough to prevent their extinction. The effects on migratory species may be mixed: the longer the migratory route, the greater the likelihood of disruption.
- Climate zones for temperate and boreal forests could shift northward, which would affect productivity and biomass generation.
- There may be changes in the location and extent of deserts and salinized lands.

Such climate change as could occur is expected to be greater as one moves poleward—this is particularly true for the Northern Hemisphere. However, the physical effects of climate change on resource use and management may not follow the same pattern (i.e., increasing effects with latitude). However, socio-economic impacts due to these effects could have a more complicated pattern. Many of the northern countries—being more developed, having stronger economies and greater wealth per capita—are better able to adapt to the effects of climate change than would many developing nations. This would be particularly true for developing nations that have relatively long coastlines.

6.1.5 Adaptation Objectives

The ultimate objective of adaptation is to maximize social well-being (which incorporates environmental and economic well-being) for a given set of climatic conditions (or trends in these conditions). Such well-being has to be maximized over the span of this (and succeeding) generations. To achieve this, society has to take advantage of any positive impacts resulting from climate change, while also reducing negative impacts. Thus, another adaptation objective would be to place society in a position to respond rapidly and efficiently to the impacts of climate change.

In attempting to maximize social well-being, it should be noted that there are several societal goals that are partly in competition with each other. These include the need for agricultural and economic development and growth to enhance both economic and food security even as populations increase, and the need to assure that such economic development and growth is done in a sustainable manner so that the resource base is not degraded and is consistent with the need for a clean and healthy environment. The importance that one society (or segment of society) places on each of these goals is determined by a variety of factors including current socio-economic status, cultural traditions, institutional systems, expectations for the future, and historical factors. Because of these competing considerations, as noted in Section 6.1.2, it is to be expected that some adaptation options could maximize social well-being for one set of social, environmental, and economic circumstances but not for another, and that different societies (or segments of societies) would choose to pursue various options to different degrees.

6.2 THE NEED FOR ADAPTIVE POLICY RESPONSES

The menu provided in this report is designed to help societies adapt to climate change by anticipating and reducing expected negative impacts or capitalizing on any positive aspects. Information on the status of resources and their use and management under a variety of climatic regimes would assist societies learn from existing analogues to conditions that might reasonably be expected in the future.

Adaptive policy responses, which could include both actions taken in anticipation of expected climate change (or its impacts) as well as actions undertaken after the impacts are evident, are desirable for several reasons.

- Whether or not there will be significant human-induced climate change, the climate's inherent variability makes adaptation unavoidable.
- Assuming human-induced climate change is significant, the expected delays, which could be decades long, between increases in greenhouse gas concentrations and changes in climate and the status of resources make some adaptation essential—regardless of how rapidly greenhouse gas concentrations are limited.
- Both limitations and adaptations must be considered as a package. This would assure the cost-effectiveness of the entire set of response strategies that might be necessary to deal with human-induced climate change.

To the extent practicable, limitations should not make adaptation more difficult, and vice versa. Options for limitation strategies should be evaluated carefully to ensure they would not be counterproductive in terms of adaptation (or its ultimate objectives). Analysis of monoculture plantations to absorb CO_2 should consider their potential negative impacts on biological diversity. Similarly, one factor to be considered in the analysis of limitation measures is that an increase in carbon dioxide concentration would make crops and vegetation more resilient by enhancing photosynthesis rates and making them more resistant to drought and salinity, but that the combined effects of CO_2 and climate change are uncertain.

- Moreover, decisions on the degree and rate of limitation(s) that may be necessary should take into consideration the rates of change to which societies and ecological systems can adapt.
- Anticipatory policies may be necessary in circumstances where project lifetimes are so long that the project's usefulness (or benefit/cost ratios) could be severely compromised if climate were to change significantly during its lifetime. Such circumstances could include construction of new dams, establishment or augmentation of conservation areas, and selection of seedlings for forestation.
- Anticipatory policies may also have to be considered for situations where the impacts or costs of reacting to climate change are expected to be very high, unacceptable or irreversible. This might be the case for some actions that might place unique or critical resources—e.g., some species—at greater risks of extinction.
- Anticipatory policies will have to consider whether there are barriers to adaptation, such as lack of technology and information or cultural or legal barriers that may prevent or inhibit efficient responses.

While noting the need for adaptive response strategies, it should also be recognized that adaptation to climate is at least as old as the human species. Even without man's influence, climate is extremely variable. At any location the timing and amount of precipitation and temperature varies at all time scales (seasonal, annual, or decadal). Moreover, droughts, floods (and other extreme events) occur regularly. These climatic variations indicate that humans and living things have some built-in ability to adapt to climate change.

While it is possible that human activities and technology could change the climate, society's ability to cope with such climatic events is now higher than ever because of technology (including better communications, transportation, and food storage), and increased wealth. The lessons learned from these events can all be applied in formulating and implementing responses to human-induced climate change. Moreover, people in one area can learn from those in other areas. We now grow several crops over a wider range of climate (and temperature) than is "predicted" under scenarios that would double greenhouse gas concentrations. Thus, if southern Canada were to become as warm and dry as, say, Texas then it may be able to learn from the agricultural practices in the latter area to better adapt to and cope with the impact of climate change on food security even though not all other conditions would be identical. As long as the new climate in an area has existing analogues anywhere in the world, there is the potential for such adaptation—especially for activities that are managed intensely (e.g., agriculture, water use, and plantation forests).

However, this ability to adapt is not uniform. It will vary from nation to nation depending upon its economic and institutional capabilities, and the degree of net negative impacts due to climate change. Moreover, as noted, even if there are similarities in the climates, other conditions may be sufficiently different to preclude use of analogues. In addition, there may be legal, institutional or cultural barriers to adaptation.

Increasing populations, and associated demand for land for agriculture, human settlements, grazing and plantation forests, and for forest products (e.g., fuelwood, timber), have reduced the area of some natural ecosystems. Moreover, human activities have made certain natural ecosystems more vulnerable in many parts of the world even though they have a degree of inherent variability. Thus, adaptive policies may be necessary to enhance the resilience of such ecosystems: the faster the rate of climate change, the greater the need of developing, evaluating and implementing such policies.

6.3 EVALUATION AND TIMING OF RESPONSE STRATEGIES

As noted above (Section 6.1.5), the basic rationale for considering and/or adopting response strategies is to maximize social well-being (which includes economic and environmental quality). Thus, that should be the basis for any evaluation of responses. While attempting this, one has to be cognizant that resources (whether they be natural or human and financial) are limited. Opportunity costs must be considered: expenditures on a response strategy will divert resources from other potentially worthwhile social uses. These include public health, environmental and safety needs, and economic growth. Wealth generated by such growth will eventually make response measures more affordable. Poverty is one of the major causes of environmental degradation. It is also one reason why poorer nations employ obsolete technologies that often are more inefficient in terms of both energy use and emissions. Therefore, cost-effectiveness and an assessment that benefits exceed costs are necessary, but not sufficient, criteria for ensuring maximum social well-being and economic efficiency: sufficiency can only be established if it can be determined that the cost (including monetized *and* unmonetized consequences) incurred in the development and implementation of a response strategy is the best use for society's resources.

Several steps should be taken prior to any evaluation of response strategies. As a start, one should differentiate between the possible and likely impacts of climate change. Inherently, anything that does not violate a law of nature (e.g., the Third Law of Thermodynamics) is possible. Thus, dealing with merely what is possible is not a wise use of resources. Ideally, one would need to know the probability distributions for climate change effects (as a function of space and time). However, the uncertainties associated with climate change and its effects generally preclude such differentiation between potential and likely effects. These uncertainties also restrict the analysis of response strategies in terms of their effectiveness and intercomparisons of the social, economic, and environmental consequences of implementing response strategies versus doing nothing. Nevertheless, adaptive response strategies can be evaluated on the basis of several criteria.

In evaluating options, one needs to keep in mind that the direction, magnitude, and timing of impacts are uncertain and take into consideration differences in the carrying capacities for various resources. Specific criteria—all of which should be met—include:

- *Flexibility.* Since the effects of climate change are uncertain, responses need to be successful under a variety of conditions, including no-climate-change. Thus, flexibility is a matter of keeping options open. For instance, a market mechanism for pricing and allocating resources will work under a variety of conditions and, therefore, is flexible.
- *Economically Justifiable Based on Other Benefits.* This is often referred to as "doing things that make sense anyway." Such policies would be justifiable in their own right, i.e., in the absence of climate change. They would necessarily have to meet other societal goals besides preparing for climate change; thus, they would be beneficial even if climate were not to change.

Such policies include those that would enhance net public well-being by, e.g., environmental quality, or food or economic security. Thus, even if climate does not change, society would reap net benefits from this approach. Factors to consider in assessing whether a policy "makes sense anyway" include economic efficiency (including environmental factors), cost-effectiveness, and opportunity costs.

- *Timing.* Since climate change may not be felt for decades, the benefits of adaptive policies may also not be realized for decades. Thus, expensive anticipatory actions will not be justified unless the expected costs of climate change are very high. For instance, a dam should not be constructed today in anticipation of being needed several decades hence. On the other hand, if a dam is being built now, it may be useful to "design in" the ability for future augmentations—if that changes the costs only marginally. Factors to consider in assessing timeliness include: (a) whether there is a critical point in time before the adaptation strategy needs to be implemented, and (b) how much time does it take to efficiently develop the response (and necessary technology), and educate and disseminate it to users/implementers?
- *Feasibility.* Adaptive strategies must be consistent with legal, institutional, political, social, cultural, and financial arrangements. These are critical aspects of their "do-ability." However, in some instances, policies may specifically be directed at modifying or removing such barriers.
- *Compatibility.* Response strategies for one sector (or activity) should not run counter to adaptive strategies in other sectors or activities. Similarly, adaptive strategies should not defeat or negate limitation strategies (or their objectives), and vice versa. See Section 6.1.5.

As noted in Sections 6.1.2 and 6.1.5, in many instances evaluations of adaptive options may have to be undertaken on relatively small geographical scales (i.e., regions or watersheds) and consider the specific social, economic, and environmental context. This is necessary to achieve a balance between various competing societal objectives, and thereby maximize net social well-being. In some instances responses may have to be evaluated at the regional, national or sub-national level. However, no evaluations were attempted for this report.

Readers, while going through the response strategy options in the subsequent sections, should keep the above evaluation criteria in mind to judge for themselves the suitability of the options in their particular context.

6.4 IDENTIFYING AND CLASSIFYING OPTIONS FOR ADAPTATION

The options identified in this report were culled from topic papers prepared for RUMS by various nations, theme papers contributed by invited speakers or organizations, and papers and comments provided at the Subgroup Workshop in October 1989. This workshop attempted to classify identified response strategies into three categories:

- Those that augment our knowledge base to make reasoned judgment on response strategies dealing with climate change and that should be undertaken in advance of the availability of accurate regional predictions (Category A)—e.g., inventorying, monitoring, assessments, and information and technology transfer.
- Responses that are probably economically justified under present-day conditions (see Section 6.3) and that, therefore, could be implemented in the short term (Category B)—e.g., measures that could improve efficiency of use of the "harvested" resource.
- Responses, that should be considered in the longer term (Category C). Because these are generally more costly, it may be prudent to consider them once uncertainties regarding climate change impacts are reduced. Examples of such measures are: preparing communities for a shift in existing resource-based livelihoods, or building new capital structures (e.g., dams).

