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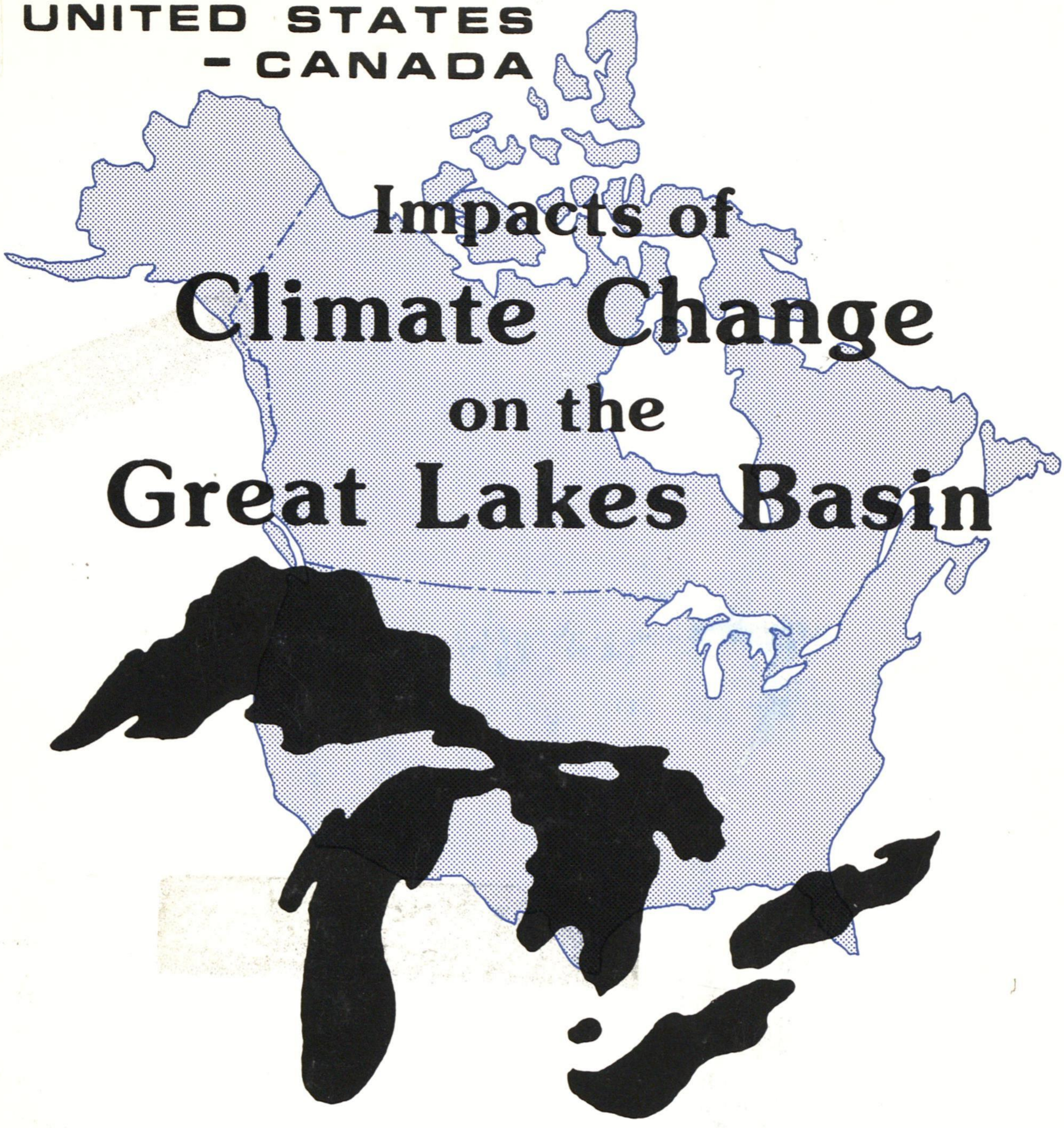
Impacts of Climate Change on the Great Lakes Basin



SYMPOSIUM 1988

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United States Environmental Protection Agency

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REPORT OF THE FIRST U.S.-CANADA SYMPOSIUM

ON

IMPACTS OF CLIMATE CHANGE ON THE GREAT LAKES BASIN

Joint Report No. 1 of the U.S. National Climate Program Office

and the Canadian Climate Centre

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Symposium Conducted on September 27-29, 1988, at Oak Brook, IL

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PREFACE

Given the high probability that climate change leading to a rise of global mean temperature greater than any in man's history will occur within the next few decades, the governments of the United States and Canada organized a symposium to bring together representatives from commerce, academia, urban and social planning, recreation, agriculture and forestry, and energy and transportation to address the implications of climate change on the socio-economic fabric of human activities in the Great Lakes Basin. The symposium was designed to examine both man-induced and natural climate change, and to inform decision makers of potential impacts and management issues likely to evolve over the next few decades due to climate change in the Great Lakes Basin.

The symposium on "Impacts of Climate Change on the Great Lakes Basin" was sponsored by the National Climate Program Office (NOAA), the Canadian Climate Centre (AES), the Office of Strategic Studies (EPA), and the Midwestern Regional Climate Center at the Illinois State Water Survey. This meeting was held September 27-29, 1988, at the Hyatt Regency Hotel, Oak Brook, Illinois, with the Midwestern Regional Climate Center serving as local hosts and co-arrangers of the symposium. Scientists, planners, and decision makers numbering 120 came by invitation to exchange information on potential impacts and management issues likely to develop over the next few decades due to climate change.

The symposium was structured with two morning sessions of U.S. and Canadian speakers who addressed various climate change issues such as the greenhouse gases, global climate response, impacts of climate change to man and the environment, and projections for future climate in the Great Lakes Basin. Four panels were convened in the afternoon sessions emphasizing climate impacts as they relate to energy and transportation; recreation, conservation, and wetlands; municipal water supply, lake pollution and lake levels; and agriculture, urban land use, and forest management. Each panel was chaired by an expert and several invited papers were presented by panelists at the beginning of the panel discussions. A rapporteur in each group summarized the panel discussion and presented the panel's issues, concerns, and recommendations for action at the final session of the symposium.

The symposium concluded that there is a high likelihood of a major climatic change in the Great Lakes Basin, and recommended that the U.S. and Canada establish a joint planning group to develop an integrated study of the Great Lakes Basin as a regional pilot project.

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Symposium Summary

Stanley A. Changnon*

There is a high likelihood of a dramatic climate change in the Great Lakes Basin and elsewhere due to the "greenhouse effect" during the next 50 years. How it may affect society and the environment was assessed by 120 persons from diverse public and private interests in the basin during a 3-day symposium structured to identify key issues and to define recommendations for action.

