



# **Report of the Global Climate Change Subcommittee**

## **Review of the Report to Congress: The Potential Effects of Global Climate Change on the United States**



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY  
WASHINGTON, D.C. 20460

April 25, 1989

The Honorable William K. Reilly  
Administrator  
U.S. Environmental Protection Agency  
401 M Street, S.W.  
Washington, DC 20460

Dear Mr. Reilly:

We are pleased to transmit via this letter the report of the Science Advisory Board's Global Climate Change Subcommittee concerning their review of the Agency's first report to Congress on Global Climate Change. This report, The Potential Effects of Global Climate Change on the United States, was reviewed by the Subcommittee on November 17-18, 1988 with comments offered directly to EPA staff.

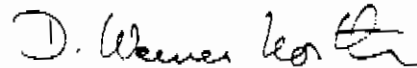
The Subcommittee had a number of specific criticisms of the draft report which have been discussed with EPA staff. These include suggestions for clarity, reorganization, and areas where we felt the report could be strengthened such as in the exposition of methods and results.

It is important to note that although the climate change effects in the United States described in this report indicate potentially serious impacts that are clearly cause for concern on the part of Congress and the public, we believe that the impacts do not warrant description as catastrophes threatening national economic or ecological disaster during the next century. Clearly we need to improve our scientific understanding of this complex issue if we are to plan appropriate strategies to adapt to the changes or to alter their possible effects.

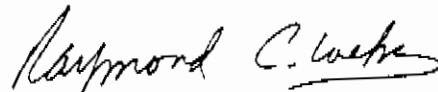
We regard this report as a good overview of a very complex subject, suitable for stimulating critical discussion in the United States and worldwide scientific communities on what science can tell us about the relationship between the emissions of greenhouse gases and impacts from potential alterations in climate. We commend the EPA staff for a good initial effort on the difficult process of translating the available science into an assessment of the environmental consequences of global climate change.

We appreciate the opportunity to provide our comments on this important long-term national and international environmental problem.

Sincerely,



D. Warner North  
Chairman  
Global Climate Change  
Subcommittee  
Science Advisory Board



Raymond C. Loehr  
Chairman  
Executive Committee  
Science Advisory Board

cc: John Moore  
Linda Fisher  
Richard Morgenstern

## ABSTRACT

This report presents the views of the U.S. Environmental Protection Agency's Science Advisory Board on its review of the EPA's report to Congress entitled "Potential Effects of Global Climate Change on the United States". The Board regards the request by Congress for the EPA to prepare an initial assessment of the potential effects of global climate change as reasonable and timely. This Effects Report examines a set of scenarios that are intended to represent possibilities for future climate change. By examining the consequences associated with these scenarios, the EPA has attempted to explore a wide range of potential impacts from the climate alteration on both a national and a regional basis. In the Subcommittee's judgment the usefulness of this effort is in providing a first iteration - a point of departure for additional research on these issues and for beginning a planning process by the Federal Government. The Board commends the Agency for a good initial effort on the difficult process of translating the science into a beginning of an environmental assessment. The Effects Report meets the goal of summarizing available information into an overview of how global climate alteration could affect the United States. As far as the Subcommittee is aware, it is the first major national effects study of its kind.

Key Words: Greenhouse Gas; Global Climate Change.

## NOTICE

This report has been written as part of the activities of the Science Advisory Board, a public advisory group providing extramural scientific information and advice to the Administrator and other officials of the Environmental Protection Agency. The Board is structured to provide a balanced expert assessment of scientific matters related to problems facing the Agency. This report has not been reviewed for approval by the Agency; and, hence, the contents of this report do not necessarily represent the views and policies of the Environmental Protection Agency or other agencies in the Federal Government. Mention of trade names or commercial products does not constitute a recommendation for use.

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## 1.0 EXECUTIVE SUMMARY

The United States Environmental Protection Agency (EPA) has been asked by Congress to report on the potential environmental and health effects of global climate change and the choices the global community may need to consider in order to limit and adapt to potential global warming. The two reports that EPA is preparing in response to this request are the Potential Effects of Global Climate Change on the United States and Policy Options for Stabilizing Global Climate. The EPA has asked its Science Advisory Board (SAB) to establish a review panel to evaluate these reports. The SAB established the Global Climate Change Subcommittee with the charge to review these two reports and evaluate their technical adequacy, uncertainties, and consistency of recommendations with the findings contained in the reports. This SAB report presents the conclusions and recommendations of the Subcommittee on its review of the first report The Potential Effects of Global Climate Change on the United States (known hereinafter as the Effects Report).

The Effects Report should be regarded as an overview of a complex subject, and it may be most useful as a stimulus to additional critical discussion in the United States and worldwide scientific communities on what science can tell us about the relationship between emissions of greenhouse gases and impacts from potential alterations in climate. Such discussion will help in refining this initial assessment into a better basis for planning, and such discussion should also contribute to the education of the Congress and the public on these issues.

In developing its scenarios for climate change in the United States, the EPA has relied on projections from three general circulation models (GCMs). Such an approach is a useful way to assure consistency in methodology for assessing a variety of impacts in different regions of the country, but it should be recognized that the GCMs were never intended for regional forecasts. The spacing of the grid points is large compared to the regions examined in the regional case studies, and much important geographical information relating to local climate is not included in the GCMs. However, the resulting scenarios seem more or less consistent with the results from simpler models of atmospheric circulation and with the consensus among atmospheric scientists for the potential magnitude of changes in climatic variables. It is therefore the Subcommittee's view that the methodology the EPA has adopted is a reasonable way to generate climate change scenarios for an initial assessment of climate change, and that the EPA has shown an awareness of the difficulties of interpretation and the uncertainties in the GCM results.

While endorsing the basic approach taken by the EPA, the Subcommittee believes that the exposition in the draft report of methods and results could be improved. The Subcommittee has made

many specific suggestions to EPA toward this purpose. The most significant of these are discussed in this report. Numerous minor suggestions by Subcommittee members made verbally at the November 17-18, 1988 Subcommittee meeting, or subsequently in their written comments have already been communicated to the EPA staff responsible for revision of the draft report, and they will not be included here.