This classification scheme is used for each of the response strategies in the following sections.

6.5 RESPONSE OPTIONS APPLICABLE TO RESOURCES IN GENERAL

This section offers a menu of options applicable to several types of resources. Measures dealing generally with technology transfer and possible financial assistance in the context of developing nations are addressed in the Response Strategy Working Group's Task B report. Many of the following options would help reduce critical lead times and planning horizons necessary to design and implement specific actions in the face of climate change or its potential impacts.

6.5.1 Research, Information, and Technology Development and Transfer

The knowledge base relevant to making policy decisions needs to be expanded (A). Clearly, there needs to be a concerted effort to undertake the requisite research to reduce uncertainties associated with predictions of the status of resources, their use and management at various geographical scales (e.g., for terrestrial resources, the regional or watershed level) and their socio-economic consequences.

This means coordinated research programs designed to (a) significantly improve the understanding and predictions of changes in critical climatic factors, the direct and non-climatic effects of changes in atmospheric greenhouse gas concentrations on the terrestrial and marine biosphere, (b) improve and/or develop methodological tools to predict the impacts of these climatic and non-climatic factors on the supply and demand of resources, and the socio-economic consequences of climate change and alternative adaptive response strategies, and (c) developing costs and benefits for both adaptation and limitation measures to help arrive at the optimal mix that maximizes social well-being.

Resource use and management practices under the widely divergent, existing climatic conditions need to be documented, catalogued, and made more accessible (A). Thus, if the future climatic regime could be predicted with sufficient confidence, such catalogs would allow one area to more easily locate analogues for its future climatic regime. There could be a variety of such catalogs. For instance, one could contain information on the performance of crops, trees, and other species under a variety of climatic (and other) conditions. This would help farmers and foresters select species for cultivation based upon their expectations of both the future climate and the resource base. There could be other catalogs on management practices for agriculture, forestry, livestock husbandry, etc.

Inventories of the current state of resources are needed by resource managers whether or not climate changes (A). Inventories which accurately describe the condition and use of resources (e.g., land and water uses, distribution, and diversity of species) would be of value. Such inventories should also describe the future state of resources, as practicable, taking into consideration different scenarios of population growth.

Studies and assessments to gauge the resilience of resources and their vulnerability to climate change may help establish priorities regarding which areas—and, within areas, which resources—authorities should focus upon (A). Such assessments would help determine the present adaptive capability of localities, nations or even systems. Moreover, it would help provide information regarding adaptability to various rates of climate change. However, given the uncertainties at the regional level, such studies should be used with caution. To help in such assessments considerable effort should be expended on researching, improving, and/or developing appropriate methodological tools to estimate the impacts of climate change on resource use and management, and their socio-economic impacts. Studies of the interrelationships between population growth, changes in greenhouse gas emissions, status and use of natural resources and any responses to climate change would be useful.

Systems to monitor the status of resources need to be established to give early warning of any potential changes and trends (A). Such systems should be designed to detect changes in resources in different locations that may be indications of the effects of climatic perturbation. Of course, such systems, while indicating changes may be in the offing, would generally be unable to indicate whether observed changes are short-term trends due to natural variability or irreversible consequences of human-induced climate change.

Improve existing institutions (or, where appropriate, establish new institutions) to assist in rational use and management of natural resources, and to help localities, nations, and regions better cope with any climate change. Technology development and transfer mechanisms also may need to be supported and strengthened (A, B, C). As far as possible, this should be done via existing institutions such as FAO, UNEP, WMO, UNRRO, UNDP, and other multi- and bilateral-aid agencies as well as institutions within nations. These institutions could also assist in the above mentioned efforts to inventory, assess, and monitor natural resource use and management.

Efforts to educate and inform the public and decision makers on the scientific, policy, and economic aspects of issues surrounding climate change need to be strengthened (B). This should be facilitated by the strengthening of the above-mentioned agencies.

Research and development on more efficient resource use needs to be stimulated (A). Such efforts could help cope with new stresses from climate change. Both public and private enterprises should engage in research and development directed to more efficient forestry, agricultural, and water use practices, and biotechnological innovation. Governments could take measures encouraging such R&D while ensuring that such work is conducted in a manner consistent with public health and safety. Nations may consider developing new or modified institutional, legal, and financial measures that (a) allow innovators to profit from their R&D, and (b) encourage individuals and communities to develop an economic stake in conservation and in efficient and sustainable resource use and management.

While there already are methods of reducing the negative impacts on resources, further research and technology development may be necessary to cope with the potentially worst consequences (A). Thus, for instance, development of more drought- or salinity-resistant cultivars using classical and modern breeding techniques (e.g., genetic engineering) would help keep farming and forestry options open. Such development is already being undertaken and is expected to be beneficial even if there were no climate change. However, given these efforts, the time taken to develop and disseminate such technology, and the fact that adaptation along these lines (for reasons of human-induced climate change) is not imminently necessary, additional emphasis is not warranted at this time.

6.5.2 MAXIMIZING SUSTAINABLE YIELDS

It is necessary to increase the efficiency, productivity and intensity of resource use consistent with the principles of sustainable growth and development to relieve pressures on resources, which will inevitably arise due to population growth, whether or not there is human-induced climate change. There are several facets to this, as elaborated below.

There needs to be increased emphasis on the research, development, and adoption of technologies for increasing the productivity or efficiency (per unit of land and water) of crops, forests, livestock, and fisheries (A, B). Some of the research and techniques developed for increasing productivity have been viewed by many with suspicion because they involve genetic engineering and food and chemical additives. Governments and consumers, in dealing with such research and/or products (e.g., in risk analysis/management) derived from such techniques, should also give due weight to the benefits of increased efficiencies in conserving land and water resources.

Such efficiencies reduce the demand for land for agriculture, plantation forests, and grazing, which is the major cause of conversion of natural ecosystems and loss of biological diversity. In turn, these contribute significantly to increased atmospheric concentrations of greenhouse gases, though plantation forests may be a useful sink for CO_2. Moreover, increased productivity and more efficient use for fuelwood and timber would help reduce atmospheric CO_2 concentrations.

With respect to livestock, increased meat or milk productivity per unit weight of animal also offers a possible means of reducing emissions of methane, which has a greenhouse warming potential twenty to thirty times that of carbon dioxide.

In addition, some areas may be able to change zoning to increase allowable limits on densities of population or development without exceeding carrying capacities. Such increases in the intensity of human settlements would help stem the loss of agricultural land to human settlements and generally reduce pressures on land. Moreover, higher population densities make more viable many energy and resource conservation measures, including mass transit, district heating, reductions in heating or cooling requirements, and waste recycling. This would help reduce greenhouse gas emissions. On the other hand, in areas where carrying capacities are strained or extended, appropriate measures to expand carrying capacities should be considered—e.g., implementing pollution-control measures, improving access to potable water or transportation infrastructure.

Another option to improve the efficiency of resource use would be to *identify and review subsidies for resource use* (B-C). Subsidies encourage use of marginal resources. For instance, crop subsidies can often result in cultivation of more land than is economically justifiable. This removes land from its natural unmanaged state, which leads to deforestation and potentially a loss of biological diversity. Moreover, it contributes further to greenhouse warming. Extension of cultivation through subsidies also reduces water available for other purposes. Grazing subsidies have similar consequences. In addition, these help enlarge livestock populations, which, from the point of view of climate change, contribute to increased methane emissions. However, it should be noted that societies may rationally elect to subsidize various activities for reasons of equity and other social benefits that may not be easily amenable to monetization. In such circumstances, it may be worthwhile to examine if subsidies could be re-formulated so that they still achieve their social goals while diminishing their environmental impacts.

Promoting resource conservation and sustainability of resource use (A, B-C). Conservation practices could assist resources to withstand climatic stresses by helping moderate local climates, water use, and soil erosion, increase genetic variability, and reduce other stresses from environmental degradation. Particular attention may be given to reducing deforestation, promoting reforestation and afforestation, improving water use efficiency, and increasing the use of sustainable agricultural practices.

Strengthening conservation and protection of highly vulnerable areas (A, B-C). Climate change may or may not exacerbate conditions in marginal and endangered ecological and agricultural systems and overused water basins. Assessments of the potential impacts of climate change (see Category A) might help sort this out.

In areas that could be further stressed, various initiatives could be taken for conserving the most sensitive and valuable resources, including strengthening conservation measures and managing development of highly vulnerable resources. Identification of the most sensitive and valuable resources would necessarily be based upon each society's consideration of relevant social, cultural, environmental, and economic factors.

6.5.3 Increasing the Flexibility of Resource Use and Management

Flexibility for resource management needs to be maintained and/or enhanced (A, B-C). Greater flexibility will increase opportunities to adjust land and water uses to a wide range of possible climatic conditions. Climate change could affect the suitability of a tract of land for various purposes. Its productivity and potential will change in ways that cannot currently be predicted. If today it is used for production of a specific crop, that crop may not be viable in the future; land devoted to conservation of a particular species may be unable to support the appropriate habitat for that species in the future. Thus flexibility is a necessary condition for successful adaptation. There are several implications to this.

First, *consideration should be given to decentralizing, to the extent practicable, decisions on resource use and management* (B-C) i.e., they may be left to individuals and local authorities. They are more likely to have a better understanding of the local context and therefore less likely to err in their evaluations. Moreover, decentralization assures that any errors in judgment—and some are inevitable—are not universal. The other side of the decentralization coin is that there should nevertheless be coordination between adjacent jurisdictions. Moreover, local concerns often override the broader good, which leads to a "not in my backyard" mentality. To deal with this, methods need to be explored on how smaller segments of society may accept taking actions benefiting the larger society even at some additional risk or burden to themselves. Second, *quick and accurate information and technology transfer is critical to maintaining such flexibility* (A). Third, *there is a need to research methods of increasing the flexibility of land and water use for various purposes* (A).

6.6 WATER RESOURCES

6.6.1 SPECIAL CONSIDERATIONS FOR WATER RESOURCES

Water is essential for human civilization, living organisms, and natural habitat. It is used for drinking, cleaning, agriculture, transportation, industry, recreation, animal husbandry, and producing electricity for domestic, industrial, and commercial use.

Even in the absence of human-induced climate change, there is a great deal of climatic variability. In many areas it is an ongoing challenge to match water supply with demand. The problems that do occur with respect to water are usually on a regional (multi-basin), basin, or smaller scale. Even in "normal" times, problems may occur in one season but not in another. To achieve the goal of matching supply and demand, societies have established elaborate structures and institutions to store, treat, and distribute water; have mined groundwater; and have used demand-side management such as rationing or pricing. In spite of such measures, most societies expect to be forced to cope with various incidents of floods, droughts, and degraded water quality.

Human beings have faced other circumstances with lessons that could be valuable in adapting to any adverse impacts of climate change on water resources. These circumstances include increased pressure on limited surface and ground water resources due to population growth, migration into arid or flood-prone areas, periods of short-term and prolonged drought, and degraded water quality. Detailed institutional and legal mechanisms and arrangements have been established to make water more available and dependable, or of better quality. There are hundreds of international compacts, treaties, and agreements dealing with water. In addition, numerous other arrangements dealing with water resources exist within nations. Thus, there is a fund of knowledge that can be drawn upon to help devise response strategies that would mitigate adverse impacts or capitalize upon positive impacts that may result from a greenhouse warming.