The Issue

In recent years there has been mounting evidence that the ever-increasing emissions of carbon dioxide and other trace gases into the atmosphere have begun to influence the world's climate. Atmospheric scientists, aided by large computers able to handle global climate models, utilized various estimates of the growth of these trace gases to analyze the greenhouse effects on global climate over the next 70 years. All model outlooks agreed: Relatively rapid changes will likely occur in global climatic conditions, including temperature increases beyond anything in recorded history. Although global climate models have a relatively coarse grid resolution for areas the size of the Great Lakes, their outputs estimate sizable increases in temperature as well as changes in other hydrometeorological conditions across the Great Lakes Basin.

Government policy makers in the United States and Canada, along with representatives of other nations and international groups, began serious consideration of the evolving problem in the 1980's. Scientific consensus has developed around the concept that global warming due to the greenhouse effect is extremely likely.

In 1985, the heads of the U.S. and Canadian climate programs began a dialogue about how this issue would affect North America. They decided that scientists and policy makers from the two countries should become better informed, and they conceived a series of symposia to discuss, consider, and plan for the actions and research needed in both countries to address impending climate change. Immediate concern arose over the regional effects on the Great Lakes Basin, a jointly shared resource of the two nations.

The Great Lakes contain 20 percent of the world's freshwater supply. The basin is home to millions of Canadian and U.S. citizens and is the heartland of industry and commerce of both nations. The economic and environmental importance of the basin and its great sensitivity to climate fluctuations are clear. The potential impacts of climate change on the region's environment and socio-economic fabric are serious and complex.

These considerations led to a decision to focus the first of a series of climate change symposia on the Impacts of Climate Change on the Great Lakes Basin.

The Symposium

The first symposium was held in the Chicago area on September 27-29, 1988. A select audience of 120 persons representing a wide variety of climate-sensitive interests attended the three-day symposium. Attendees came from municipal, state, provincial, and federal government agencies and universities concerned with natural hazards, agriculture, water resources, climate, transportation, conservation, natural resources, and policy. Private sector representatives were from the transportation industry, electrical utilities, business and commerce, news media, and agriculture.

***Midwestern Climate Center, Illinois State Water Survey.**

The primary objectives of the symposium were to define 1) the dimensions of the potential impacts of future climate change on the Great Lakes, and 2) the joint research needs for the two nations. These objectives were approached in a synergistic fashion.

First, the symposium provided, through a series of eight strategic background papers, information about the climate change issue and the current state of knowledge about climate impacts in the region. Eight experts presented background papers to "set the stage" for the deliberations of the attendees. The papers touched on five major topical areas:

1. Historical fluctuations in the Great Lakes Basin climate
2. What is known and unknown about future climatic conditions in the basin based on results from the global general circulation models
3. The degree of knowledge about the impacts of climate on the biosphere and, in turn, on the socio-economic fabric of the basin
4. The existing regulatory and policy framework and economic mechanisms that affect responses to transboundary problems in the basin
5. Difficulties in estimating future changes in society, with or without climate change in the Great Lakes Basin

These talks brought forth questions and discussions that clarified the broader issues and provided attendees with a comprehensive background.

Following the background papers, the attendees convened in four panels—agriculture, urban land use, and forestry interests; water resources; conservation and environmental concerns; and transportation and energy interests. Selected invited talks were given to each panel about climate impacts specific to the particular sector. Panel discussions then focused on 1) identification of key issues and 2) selection of recommendations.

After two half-day sessions, the panels identified 30 diverse issues, most of which can be grouped under the following four major topics.

1. ***Considerable uncertainty exists about the potential future physical and socio-economic impacts, responses, and adjustments to sizable climatic change.*** This uncertainty derives from a recognized lack of specific knowledge about how individual portions of the physical environment and society would react, their sensitivities to atmospheric conditions, the lack of techniques for performing analysis of complex interrelated responses to changes, and the role of external effects due to climate and social changes outside the Great Lakes Basin.
2. ***Better climate modeling information is needed.*** Current weaknesses relate to general uncertainties over future climatic conditions, the role of the oceans, the rate of climatic change, and the limited, as yet, time and space estimates of conditions for the Great Lakes Basin.
3. ***Existing planning bodies and policy and regulatory entities are inadequate to address the problems of basinwide climatic change.*** Current environmental and resource management regulations are seen as inadequate, and current governmental approaches to policy making will be inappropriate.
4. ***Several conflicts could develop during rapid and sizable climatic change.*** These include water versus land transportation modes in the basin and differences in U.S. and Canadian policies on management of the Great Lakes, including diversions, and on use and management of natural resources, including land and water.

Synthesis and Summary

The symposium ended with a half-day devoted to reports from the four panels, each followed by group discussion. Next, Alan Hecht, Director of the U.S. National Climate Program Office, presented a synthesis. A group discussion ensued and a series of recommendations and a plan of action evolved that the attendees supported. Key points from this group synthesis follow.

Summary. Despite uncertainty about timing and magnitude, there is a high probability of a major global climatic change due to the effects of carbon dioxide and other trace gases that will affect the Great Lakes Basin during the next 20 to 70 years.

On the basis of historical records and the prospect of a future climatic change, public and private decision makers can expect to face a wide range of major environmental, economic, and other policy issues.

Present understanding of the Great Lakes ecosystem is inadequate as a basis for effective long-term management of the Great Lakes system, regardless of climatic change. The issue of climatic change, however, adds great emphasis to the immediate need for anticipatory planning and action.

Specific Recommendations (with selected examples)

1. *Enhance atmospheric research.* Study of the past and present climatic conditions in the Great Lakes Basin should be augmented, with increased emphasis on refining global climate models to yield more specific outlooks of future climatic change in the basin. More definitive studies are needed by atmospheric scientists concerning the dimensions of future conditions.
2. *Conduct research on climate impacts and responses.* Research is needed about the physical and socio-economic impacts and responses to climate, both for present and future conditions. These studies should include developing better baseline information, defining the many sensitivities to specific atmospheric conditions, establishing joint U.S.-Canada interdisciplinary research activities, identifying wilderness areas, and developing quantitative models to estimate the ecologic, economic, and hydrologic impacts.
3. *Develop data bases and information systems.* There is a need for better, more integrated data bases for ecological, hydrological, climatic, and economic monitoring and studies; directories for these data; and near real-time climate and hydrologic information systems for more rapid response to climatic fluctuations and their impacts.
4. *Study how to cope.* Several recommendations related to the study of means to cope with climatic change. Specifically, these would focus on conservation and better management of resources; adaptation, such as through development of improved crop varieties; shifts in energy policies; and ecological reserves.
5. *Plan and assess policies.* Assessments are needed of public and private planning efforts and of current policies to address climatic change. Recommendations emphasized development of strategies for dealing with future change and plans for conflict resolution. Other recommendations related to the need for modifications of current environmental and management regulations; the development of U.S.-Canadian agreements on long-term goals for water use; adaptive management of parks and natural areas, including wetlands; and the need to tie policy programs to external events, including international efforts to address climatic change. It was also recognized that the legal framework relating to water laws would need to undergo change and that the study and assessment of water law would be essential.