In producing the Effects Report the EPA has limited its attention to the direct effects in the United States. This limitation is understandable given the time and resources available to the EPA. However, there may be considerable importance to effects from climate change outside of the United States. The United States, as an affluent nation with extensive technological skills and resources, may be in a better position to deal with the effects of climate change than many other nations. The indirect effects on the United States of disruption in other parts of the world caused by climate alteration may be as severe as any of the effects portrayed in this report. Further study of impacts in other countries and their implications for the United States is an important task for EPA and other Federal Agencies.

The direct effects of climate change as presented in this report indicate potentially serious impacts that are clearly cause for Congress and the public to be concerned. However, these climate change effects do not warrant description as catastrophes threatening national economic or ecological disaster during the next century. In some regions and for some ecological systems the effects of climate change could be severe, and the Effects Report indicates where the United States appears to be most vulnerable. But the magnitude and timing of these effects suggest that a determined effort should allow the United States to adapt to most of them, at economic costs that are large in absolute terms but relatively small if measured as a fraction of the United States economy over a time period of fifty years to a century. This conclusion is necessarily weak, because the current scientific understanding of the global climate system and the consequences of climate change is so limited. There is a clear and immediate need to improve our scientific understanding. The Effects Report suggests that global climate change presents the United States with a problem that is substantial in terms of its potential demand for planning and for economic and technical resources, but not overwhelming in magnitude compared to the other long-term national and international problems that Congress must address in the last decade of this century.

The EPA should be commended for a good initial effort on the difficult process of translating the science into a beginning of an environmental assessment. The draft Effects Report meets the goal of summarizing available information into an overview of how global climate alteration could affect the United States. As far

as the Subcommittee is aware, it is the first major national effects study of its kind.

## 2.0 INTRODUCTION

There is an emerging consensus in the scientific community on the importance of global climate as an issue deserving attention by policy makers in the United States and other nations. On the basis of past anthropogenic activities and those foreseeable within the next several decades, it seems likely that global climate may be altered. While warming is expected, the character, magnitude, and timing of the alteration in climate are highly uncertain. It is not possible with existing scientific information to make precise predictions of either global or regional impacts that may occur as the result of the increased loading in the atmosphere of carbon dioxide and other greenhouse gases. The climate impacts of greenhouse gases could be significant, and early planning may help to mitigate or avoid adverse effects associated with climate change.

It is, therefore, appropriate for the U.S. Federal Government to begin the assessment and planning process. The Subcommittee regards the request by Congress for the EPA to prepare an initial assessment of the potential effects of global climate change as reasonable and timely. The expectations for this initial assessment should be modest since this is an effort to characterize an exceedingly complex issue that cuts across a large number of academic disciplines. What the assessment can do is to indicate the relationships between emissions of greenhouse gases, changes in the atmosphere and climate that may result, and potential changes in hydrological, biological, and economic systems that are sensitive to climate. We cannot expect that this Effects Report can provide us with predictions of what climate changes may occur and how these changes will affect the United States. Rather the Effects Report examines a set of scenarios that are intended to represent possibilities for future climate change. By examining the consequences associated with these scenarios, the EPA has attempted to explore a wide range of potential impacts from the climate alteration on both a national and a regional basis. In the Subcommittee's judgment the usefulness of this effort is in providing a first iteration - a point of departure for additional research on these issues and for beginning a planning process by the Federal Government.

Some may contend that the uncertainties in predicting the extent and character of the climate changes are so large at this time as to make such an assessment of little value. The Subcommittee believes that the assessment and planning process should not be deterred by the large uncertainties, which arise in large measure from our lack of understanding of natural variations in climate. In the Subcommittee's judgment, there is a broad

scientific consensus on the type of climate change that could occur from alteration of the composition of the atmosphere. Such alteration of the levels of carbon dioxide and other trace gases affecting the earth's radiative balance is clearly demonstrated in the data, and these alterations can be expected to accelerate in the next century as the result of population growth and energy, forestry, agricultural, and industrial practices in all the countries of the world. The extent of these practices, and their implications for emissions of greenhouse gases, can be estimated with fair precision using available methods.

What are not available now are methods for predicting natural variations in climate and understanding the complex ocean-atmosphere interactions that determine the earth's climate. We are unable to predict weather more than a few days in advance, and we are just learning about the causes of shifts in the world's weather patterns, which have occurred throughout recorded history and back through geological time. At this time, our most advanced general circulation models (GCMs) may give us little better predictive capability than simple radiation balance calculations showing how increasing levels of greenhouse gases will cause a warming of the earth by absorbing infrared radiation that would otherwise be radiated through the atmosphere and out into space. We do not have the predictive capability to assess how increasing levels of greenhouse gases will alter atmospheric circulation, and we have far less confidence in predicting regional climate impacts than in predicting that increasing levels of greenhouse gases will lead to global aggregate warming. Since we have little ability to predict the natural fluctuations in climate, we cannot rule out the possibility that a natural cooling trend may offset the warming induced by greenhouse gases over the next several decades. We also cannot rule out the possibility of larger temperature increases than those predicted by the models currently available. Changes in regional precipitation and in the frequency of extreme meteorological events are even more difficult to predict than temperature changes with our current level of scientific understanding.

## 2.1 Background

In early 1988, the EPA's Office of Policy, Planning and Evaluation (OPPE) requested that the Science Advisory Board (SAB) establish a review panel to examine the two EPA reports to Congress on global climate change. These are The Potential Effects of Global Climate Change on the United States (Effects Report) and Policy Options for Stabilizing Global Climate (Stabilizing Report). Based on this request, the SAB established the Global Climate Change Subcommittee as an ad hoc subcommittee of its Executive Committee. The first of these EPA reports, the Effects Report, was provided to the Subcommittee in October 1988, with the review meeting held on November 17-18, 1988 in Washington, DC. The

Stabilizing Report is scheduled for release to the Subcommittee in March, 1989, with subsequent public review April 4-5, 1989. The Subcommittee will provide a separate report on its review of that document.