As noted in Sections 6.1.3 and 6.1.4, there are significant uncertainties regarding the effects of increased greenhouse gas concentrations on resources. The spatial and temporal distribution of precipitation, soil moisture, and run-off, and the frequencies and magnitudes of droughts and floods will change in a manner that is not currently predictable with confidence. While the world may receive more precipitation on a globally averaged basis, some areas will get more, and others less, precipitation. Precipitation, though, is only one factor determining water availability and run-off. Other critical factors include temperature, wind speed, humidity, the nature and extent of vegetation, and the duration of accumulated snowpack. Each of these factors would also change in the event of climate change: higher temperatures would result in greater evaporation and transpiration and earlier spring melting of snowpack; higher wind speeds and changes in humidity would change the frequencies, magnitudes, and patterns of storms; higher carbon dioxide concentrations could result in more efficient water use by vegetation and crops, thus modifying evapotranspiration; annual and seasonal variability of precipitation, temperature, and other climatic factors would change.

The ability to predict the spatial and temporal distribution of precipitation is quite limited (see Section 6.1.4). This predictive ability declines as one goes from global to regional or watershed scales, and from annual to shorter time periods (e.g., seasonal and weekly periods). Moreover, current estimates for run-off and water availability in the event of climate change so far have omitted consideration of many critical factors, such as the effects of changes in vegetation on evapotranspiration and run-off, humidity, and wind speed. Thus, the present ability to predict the direction, magnitude, extent, and timing of changes in water availability, run-off, and other parameters relevant to water resources management for specific areas and basins is limited at best. Although there is some agreement among current models on the likely direction (but not the magnitude or timing) of change in certain geographic regions (e.g., a likely increase in temperature in the arid sections of the western United States), such agreement does not imply accuracy: it could be a result of similar assumptions and simplifications in current models. In addition, the demand for water supplies could also be modified because of changes in rainfall, cropping patterns, and water-use efficiency and in managed and natural ecosystems.

While site-specific effects on water resources cannot generally be identified at this time, the adaptive measures available today to manage water resources would in all probability be valid for future conditions.

The precise options selected by each area need not, of course, be the same as those it employs today. Nevertheless, many responses would be appropriate today as well as in the event of climate change.

Water-resource management in the face of climate change will face somewhat different challenges compared with past water planning. In the past, when climate was assumed to be constant, one could estimate new demands for water by more easily measurable or observable factors—the rate of population growth, the rate of decline of groundwater supplies, or the degree of aridity in areas being newly settled. However, for many years hence, the ability to model future atmospheric changes and their interaction with the hydrologic cycle is unlikely to provide as great a degree of certainty about the degree, or (in many cases) even the direction, of climate change on a regional level. This increases the degree of uncertainty concerning which responses are prudent. Clearly, the more expensive the response strategy, or the greater its adverse social, economic, or environmental consequences, the greater the caution regarding its adoption.

6.6.2 Response Strategies

Timing of strategies. Although climate change may occur over many decades, it is uncertain whether these changes—should they come—would be gradual or sudden. Many water supply systems are designed to operate under extreme conditions (greatly increased or decreased run-off), but water resources managers will have to consider that the frequency and magnitude of extreme events may be altered. Given the uncertainties regarding the extent, magnitude, and timing of climate change and its effects on water resources, it may be prudent to delay consideration of more costly adaptation measures (Category C) until after these uncertainties are reduced. By the same token, many of the less costly response strategies (Categories A and B), especially those with other benefits, may be appropriate today, as well as in the event of climate change. Some response strategies and programs can be implemented effectively during the short term; e.g., flood warning, evacuation, disaster relief loans or subsidies, and emergency operations. Other strategies may require a longer lead time to respond to climate change; e.g. conducting studies of modifying reservoir operations to meet shifting demands under climatic uncertainty, and incorporating considerations of climatic uncertainty into the design of new water resource structures. Fortunately, many responses to climate change are already embedded in current planning, design, and management practices, and their general application in industrial and developing countries should be promoted.

Determining the flexibility and vulnerability of current water supply systems (A,B). Given the uncertainty over the nature of hydrologic changes to be expected in any particular region and the cost of making any significant changes in existing water supply structures, a logical first step would be to evaluate the flexibility of current water supply systems to the type of changes that might be expected under climate change. Models could be used to estimate the sensitivity of water systems to increased aridity and increased run-off (such as might occur from a shortening of the run-off season). Such models could utilize altered run-off data from a number of possible sources: arbitrary increases or decreases, the use of proxy data on seasonal temperature and precipitation obtained through paleoclimatological methods, or global climate models used in conjunction with hydrologic models.

The greater the vulnerability and/or inflexibility in a particular water system, and the greater the impact on human population and on ecosystems, the more important it is to monitor relevant parameters with a view toward determining trends, to strive to reduce uncertainties regarding the effects of climate changes on water resources, and to consider measures to enhance the flexibility of the water supply system. Such system models would also necessitate assimilating data on current facilities, streamflow, and other statistics—data that would be required for many of the additional response strategies.

System optimization (A,B). Water supply facilities are often built by one particular jurisdiction or agency to service its needs, and the reservoir operating rules are developed to serve the needs of that jurisdiction or agency only. Hence, system operation may not be optimized across existing jurisdictions or agencies. Significant increases in system yield can often be obtained by joint use and revised operating rules if different jurisdictions or agencies are willing to execute agreements to do so. These agreements involve exchange of storage and flood control capacity between reservoirs at different times of year, as well as specifying rules for joint operation of facilities. The increases obtainable from such measures can be enhanced by more up-to-date data on meteorological and soil moisture conditions, as well as the application of more sophisticated computer models. In the long-term, once the flexibility and vulnerability of a water supply system to respond to a variety of hydrologic changes is better understood, the next step would be an attempt to optimize the water yield, hydropower production, flood control, recreational use, maintenance of fish and wildlife habitat, and other outputs available from existing facilities under various climate change scenarios, as well as under current climate. Optimization of international water-resource systems may require intensified international cooperation among countries sharing river basins.

Enhancement of scientific measurement, monitoring, knowledge, and forecasting (A). Given the natural variability in meteorological and hydrologic conditions, one of the initial challenges of planners may be to determine whether long-term changes are, in fact, occurring or are expected to occur in a particular region. Such assessments are based on comprehensive and accurate monitoring of hydrological and meteorological factors. However, the relevant observational networks are far from satisfactory in most of the developing world. As climate change is a global phenomenon, there is a need for a global approach in monitoring. There should be continued study of the interaction of the hydrologic system with the rest of the climatic system with the eventual goal of enabling area or basin-specific predictions, or detection of trends, with respect to changes in water availability and other parameters useful for water resources management. This could eventually enable planners, designers, and managers to incorporate predicted climate trends in their use of stream flow and other time-dependent data series.

Water conservation (A,B). Water conservation measures have been widely discussed over recent years for a variety of reasons, including the increased demands for water and the high financial, social, and environmental costs of construction of additional storage facilities. Under conditions of increased aridity, conservation measures may become even more important. Large savings in water are possible in agriculture. Irrigation is the largest consumer of freshwater in many areas and relatively small percentage reductions in irrigation water use can make large amounts of water available for new uses.

Agricultural water conservation measures include irrigation management scheduling (monitoring of soil moisture and atmospheric conditions to more precisely schedule the amount and timing of water deliveries), lining of canals to prevent seepage, tailwater recovery (recycling water that reaches the end of field rows), drip irrigation, using more drought-resistant crops and/or cultivars, and tillage practices that retain soil moisture. Conservation of municipal and industrial water supplies can be achieved through education, better measurement and metering, technological improvements, specifying the use of more efficient water-using appliances in building codes, and, in arid climates, use of low-water-use landscaping, rather than grass lawns. Under extreme drought conditions over one or two dry years, voluntary rationing of domestic use and mandatory restrictions (allowing water use during just certain hours, restricting lawn watering, etc.) have also proven effective. In addition to these measures, pricing has more potential as an incentive for water conservation.

Demand management through pricing (B). Water prices provide signals and incentives to conserve water, develop new supplies, and allocate limited water supplies among competing uses. Since water use is sensitive to price, water users facing higher prices will generally conserve water and modify technologies and crop selection. Therefore, pricing by water supply authorities to reflect real or replacement costs promotes efficient use. However, the cost of water supply facilities constructed by government entities is often recovered partially through property taxes or means other than through commodity charges levied on final consumers. In other cases, the facilities are subsidized, with the cost being financed through general government revenues or income taxes. The result is that water is often priced inefficiently, below its cost of delivery or its long-run marginal cost. This leads to overuse of water and the other resources needed to construct water supply facilities. There is substantial additional opportunity for cities and irrigation districts to utilize pricing as a means of conserving water by employing marginal-cost pricing (charging for the cost of the last-added and most expensive increment of supply) or progressive-rate pricing (charging more per unit to users of large amounts). A first step would be to perform studies of the effect of higher prices and different water-rate structures on water use in the particular area under consideration.

It would also be possible to extend these concepts to employ pricing as a means of allocating water use during drought episodes. To some extent this is already done: some areas have a two-tier rate structure, where lower rates are charged for interruptible supplies of water. As discussed below, allowing water entitlements to be traded at market value may achieve results similar to raising prices. Institutional arrangements for pricing and for trading water would need to take into account potential adverse (or beneficial) impacts on public uses of water, such as recreation and preservation of wildlife, whose value is often not incorporated into current pricing practices.

Voluntary water transfers or markets (B). One response to more arid conditions is to establish institutional arrangements to assure that water is directed to where it is most needed and where it will be the most productive. One means for doing this is to establish a system of property rights in water that can be traded as economic or hydrologic conditions vary.

For example, a growing city or a new industrial user desiring a senior water right can enter the market place to purchase a senior right from an existing irrigation water user.

The amount of water a rights holder could transfer is normally limited to the consumptive-use portion of his entitlement rather than his full diversion entitlement from the stream, in order to assure that other water users are not injured in the transfer process. Government also has a role in protecting instream, public uses of water for water quality, fish and wildlife, and recreational and other uses. Water transfers can be annual rentals, short-term leases, permanent sales of water rights, payments for conservation investments in exchange for the conserved water, or dry-year option agreements under which the water is transferred only under specified drought conditions. The viability of such approaches would vary, depending upon the extent to which property rights and markets have been relied upon in the past.

Modification of cropping systems (C). Any long-term changes in temperature, evaporation, the length of the growing season, the amount and temporal distribution of precipitation, or other climate-related parameters may lead to the modification of cropping practices. Modifications in response to climate change can include: shifts to more (or less) drought- or heat-tolerant species or varieties, changes in planting and harvesting dates, selection of varieties with shorter or longer growing seasons, and adjustments in the number of crops grown per season (e.g., conversion from double cropping to single cropping or vice versa). Therefore, changes in climatic factors may also result in (1) migration of current crops to new areas to take advantage of changed conditions or (2) changes in the demand for irrigation. These changes could, in turn, affect water demand and supply in the new as well as old areas, as well as having impacts on the volume of contaminants in agricultural run-off.