6. ***Communicate and educate.*** The diversity of climate change impacts requires better and continually updated information about climatic variation in the Great Lakes Basin and its consequences. The recommendations focused on the need to know more, both in the special-interest and highly impacted sectors, as well as among the general public, where decisions about new policies and regulations eventually will be resolved. These efforts should focus on the concept that the basin is an ecosystem with air, water and land linkages with the global environment and economy.

Plan of Action. The broad and challenging extent of the above recommendations for studies, assessments, research, and changes in various public and private activities led attendees to recommend development of a plan of action that recognized 1) the needs of the Great Lakes Basin communities and 2) the evolving international concerns over climatic change.

The United States and Canada share joint management of the Great Lakes. Attendees agreed that although future climate is uncertain, ***now is the time to translate past experience into future programs aimed at ensuring availability of the widest possible management options for current and future planners based on application of the broadest scientific knowledge.***

To this end, the conferees strongly recommended two actions:

A. ***Develop a U.S.-Canada integrated study of the Great Lakes Basin as a regional pilot project for an international response to global climatic change.***

B. ***Establish a joint planning group to organize and develop the pilot project. The recommended activity should be integrated with and built upon two major on-going basin efforts, the Remedial Action Plan (RAP) program for the areas of concern in water quality, and the ongoing International Joint Commission (IJC) Lake Levels Reference Study. Both of these programs contain activities and elements that should be considered in the planning and development of the recommended global change pilot project.***

Luncheon Address

Tuesday, September 27, 1988

William Evans*

I am really very pleased to be able to contribute to this meeting, the first U.S.-Canada symposium jointly organized by the two national climate program offices. No topic may be more important to the world in the next decade than climate change and its potential impact on society.

And we just had a summer that gave us a very good taste of what some of the impact might be. The events during the past summer underscore the important potential impacts that future climate changes may have on the economic and social well-being of society. The extensive drought in the midwestern United States and western Canada may not be outside the normal range of climate variation for that region. But should climate change produce events like this on a frequent basis, we see a hint of what the real consequences could be.

As an example of something that doesn't have anything to do with climate at all but has to do with economics, I was called by the Federal Exchange Commission during the drought, and was asked whether or not NOAA would embargo the six- to ten-day weather forecast. And I said, "Certainly, if you feel that's necessary." They said, "Well, your six- to ten-day weather forecasts are driving the commodities market in Chicago up and down like a yo-yo."

And indeed, we did embargo that information. And we also embargoed the 30-day outlooks. That was a direct effect of what was being thought to be potentially an economic effect of a climate condition. It's pure economics. So, when we look at some of the things that you're discussing, I would like to ask that, if you get nothing else out of the comments I make today, you at least look at these problems on a much broader scale than perhaps has been done in the past. Then maybe I have contributed something to the meeting.

While, on the whole, the United States will not suffer any major damage due to the drought, there will be specific economic sectors, occupations, and regions of the country that will be greatly affected. It may be two or three years before we know what its total impact was.

The obvious and not so obvious linkages of climate and economics illustrate the importance of our understanding of how climate effects are transmitted throughout society. Most of the immediate attention on the recent drought naturally focuses on crop losses. Yet the full measure of the impact of this climate event will only be known after we measure the impacts as they ripple through the United States and international economies.

I had the pleasure of accompanying the Secretary of Agriculture, Dick Lyng, on a two-day swing through ten states that were affected by the drought. One of the things that we found out was there is an adverse effect on fisheries and wildlife. In fact, when we were near the Missouri River, one of the farmers was saying that it was so dry in that area that they were spraying the catfish for ticks.

***Undersecretary, Department of Commerce, and Administrator, National Oceanic and Atmospheric Administration**

I think there is another lesson from this summer's drought that this conference addresses, and that is the impact of climate change on the Great Lakes. Now, a lot of you will say it's very nice for somebody from Washington, D.C., and originally from California, to come back and talk to you about policy on the Great Lakes. I have a personal tie here. I was born in Elkhart,Indiana, which is not very far from here. My whole family, for years, was influenced by what happened on the Great Lakes. I was raised in Ashtabula, Ohio. I worked on the Great Lakes. I learned about my first interest in biology on the Great Lakes.

I feel very close to the problems and the things that have an effect on the Great Lakes. And when I listen to the things that are being said about what's going to happen in the future to the Great Lakes Basin, I recognize my personal interest in it. I have a family here. And they will continue to be here. They have been here for five generations, and hopefully will be for a number more. Maybe long enough to see some of those changes that were talked about this morning.

There was widespread publicity in the media that the drought in the midwestern United States may be the first sign of a changing of the climate due to greenhouse warming. Even more recently scientists have suggested that the extensive flooding in Bangladesh and even the severe hurricanes in the Gulf of Mexico may be linked with global climate change. I think the record must be made very clear that such linkages are premature in the judgment of the majority of the scientists working on this problem.

The United States National Climate Program Office recently convened a conference in Washington to analyze data for evidence of man-induced climate trends. The feelings of the scientists in this group representing the United States, England, and the Soviet Union were quite clear. Current trends in global temperatures and current drought cannot be easily linked to global warming due to greenhouse gases. However, this in no way undermines the importance of potential serious effects of greenhouse gases. The greenhouse theory is very robust. The earth's temperatures will eventually rise as the concentration of trace gases increases. And global climate will change. Some regions will get wetter; others will get drier. As we heard this morning, this is a process that has been going on for at least 1300 centuries based on the records that we have, and maybe longer than that.

I don't know how many of you watch or read the funny papers, but I do. And I see B.C. once in a while. There are two little characters, maybe back 13,000 years ago. Can you imagine what the impact would have been if we would have had the same kind of media coverage back then that we have today? If they could have walked into a cave and picked up *Global* or *Neanderthal Today Magazine* and looked at it and read the headline, "Glacial melt due to global warming. Musk oxen moving north."

Now, this could have absolutely changed all of society as we know it today. And the reason I say that is, first, to try to be humorous, but secondly, to emphasize one of the points that was brought up by Dave Phillips. I think it's very important. That is, that global change and climate effects, greenhouse warming, and the attention that we are paying to it are really a function of the fact that we are in the communication age; the age of information. The public is repeatedly exposed to these concepts.

It's transmitted. We see it from satellites, and this has an effect on all of us, especially those of us who are scientists and those of us who are policy makers. And I think we need to keep that in mind, because sometimes with too much information, we may have a tendency to over-respond.

And I think that's something we need to guard against. The good side is that we have probably been able to save millions of dollars and tens of thousands of lives because we have timely communication.

So, we have a very serious task ahead of us. And that task is to be able to learn how to use all this new information and respond to it in a rational fashion but not over-respond to it. Over-response can cost lives and cost money, also.