## 2.2 Charge to the Subcommittee

The Subcommittee has been tasked with the responsibility to review the two EPA reports to Congress and to provide advice to the Agency on the following:

- Assessment of the technical adequacy of the two reports, especially the degree to which they address the environmental and other effects of climate change.
- Identification of areas of uncertainty in the reports, and the degree to which this uncertainty may affect the recommendations.
- Consistency of the recommendations with the findings contained in the reports. Specifically (for the Stabilizing Report), are policy options identified that, if implemented, would stabilize current levels of atmospheric greenhouse gas concentrations.
- Other related issues that the Subcommittee believes should be addressed.

## 2.3 Review Process and Format of this Report

The Subcommittee's task was to review the draft Effects Report and to provide advice to EPA on means to improve the report, not to provide ongoing oversight of the document as it may evolve from the point of the review. At the November 17-18, 1988 meeting, the Agency staff were provided with detailed comments on each chapter of the report. Following the meeting, they were provided with detailed written comments and a transcript of the meeting.

This report contains information compiled from the meeting transcript and from written comments submitted by each Subcommittee member. Editorial items are generally omitted since they have already been provided to EPA. The Subcommittee's primary goal is to summarize the main points of our advice to EPA, not to reiterate all the advice given to EPA at the public meeting and in our written comments.

This report contains six major divisions: an Executive Summary which highlights the major issues we wish to emphasize; an Introduction which provides a discussion of broader issues along with the background and purpose of this review; and four sections

which review the individual chapters of the Effects Report by groups. The first of these sections (3.0) contains our review of the Executive Summary and Chapters 18 and 19; the second section (4.0) contains our review of Chapters 1 through 3; the third section (5.0) contains our review of Chapters 8 through 17; and the fourth section (6.0) contains our review of Chapters 4 through 7. We have suggested some reorganization of the Chapters and our comments will follow these suggestions while referencing the chapter numbering used in the draft Effects Report.

### 3.0 REVIEW OF THE EXECUTIVE SUMMARY AND CHAPTERS 18 AND 19

This section contains our review of the Executive Summary, Chapter 18 - Research Needs, and Chapter 19 - Preparation for Global Warming. These three chapters were grouped since they represent the major summary and recommendations of the Effects Report.

#### 3.1 Review of the Executive Summary

This chapter covers a vast amount of material, and as such, loses the clear and concise style expected in an executive summary. We found the length to be excessive, even for a document of the size and complexity of the draft Effects Report. Moreover, the summary did not always cover the most critical issues, nor did it provide all the necessary caveats. The Executive Summary needs a more balanced tone, indicating that the potential effects in the United States are significant, but that they do not appear to be catastrophic and unmanageable. In addition, the Executive Summary should contain the main ideas from Chapter 19. More focus on the relevance of information on effects for decision-making may help to make the Executive Summary more concise and to integrate its insights with those from the Stabilizing Report.

While EPA has strived to write a comprehensive, balanced assessment of potential effects that could result from a change in climate, the inconsistent use of language will almost certainly lead to misrepresentation, especially by readers who see only excerpts from the text. While the draft frequently states that the assessments are only scenarios and are not meant to be predictions of the future, this message is often muddled by the use of language such as "will occur". The Executive Summary should strive for more consistent and concise wording describing the objectives and conclusions of the Effects Report.

#### 3.2 Review of Chapter 18 - Research Needs

This chapter should include a clearer statement of research needs for better prediction of climate change at the regional

level, and better quantification of the consequences of any such climate change. The chapter should not discuss which agencies should be responsible for different aspects of the needed research; rather, reference should be made to other documents, such as the report of the Committee for Earth Sciences (1989) and the research program description being prepared by EPA's Office of Research and Development. The chapter should address the issue of inter-agency coordination both for science and policy. There should be explicit acknowledgements of the United States Global Climate Change Program and the International Geosphere-Biosphere Programme.

The section on atmospheric research needs was well written and well thought out, with clearly defined discussions of the uncertainties in our understanding and clearly posed research questions. Similarly, the discussion of the scenarios-assessment methodology was well done. This methodology offers a reasoned approach to assessing potential climate effects and policy implications. In contrast, there were a number of areas in which we felt that the ecological research discussions were deficient. Our suggestions for improvement in this area are identified in our detailed written comments that were submitted earlier.

The issue of integrated regional assessment is a tremendous research challenge. It will require the construction of a regional framework of linked models which by necessity must include regional economic models. Research on the linkages between environmental changes and economic changes needs to be a high priority. At present, economic changes are considered only in individual sectors (e.g. agriculture). Greater involvement of economists and policy analysts in effects research should be encouraged.

General circulation models appear to be a paradigm for producing necessary information for impact assessment. However, this chapter points out current major limitations of GCMs. To date, GCMs provide uncertain predictions for an incomplete subset of the required variables. Therefore a major component of the research should involve specifications for the types of information needed, and programs of model validation to assess the reliability of the GCM results. It is important that such model validation (a) identify strategies and (b) acquire data both to demonstrate the extent to which climate change is occurring, and to calibrate the behavior of the models.

Both for impact assessment and for the evaluation of policy options for stabilization, EPA ought to have in place its own mechanisms to assess the reliability of model information and the sensitivity of conclusions to uncertainties in model data and structure. Since model results involve substantial scientific uncertainty, it is important to estimate when effects ought to be observable, and to confirm them by direct observation as soon as possible.



### 3.3 Review of Chapter 19 - Preparation for Global Warming

We found this chapter to be very strong. It appears to have been written very carefully, with proper consideration of scientific uncertainties, and it raises a broad range of questions that cut across disciplines. Because of its focus on decision-making, it is an appropriate closing chapter. However, since it is preceded by a discussion of research needs (Chapter 18), the reader may see this as being somewhat similar. Chapter 18 becomes a shopping list for "scientific" research, while Chapter 19 provides a list for "policy" research.

In our review of Chapter 18, one complaint was that regional (or national) environment-economy linkages was not an explicit part of the research list. Many of the questions asked in Chapter 19 require consideration of these linkages. Otherwise, the "strategic assessments" use "old" economics to answer new questions. The chapter points out that cost and profitability may be important factors in decision-making, and that the cost of doing nothing may be greater than anticipatory action. But there are advantages and disadvantages to using benefit-cost, input-output, econometric or other methods in performing these assessments, and there has been no attempt in this chapter or Chapter 18 to identify and discuss these methods.