Modifications of tillage systems (B, C). Although historically the primary functions of soil tillage have been to prepare a seedbed and control weeds, certain tillage systems are effective measures for conserving soil and/or water. Practices that leave crop residue on the soil surface tend to increase surface roughness and organic matter, thereby increasing infiltration and reducing the potential for soil erosion. Surface residues also help to reduce soil loss due to wind erosion. Any tillage system that avoids exposing subsurface soil moisture to evaporative loss or that creates a surface soil barrier to evaporation can contribute significantly to agricultural water conservation, especially in rain-fed areas. Thus, tillage systems can be used to make more efficient use of precipitation in more arid areas, to reduce erosion resulting from excess precipitation and to reduce the off-farm impacts of soil erosion and farm chemicals transported by run-off. These modified tillage practices can be combined with other land management practices designed to reduce water use and soil erosion, such as terracing, laser-leveling of fields, and water harvesting systems that recover water run-off.

Natural resources management (B, C). Natural resources management programs are implemented in many regions of the world to address deforestation and desertification and to promote the sustained yield and conservation of natural resources. By including considerations of the potential impacts and risks of climate change, such programs may mitigate the impacts of climate change on water resources.

Examples of such programs include integrated river basin or watershed management programs; integration with forestry practices and reforestation in upland areas; soil conservation, forage selection, livestock grazing practices, land management, and other agricultural practices in the plains; and coastal estuarine, marsh, and mangrove management.

Flood management. Flood management strategies are now based on the computed magnitude and frequency of flood events based largely on historic data. The potential effects of climate change are changes in the magnitudes and frequencies of storm events and in the magnitude, rate, and timing of the melting of snowpack. Therefore, some areas can expect increased run-off over shorter time periods. In addition to systems operation studies designed to accommodate a wider range of future climatic conditions, potential response strategies include the following:

- *Improvement of flood forecasting* (A). Collection of hydrometeorological data by GEOS satellites and other advanced systems provides real-time information on rainfall, streamflow/stage, and reservoir levels. Broader collection and use of similar real-time data in concert with improved quantitative precipitation forecasting techniques could enable water managers to respond more rapidly and effectively to potential flooding.
- *Evacuation plans* (B). Comprehensive flood preparedness plans may include provisions for temporary evacuation of flood plain occupants during flood events. Improved flood warning and forecasting abilities could enable additional actions, such as removing or raising building contents to reduce flood losses.
- *Flood warning* (B). Implementation of flood warning systems can often be relatively inexpensive, quick to design and build, and easy to modify to changing conditions. Generally such systems can be operated by local people in a decentralized, independent mode.
- *Floodplain zoning* (B). Zoning flood plain areas to prevent construction of structures and activities likely to suffer from floods is another means of avoiding losses.
- *Flood insurance* (B). Flood insurance can serve a double function. The flood insurance premiums can be price signals to the insured to discourage locating in flood-prone areas. Second, once flooding has occurred, insurance can be an effective means of reducing the economic impact of losses. Climatic change could necessitate more frequent review and revision of flood insurance programs.

Disaster relief and emergency preparedness (B, C). Because of the uncertainty concerning the impacts of climate change, improving disaster relief programs may be an effective response. Flood insurance or financial assistance in the form of emergency loans and subsidies could reduce the impact of economic losses and social disruption. Grants or loans could be used to fund such measures as construction of emergency levees (e.g., sand bagging) and emergency debris removal to impede imminent flooding, as well as for post-flood rehabilitation efforts.

Advance planning of these programs would reduce conflicts over their implementation and make potentially affected parties aware of their availability.

Design modifications (B, C). In situations where it is cost-effective, designing more capacity into spillways at the time of project construction and other design modifications, such as increased capacity for levees and dikes, can assist in handling larger flows of water.

Adjustments in river transportation (C). Increased precipitation could help inland navigation systems by providing a more constant depth of water in the free-flowing reaches of inland systems. If climate changes result in less run-off, there is the possibility that interruptions could occur in the free-flowing reaches. If greenhouse warming results in a more extreme hydrological regime, river navigation will tend to be adversely affected by more frequent floods and droughts. Response strategies include dredging of shoals or sand bars in the major river systems to maintain adequate depths; lessening the likelihood of groundings by lightening barge loads; placing greater reliance on other forms of transportation during drought episodes; and augmenting low river flows.

Education, technology transfer, and financial assistance and special considerations for developing countries (A). In many developed countries a comprehensive system of physical structures is already in place to deal with excess or inadequacy of water supply and to manage distribution. Similarly, such countries have well-established institutions with a long record of dealing with water resource problems and making adjustments. Furthermore the costs of making the necessary adjustments can be accommodated largely within the financial and human resources of the countries concerned.

In other, less well developed countries, the converse may be true. In many cases, developing countries are not able to cope with adverse water resource conditions under existing climate. Thus, in such countries, additional efforts may first be needed to raise standards of water resource management. Education, training, and technical assistance efforts directed at water managers and water users could play a role in making water use more efficient and in responding to climate change. These programs could include national, regional, and international efforts such as joint scientific research; exchange of research results on new crops, products, and technology; and assistance to developing nations for training and technical assistance. The United Nations, the World Bank, and other international and bilateral agencies provide a framework through which technical and financial assistance is provided to developing countries and regions.

Where it does not already exist, nations could develop an infrastructure (e.g., extension services similar to that existing in the United States) to assist in rapid dissemination of new and appropriate technology, management techniques, and practices to help assure sustainable use of forest and agricultural resources. The same infrastructure could also be used to educate farmers and the local public about the role of vegetation in controlling erosion and in modifying the hydrological cycle.

In order to enhance the robustness and resilience of water systems, it would be important to identify appropriate technologies, depending in part on the economic base and level of economic development in a region; cultural and institutional factors (for example, market-based strategies may be more difficult to implement in some settings); international and bilateral trade and debt policies; and guidelines for development projects.

Countries where water resource systems have not been developed may first want to concentrate on the provision of adequate storage and delivery systems, conservation practices, and appropriate water allocation institutions under conditions of current climate.

Modification of storage and other augmentation measures (C). Although nonstructural measures are generally less expensive and should be exhausted first, additional storage may become a method for responding to climate change to accommodate changes in the magnitude and timing of precipitation and/or snow melt, either through raising existing dams, construction of new facilities, inter-basin transfers of water from areas of surplus to deficit water areas, or recharge of underground aquifers from available surface supplies. Planning for such measures would need to take into account potential adverse and beneficial environmental and economic impacts. Transportation of emergency water supplies could be provided when drought conditions threaten public health and well-being.

In those coastal areas where water has reached a very high value, desalinization technologies could be used to augment supplies.

For a number of years, research has proceeded on cloud seeding to determine whether this technique has value for augmenting water supplies in certain areas. One of the main problems has been that it is difficult to separate out the amount of additional water that is the result of cloud seeding, and therefore it is difficult to find financial sponsors of cloud-seeding experiments.

Dam safety and other design criteria (B, C). Response strategies to safeguard the integrity of existing deficient impoundment structures generally include some combination of enlargement of spillways, raising of dams, and modification of water-control plans. Increased run-off due to climate change could potentially pose a severe threat to the safety of existing dams with design deficiencies. Design criteria for dams may require re-evaluation to incorporate the effects of climate change.

Adjustments in protecting water quality in rivers and reservoirs (B, C). Climate change could modify the amount of fresh water available. If freshwater quantities are reduced, this could affect the ability to dilute contaminants and salts, to dissipate heat, to leach salts from agricultural soils, and to regulate water temperatures in order to forestall changes in the thermal stratification, aquatic biota, and ecosystems of lakes, rivers, and streams. The potential effects of climate change on water quality also relate to the magnitude and frequency of storm events as well as seasonal changes in temperature. For example, the onset, duration, and characteristics of reservoir and lake stratification would respond to seasonal temperature changes, particularly in temperate regions. Dissolved oxygen concentrations could also be affected, and eutrophication problems could worsen. Climate change could also affect the recharge rates of aquifers, which could affect the quality of underground water supplies. However, if climate change involved increased flows in a region, greater dilution of pollutants and other water-quality benefits may result. These various changes in water quality may affect the usable supplies of fresh water.

The efficient operation of systems to manage water quality may become more critical. Transferable discharge permits are one means to allow ambient water-quality standards to be met at the least cost by trading pollution reduction capabilities among dischargers.

Various in-place technologies, such as aeration and destratification and localized mixing systems, can mitigate adverse changes in water quality. Modifying the operation of reservoirs with multi-level withdrawals, or adding this capability to existing reservoirs, would increase the ability to manage changes in water-quality conditions. Water-quality problems are also affected by the level of discharges into a stream, including non-point source run-off from the watershed. Therefore, watershed-management programs to control non-point sources as well as point sources can help maintain water quality.

Adjustments in protecting estuarine water quality (C). Estuarine water quality will be subject to similar hydrometeorological changes that affect fresh water, as well as changes that may occur in the oceans, such as sea level rise or tidal variations. One of the effects could be saltwater intrusion into surface and ground water, having unpredictable and possibly adverse impacts on fishery resources and wildlife and on water supplies.

In addition to the response strategies listed for maintaining river and reservoir water quality, the following could prove useful: relocating water supply intakes out of areas that may be susceptible to higher saltwater intrusion; and providing saltwater barriers to further saltwater intrusion in estuaries and tidal rivers (such barriers would have to be evaluated against possible adverse effects on migratory fish and shellfish resources passing seasonally through the system).

Utilization of hydropower (B, C). There is considerable potential for developing hydropower in Asia, Africa, and Latin America, as well as in other parts of the world. Development of these resources could help reduce combustion of fossil and wood fuel, thereby reducing carbon dioxide emissions directly. Moreover, conserving forests would reduce erosion and the frequency and magnitude of flooding, especially in mountainous terrain. In planning for hydropower projects, consideration would also have to be given to potential beneficial and adverse environmental and economic impacts (such as inundation of agricultural lands, forested lands, and wetlands; downstream impacts on navigation, flood control, and water supplies; and effects on aquatic resources and recreation).

6.7 LAND USE AND MANAGED AND NATURAL ECOSYSTEMS

6.7.1 Introduction

This section deals with adaptive responses to the impacts of climate change on land use and managed and unmanaged ecosystems, including forests and biologically diverse areas.

Biological diversity refers to the variety and variability among living organisms and the ecological complexes in which they occur. Biological diversity is organized at many levels, ranging from complete ecosystems (i.e., systems of plants, animals, and microorganisms together with the non-living components of their environment) to the chemical structures that are the molecular basis of heredity. Thus, the term encompasses different ecosystems, species, and genes, and their relative abundance.

More important, while biodiversity is related, it is not identical to the number or abundance of particular species. There are economic and non-economic reasons for maintaining biological diversity, forests, and other ecosystems. In many areas, food production and livelihood (e.g., tourism, forest products) depend directly upon these functions. Nature contains blueprints for substances that could be of great benefit to agriculture, medicine, and forests under a variety of climatic conditions. If climate were to change, such blueprints could be the source of new cultivars better adapted to future conditions. There are also aesthetic and cultural reasons for protecting biological diversity. Moreover, disruption of forests and land cover can affect availability of quality water, run-off, and soil erosion.