We must better understand the natural variability of climate, and we must devote considerable energies to understanding the potential range of future climates and their impacts. And that goes into the area of prediction. The very importance of this subject requires that we exercise caution in making premature statements that the greenhouse warming is here today. However, neither can we ignore the growing evidence that the global climate will be changing in significant ways. A careful balance must be maintained between scientific credibility and policy action. Regardless of the causes of future climate change, we know enough about the past to expect that society faces stress due to climate variability. This means times of extreme high or low lake levels. This means periods of drought such as the 1930's, the 1950's, and the drought of this last summer, and periods of excessive rains such as the 1970's and the 1980's.

The major impact of future climate change relates to the degree to which this variability will be changed. Increased variability and/or increased frequency of extreme events will present serious problems to environmental managers at all levels of government and industry. The technical ability to deal with those problems is central to this meeting and is central to government and private sector strategies for the future.

Let me now take the above ideas and themes and apply them to the Great Lakes. The Great Lakes are a shared natural resource of the United States and Canada. And that's what makes this a very important meeting. They are the largest system of fresh surface water on the earth, containing roughly 20 percent of the world's supply and 95 percent of the United States' supply. The Great Lakes Basin represents less than three percent of the entire surface area of North America, yet, one-seventh of the entire North American population lives within the Great Lakes Basin. One-quarter of the United States and three-fifths of the Canadian annual gross national product are attributed to activities on and around the Great Lakes.

The effects of climate change in this region can thus have major national and international consequences. As you know, many agencies and international organizations have responsibilities related to the Great Lakes Basin. Regulatory control of the lakes rests with the International Joint Commission (IJC) established in 1909 by the Boundary Waters Treaty between Canada and the United States. The United States Environmental Protection Agency (EPA) has the lead responsibility for meeting the obligations of the United States under the Great Lakes Agreement on Water Quality.

I would like to acknowledge their support for the organization and financing of this conference, because I think this conference may be the very beginning of a series of conferences which will have a lasting impact on what happens, not only in terms of our ability to be able to understand the resources in the Great Lakes but also in our ability to deal with them and our relationships with our neighbors to the north.

NOAA has broad responsibilities that deal directly with the meteorology and climatology of the lake. The Great Lakes Environmental Research Lab (GLERL) constitutes the largest United States research presence on the Great Lakes. The Great Lakes Environmental

Research Lab was established by NOAA in 1974 in Ann Arbor, Michigan. Its missions of physical, chemical, and biological research have far reaching importance for all industries and citizens that depend on the Great Lakes.

For example, the large basin runoff model, developed at this laboratory, gives us physical data obtained by NOAA's National Weather Service and Canada's Atmospheric Environment Service to predict the volume of weekly to monthly basin runoff. The precipitation and hydrological runoff data in turn are incorporated into the laboratories' hydrologic response model, which is then used to calculate the water balance levels and lake levels and flows through the entire Great Lakes system. This vital information is used by a wide variety of interests representing government, regulatory agencies, and industrial and commercial enterprises such as lake shipping and hydroelectric power plants. Water quality and sediment studies conducted by our GLERL provide valuable information required for the management of the ecology of the region. I can cite many other examples that reflect NOAA's long-term presence in the Great Lakes.

The Great Lakes Basin, its people and its commerce, is a microcosm of society as a whole. This basin, jointly managed by two countries, is a unique natural resource and vital to the economies of both our countries. It must be used wisely and protected. What happens here in the future due to climate change will have enormous impacts on both the United States and Canada.

What can we do to increase our capability to understand this system and manage it wisely in a changing world?

First, we must document the natural changes that have occurred in this region. We must understand the interactions of climate with hydrology and biology. We must maintain a strong research effort to baseline the natural change against which man-induced changes can be measured, the new modernization and use of equipment that we are going to have in our weather service as the next generation of radar, Alpha radars, and programs which would provide us with better estimates of precipitation.

Second, we must encourage greater understanding of how climate affects society. The field of climate impact analysis or applied climatology has not been in the headlines much, but it is a vital part of the understanding of climate change. Through the National Climate Program in the United States we are encouraging a renewed effort in this area. In the long run we need to better understand the resilience of our natural resources, natural systems, and our management systems for the Great Lakes and for other areas. We need to estimate how likely these systems are to be stressed by climate change.

Third, we need to improve our understanding of climate change. The National Climate Program in the United States, the International World Climate Program (WCP) of the World Meteorological Organization (WMO), and the emerging program of global change all contribute to the better understanding of what future climates are likely to be. Increased emphasis on climate research is a major priority for NOAA.

For example, the GLERL has developed models for simulating moisture storage and runoff from the 121 subbasins draining into the Great Lakes for calculating over-lake precipitation into each of the Great Lakes and for measuring heat storage and evaporation from each of the lakes. Each of these components is modeled separately and then used in conjunction with operational models to estimate water level. The integration of these models with global circulation models allows first-order estimates of the impacts of climate change over the total hydrologic system of the lakes. As we better document the ability of these models to predict current conditions, we will increase our confidence in their use for future projections of climate change.

The international community has begun a discussion of how best to deal with climate change. In November [1988], delegates from 30 countries from around the world will meet in Geneva under the auspices of WMO and UNEP, to organize an intergovernmental panel on climate change. This panel will discuss how best to improve our understanding of climate change and how best to prepare to respond to climate change on a global level. The United States will be an active participant in this panel. Of all the challenges that we face today, the challenge of understanding the earth, protecting its natural systems, and predicting future changes seems to me to be one of the greatest. It's a challenge that we cannot afford to ignore, and I use the word afford in an economic sense. These are times of fiscal constraint for many countries, including the United States. Changes in global climate could cause economic problems that we cannot afford to ignore. We need to address them now.

Thank you very much.

Luncheon Address

Wednesday, September 28, 1988

H. L. Ferguson*

Good afternoon ladies and gentlemen. The first thing I would like to do is to thank the organizers of this symposium for inviting me to participate in what has been a really interesting event.

And secondly,I want to chastise them for selecting such excellent speakers for the first day and a half, in that much of what I was going to say today has already been said rather forcibly by some excellent communicators.

What I would like to do today is to share with you my thoughts on three of the questions that seem to pop up most frequently when I discuss the matter of climate change and related issues with the Minister of the Environment, my boss. I think the same kinds of questions are being asked rather broadly by leading decision makers in the United States and other countries.

I will also be referring to the recent Toronto Conference on The Changing Atmosphere. And I will be flavoring my remarks with some observations concerning the climate change impact on the Great Lakes.

The three questions that I would like to talk about are as follows: Number 1, can I believe the scientists? And I think all decision makers have a certain amount of mistrust, if you like, of scientists, particularly when they talk about having to do more research. It looks as though we are feathering our own nests a little bit.

The second question that a decision maker might ask is: If I do believe the scientists, are there any actions which need to be taken now other than supporting more climate research on the greenhouse gas problem?

The third question might be: If they are so inclined, what can individuals, international agencies, and governments do to help minimize the adverse impacts of greenhouse warming?