This chapter reflects the kind of "tone" in language towards which the rest of the report should move. Prolific use of examples in this section is useful in enhancing understanding. In addition, the notion of "de-centralized" decision-making relative to climate change planning is appropriate. We believe that the entire report should be carefully edited to be consistent with the message of this chapter.

## 4.0 REVIEW OF CHAPTERS 1 THROUGH 3

The material contained in Chapter 1 (Introduction) provides a brief description of the charge given by Congress to EPA, a description of the goals and scope of the Effects Report, a history of the process by which the report was produced, and a brief discussion of related national and international activities on the assessment of global climate change. This chapter was not specifically reviewed by the Subcommittee, other than to ensure consistency with other portions of the draft Effects Report. Our comments regarding the scope of the Effects Report have been given above in the Executive Summary.

### 4.1 Review of Chapter 2 - Global Climate Change

This chapter is a summary of scientific information about global climate change intended to provide the reader unfamiliar



with this subject with sufficient technical background for the remaining chapters of the Effects Report. The Subcommittee found the chapter to be in need of substantial rewriting, both for the expository style and to correct specific technical problems. The chapter contains material that is misleading or technically inaccurate, and the specific problems have been described in the Subcommittee's earlier comments to EPA. The chapter needs to communicate key elements of the scientific information about global climate change in a journalistic style that sets forth clearly and simply the major scientific data and areas of uncertainty. The following are key points that should be emphasized:

a) Trace gas concentrations are increasing, and they are now above previous historical maxima.

b) These gases are infra-red active, so that they perturb the radiative balance of the atmosphere.

c) There is evidence suggesting an increase in atmospheric temperatures, but the magnitude of the increase is uncertain, and the observed pattern of changes over time to date differs from the model predictions. Sea surface temperatures are not fully consistent with the air temperatures.

d) Knowledge about key climate feedback processes, such as the role of clouds and the exchange of energy and gases between the atmosphere and the oceans, is quite limited.

e) The general circulation models (GCMs) are limited in their ability to predict regional climate and climate changes.

f) The fact that we cannot accurately predict the magnitude and rate of climate change is cause for concern.

#### 4.2 Review of Chapter 3 - Methodology

This chapter describes the GCM runs that were used by EPA. The model calculations should be viewed as highly uncertain, since, as EPA notes, the models do not adequately incorporate the role of oceans in controlling global climate, or the role of clouds in modifying regional climate changes. The chapter does a good job of placing GCM results in their proper context, including most of the necessary caveats. However, the rationale for using the three GCM outputs should be better articulated. It is essential that the chapter not try to defend the ability of GCM's to predict regional climate changes. While the GCM's are mathematically consistent, they may not represent a true climate consistency. EPA should show that they recognize that the range of climate changes predicted by the models may not encompass the actual changes that may occur.

Some added discussion concerning general circulation model verification would be useful. This involves availability of data and the development of strategies to reconcile, tune, and validate the models. Description of the assumptions used in the three major GCM's is lacking, and the report does not include specific outputs from these models. This information is needed to help readers to assess the validity of many of the conclusions in the Effects Report, which are based on results from the GCMs. In addition, the methodology discussion is confusing, because it is not clear if the same GCM runs were used for all the assessments. If not, the scenarios need to be clearly stated for each assessment area.

Although the EPA authors note that the coarse grid resolution of the GCMs makes their application to state-level effects analyses problematic, the limitations of the poor spatial scale of the GCM's should be acknowledged and discussed in more detail. The chapter should also discuss the specific limitations of the transient model. The GISS Case A and B scenarios should have more discussion in light of the Montreal protocol. In addition, more discussion using the 1950-1980 30-year record of variability is needed. The sensitivity of the results to this particular period is a key point for the discussion.

## 5.0 REVIEW OF NATIONAL CHAPTERS

### 5.1 Review of Chapter 8: Water Resources

This chapter is viewed by the Subcommittee as a solid effort, requiring only modest revision. The discussion is policy oriented, focusing on economic and legislative aspects of United States water resources management and how these might have to change in response to climate change. The list of research needs reflects this orientation; these research needs are reasonable if one is not concerned about specific scenarios of climate change. The change in seasonality needs greater emphasis. The background material is authoritative; the key role of temperature increase is essentially independent of scenarios; the range of studies commissioned and used is adequate; and the treatment of impacts and their policy implications is also satisfactory. There is enough material in this chapter to provide ample food for thought to policy researchers and analysts, as well as Federal, State, and local government agencies concerned with water resources.

We note that there are no recommendations regarding hydrologic and water resources modeling. This could be misinterpreted that we know all the answers on issues such as climate/water demand relationships, effects of CO<sub>2</sub> enrichment on plant water use, or projections of runoff for specific watersheds that have not been done in this work (e.g., Great Plains and Tennessee Valley Authority (TVA) basins). Overall, caveats should be added to avoid the possibility of such misinterpretation.

We concur with the recommendation to integrate drought planning into water resource management (page 8-30). Water resource impacts, particularly groundwater, may be the largest potential cumulative problem in climate warming for North America. A means of prioritizing this and other potential effects for possible severity and human or biological resource impact would be useful.

## 5.2 Review of Chapter 9 - Sea Level Rise

The chapter provides a good summary of today's knowledge and experience. It covers a wide spectrum of effects in a very competent series of analyses, including discussions of limits and constraints. The authors clearly describe the scenarios used and the application of the scenarios is consistent. The discussion includes analysis of possible responses and potential conflicts, particularly coastal protection vs. wetland loss. Research needs are not restricted to the technical aspects of coastal erosion, but also include modeling and monitoring of climate change.

The effect of increased sea levels on bars, beaches and wetlands is comprehensively dealt with, except for the almost unpredictable action of waves on beaches. We have much experience from hurricanes as to the capriciousness of wave action. During El Nino there was a twenty centimeter rise in the ocean level at La Jolla, California; data from such episodes of sea level change could give clues as to the reality of predicted effects. Recent analyses by Bassett and others indicate that in some areas an increase in ocean temperature was not accompanied by a corresponding rise in height.