Climate change could alter the physical suitability and economic viability of land for different uses in many areas. The climate has played a significant role in present land-use patterns and on the occurrence and distribution of present-day agricultural and forest lands, human settlements, and biota. Hence, it seems likely that these distributions could be altered if significant changes in the climate occur. In this process, forests and other ecosystems could be altered with change in inter- and intra-species diversity with some species extinctions becoming possible (appropriate actions could reduce these impacts), while some species could benefit.

Adjustments, including changes in land use and improved biodiversity conservation efforts, can be made in response to changing climatic conditions and population growth rates. In open market economies, many of these adjustments will be made by private resource managers who are guided by market incentives (changes in prices and costs). Yet, many decisions on land use and biodiversity conservation have environmental and social consequences that are not considered in private benefit-cost calculations.

Section 6.7 outlines the changing pressures on land use that could result from global climate change and suggests planning and management options for adapting to climate change. It also makes suggestions for helping rapidly growing populations meet the demand for land for various human activities, while assuring conservation of the environment and maintenance of biological diversity.

6.7.2 Current Pressures on Land and Ecosystems

The effects of increasing greenhouse gas concentrations and associated climate change on land use and biodiversity must be considered against a backdrop of rapidly increasing population growth. Such growth alone will result in increasing demand for food, fiber, and forest products and for living and recreational space. These demands increase pressures to (a) remove more land from its unmanaged state, thus increasing stresses on less intensively managed habitats, biodiversity and ecosystems and increasing atmospheric concentrations of carbon dioxide as forests are converted to other land uses, (b) adopt more intensive land uses that could increase soil erosion and further degrade water and other environmental quality, and (c) convert agricultural and other lands to urban and suburban uses.

6.7.3 POSSIBLE ADDITIONAL PRESSURES RESULTING FROM CLIMATE CHANGE

Increasing greenhouse gas concentrations and associated global climate change could affect patterns and intensity of land use in significant ways. Climate change could shift regions of suitable climate for a particular species toward the poles and higher elevations. Over a period of decades or centuries, the species present in plant and animal communities could dissociate as a result of differences in thermal tolerances, habitat requirements, and dispersal and colonization abilities, and assemble to form new communities under the new climatic conditions. At this time, however, neither the precise direction, rate, distance nor success of migration of species can be predicted.

While such changes provide information on possible shifts in ecological systems, they cannot easily be translated into specific shifts in uses of land for agriculture, forestry, or other purposes. Current land-use patterns could change: some areas that today are used for agriculture may change in the intensity of use because of changes in climate or availability of water; for the same reasons, other areas that today are not used for intensive agriculture may be able to support it in the future. Switches in crops or cultivars will likely occur to optimize expected farm income. The demand for lands for human settlement may be affected: some coastal areas may become uninhabitable in the event of sea level rise; areas in the higher latitudes may become more hospitable for human habitation. In some areas, current land uses may be continued only if relatively expensive measures are taken to mitigate the effects of climate change; in other areas, adapting the land to new uses may result in a net social benefit (over current uses).

Changes in the habitat could lead to a species invading the range of another species. In at least some cases this may lead to a reduction of population size or even extinction of the competitively weaker species. (Appropriate actions could reduce these impacts.) Declines in populations and species extinctions could occur due to loss of habitat, lack of new land suitable for colonization, and inability to keep pace with changes in the climate. On the other hand, other species may benefit because certain habitats may become more abundant and productive. Ecosystems restricted by human activities to small isolated areas could face the greatest risks from climate change due to the exacerbation of current stresses on such systems and the fact that colonization by new individuals may be hampered by the fragmented nature of the landscape. Any inter- and intra-specific declines in biodiversity could result in irreversible loss of genes and gene complexes.

Some migratory organisms may also face increased threats. Migratory species are dependent on the quantity and quality of habitat in more than one area and they may be adversely affected if suitable habitat in only one of these areas is reduced. These effects could be mitigated because migratory species have the mobility to locate suitable new habitat. Moreover, suitable habitat may expand or become more productive. In these instances, migratory species may benefit.

6.7.4 ADAPTATION MEASURES

To meet the various demands on land and to conserve natural resources under future climatic regimes, resource users and managers would need to consider management and development efforts to maintain or enhance economically efficient, sustainable land use and biodiversity. However, responses to climate change should optimize socioeconomic well-being and growth subject to environmental constraints.

Moreover, both adaptation and emission limiting strategies should be considered as a package (see Section 6.3). Since the rate of climate change has such a strong influence on the ability of various ecosystems to adapt, efforts to slow the rate of global warming, particularly reducing deforestation and promoting forestation, can go a long way toward limiting adverse impacts. In addition, several adaptive responses should be considered to improve resilience to changes in the climate.

With respect to adaptation, emphasis should be on identifying and considering removal of barriers to rapid and efficient adaptation, identifying decisions with long-term consequences, maintaining flexibility and improving resource use and management where possible, limiting costs and administrative burden, and promoting public input and acceptance. Effective adaptation to climate change is largely dependent on the integration of information on the impacts of climate change with land use planning and biodiversity conservation efforts. It may also require more dynamic nature conservation (i.e., greater human intervention) rather than strict preservation. Adaptive measures that meet the above objectives are described below under the categories of research and short- and long-term actions.

6.7.4.1 *Research, Planning, and Information Dissemination (A)*

This subsection identifies measures that should be considered to increase the knowledge base so that societies can respond rationally and efficiently to possible changes in the climate. These options are classified Category A according to the classification scheme adopted in Section 6.4. Studies of climate change impacts on land use and biodiversity are needed to identify the resources that are the most vulnerable to climate change and to characterize the dynamics of the responses of managed and unmanaged ecosystems. This information, together with assessments of the effectiveness of particular response strategies, will allow for timely and efficient planning for and modification of land use and conservation of biodiversity.

i) *Inventory* (A). Resource managers could use information on the current state of resources to analyze what is vulnerable to climate change and what might be done about it. Inventories that describe the current uses of land, such as now exist in some countries, and the current distribution and diversity of species, would be of value. Developing such inventories where they do not exist would be a useful step regardless of whether climate were to change.

ii) *Assessment* (A). Based on the above-mentioned inventories, resource managers could examine vulnerabilities of natural resources to climate change, assess how various ecosystems and land-use patterns could be affected by increased greenhouse gas concentrations, and identify potential land-use conflicts resulting from climate change. Significant effort needs to be devoted to the development of biogeographic models to investigate the response of various species, including migratory species, to higher greenhouse gas concentrations and associated climate change. Research is also needed to improve the understanding of behavior of collections of isolated populations of species in a fragmented landscape and rates and constraints to colonization and dispersal. To achieve this, research is also needed on: (a) the size and location of protected natural areas to satisfy various uses and what practices may be necessary, given the existing or expected size limitations; (b) utility, extent, and placement of conservation corridors; (c) rates of population migration, and (d) behavior of species. Monitoring systems also need to be established to detect any changes in disease and pest outbreaks.

iii) *Development and dissemination of new technologies* (A). R&D efforts that result in more efficient and sustainable land use could help in coping with new stresses from climate change by reducing land use demand. Both public and private enterprises should continue research and development directed to more efficient and resilient forestry and agricultural practices (e.g., development of drought- and heat-tolerant species and crop rotation techniques) and biotechnological innovation. Governments should take measures encouraging such R&D while ensuring that such work is conducted in a manner consistent with public health and safety. Nations may consider developing innovative institutional, legal, and financial measures that would take advantage of innovation, including measures that would allow innovators to profit from their R&D. Nations might also consider institutional, legal, and financial measures that would encourage individuals and communities to develop an economic stake in efficient and environmentally sound land use and development.

Research is also needed to improve methods for internalizing the true social costs in land-use decisions to ensure that these decisions reflect such externalities as ecological damages and infrastructure improvement.

Several approaches for limiting adverse impacts on biodiversity need research. If deemed effective, development should be encouraged. These approaches may include (a) techniques for establishing and maintaining conservation corridors between protected areas; (b) *ex situ* conservation techniques (e.g., preservation of species in zoos, botanical gardens, and germ plasm banks); and (c) community restoration and development techniques to introduce species unable to colonize new regions naturally.

Research and development need to be undertaken to promote fuller and more efficient use of forest products especially as sources of biological energy, materials, and chemicals. This includes research and development to assure more complete utilization of felled trees; assure longer life of timber and wood products by improving resistance to fire and pests and diseases; increase efficiency of industrial plantations through genetic selection, breeding, and propagation; increase efficiency of fuel plantations by screening of tree species for charcoal making; develop new uses for felled trees that could displace fossil fuels (e.g., in electrical generation); promote fuller use of forest products other than timber (e.g., resins, oil, fruits, fiber, materials) by researching and enhancing traditional practices, and focusing on "multipurpose" trees (i.e., trees that can provide a variety of benefits—e.g., fruits for human consumption, fodder for livestock, and fuelwood from branches).

Increasing the rate of dissemination of research results and technologies to users (e.g., land-use planners, farmers, foresters, wildlife biologists, and public policymakers) to enable them to quickly adopt new practices, plans, and technologies. The United Nations and its member organizations (FAO, UNESCO, WMO, UNEP), the World Bank, other multi- and bilateral agencies, and several national institutions provide a framework through which technical and other assistance could be provided to developing countries and regions. Information to planners, farmers, foresters, and other land users is needed. Extension services, such as that supported by the U.S. Department of Agriculture (USDA), could be used to disseminate information and educate planners, farmers, foresters, and other land users.

iv) *Research that enhances the stake of local population in preserving biodiversity* (A). Research needs to be undertaken on how to give parties a stake (including an economic stake) in preserving biodiversity—e.g., developing economic incentives to preserve existing (natural) germ plasm and maintain genetic diversity in breeding populations. Increased research is necessary on the economics of biodiversity.

6.7.4.2 *Short- and Long-Term Responses (B or C)*

This subsection describes options that some societies may be able to undertake:

- in the short term, to improve resilience to climate change if they result in little or no additional costs (or consequences). (Category B responses under the classification scheme of Section 6.4.) The options include maintaining flexibility in land use, managing development of highly vulnerable areas, and increasing and maintaining the sustainability and efficiency of land-use management;
- in the long term, as uncertainties regarding climate change are reduced. (Category C, as discussed in Section 6.4.) Possible long-term

initiatives include creation of conservation corridors, strengthening protected areas, and modifying economic incentives affecting land use.

i) *Maintaining flexibility in land use* (B). The uncertain, but potentially significant, shifts in land-use suitability associated with climate change argue for enhancing and maintaining flexibility in land-use decisions. Nations could explore methods of making future land use more flexible and adaptable to climate change. Such flexibility might allow for switches in land-use practices to activities that are expected to provide the highest social values under future climatic regimes. For instance, programs designed to acquire and manage recreation or conservation areas should have the capability to adjust to shifts in the needs for—and suitable locations of—these areas.

Greater use of property easements is one way for maintaining flexibility in land use. More flexible methods of acquiring, developing, and managing areas to be set aside for fuelwood, forage production, and expanding human domicile needs (including recreation and other amenities) within or in close proximity to existing human settlements should be explored. However, in many countries ownership of land is perceived as a fundamental right and one not lightly abrogated. Thus, any methods of increasing the flexibility of land use must be consistent with the principle of fair and equitable compensation to land owners. Moreover, if there are uncertainties regarding "property" rights or length of tenure, they will lead to abuse from resource managers (see (iii), below).