With respect to the first question, "Can we believe the scientists?", I find that elected officials and the media are constantly reminding me that a decade or two ago many reputable scientists were warning everyone about the impending ice age.

I find it's not easy to explain to nonscientists that the climate warming scenario is a great deal more imminent, has a much steeper trend line, has stimulated a much broader scientist consensus, and is altogether more threatening in terms of potential socio-economic impacts. But I believe that to be the case.

Of course, there will always be uncertainty in our understanding and modelling of the complexities of the global atmosphere. And I must admit that I take a kind of perverse comfort in that, because if it were not the case, weather forecasters would be out of business.

General circulation models dealing with climate change, like numerical weather prediction models, are still very far from perfect. And that is particularly true in their ability to simulate current or future climates on the local scale. It's also true that given the

***Assistant Deputy Minister, Atmospheric Environment Service, Environment Canada**

magnitude and complexity of our global environment, the media will continue to have little difficulty in finding scientists who reject a strong scientific consensus among their peers.

However, I have noticed that the media's natural preference for a balancing act seems to be giving way now to a recognition of the scientific consensus, and this is changing the public and political perceptions as well.

Of course, we are all aware of the importance of scientific uncertainty. It's also true that all kinds of policy decisions are made, and have to be made, in the face of significant uncertainties, especially in the case of possible serious impacts on the public well-being.

And as several speakers have noted, what we are dealing with here is really risk analysis and risk management. Scientific expertise is much more sophisticated and broader based today than it was in the time of Copernicus. Nevertheless, we must continue to narrow the scientific knowledge gaps, and scientists today are required to establish a great deal more credibility than Galileo had in his day. And, for that matter, I understand there are still a few diehard members of the Flat Earth Society!

A strong consensus on Great Lakes warming emerged in the international scientific meeting which I attended in Villach in 1985 and which Dennis Tirpak and Michael MacCracken referred to yesterday. The consensus was reaffirmed at another international meeting in Austria in September of last year and at a subsequent meeting held in Bellagio, Italy, both sponsored by the Beijer Institute. There have been several other recent international conferences where it has been clear that the overall opinion of world class scientists continues to grow on the side of unprecedented greenhouse warming of the globe. I use the word unprecedented advisedly.

In one of his slides yesterday, David Phillips showed us that significant warming took place over the Great Lakes Basin in the period between 14,000 years ago to 5,000 years ago. But that change of up to 13°C during that time period represented a rate of warming that is approximately one to two orders of magnitude less than the rate that is predicted with an enhanced greenhouse effect. And it took place even before the National Weather Service and the Atmospheric Environment Service were there to record the temperature readings!

The predicted warming will, in effect, take our society outside the range of its climatic experience. Reliance on the technological fix and society's adaptability, those factors which have served us so well in North America in the past, may in this case be looking at the greenhouse world through rose colored glasses.

Many experts believe that there is sufficient scientific evidence to take other actions, actions which may be more expensive and politically contentious than simply an enhanced research program.

The actions I am referring to would include a new approach to national and local decisions associated with major investments, such as coastal public works and hydroelectric power projects (including both capital projects and supply planning which Ken Hare referred to yesterday), and the possible adjustment of building construction standards.

These major investments involve billions of dollars in North America and structures supposedly designed to function effectively for several decades. It's time we put more effort into a risk management approach to the use of the essential climatic, and other environmental, data used by mega-project engineers. As taxpayers, we should require this kind of wisdom and accountability in the expenditure of public funds.

The Bellagio meeting recommended, as a matter of urgency, the development of socio-economic policy options pertaining to energy development and other major factors of the national economies. That meeting also came to the conclusion that the degree and rate of climatic warming anticipated would cause adverse impacts which would certainly outweigh positive impacts on the global scale and that, in fact, most countries would experience net adverse impacts.

They also found no evidence that the man-induced greenhouse warming would not continue indefinitely in the absence of action to control emissions. Therefore, adaptation to the climate warming, while necessary, would not be a sufficient response in the longer term. Eventually the heating effects would also be so harmful that only limitations on the emissions of greenhouse gases would be able to resolve the problem.

If this is indeed the case, the question of stopping global greenhouse warming through emission reductions is then one of timing. We know that such reductions may take a long time to implement and an even longer time to affect the warming trend. And the experts tell us that if we don't ante up now, the cost of paying up later will be much higher.

It seems likely we have already committed the globe to one or two degrees Celsius of temperature increase over the next two or three decades, even if we were able to start action today on controlling greenhouse gas emissions.

In Canada, the public has expressed concerns that will not be satisfied by a one-dimensional, narrow, "more research" approach. To paraphrase a comment by Harlan Cleveland at the Toronto conference, we are adults, we can and should be doing several things concurrently and not waiting several years for more research results before considering socio-economic impact scenarios and policy options. We can take actions now on incorporating our current scientific understanding and risk assessment in long-term economic planning and decision making. We should be working now on precautionary strategies and options for adapting to the probable climate warming and limiting the buildup of greenhouse gases.

In Canada, we have made a start in publishing several sectoral studies on possible socio-economic impacts of climate warming. I'm sure that the authors of those reports would be the first to acknowledge that they are simplistic and barely scratch the surface of what needs to be done.

In examining possible impacts on agriculture in the Great Lakes Basin, for example, the climate change impact on other competitive crop regions of the world would have to be examined, as well as the subsidies, tariffs, and other factors affecting international food markets and trade.

The third question that I promised to address involves the responses of countries, international organizations, and individuals. It's clear that those countries with the greatest industrial capacity must be leaders in the global effort required to deal with the greenhouse gas problem.

For example, the Soviet Union and the United States are said to consume over 40 percent of the current global utilization of fossil fuels. Obviously, if concerted international action is to be taken to reduce fossil fuel use, it will be ineffectual unless the superpowers are signed on.

Of course, Canada, which contributes a relatively modest amount to the total greenhouse gas loading of the atmosphere, wants to continue to play a significant role in the arena of scientific research, socio-economic impact studies, support of the World Climate Programme, and the development of effective international action to protect the global environment.

Intergovernmental organizations such as WMO and UNEP must also play leading roles in addressing these issues. WMO has a very long history of international cooperation in the exchange of meteorologic information and the sharing of scientific knowledge. It also has the technical expertise to spearhead the coordination of longer term global atmospheric studies. UNEP has a proven track record in the development of many international agreements dealing with the protection of natural resources and the environment.

What about the individual citizen? Well, most of us, I think, can be less wasteful of energy in our personal lifestyles. Canadians and Americans, with just over 5 percent of the world's population, account for 25 percent of the world's fossil fuel consumption. We can be more active in consumer advocacy, more supportive of waste recycling programs, and more insistent on responsive political action. In fact, one of the major hurdles in coming to grips with environmental problems of this magnitude will be public attitudes.

The last four years have reminded us that the Great Lakes water levels can fluctuate significantly from year to year. Consumptive uses, diversions, and interbasin transfers are all relatively minor influences on lake level variations in comparison with climate variability.