The policy analyses in this chapter are weak and do not make a significant contribution. We recommend these sections be strengthened or deleted. The financial figures for protecting developed coastal areas against sea level rise are impressive, but the expenditures suggested are spread over 100 years. On an annual basis, the rate of expenditure is estimated to be approximately a billion dollars per year. Compared to the amount already being spent on coastal stabilization each year, that figure is not large. However, the central point is that leadership, education, and coordination are needed to manage these financial expenditures wisely.

## 5.3 Review of Chapter 10 - Agriculture

The chapter presents an excellent summary of the sensitivity of agriculture to changes in climate. The objectives and the limitation of the studies undertaken by the EPA on agriculture are clearly stated. The discussion of potential direct CO<sub>2</sub> effects on crop yields is very good. The methodology and limitations of the

regional and national studies are well defined, and the results and implications are quite explicit.

The chapter on agriculture includes a range of studies, not only of the effects of climate change and of increasing atmospheric CO<sub>2</sub> on crop yields, but also of possible changes in cropping patterns that may result from farmers responding to the differential pattern of yield changes and the land use shifts that may flow from these yield changes. In addition, consideration is given to possible changes in irrigation requirements, infrastructure changes in the agricultural sector, the adoption of new agricultural technologies and management systems, effects on pests and diseases, possible changes in pesticide and fertilizer use, and the implications of these for the ecology of the farmed areas. In addition, the authors point out implications for the price of agricultural products both in the United States and overseas. They emphasize that changes in productive potential in competing food-producing areas outside the United States will be important, both for agricultural exports and for domestic food prices. To expect a comprehensive and quantitative statement of all these possible effects is unrealistic but, overall, the authors have succeeded in presenting a balanced, partially quantified statement of the wide range of potential effects that may accrue both in the agricultural sector and in related ecological and economic regimes.

The results presented in the chapter should be balanced by three considerations that merit additional discussion:

a) The global nature of climate change - The chapter notes that agriculture will be affected globally. A stronger indication of the types of effects in other countries could be made. For example, warming may enhance the agricultural capabilities of the U.S.S.R. While the net effect of climate change on the rest of the world is uncertain, the global effects could overwhelm in importance the effects in the United States. A net negative effect on agriculture could improve the position of United States agriculture producers through enhanced exports, but adversely affect U.S. consumers through increases in global commodity prices.

b) Potential benefits - Unlike many environmental concerns where impacts are clearly adverse, climate change offers opportunities for benefits as well as costs. The chapter identifies potential benefits of CO<sub>2</sub>-induced climate change, such as CO<sub>2</sub> fertilization and longer growth seasons in northern areas. A focused effort to identify potential benefits of climate change would be a major contribution toward determining appropriate adjustment policies.

c) Timing - The element of timing is not treated directly in the agricultural study. When will a doubling occur? If warming occurs rapidly, will there be greater costs? Do the agricultural

costs of more than doubling rise linearly, or at an increasing rate?

In general, economic and policy implications and agricultural research needs are clearly set forth in this chapter. However, there are some significant omissions. Except for soil erosion, there is little discussion concerning the impact of climate change on the resource base. There is no mention of current soil degradation problems or the possibility that climate change might exacerbate these problems. Another significant omission concerns the potential implications of changes in population dynamics on the agricultural system, both in terms of increasing demand, and for pressures that will be put on the resource base to meet future population increases. Changes in population dynamics also have major implications for water use, water quality, and environmental impacts. Future studies involving climate change certainly should incorporate changes in population into the scenarios developed.

#### 5.4 Review of Chapter 11 - Forests

This chapter seems to be a reasonable, well-written summary of potential effects on forests. It appropriately stresses the uncertainties associated with our lack of knowledge about migration rates of plant species, mitigating effects of elevated CO<sub>2</sub>, possible changes in frequencies of fires and other disturbances, and unknown impacts on competition and how various stresses interact to determine forest community composition. The discussion is always in terms of "may" and "could", in recognition of the fact that we do not know how climate will change. The chapter repeatedly emphasizes the complexities and uncertainties involved in projecting effects on forests. It is clear that if the climate changed as much as the models predict, the effects on forests could be dramatic. The multiple implications for timber production, recreation, and environmental quality are objectively noted.

The conclusions in the chapter should be better supported. The chapter should state more explicitly what climate change scenarios were used. There is too much reliance on the unpublished reports by the EPA contractors, and the limitations in those contractor reports are not adequately presented. For example, the remarkable rapidity of forest changes in the Great Lakes region suggested by the forest modeling of Botkin et al. may be correct, but the timing fundamentally depends on the moisture-stress-induced mortality for adult tree species. This mortality is difficult to measure, and the sensitivity of the cited results to the mortality should be explicitly stated in the chapter. Similar caveats may apply to the conclusions on the rapidity of species changes in the southeastern and western forests, which also are indicated to have rapid species shifts from climate change. More supporting information from the technical studies should be included in the chapter.

## 5.5 Review of Chapter 12 - Biological Diversity

It is clear that the rates of change are central to understanding impacts. In this chapter, there isn't a sufficient attempt to place the findings into the general framework of how fast changes occur, as a result, this chapter is very mixed. Much of the discussion in the chapter is general, since there are few specific case studies to draw on, and therefore, few quantitative estimates of impacts are presented. Important problems have been identified, including management of reserves during climate change. Research needs include a number of fundamentals, such as identification of species and the influence of CO<sub>2</sub> enrichment.

Several specific findings that we wish to highlight are the following:

a) Varying definitions for "biological diversity" throughout the chapter lead to confusion. In some cases it is a narrow concept of species diversity, and in others it is the broad definition encompassing species diversity, genetic diversity, and ecosystem diversity. Usage of this term should be made uniform throughout, hopefully, utilizing the latter broad definition.

b) There is a misuse of the concept of adaptation. What is implied here is that species can adjust to change through dispersal, etc. Species are not changing their genetic constitution necessarily in order to do this. The term adaptation implies such a genetic adjustment.

c) It appears that only aquatic studies were conducted for this report (Table 12-1), when most of the discussion in the text concerns terrestrial areas. This balance needs correction.