In some cases it may be useful to vest or empower local organizations with clear responsibility and authority for coordinating land-use planning that reflects the likely impacts of climate change and rapidly growing human populations. Land-use planning efforts should incorporate climate change concerns and operate with full participation of concerned organizations and interests.

Nations should consider methods such as exchanging land-use rights, "impact" payments and other schemes to satisfy the concerns of local communities with respect to uses that, while beneficial to the larger society, may not be desirable from the local perspectives.

Ideally, land-use planning should be decentralized and conducted at the local level. Nevertheless, since climate change could exacerbate conflicts between competing resource users, increased coordination between managers of different programs (e.g., biodiversity, agriculture, forests, water supply), between public and private resource managers and between all levels of government could be necessary. In a changing climate, it may become more important for bodies with jurisdiction over different geographic areas and uses to coordinate land-use policies. For example, agricultural and other local interest groups and parks managers should confer where their interests overlap. Coordination might usefully be extended to large areas to incorporate potentially major shifts in land use. Opportunities to strengthen the institutional mechanisms for such coordination could be explored.

ii) Creating an economic stake for local populations in conservation areas (B). Opportunities for increasing the economic stake and social value to surrounding populations in conservation, preservation, and recreation areas should be explored. Without strong ties to the protected area, populations may have a strong incentive to respond negatively to altered land-use demands caused by climate change, resulting, in some cases, in destruction of protected areas.

iii) *Invest resource users with clear "property" rights and long-term tenure so that resource conservation and regeneration are enhanced* (B). Many users of resources do not have an interest in long-term sustainability, since they either have no land tenure rights or have leases with short-term durations.

iv) *Strengthening conservation and protection of highly vulnerable areas* (B). Certain areas that are already under significant stress, such as highly erodible farmland, heavily used water basins, and some natural areas, may be particularly sensitive to climate disturbances. In some currently stressed areas, climate change could relieve existing pressures. Assessments of the potential impacts of climate change would help identify which areas could be subject to increased stress. Future development in areas that may come under increasing stress could consider management tools such as regulation of development, purchase from or payments to the owner, tax incentives, and impact charges. For example, highly erodible or other marginal lands may be protected by offering farmers annual payments in lieu of cultivating such land—with participation in such programs being strictly voluntary. More active management and intervention such as the creation of protected areas, where appropriate, may be necessary to maintain viable populations of certain endangered or threatened species. As for all responses, social, economic, and environmental consequences must be considered in evaluating and selecting options.

v) *Promoting resource conservation* (B). Conservation practices could increase the resilience of resources to climatic stresses by moderating local climates, promoting water retention, decreasing soil erosion, increasing genetic variability, and reducing other stresses from environmental degradation. This may allow for the maintenance of long-term productivity.

Particular attention might be given to reducing deforestation, improving water-use efficiency, increasing the use of sustainable agricultural and forestry practices, and ensuring that the intensity of resource use is consistent with carrying capacity. Also, analysis of land-use options should consider factors such as simultaneously accomplishing several objectives (e.g., floodplain hazard reduction, wetland and fisheries protection, and migration corridor needs, as appropriate).

vi) *Improve storage and food distribution of agricultural products* (B). Improved methods of storing and distributing food and agricultural products, supplemented by methods of minimizing storage losses, would lessen the severity of future food deficits, whether or not caused by climate change, and would reduce pressures for additional land for food production, thus enabling the world to better cope with future supply instabilities, especially as human populations grow substantially.

vii) *Encourage efficient and environmentally safe levels of agricultural and forest practices, and location and densities for human settlements* (B). Government review of practices, products, and technologies that enhance agricultural and forest productivity and efficiency of land use for human settlements should proceed expeditiously, while balancing the potential benefits of such reviews against the costs of delays. Such reviews must carefully evaluate environmental and health impacts, yet still meet the needs of a substantially increasing human population. In some areas, changing zoning to allow higher population densities would slow the amount of land devoted to human settlements and result in less agricultural land taken out of production. Increased human settlement density would also make more efficient energy use possible by, for example, increasing the economic feasibility of mass transit and district heating and cooling. Enhanced research and field trials are necessary to improve identification and dissemination of new production technologies which take into account all externalities of production usually left out of the resource management calculus (e.g., soil erosion rates, net emissions of greenhouse gases, deleterious side effects of pesticide use on wildlife). In addition to focusing on local environmental effects, environmental reviews should take into consideration broader effects such as net efficiency of land use.

viii) *Modifying economic incentives* (B or C). Direct and indirect subsidies to agriculture, forestry, and development of human settlements can influence land-use practices. Incentives should be reviewed to ensure that they are economically efficient and consider the sustainability of land use and conservation of biodiversity. However, some nations may rationally elect to subsidize certain activities for reasons of equity or to meet other social goals that may be hard to monetize.

ix) *Strengthening and enlarging—and establishing conservation corridors between—protected nat-*

ural areas (C). Depending upon the outcome of the research outlined in Section 6.7.4.1, item (ii) above, further strengthening or enlargement of protected areas could be beneficial for the maintenance of biodiversity and recreation opportunities; poleward or up-slope additions in ecotone (i.e., transition) regions could be particularly beneficial under a warmer climate. In areas/regions that are built up, or fenced off, or where very little land is in its natural condition, conservation corridors, such as greenways, river corridors, trails, hedgerows along the edges of fields, and transportation and transmission corridors could serve to facilitate migration of species as well as increase the degree of protection to the species involved.

This, too, would be more beneficial to ecotone areas. In addition, corridors could enhance the capacity for species to shift distributions in response to climate change. On the other hand, in areas where there is sufficient land in its natural state or which is not fenced off or built up, such corridors may not be functional and might even serve as a barrier to efficient migration. Another potential problem with purchasing lands for natural areas or corridors is that, given the uncertainties about regional climate change, the eventual direction and magnitude of dispersal cannot be predicted with certainty. An approach that could be explored would be to set aside protected areas with concentric buffer zones of protection (e.g., as in biosphere reserves). The most sensitive zone could be the most protected, with other zones allowing more human use and occupancy. Such a design should also consider the possibility that species in the highly protected zones could migrate out of the area in response to climate change. In many cases strengthening of existing protected areas through the provision of greater financial or managerial support or increasing the economic stake and social value to local communities in protected areas may be the best management approach. In any case, the social and economic consequences of designating lands as protected areas should be considered in view of the ecological benefits.

6.8 FOOD SECURITY

6.8.1 INTRODUCTION

Over the last 50 years, technological advances in irrigation, mechanization, pesticides, fertilizers, and crop and livestock breeding have stabilized and increased agricultural production in many parts of the world. Our ability to produce food and fiber is greater now than at any time in the past. Yet we have not succeeded in ensuring food security for all the world's population.

It is estimated that between 500 and 700 million people in the developing world do not have access to enough food. Malnutrition contributes to the deaths of 35,000 children each day. Despite great progress in countries such as India, many less-developed countries already have a serious food security problem. Food security is determined by the availability of food and the ability to acquire it by "dependable long-term access to food through local production, or through the power to purchase food via local, national, regional, or international markets." Even in the absence of any climate change, several countries will find it difficult to maintain or enhance food security given expected population growth.

To ensure food security for the world's increasing population, it will be necessary to sustain and enhance the natural resources on which we depend. Economic growth and equity are also musts. But most important, the spatial and temporal uncertainties about the impacts of greenhouse gases and associated climate change may demand the development of flexible policies that allow and encourage local adaptations/solutions, allow course corrections, and take a long-term approach.

6.8.2 FACTORS AFFECTING FOOD SECURITY

Food security at the national level has three main elements: adequacy of supplies, stability of supplies, and access to supplies.

Ensuring *adequacy of supplies* involves determining the appropriate balance between domestic production and trade. Increasing domestic production is not simply a resource or technology problem, although the availability of both are critically important, and this will become increasingly the case in those countries where climate change has negative effects on food and agricultural production. It is a function of four interrelated factors—the four "i's" of agricultural development: *incentives* to encourage farmers to produce surplus food for the market; *inputs* to boost productivity; *institutions* to provide credit, technical advice, marketing services, etc.; and *infrastructure* in the form of roads, storage, facilities, etc., to link the farmer with input supplies and food markets, particularly urban ones.

For some countries and communities the most serious issue is not the long-run adequacy of supplies but year-to-year *instability of supplies*. Such instability arises primarily from dependence on rain-fed agriculture in drought-prone areas; from population pressures that have forced people to cultivate more marginal land and/or to maintain more livestock than the rangeland or pastures can feed, with consequent wide fluctuations in crop yields and high livestock mortality during times of drought; from the unwillingness or inability to maintain sufficient stocks; from cyclical supply/demand patterns in the world food market; and from frequent changes in government policies, support prices, etc.

Access to supplies has two major dimensions: a national dimension reflecting the ability of countries to enter the world market to buy additional food, which in part is a function of the openness of the trade system and the ability of food deficit countries to earn foreign exchange through exports; and a personal income dimension, in that extensive poverty restricts the ability of individuals and households to buy all the food they need for a healthy diet. Thus, local or imported supplies must be matched by effective demand and appropriate mechanisms to ensure access to supplies by those lacking purchasing power. Without such mechanisms the market will maintain supplies at levels that leave many people hungry.

It is apparent then that the solutions to food insecurity are not simply technological, but also involve economics, infrastructure, and governmental policies. Developed countries, with their strong economies, well-established infrastructure, institutions and governments, as well as with less dependence on the agricultural sector (farming contributes approximately 2 percent of the annual GNP in the United States, compared with 40–60 percent of the annual GNP in some less-developed countries), are not as vulnerable to the impacts of climate change. Although developed countries will no doubt undergo adjustments in their economies and agricultural sectors in the event of climate change, national food security should be relatively unaffected. They will buy food and fiber that they cannot produce.

Low-income countries are more seriously affected by food insecurity. In order to reduce existing poverty in developing countries from 50 to 10 percent of the population and thereby improve food security, it has been estimated that a 3 percent annual growth in per capita income would be necessary over the next 20 to 30 years. With expected population increases, this translates into an overall national income growth of 5–6 percent. Such economic growth will be difficult if not impossible even under the best of circumstances, unless the countries receive greater international support.

Without technical assistance from developed nations and significant gains in sustainable economic growth and development, food security problems could be exacerbated in many nations.

6.8.3 FOOD SECURITY IMPLICATIONS AND IMPACTS

Climate change will not affect each of the three elements of food security uniformly, and within each element the effects may differ as to their global, regional, or national importance.

6.8.3.1 *Climate Change and Adequacy of Supplies*

While the impacts of climate change are uncertain, it is possible that the overall impact on global food and fiber supplies could be positive. In general there may be positive impacts due to increased productivity resulting from higher CO_2 levels. Production could be further augmented in some areas because of longer growing seasons and reduced frost damage. On the other hand, production may be reduced in some areas due to higher temperatures, less soil moisture and greater pest infestation, and loss of land due to sea level rise (see below).

At the regional level the picture is less certain, but there could be substantial potential for intra-regional compensation.

Such problems as may occur are likely to be at the national or subnational level, particularly in some of today's food-deficit developing countries. Food security in these countries is already a problem because of poverty and the lack of effective demand, stemming in part from the impact of high population pressures on limited and low-quality natural resources.