But even the recent significant fluctuations in water levels and the associated socio-economic dislocations pale in comparison to the possible effects of longer term climate warming.

As pointed out by several speakers at the conference, we must be concerned with the impacts of much lower water levels, for example, on such uses as navigation and hydropower generation. If, in fact, average water levels decreased by several feet over the next several decades, as predicted by both Canadian and U.S. studies, there is a potential for significant increases in local concentrations of toxics resulting from industrial discharges, especially in shallow bays, channels or impoundments.

Clearly, dredging to keep the navigational channels open for business will have to increase significantly. On the Canadian side alone the cost of the additional dredging might be in the tens of millions of dollars annually.

Dredging, of course, could stir up several decades of toxic accumulation in bottom sediments. Releasing these contaminants into the water column could have disastrous impacts on living organisms, especially in and near many of the Areas of Concern identified by the International Joint Commission. And where would the contaminated dredging spoils be disposed of? Economic and environmental feasibility studies are needed to evaluate these factors.

There are also potential undesirable side effects associated with any long-term reduction of Great Lakes hydroelectric generation capacity. Power utilities have few options to make up the shortfalls. One is to increase thermal power generation, thus increasing the emissions of acidifying sulfur dioxide as well as carbon dioxide into the atmosphere.

Another option is increased nuclear generation which is considered highly risky by many people. You must remember, too, that the peak demands for power may be modified with climate warming.

Someone with a nice choice of words described this year's drought as a possible "dry run" of what we can expect more frequently with an enhanced greenhouse effect. In the Toronto area, the extraordinary use of air conditioners during summer resulted in several "brown outs."

Important relationships thus exist between the greenhouse gas problem and other major environmental issues. As another example, the degradation of agriculture soils in the Great Lakes Basin through the overuse of pesticides and herbicides and poor farm practices must be reversed. According to the Science Council of Canada, the Great Lakes Basin is home to almost two-thirds of the Canadian population and provides almost half the dollar value of Canadian agricultural production. Climate change models suggest more frequent and severe droughts in the future, with increased irrigation requirements and more pressure on soil quality.

Forest mining, as many people have said, must be changed to forest harvesting. The rapid decline in the world's forest cover is contributing significantly to the buildup of carbon dioxide in the atmosphere.

Currently in some forested regions in Canada, four trees are cut down for every tree planted. In some developing countries the ratio exceeds ten to one. Here in the Great Lakes area, where 58 percent of the land basin is covered by trees, we may be lulled into a false sense of complacency. But we need to promote a more global perspective here as well as in other parts of the world. It could even be said that we need to turn over a new leaf! For every tree cut down, a tree should be planted.

It's gratifying to note that at the economic summit meeting of seven leading industrial nations, the G-7 conference held in Toronto in June of this year, all of the leaders including President Reagan and Prime Minister Mulroney supported the principles of sustainable global socio-economic development as outlined in the report last year of the Brundtland Commission.

The G-7 conference was followed by an international conference on The Changing Atmosphere held in Toronto and sponsored by the Canadian government with the support of the United Nations Environment Programme and the World Meteorological Organization. Many of you were able to attend or followed the extensive coverage by the media. Some of you, when you registered at this conference, may have picked up a copy of the Toronto Conference Statement.

Well, the Toronto conference was a pioneering effort in many ways. It attracted 300 experts from 46 countries. The experts were drawn from a very broad range of disciplines. They included agriculture specialists, oceanographers, foresters, industrial leaders, energy planners, senior policy advisors, and representatives of the legal community.

Over 50 of the participants were from developing countries. The expertise was not only multidisciplinary but also representative of different sectors of society including various levels of government, international organizations, the private sector, public interest groups, and the academic community. The consensus conference statement surprised many people in the detail and extent of its explicit recommendations for action.

On the opening day of the conference, the stage was set by a number of theme papers which provided an up-to-date analysis of the scientific basis for concern. While the greenhouse problem was a predominant theme, attention was also paid to related larger atmospheric issues.

The design of monitoring networks and research programs required to address the greenhouse gas problem must, in the interest of efficiency, take into account the fact that many of the same chemicals are involved in these other issues such as acid rain, arctic pollution, and protection of the stratospheric ozone layer.

Among the various options for limiting emissions of greenhouse gases, there are alternatives which will provide spinoff benefits in reducing acid rain or threats to the ozone layer.

It's for this reason that Canada began, in 1986, to advocate international action leading toward the development of global "Law of the Atmosphere." Some words of explanation might be in order.

What we in Canada call a Law of the Atmosphere is a comprehensive framework agreement that would recognize the need for all countries to address the problem of better housekeeping of our shared global atmosphere.

This framework convention would be a basic legal document to which could be attached, over time, specific individual protocols dealing with greenhouse gases, acid rain precursors, and perhaps a systematic early international warning of major environmental accidents such as Chernobyl.

Of course, we in Canada recognize that an international framework agreement of this kind may take many years to develop. The Great Lakes Water Quality Agreement of 1972 had a long gestation period. The beginnings might even be traced back to the Boundary Waters Treaty of 1909 and the Trail Smelter case of the 1920's. And scientific concern about the stratospheric ozone layer really surfaced in the early 1970's. The United States National Academy of Sciences produced a report in 1975 which identified chlorofluorocarbons as a potential concern. It wasn't until 12 years later that the protocol was finally signed, and the initial regulatory cutbacks of the CFC's will not take effect until 1990.

The message is that it takes one or two decades (or has in the past) to move from conceptual concern expressed by scientists to the implementation of controls established through international agreement.

So, I believe it's not too early to start thinking about an international framework agreement to protect our atmosphere if we think we need to have such an agreement in place internationally by the end of the century.

One of the recommendations of the Toronto conference was that the development of such a comprehensive global convention should be initiated. Further work on that framework convention will be carried out at an international conference of legal experts in Ottawa in February of next year [1989].

It's likely also to be the subject of some discussion at an intergovernmental meeting to take place in The Netherlands in the fall of 1989. It may also draw some attention at the Second World Climate Conference co-sponsored by UNEP and WMO which is planned for Geneva in 1990.

Recognizing that fossil fuel usage must be reduced if the greenhouse warming trend is to be slowed down, the participants of the Toronto conference challenged countries to reduce emissions of carbon dioxide by 20 percent by the year 2005. That's a bit mind boggling. Is it at all possible?

Well, in Canada we will undertake a feasibility study to determine whether such a target is achievable and, if so, what methods are available for meeting it. These methods might include increased energy efficiency in both production and delivery systems, energy conservation, and switching from energy sources with high carbon dioxide emissions to those with lower CO_2 emissions.

We know very well that a significant change in direction of national energy policy is a multidecade venture. We consider this to be a good reason for getting started.

Current general circulation models and studies indicate that to bring the upward trend in global temperatures to a complete halt would require reduction of at least 50 percent in global carbon dioxide emissions.