Overall, the findings and the discussion of the value of biological diversity seem adequate. Section III, Components, provides clear definition and perspective. Section IV, Factors Influencing Diversity Response to Climate Change, tends to oversimplify the complexity and uncertainty and focuses primarily on "barriers" to response, which may not be the most important factor. Section V, Effects, and Section VI, National Policy, are adequate. In Section VII, Research Needs, the need for additional information on current diversity is emphasized. Other research goals seem less clear. Perhaps some mention to EPA's Ecoregion concept, and opportunities to use this strategy to predict changes in ecoregion boundaries from climate change, would be appropriate.

## 5.6 Review of Chapter 13 - Air Quality

This is a useful, generally well-written review of issues, particularly linkages between climate change and air quality (including acid rain) and implications for National Ambient Air

Quality Standards (NAAQS). Research needs include modeling and policy analysis. The chapter concludes that there is a likelihood of increases in concentrations, or number of exceedances of standards, for criteria air pollutants as a result of predicted climate change during the next several decades. The presumed climate change may result in increased occurrence of stagnation and clear-sky high-pressure systems, increased surface air temperatures, higher levels of ultraviolet (UV) light, and higher emissions of pollutants or precursors as energy demand goes up with temperature.

Regional modeling studies were carried out for central California and for the midwestern/southeastern United States, using a model of regional transport and photochemistry, RTM-III, and an assumed scenario of increased temperatures. Comparisons with runs using currently-observed temperatures showed an increase of up to 20% in maximum ozone levels in Central California. In the midwest/southwest region, the increase in the maximum ozone level was insignificant (4%). In both cases, the areas predicted to exceed national ozone standards increased substantially (nearly doubling and tripling, respectively). Some interpretation is provided of possible regulatory implications for these scenarios. For example, areas that just attain national ambient standards for ozone currently may find themselves exceeding the standards if temperatures increase.

Deposition of acidic gases and aerosols may be altered by climate change, but no calculations of the magnitude of these effects are reported in the chapter. Since the GCM parameterizations of the surface and boundary layer are crude at regional scales, few firm conclusions on these pollutants are possible at this time. Potential linkage of GCMs with regional models that contain details on air chemistry might be a useful research direction, to look not only at regional climate but also changes in ozone, acidic gases, and aerosols. Throughout this chapter there should be more detailed information on the basis of the calculations, and a discussion of uncertainty factors like increased cloudiness and increased daytime mixing height.

#### 5.7 Review of Chapter 14 - Human Health

This seems to be a reasonably comprehensive and clear analysis of the potential impacts of global warming on human health in the United States. The discussion is interesting, though very little is presented on cold weather illnesses (e.g. influenza). Winter will be very different in northern areas that now experience several months of snow. What will happen if northern winters become warmer (and wetter?) with rain replacing some or most of the snow? There are other potentially important omissions, and there is a need to be more specific in the use of certain terms to enhance the clarity of this chapter.



A major omission concerns the indirect impacts of global warming on the United States. The primary effects of global warming on human health will occur outside the United States in underdeveloped countries because of their inability to take adaptive or preventive measures. External health effects will have an impact on our country by means of our participation in international aid and relief programs and from the potential for introducing diseases into the United States through travel, immigration, and disease vectors. In fact, one of the potentially most serious consequences of global warming may be the escalation of international tensions as a result of diseases, flooding, or water and food shortages in other parts of the world. To ignore these indirect effects on the United States seems quite remiss, not only in the area of health effects, but in the other areas as well. We strongly urge that the international implications of global warming be included in this document where appropriate because they are likely to have important political, economic, and health consequences in our country.

A second omission is a consideration of possible increases in mortality from cataclysmic weather-related events, such as floods, tornados, cyclones, etc. If such events increase as a result of warming, their associated mortality will also increase. Perhaps this would represent a very small contribution to national mortality figures, but internationally, it could have serious consequences, which would affect the U.S. indirectly.

There is great imprecision in the description of weather-related illnesses. An increased effort should be made to specify the nature of particular relationships to weather. For instance, are weather-related summer deaths or illnesses due to increased average temperature, increased season length, increased frequency of high temperature extremes, increased humidity, or increased smog? There is also a lack of precision in the discussion of the various illnesses. The chapter should distinguish between increased incidence, morbidity, and mortality whenever possible.

More emphasis should be given to the idea that the groups at greatest health risk from global warming are the poor, the elderly, and infants. These are the persons least able to adapt to environmental changes, and hence they will bear the brunt of the effects on illness and mortality.

#### 5.8 Review of Chapter 15 - Urban Infrastructure

This chapter is well-written, and in some respects, one of the most important contributions in the report. The case studies on three United States cities provide a valuable set of insights on the impacts and potential adjustments by U.S. cities to climate change. These case studies indicate the need for planning, but viewed in the context of the massive expenditures on urban



infrastructure over a period of 50-100 years as this infrastructure is renewed, the incremental expenditures resulting from climate change appear very small.

The policy discussion is very useful, even though it is based on only a few case studies. More case studies of other U.S. cities are clearly needed. The challenge will be to encourage direct involvement by state and municipal agencies in research and planning efforts. So far, these efforts have been confined largely to federal agencies.

#### 5.9 Review of Chapter 16 - Electricity Demand

This chapter needs a qualitative discussion at the beginning that looks more broadly at potential impacts on the energy sector. The existing discussion is mainly centered on utilities, and it should briefly review the non-utility energy impacts and state the reasons for focusing on electric utilities. In reviewing utility impacts, more discussion is needed on loss of hydro, population shifts, cooling water loss, pumping for irrigation, pumping for coastline management, and other potential changes affecting utilities and energy producers.

The effect of planning for climate uncertainty should be noted. The conclusions regarding the need for additional generating capacity seem to imply that the only energy alternative is more fossil fuel power plants. The nuclear option is never mentioned.

The role of energy conservation could be discussed in more detail. Conservation is important as a stabilizing strategy, to be discussed at length in the next report, but in the context of demand projections it should be acknowledged. The magnitude of the impact of climate change in increasing electricity demand appears small relative to uncertainty in demand growth and in the replacement of existing capacity with new generating equipment over a 70 year period. However, at the regional level, climate change could have an important impact on the planning of electric utilities, so that the insights from this chapter are potentially important.