The adequacy of supplies could be affected in four principal ways: spatial shifts in the agroclimatic zones suited to the growth of specific food crops; changes in crop yields, livestock output, and fisheries productivity; changes in the water available for irrigation; changes in productivity and use of land because of sea level rise. Other impacts, such as alterations in the protein or starch content of crops seem likely to be of far lesser importance.

Shifts in agroclimatic zones. Climate change could shift agroclimatic zones with both positive and negative effects. In general, zones would shift poleward. In the middle and higher latitudes, higher temperatures may extend the growing season and reduce frost damage, though some of this positive potential may not be realizable (see Section 6.8.3.2). At the same time, there may be a loss of agricultural land if conditions become drier in currently arid or semi-arid regions (though higher carbon dioxide concentrations may increase water-use efficiency of many—especially cool season—crops). Such shifts in agroclimatic zones could cause regional dislocations.

Sea level rise could have a major effect on food security in several areas. Some of the most productive areas are low-lying coastal plains and estuaries with fertile alluvial soils. In Asia, for example, a high proportion of rice production comes from low-lying coastal areas, mainly former swamps and marshes.

Production on these lands could be lost through submergence, longer or deep freshwater flooding in some inland parts of low-lying coastal areas, and increased saltwater intrusions in coastal aquifers used for irrigation or for livestock drinking water. However, while these lands could be lost to traditional uses, new uses (such as fisheries and aquaculture) could also take their place. In reality it may be a major threat to food security only in those areas already at risk in certain low-income food-deficit developing countries.

Changes in irrigation potential could occur in two main ways. First, through changes in the spatial and temporal patterns of precipitation, surface run-off and recharge rates of aquifers. Second, through saltwater intrusions into coastal aquifers. In some regions these changes, coupled with changes in demand, could exacerbate existing water shortages; in other areas, existing shortages could be mitigated.

Impacts on crop yields. With changes in temperature and rainfall regimes and in CO_2 concentrations, countries will become more or less optimal for the production of certain crops. Thus, yields will rise, or fall—unless there are compensating management actions or developments in technology.

While there are uncertainties associated with model results, especially on the regional and local levels, they project the following.

a) Considerable increases in potential crop yields in northern temperate countries—up to several percent in some instances; however, such increases may have little impact on national food security since these countries are already able to import all of the foods they cannot currently produce by spending a small fraction of their national income. Even so, such gains in potential production may not be fully realizable because of plant pests and diseases (see Section 6.8.3.2).

b) In the middle latitudes, potential declines in yields in the hotter, drier interior of continents because decreased rainfalls and increased evapotranspiration may offset positive CO_2 impacts on photosynthesis and water-use efficiency.

c) Limitation of yields may occur in some semi-arid tropical and sub-tropical areas if the net effect of change in temperature and precipitation is a reduction in crop water availability.

Animal husbandry. The effects of climate change on animal husbandry will largely mirror those on cropping. Any change which reduces or enhances biomass production will likewise reduce or enhance livestock carrying capacity. Whereas climate changes are expected to have little effect on crop quality, they may have a significant impact on forage quality. High temperatures may adversely affect reproduction, milk and meat production, but conversely will reduce maintenance requirements—particularly in temperate areas.

As with crops, warmer temperatures and increased precipitation will provide favorable conditions for parasites, fungi, bacteria, viruses, and insects. This can be expected to contribute to the more rapid deterioration of animal products. Increases in variability or intensity of rainfall resulting in droughts or flooding can cause tremendous losses at the local level.

Fisheries. Fisheries may experience problems similar to cropping and animal husbandry due to changes in temperature and precipitation. Current ranges of important commercial species may shift poleward along with marine habitats of higher productivity. Freshwater ponds which are already near the upper temperature limits of tolerance will be lost as habitats to some species. Changes in evaporative demand, surface run-off and melting in the high latitudes may also affect streams and lakes. Coastal wetlands, marshes and shallows (which are important to most fisheries) and aquaculture facilities may be relocated as existing areas are lost and new areas created as a result of sea level rise. (However, creation of suitable new areas may be hampered because of human barriers in their path.) Again, the impact of these effects on economies and food security will be felt mostly on a local or national level.

6.8.3.2 *Climate Change and Stability of Supplies*

Although it is difficult to determine the potential net effect of climate change on supply stability at the global level, at least four sources of changes need to be considered here:

- Reduction of snap frost damage in high altitude tropics and in northern latitudes. Early and late season frosts currently have irregular, but at times severe, impacts on production, although the damage is largely confined to fruit and vegetable crops.
- Possible increases in the geographic range and severity of both plant and animal pests and diseases. In the absence of corrective actions the overall net effect could be negative. Higher temperatures will allow pests and diseases to over-winter for the first time, or to over-winter in larger populations, thereby providing the conditions for rapid spread early in the growing season to epidemic levels, consequently resulting in greater production losses. Heavier and more prolonged rainfall could have similar effects. Such outbreaks currently occur on an irregular basis, causing food supply to fall by as much as 50 percent over substantial areas. Climate change could make such outbreaks a much more frequent and widespread event.
- Possible changes in the annual variability of the climate, i.e., reliability of arrival of seasonal rainfall, its frequency and intensity. Erratic climate can lead to delayed planting, mid-season and other droughts, and incomplete plant growth cycles. In some present instances it can reduce cereal production by as much as half, and cattle populations by a quarter, leading to wide annual swings in food supply. How climate change will affect annual climate variability is not known.
- Possible changes in the frequency and magnitude of rainfall may lead to changes in flooding and erosion. The effect of climate change on these factors is also unknown.

In addition, changes in climatic variability could have impacts on grain quality and, therefore, market and nutrition value. However, the direction of the net change on this aspect is currently unknown.

6.8.3.3 *Climate Change and Access to Supplies*

Given that global food supplies may be sufficient to meet world demand (and possibly increase), and export supplies may be available, any problem of access to supplies will likely be more acute in low income food-deficit countries, and in low income low-lying islands. Although climate change may have negative impacts on agricultural production in high- and middle-income countries, the consequent falls in export earnings or food production are unlikely to be critical for national food security since food imports or average per capita food expenditure are low in proportion to the respective totals. Nonetheless, even within these countries there may be particular income groups whose food purchasing power will be reduced, either directly or indirectly, by climate change.

Access to food supplies could be affected by changes outside agriculture, e.g., loss of tourist revenues by low-lying islands and other areas following sea-level rise. The main impacts, however, will come from within agriculture. It is conceivable that a number of countries could suffer from decreased production of their major export crops, e.g., ground-nuts and cotton, which would also have serious impacts on employment and agricultural incomes, thereby reducing the ability of individuals and households to buy sufficient food.

Where domestic food production decreases, significant income effects are also likely to arise.

6.8.4 Response Strategies and Adaptation Measures

The uncertainties concerning the magnitude, timing, and spatial distribution of the impacts on food security point to the need for response strategies with two principal objectives. First, the alleviation or elimination of those current food security problems that might be intensified by climate change—e.g., flooding in Bangladesh and drought in the Sahel. Second, the maintenance for future generations of as wide a range of adaptation measures as possible—e.g., breeding from rare livestock breeds and crop land races that are well adapted to the agroclimatic conditions that could emerge but that are currently dying out through the lack of adequate conservation efforts.

The first objective can be achieved through general improvement in economic conditions, especially in developing nations, and through a range of economically justifiable adaptation measures, most of which already exist or could be developed, given the likely time scale of climate change.

These measures include capital investment, technology development and dissemination, and resource management changes. They are considered in the following sections.

The second objective has essentially three components: (a) changes in land-use policy to ensure, for example, that high quality agricultural land is not lost permanently through urban and industrial development and is kept in good condition through appropriate management; (b) enhancement of biodiversity conservation efforts—both *in situ* and *ex situ*; and (c) changes in policies to intensify and sustain agricultural production on the best lands in order to remove pressure from some of the more marginal lands. Response strategies for these are given in Section 6.7 of this document.

The following subsections present options to enhance and/or maintain food security. They employ the classification scheme described in Section 6.4. Under this scheme, Category A consists of options that would improve the knowledge base necessary to fashion rational and efficient responses to increases in greenhouse gas concentrations and associated climate change. Category B consists of options that some societies may be able to undertake in the short term if they result in little or no additional costs (or consequences). Category C identifies long-term options that may be considered once uncertainties regarding greenhouse gas concentrations and climate change are reduced.

6.8.4.1 *General Response Options*

1) Since the developing countries have largely resource-based economies, efforts concentrating on the improvement of agricultural and natural resources would be beneficial (B, C). However, some assistance in improving economic conditions in developing nations comes directly or indirectly from developed nations, some of whom are themselves beset with budget difficulties.

2) Improve agricultural and natural resource research/extension institutions, specifically: (a) national coordination for local level efforts due to the uncertainty of local level effects of climate change; (b) regional networking activities to pool resources and share technology/responses; and (c) support for these activities from developed countries in terms of training researchers, extension agents, and natural resource managers, and technological assistance (A).

3) Gradually reduce international trade barriers and farm subsidies in both developed and developing countries to foster economic growth in less-developed countries and allow the agricultural sector to compete in a more global marketplace (B-C).

4) Intensify agricultural production on a sustainable basis on the best lands in order to remove pressure from some of the more marginal lands. Better water and soil management and more efficient use of water, fertilizer, and pesticide will also be necessary to sustain this intensive production (B, C).

5) Develop new food products that can be more easily stored, and improve storage facilities where yields tend to be unstable (A).

6) Develop baseline information on and monitor changes in climate, crop production, pest and disease incidence, livestock fecundity and quality, and fisheries, at local, regional, and global levels (A). Look for irreversible changes, and changes that can be used as indicators of climate change.

7) Protect germ plasm resources and biodiversity. Increased research on the preservation of plant, animal, insect, nematode, and microorganism resources may be needed. New breeding efforts (including genetic engineering) may be necessary to develop crop and livestock tolerance to both physical and biological stresses. Research on biocontrol and the plant rhizosphere may uncover new, beneficial uses for insects, nematodes, and microorganisms (A).

8) Review the current knowledge base of agricultural technology and identify best bets for further investigation and possible transfer to other locales and regions (A).

9) Continue development and maintenance of data bases for species, technology, and management and land-use practices employed under different climatic conditions, for possible transfer to other locales and regions if, and when, climate shifts become more certain (A).

10) Continue research and development of heat- and drought-tolerant crop and livestock varieties (A).

11) In the long run, as and when uncertainties regarding climate change and its impacts at a regional level are sufficiently reduced, in areas that are likely to be significantly adversely affected agricultural communities may have to shift to new crops and possibly accelerate changes that may have occurred anyway—e.g., by adoption of new technologies, practices, and even new livelihoods (C). Implementing the above set of responses 1–10 would help facilitate any such transitions.

6.8.4.2 *Adaptive Measures for Crop Production*

Options are available for both investment and management (technical change) and could be used to enhance or maintain food security.

Many of the arid and semi-arid areas vulnerable to climate change have undeveloped irrigation potential. In other similar areas, current irrigation water use is depleting water tables. Solutions to both these situations may be expensive and, therefore, may not be economic for low-value food crops. This cost constraint can be overcome partly by secondary investment in raising water-use efficiency so that a larger area can be irrigated with a given volume of water, and by improving drainage to prevent salinization. Drainage investment will also be required in rain-fed areas where soils are already waterlogged periodically (B-C, depending on whether or not it can be economically justified now), or which could become waterlogged as a result of increased rainfall (C).