The Toronto conference also called on governments and international bodies to support the use of the Intergovernmental Panel on Climate Change referred to yesterday by Dr. Evans. Canada is represented on the IPCC and I can assure you that we are looking forward to working with the United States and over 30 other countries who will be represented on the panel. The first meeting of the panel will be convened in mid-November [1988].

Here in the Great Lakes Basin we have the opportunity to contribute to the solution of the greenhouse gas problem by building on our experience in the management of a vital bilateral ecosystem. While many problems remain, we have also had our successes in managing these boundary waters. The Great Lakes Water Quality Agreement is still viewed from abroad as a model of bilateral cooperation.

A draft NOAA report on the effect of climate changes on the Great Lakes levels contains the following statement: "The climate change effects modelled here, even if they occur, will require new paradigms in water management in the Great Lakes Basin."

I suggest that we also need to extend our concerns, our involvement, and our responsive actions to those broader global issues which will increasingly impact on the Great Lakes region. We need to think globally and act both locally and globally.

This morning Peter Timmerman referred to the technological uncoupling of our advanced countries' economies from the natural environment, and how this is related to the shift in national strategies from the earlier idea of minimizing potential losses to the current emphasis on maximizing potential gains.

He also spoke about the "tragedy of the commons." I would suggest that now that man's influence on the atmosphere is global in scope and potentially of unprecedented magnitude, and our economic interdependencies are also global, we need to change course toward technological recoupling of the economy and the environment, global strategic thinking, sustainable development, and the minimization of potential harmful impacts.

Our most pervasive "global commons," the atmosphere, is showing signs of a long-term illness. Let's make sure that, while working toward the ideal of a perfect diagnosis and seeking less onerous cures than the obvious but difficult ones currently available, we take wise precautionary measures based on our current expertise and the sensible management of our shared environmental future.

Thank you very much.

Climate Change In the Great Lakes Region

D. W. Phillips*

Importance of Climate

It is difficult to imagine any facet of human life or economy that is not in some way affected by climate. Climate is essential to the production of trees and crops, to the success of fisheries, and to the management of water resources. Climate is important in the design of, among other things, buildings, transportation terminals, and water control structures. It is a key factor in the manufacture and sale of consumer products such as tires, umbrellas, food, clothing, and fuels. Clearly, it makes a difference in the performance of equipment, materials, and workers. Climate influences dress, the food we eat, our feelings and behaviour, the cost of heating or cooling our homes, and our vacation plans.

Climate itself can and does change. Throughout geological time and human history, the climate has cycled through periods of warmth and cold. At various times the Great Lakes region has been covered by glaciers, tropical vegetation, freshwater lakes, and the oceans. The evidence around us is irrefutable: salt mines in Windsor, coal beds in Illinois, oil and gas deposits in Ontario, peat and gypsum reserves in Michigan, a medieval period of corn growing in Georgian Bay basin, and the most dramatic of all—the Great Lakes.

Climate change and variability should be viewed as both a threat and an opportunity. In both good and bad times, abnormal climate has led to mass human migration and to the growth and decay of major civilizations (McKay *et al.*, 1981). Climate diversities such as drought, floods, and excessive cold impose immediate threats to life, food production, property, and economic operations. However, climate variability offers humankind opportunities and challenges. We have taken advantage of times of plenty—filling reservoirs, opening new lands, and navigating uncharted waterways. However, not everyone has been able to capitalize on the favourable seasons or years and enjoy the more commonplace opportunities.

Climate change is particularly critical in the Great Lakes region because of the basin's dependence on natural resources and its reliance on out-of-basin markets. Agriculture is practised near its northern economic limit in the basin and therefore is vulnerable to slight shifts in climate. The basin's freshwater system is used for navigation, hydroelectric power, recreation, and riparian uses; thus it depends on a steady supply of water to maintain levels within a narrow range.

Purpose

The emphasis in this paper will be on reconstructing the climate of the Great Lakes Basin during geological and historical times and to show how the recent climate, documented by 100 years of instrumental records, compares with that over past centuries. Little time is spent on the whys and wherefores of climate change, or in assessing the worth of the various theories of climate change, or in what might be expected to happen in a succeeding decade or so—my story ends in 1988. I also do not intend to discuss the implications of an altered climate and of a changing atmosphere.

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It would be presumptuous of me to attempt to present some new information about climate change in the Great Lakes Basin. Instead, this paper is a primer on climate change. First you will hear an explanation of the difference between variability and change. Then you will be taken on a guided tour through 1300 centuries of climate history in the Great Lakes Basin, which in the total history of the planet earth is equivalent to describing one day of the 20th century. It is hoped that this will set the stage for other speakers and for you in your Working Group sessions on the implications of future climate on the Great Lakes.

Somewhere along the way, I want to make the following points:

- Variability is a normal part of climate.
- Climate is neither more nor less variable today than in the past.
- Vulnerability to climate variation has changed more than climate has changed.
- What has occurred can occur again, yet what will happen has not necessarily happened.

A popular dictum in science and the humanities is that the past is the key to the future. From the past we can learn more about the climate system and its interactions with society and the environment. Also, from past climates we can develop scenarios for predicting and coping with the consequences of climatic anomalies and in doing so begin to develop the basis for planning for change and variability.

In recent years, the dictum has been reworded to, "What will happen in the future is not necessarily limited to what has happened in the past." The revision is brought about by the realization that human activities, e.g., urbanization, industrialization, tillage, and deforestation, have become and will continue to become dominant factors in shaping future climate. It is now popularly felt that information from the past cannot adequately portray future conditions because of the changing chemical composition of the atmosphere. However, long before humans occupied the earth, massive chemical and land-use changes were taking place on the planet. Vulcanism, mountain building, and global fires brought about major atmospheric alterations that resulted in climate change. By careful analysis of the geological and historical record it may be possible to identify catastrophic periods in the history of the earth and interpret major atmospheric-change-induced global climates.

Understanding Change and Variability

Defining climate is easy. We use normals, reference means, and measures of stability to describe long-term weather. Climate change is a much more difficult notion to define and understand and a much more important concept. The term embraces all types of climate inconstancy: trends, discontinuities, fluctuations, anomalies, periodicities, rhythms, oscillations, and vacillations on time-scales that range from geological periods to a few weeks and over areas ranging from global to local. Adding to the difficulty in defining change are considerations of individual climate elements or combinations of elements including temperature, precipitation, wind, and others, and considerations of persistence, intensity, amplitude, and duration.

As it turns out, no generally accepted definition of climate change exists. In this paper, a distinction is made between short-term, relatively transient "variations" or fluctuations between one season/decade and the next, and long-term "changes" on the time-scale of centuries or millennia. Instrumental records are often used to document short-term variability of climate, especially over the past 100 years. Over much longer historical and geological periods, proxy sources—pollen, tree rings, ice cores, lake sediments—are used to reconstruct past climates.