This chapter draws upon a very sparse literature base, but there is some good discussion particularly on utility operations and planning. As in Chapter 15, the policy challenge is to get direct participation by the utilities themselves in research activities. A start has been made in the Great Lakes region with Ontario Hydro and the New York Power Authority (see Proceedings, First U.S.-Canada Symposium on Impacts of Climate Change on the Great Lakes Basin, in press), the Tennessee Valley Authority (TVA), and the research underway at the Electric Power Research Institute (EPRI).

## 5.10 Review of Chapter 17 - Variability

The chapter begins with a summary stating that the two models chosen for the study (the NCAR spectral model, apparently in three or four variants; and the GISS grid-cell model) performed poorly in replicating observed variability in four study regions of the United States, hence no change in variability with a climate change could be reasonably assumed.

Discussion of the National Center for Atmospheric Research (NCAR) model describes several versions used, though it is not clear which was used for which study, nor why. Since the NCAR model is spectral, it ought to have been relatively easy to adjust the truncation to generate averages more closely matching the spatial scale of the GISS model runs. Instead, "grid cell" averages for smaller areas are produced, making comparisons between model results difficult. This is countered, however, by the NCAR study's choice of more closely-spaced ground stations to fit their small grid spacing; these stations appear more climatically consistent than those for the GISS study.

Model comparisons with current observations appear to show both models did better in simulating winter than summer observations. No quantitative data are presented on variability calculation for doubled CO<sub>2</sub> climate.

When intercomparing model results, it is important to find more objective tests than accuracy of matching current data. There is an important distinction to be made between tuning, calibration, and predictive capability. If a model does a better job in one grid cell, is it the one to use? Model validation is clearly a key ingredient. It must contain elements of data acquisition, as well as strategies to use the data to tune and validate the models. Verification will be especially difficult for higher order effects such as variability, or, worse yet, for estimating the frequency and magnitude of rare events like hurricanes.

Climate extremes - winds, rainfall, hurricanes, floods, droughts - are not defined in a consistent manner. Extreme temperatures are discussed briefly, with the focus on public health and agriculture. The public health discussion is also brief, with no information on mortality norms vs. increases, and how those vary with length vs. severity of temperature extremes. The agriculture discussion is slightly longer, but is limited to individual crop experiments or qualitative summaries. Climate variability modelling results are discussed in great detail, yet no information is provided on how variability is actually calculated.

This chapter makes a good attempt at discussing some of the problems of using climate statistics being generated by current GCM's. The basic finding that no change in variability is a reasonable assumption is not surprising. This is because of the

resolution of current models - 500m<sup>2</sup> or 4 by 8 degree latitudinal grid squares are simply too large to describe accurately the weather within. Many of the extreme features concerning severe storms cannot be accurately be reproduced at these scales. A major improvement in resolution is needed, which raises the question of the computer power necessary to do the job. A second point concerns the observational data being used to compare with the GCM results. It can be argued that the actual data are not representative of the area of concern, which leads one to ask which is correct; discussion of interstation differences in variability would be a useful addition to the chapter. There is no question that validating the results being generated by the GCMs should be a major research priority. However, we are not sure that the technology exists at the present time to do such validation adequately.

This chapter discusses the potential implications of changes in variability, clearly points out their importance, and indicates that forecasts of changes in variability will be very difficult to confirm. While the chapter describes the intercomparisons among models, the models now available have little relevance for assessment of changes in variability as causes of impacts from climate change. However, variability is a key issue that should stand out in the report; placing the discussion of variability at the end of the report downplays its importance. We suggest moving the discussion of variability closer to the front of the report, perhaps by incorporating it into Chapter 3, Methodology.

## 6.0 REVIEW OF THE REGIONAL CHAPTERS

### 6.1 Review of Chapter 4 - California

California is the most complex of the case studies, because of the range of issues involved for this heterogeneous state. While the case study has many commendable aspects, there are also many aspects in need of clarification and improvement.

California's current climate is highly variable, both spatially and temporally, suggesting a large influence of geographical features such as the Pacific Ocean and California's mountain ranges on its climate. These geographical influences are not included in GCM models with a grid scale resolution that is about the same size as the state. Instead, a single point estimate is used to describe a heterogeneous climate from the coast through Central Valley to the Sierras.

The GCM results indicating smaller snowpacks and faster snowmelt imply a potential for loss of water resources. Since the mountain rivers are heavily managed in California through an extensive networks of dams and irrigation channels, the logic supporting the authors' conclusions is not clear. Controlled

releases from California's dams has greatly reduced the effects of mountain floodwaters on lowland cities and agriculture. How adequate is California's water system under an altered climate for managing irrigation, carriage water, and flood control? This question deserves high priority in the future planning of California's water system. This case study raises the question without exploring it in depth.

Other examples of the need to consider management interactions concern the projections about wetlands in San Francisco Bay and ecosystems in sub-alpine lakes. It is not clear that the analysis accounts for the facts that the Bay is highly managed as a wetland system, and that algae production would not be managed in lakes that are heavily stocked seasonally with fish.

The limitations of the agricultural study methodologies for California are explicitly stated. Taking into account the uncertainties, the results of the agricultural studies and their implications are reasonable as presented. The chapter appropriately states that it is very uncertain how agricultural effects would be felt in California's economic and policy environment. Of the four case studies, California is the only one that is not directly comparable to the others. Additionally, the study by Dudek does not link well with the national study by Adams. However, this in no way detracts from the overall report; rather, it is further evidence to show the difference in agriculture setting and crops between regions.

Many other aspects of the California case study differ from the broader analysis and discussion in the national study chapters. The air pollution analysis is somewhat simplistic. It does not appear to account for meteorological variability in the national standard or for increase in mixing height ventilation with temperature. The support for the electrical demand estimates suffers from the heterogeneity and variability of California climates. The terrestrial vegetation study used an analogy that is different from the GCM scenarios, so it is difficult to compare its results with the other regional studies.

The extent of uncertainty in this chapter should not be underplayed, especially regarding the "definite" nature of some of the conclusions. The section on policy implications indicates clearly the kinds of concerns that planning bodies will have to deal with, starting in the very near future. If the Effects Report accomplishes nothing more than beginning the planning process, the EPA will have accomplished an important goal.