In areas where reduced rainfall could lead to lower water tables, it may be economic to consider artificial recharge of aquifers.

Similarly, it may be economic in some areas to consider coast protection, storm surge and tidal barriers, and other forms of flood control. Such measures, however, could be very expensive and result in ecological change. Given that the sea level rise will be gradual, the high-income countries should be able to afford preventive measures like higher coastal defenses and special tidal barriers. For the low-income countries, however, investment capital is already in short supply and in many of them is likely to remain too low for them to be able to afford such coastal defenses. Therefore the building of higher coastal defenses to deal exclusively with climate change should be deferred until uncertainties are reduced (C). On the other hand, augmenting an existing plan to "insure" against climate change may be justified (B).

Finally, there is investment in grain storage to "insure" against greater fluctuation in annual rainfall. When such investments are primarily at the farm level, the costs can be relatively modest and feasible since the stores tend to be built with local materials and household labor (B-C).

Most *technical change* options concern shifts in plant-breeding strategies to improve pest resistance, heat or drought tolerance, etc. Given that plant-breeding cycles are usually less than 10 to 15 years, such improvements could keep pace with slow climate changes provided appropriate germ plasm is available (A).

Adaptation and introduction of existing techniques also has an important role to play. Minimal tillage, for example, has been developed primarily as a technique for highly mechanized farming systems in industrialized countries where improvements in soil erosion control and soil water management are required. If adapted for developing country conditions it could play an important role in areas experiencing greater aridity (A, B-C).

Other techniques to conserve soil and water and increase sustainability of resources which could be more widely used include: tied ridges, conservation bench terracing, mechanical and vegetative bunding, weed control, legume and sod-based rotations, windbreaks, drip irrigation, more efficient fertilizer and pest management, and appropriate cultivars (A, B-C). Areas with adequate water resources can be irrigated, although attention should be given to drainage systems (C). Salinization can be problematic on clay soils with poor drainage and in areas with high evaporative demand. Drainage systems may also be necessary in areas with clay soils that experience precipitation increases.

Other management options include changes in the timing of farm operations—e.g., shifts in planting dates to compensate for changes in rainfall distribution (C). Additional gains could come from changes in cropping patterns through the introduction of "new" crops better suited to the modified agroclimatic conditions (C).

6.8.4.3 *Livestock Sector Options for Adaptation*

The most serious threats to food security for the livestock sector will be confined largely to the arid and semi-arid areas of the middle and lower latitudes, where nomadism or settled extensive or semi-intensive livestock systems are the only way of exploiting vast areas of relatively marginal grassland, particularly in the countries surrounding the Sahara desert.

Other agroecologically marginal areas, notably those in Australia, North America, and the USSR, could also be adversely affected, but without posing a significant risk to national food security, although individual farmers would need support.

In the most severe situations, where pasture production is substantially reduced, the main option may be to assist livestock owners and their families to move out of livestock into crop production or out of agriculture altogether into different areas of the same country (C).

Where impacts are less severe, mitigation of the effects of climate change may be achieved through the installation of water points for livestock (C); by research and breeding to select animals and pasture or fodder plants better adapted to the new environment (A). New breeding techniques, like embryo transfer, increase the probability of being able to achieve improvements on an appropriate time scale. Finally, improvements in livestock management may be possible. These could include: improved rations utilizing supplementary protein, vitamins and minerals (B); reductions in stocking rates (although this is often difficult to achieve in practice where communal grazing land is involved) (B-C); improvements in pasture management (B-C); wider use of feed conservation techniques and fodder banks (B-C).

In higher latitudes where conditions may become warmer and wetter, pasture productivity is likely to rise, but pests and diseases could become more serious. Nonetheless, the net effect on production in such areas is likely to be positive.

6.8.4.4 *Adaptation Measures for Fisheries*

Fish have food, recreational, and cultural value. There will be three main impacts from climate change: changes in the abundance and distribution of fish stocks; overall changes in the variability of individual fish stocks; and changes in inland, coastal, and oceanic habitats.

Options for the first include strengthening or, where appropriate, establishing fisheries institutions that could assist in managing or allocating changing fish stocks due to effects of climate change (B); shifting fishing from coastal to distant waters (C); development of inshore or inland aquaculture (C); and finally, employment creation outside the sector (C).

Responses to the second impact are part of wider measures to improve fisheries management. Fisheries management policies may need to be strengthened or modified, as appropriate, along with associated fish population-and-catch monitoring activities, to prevent overfishing where stocks decline or to ensure sustainable exploitation of improved fisheries stocks (B,C). In some areas, it takes many years for changes in fisheries policies to be developed and become fully effective. The time scale of policy change should be considered in weighing various management options.

Consideration of options regarding changes in inland, coastal, and oceanic habitat is necessary to reduce any potential negative impacts as well as to take advantage of new habitat that may be created. One option is to consider fisheries (wild and aquaculture) habitat needs in planning coastal protection measures (B,C).

Other options are strongly research-based and will need general strengthening of research institutions (A) as well as more specific actions. The latter include restocking with ecologically sound species following biological and commercial evaluation of indigenous and non-indigenous species (A, C). Fish breeding supported by measures to conserve the genetic diversity and inherent variability of existing fish populations could also play an important role (A). Furthermore, increased research into population dynamics and adaptive measures is needed (A). Moreover, the use of aquatic and marine species as indicators of change needs to be explored and, if necessary, enhanced (A).

Given the close interaction between land cover and maintenance of adequate fishery habitat, fishery managers need to cooperate closely with forestry and other resource managers (B). This is critical for policy success in this field.

Marine mammals (e.g., whales, dolphins, seals) are of increasing cultural importance and decreasing significance for food. Most stocks of these animals will likely move as marine ecosystems shift to adapt to changes in temperature and circulation patterns and, as a consequence, may not be significantly affected, at least in abundance. Required adaptation measures are probably limited to scientific monitoring (A) and ensuring that habitat needs are also considered from the standpoints of coastal planning and in ocean pollution control efforts (B-C).

APPENDIX 6.1

LIST OF PAPERS PROVIDED TO SUBGROUP

FOOD

Australia, Department of Primary Industries and Energy. "Potential Impact of Climatic Change on Animal Husbandry—An Australian Perspective," May 5, 1989.

Brazil, EMBRAPA. "Future Scenarios and Agricultural Strategies Against Climatic Changes: The Case of Tropical Savannas," by A. Luchiari, Jr., E.D. Assad, and E. Wagner, October 30–November 1, 1989.

Canada, Fisheries and Oceans Department. "Fisheries: Response Strategies to Climate Change," draft working paper, July 11, 1989.

Food and Agricultural Organization. "Implications of Climate Change for Food Security," Theme paper prepared for IPCC Working Group III, Resource Use and Management Subgroup, by D. Norse, September 1989.

France. "Combatting Desertification and Salinization," 1989.

India, Ministry of Environment and Forestry. "Effect of Climatic Changes Due to Greenhouse Gases on Agriculture: Some Salient Points," 1989.

Jodha, N.S., ICIMOD, Kathmandu, Nepal. "Potential Strategies for Adapting to Greenhouse Warming: Perspectives from the Developing World," October 30–November 1, 1989.

Okigbo, B.N., Michigan State University, East Lansing, United States. "Comments on Response Strategies Related to Food and Agriculture in the Face of Climatic Change with Respect to Tropical Africa," November 1, 1989.

Swaminathan, M.S., President, IUCN. "Agriculture and Food Industry in the 21st Century," October 30, 1989.

FORESTRY

Brazil. "Forestry Report," 1989.

Canada. "Socio-economic and Policy Implications of Climate Change on the World's Managed Forests and the Forest Sector," by Peter N. Duinker, Working Group II (Environmental and Socio-economic Impacts of Climate) of the Intergovernmental Panel on Climate Change, Geneva.

India, Ministry of Environment and Forestry. "Some Salient Points—Agriculture: Effect of Climatic Changes Due to Greenhouse Gases on Forests and the Strategies Needed to Tackle These Effects," 1989.

Japan, Ministry of Agriculture, Forestry and Fisheries. "Japanese Report on Forest and Forestry," 1989.

United Kingdom. "Note on Tropical Forestry and Climate Change," prepared for Intergovernmental Panel on Climate Change, Working Group III, Resource Use Management and Agriculture, Forestry and Other Human Activities Subgroups, August 1989.

United Kingdom, Forestry Commission of Great Britain. "United Kingdom Contribution to Consideration of Adaptation to Possible Climatic Impacts on Forests," by A.J. Grayson, 1989.

United States Interagency Task Force. "Agriculture and Forestry: Adaptive Responses to Climate Change," draft, April 7, 1989.

United States Interagency Task Force. "Land Use and Biological Diversity: Adaptive Responses to Climate Change," September, 1989.

LAND USE/UNMANAGED ECOSYSTEMS

Netherlands. "Climatic Change and Biological Diversity," paper prepared for RUMS workshop, October 30–November 1, 1989.

United Nations Environment Programme. "Biological Diversity: A Unifying Theme Paper," by H. Zedan, prepared for IPCC WG3, Resource Use and Management Subgroup, 1989.

United States Interagency Task Force. "Unmanaged Ecosystems—Biological Diversity: Adaptive Responses to Climate Change," September 13, 1989.

United States Interagency Task Force. "Land Use Management: Adaptive Responses to Climate Change," September 13, 1989.

WATER RESOURCES

da Cunha, L.V., NATO. "Impacts of Climate Change on Water Resources and Potential Response Actions: An Overview of the Situation in the EEC Region," Workshop on Adapting to the Potential Effects of Climate Change, Working Group III of the Intergovernmental Panel on Climate Change, Geneva, Switzerland, October 30–November 1, 1989.

Kaczmarek, Z., NASA, and J. Kindler, Warsaw Technical University. "The Impacts of Climate Variability and Change on Urban and Industrial Water Supply and Wastewater Disposal," prepared for IPCC Working Group III, Resources Use and Management Subgroup, October 30, 1989.

Lins, H., U.S. Geological Survey. "Overview and Status of WG-II Hydrology and Water Resources Subgroup Activities," prepared for Working Group III, RUMS Workshop, October 30–November 1, 1989.

Nepal, Department of Hydrology and Meteorology. "Technology and Practice Summary Report on Water Resources," prepared by S.P. Adhikary, 1989.

Rogers, P., and M. Fiering, Harvard University. "Water Resource Use and Management in the Face of Climate Change Considerations in Establishing Responses," presented at UNEP/WMO Intergovernmental Panel on Climate Change, Resource Use and Management Subgroup, October 30–November 1, 1989.

Stakhiv, E.Z., U.S. Army Corps of Engineers and H. Lins, U.S. Geological Survey. "Impacts of Climate Change on U.S. Water Resources (with reference to the Great Lakes Basin, USA)," presented at the IPCC Resource Uses and Management Strategies Workshop, Geneva, Switzerland, October 30–November 1, 1989.

United States Interagency Task Force. "Water Resources—Adaptive Responses to Climate Change," draft working paper, August 23, 1989.

Waggoner, P., Chairman, AAAS Panel on Climate Change and Water Resources. "Theme Paper—Water Resources Session," prepared for IPCC WG3 Resource Use and Management Subgroup, Geneva, Switzerland, October 30–November 1, 1989.

APPENDIX 6.2

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