## 6.2 Review of Chapter 5 - Great Lakes

This chapter discusses impacts on lake levels and temperature, water quality, fisheries, forestry, agriculture, shoreline

infrastructure, energy demand, and United States shipping and recreation. There are some articles omitted from the literature review at the beginning of the chapter, which is unfortunate since the new research effort complements the existing literature on many issues (e.g. lake levels, shipping, etc.). Notwithstanding this omission, the discussion of effects, potential response, and conflicts is very good. Potential water-use and land-use conflicts are described, including possible expansion of agriculture into forest lands, shift in forest species with subsequent impacts on wood industries, and water management responses to declining lake levels. The "Findings" and "Climate-Sensitive Natural Resources..." sections occupying the first twelve pages are quite authoritatively written, and the studies undertaken seem to have been well chosen. In general, the material presented contains good balance between the "advantages" and "disadvantages" of climate change.

The sections related to agriculture are well done. The methodology, assumptions and limitations are clearly stated, and the results and implications are reasonable. The references to complementary work being done in Canada are useful and informative - a valuable addition to the work being undertaken in this study. The bottom line is that it is not clear whether crop yields will increase or decrease in this region. It really depends on direct CO<sub>2</sub> effects on crop growth and how hot and dry the summers get. The results suggest that there will be a shift in agricultural boundaries northward. The major question is whether the land resource base in this region, particularly, the more northerly areas, is capable of supporting this shift.

### 6.3 Review of Chapter 6 - Southeast

This is a reasonably well-written discussion, with good integration of topics. The impacts, which include technical, economic and legal factors which will influence future responses to climate change, have been described carefully. Of particular interest are the legal constraints on water management responses, the potential accelerated abandonment of agriculture should CO<sub>2</sub> enrichment be realized (as in Chapter 4, there needs to be more discussion about uncertainties related to direct effects of CO<sub>2</sub>), and the possibility that grassland would dominate the future landscape.

The agriculture portion of this chapter is well written; the methodology limitations are clearly defined, and the results and implications of the work presented are generally reasonable. However, the southeast regional assessment did not faithfully reflect the conclusions of the national studies. Most notably, the regional assessments gave much more credence than did the agriculture chapter to the possibility of very large mitigation of adverse effects from climate change on crop production by increased

productivity associated with CO<sub>2</sub> enrichment. The agriculture chapter correctly highlighted the lack of an extensive data base on this issue, especially at a level higher than simple laboratory studies on photosynthesis and water-use efficiency as a function of CO<sub>2</sub> enrichment. There are many reasons why the physiological-level responses would not be realized in the real world, such as interactions of CO<sub>2</sub> enrichment with elevated temperature, increased productivity of competing plants, limitations by nutrients and water (which, after all, are the limiting factors for terrestrial systems including agriculture, not carbon availability), and so on. These limitations are given insufficient attention in the regional case study chapter, and, indeed, scenarios of major offsetting of temperature effects or even increased crop yields are presented as if the CO<sub>2</sub> enrichment is as well-known as crop yield as a function of temperature and moisture. The difficulty is that how the CO<sub>2</sub> enrichment issue is treated determines the magnitude and even direction of effects, and subsequent economic and land-use analyses therefore can be quite misleading.

Potential impacts on forest systems in the Southeast with warming are potentially quite extraordinary. Instead of forest change, the potential exists for forest loss. With regard to the value of Southeast forest resources, and the tendency for forest industry to move toward intensive plantation culture (independent of climate change), the prospect of irrigated forest stands is real.

One drawback noted with this chapter is that the level of the discussion is often inconsistent, with excessive detail on a limited number of issues (e.g., water management issues on Lake Lanier and the Tennessee Valley Authority system) to the exclusion of more broadly applicable synthesis statements about the southeast as a region. Also, there seemed to be too much attention given to sea-level rise, without an appropriate balance given to other potentially serious problems for the region. If the intent of the chapter is to identify the vulnerabilities of environmental and human systems in the southeast to climate change, it did not adequately accomplish that objective. In addition, in the summary of findings there are 5 major conclusions related to agriculture including the possibility of major yield and acreage declines. There is no mention of the implications of these for policy and the economy. Finally, statements in a number of places not to take the results seriously detract considerably from the implications sections. The caveats should be written more carefully and consistently.

#### 6.4 Review of Chapter 7 - Great Plains

The discussion in the Great Plains regional case study focuses primarily on agriculture, and secondarily on water supply and quality, water resources management and energy demand. However,

this chapter needs to be made somewhat more substantive. The existence of a separate chapter on agriculture should not weaken this chapter to the point where it can not stand alone. There is a lack of differentiation between the Northern (particularly neglected), Central, and Southern Plains and between the opposing crop yield influences of CO<sub>2</sub> enrichment and heat/moisture stress.

The fact that the basis for the hypothesized growing season moisture stress is really only limited to the GFDL model (which has hydrological peculiarities) is not adequately stressed. A further key issue not fully addressed is the extent to which irrigation can provide (on economic grounds) a buffer against the suggested climate change (reduce moisture stress more than heat stress). The choice of dryland agriculture vs. irrigation will be a difficult one, given potentially more severe water supply problems in a future warmer climate and the uncertainties of results of CO<sub>2</sub> enrichment scenarios. The models used, assumptions and limitations concerning the agricultural studies are clearly stated. The results and implications stemming from the model studies are reasonable. The challenge may be to find a land and water resource management scheme that can adapt to a more arid regime without causing severe economic problems to the region's population.

The fact that the area is often "marginal" agriculturally means that climate-induced interannual variability can be high, as is indicated. But such variability is not as devastating in a national production sense as it would be for "core" agricultural states like Illinois and Iowa. This aspect needs further discussion.

The portion of the report labeled as dealing with energy should be relabeled as dealing with electricity, and the reasons for increasing electricity demand should be stated in the Findings section. Presumably heating demand for natural gas and oil would be reduced with milder winters. In addition, the report appeared to have somewhat inconsistent statements regarding water quality impacts. The Findings section indicated possible benefits to groundwater contamination due to less leaching. Overall, the chapter appears to rely on fate and transport results to determine groundwater impacts when the impacts will depend on total acres under production, application rates, soil type under cultivation, and changes in irrigated versus dryland acres.