Previously, climate was considered a constant, interrupted every 100,000 years or so by an ice age. Mean climatologies, as we used to say, were the basis for climatological studies. As a result, climate classifications failed to recognize the importance of variability and instead reinforced the stability or normalcy of climate. The truth is that the only constant in climate is its inconstancy. Variability has always been with us and it is an intrinsic property of the climate system. As Gordon McKay once said, "Extremes are not averages, but extremes are a normal feature of climate." Extreme events have happened before, perhaps not with precisely the same duration and intensity, but assuredly there will be more extremes.

In describing climate change over the ages, it is important to decipher real change from climate noise. Short-term change can be long-term noise. Keeping the time-scale in perspective is important in deciding what is significant change. For example, the past 10 years on geological time-scales are anomalously cold; on glacial and historical time-scales are warm; and in the last century are neither cold nor warm.

Most of the attention in climate change studies focuses on change and trends of a minuscule amount across enormous areas and over time measured in centuries or eons. Superimposed on this change and masked by statistical averaging are climate variations of a much shorter duration and much greater amplitude and intensity. For example, in a 100-year time series for temperature and precipitation in the Great Lakes, to be discussed in detail later, none of the following occurrences show up:

- Twelve droughts in 60 years
- At least half a dozen wet periods with extensive flooding
- Lake level variations of 2 m in 10 years
- Seasons and years of intense storms, cold, and drought at a time when the climate was described as being normal or even benign

Focusing on any segment of the climate record reveals complex patterns, persistent but temporary anomalies, and wide interannual changes that dwarf long-term trends by comparison. These smaller scale events are often of greater economic and social importance than slow trends because they lead to famines, energy shortages, inflation, and migration (McKay and Findlay, 1978). They are not in themselves signals of major long-term changes in the climate system, but are just natural manifestations (McKay, 1978).

Climate History of the Great Lakes Basin From Geological and Historical Evidence

Ancient Climates

Let me begin my tour of climate history with the pre-Pleistocene era. Paleoclimatic information from sediment cores laid down in ancient lake bottoms, from rocks whose ages date back three billion years, from plant and animal fossils, and from the land itself shows clearly that the Great Lakes went through millennia of both relative climate stability and prolonged, sometimes rapid, episodes of climate change that differed substantially from those detected by instrumental records.

The study of sedimentary deposits and fossils calls attention to many indicators of climate diversity. There were warm, alternately wet and dry climates, semi-arid climates, and glacial climates. Variation in climate seems to be associated with the size, placement, and amount of topographic relief. Lowlands and very extensive seas were marked by a widespread warm and humid climate, whereas uplifted lands and prominent mountain ranges were associated with a colder climate.

During the warm periods, which have prevailed 90 percent of the time, average temperatures were probably 5 to 10°C warmer than the basin's average temperature today (Thomas, 1957). Salt beds and gypsum deposits attest to higher evaporation rates and more aridity than at present. The sustained warmth and humidity of the Carboniferous Period of 350 to 290 million years before present (BP), supporting different life forms and an abundance of marshes and luxuriant vegetation, was responsible for the basin's oil and gas fields and coal deposits.

Quaternary Climates (past two million years)

During the Pleistocene epoch, which began almost two million years ago, four to eight major glaciers advanced over the Great Lakes. Model calculations of surface temperature, albeit sketchy and approximate, suggest that the temperatures of the past two million years were substantially cooler than has been usual in recent history (Hare, 1979). Ice more than 2000 m thick edged across the region scouring the surface and levelling the hills, reaching as far south as 37°N and covering more than 60 percent of North America. About 15,000 years BP the climate began to warm, melting slowly the last of the great glaciers, the Wisconsin, and returning the region to the milder climate of the present interglacial cycle.

At the peak of the Wisconsin glacier (20,000 years BP), there is evidence that spruce forests engulfed Florida and Texas and muskoxen roamed the central United States (Sellers, 1965). There is also evidence of substantial cooling with summer temperatures over the ice fields as much as 8°C below present values and precipitation about 30 percent less than at present (Thomas, 1957). In late Wisconsin time, 12,000 years BP, when ice lay across Manitoulin Island and Lake Superior, a tundra climate dominated northeastern Minnesota, New England, and the Allegheny Plateau (Beltzner, 1976). At the beginning of the present interglacial, about 10,000 years BP, temperatures were 10°C below the period mean. Cushing (1965) reviews the work of several paleoclimatologists who postulate a dramatic jump rather than a gradual change in climate in late Wisconsin time. Evidence for this comes from the "sudden" replacement of spruce, as a dominant pollen, by deciduous pollen during a period of 200 to 1200 years. The only mechanism seen sufficient to produce a change of this kind would be a "rapid" change in temperature and/or precipitation.

Present Interglacial

The present interglacial climate or Holocene has existed for 10,000 years. For only the last two centuries have instrumental data been available. Before that time, proxy data—pollen samples in bogs and lakes, seasonally layered sediments, soil profiles, and tree-ring analysis—and historical data are used to infer the climates.

Some areas in the southern Great Lakes became ice-free some time before 12,000 years BP. While the transition to the Holocene occurred, westerly air masses became more frequent, the summer temperature warmed, and precipitation increased (Webb and Bryson, 1972). In time, boreal forests and tundra gave way to flourishing deciduous trees and prairie grasslands.

Between 7000 and 3500 years BP, at the time of the great Egyptian Empire, the Great Lakes region was quite warm during the Climatic Optimum or Hypsithermal. Westerly air masses with drier and warmer weather prevailed across the basin. It was a warm period globally, probably warmer than at any time since the retreat of the Pleistocene ice sheets (Eichenlaub, 1979). The works of many writers (McAndrews, 1981; McKay and Findlay, 1978; Terasmae, 1961; Roberts, 1981) suggest that Great Lakes summers were 2 to 3°C warmer than at present. At that time, the Arctic ice pack was considered to have retreated north of 80°N. The climates of the Arctic, North Africa, New Mexico, and Europe were warmer and more humid, and North America's Great Plains and Great Lakes were arid. The boreal forest extended into the Arctic Islands. Sea levels were not much different than at present. Spruce-fir forests flourished in the north, and deciduous hardwoods in the south.

Following the warm Optimum, conditions became much drier and drought-resistant vegetation moved into the basin from the southwest. About 4000 years BP there was a rapid and drastic change to a cooler climate, a shift of boreal forests, and a growth of extensive peatbogs in middle North America (Beltzner, 1976).

Figure 1 shows a mean annual paleotemperature curve for southeastern Canada from Terasmae (1961) for the 14,000 years since deglaciation. Values above and below the present mean range 13°C. Temperatures at deglaciation were 10°C below the present mean and tended upward toward modern values at 10,000 years BP. The Optimum is identified by a 3°C warming above 20th century mean values beginning about 7200 years BP, peaking at about 5000 years BP and ending about 3200 years BP. A post-Optimum cooling occurred by 2500 years BP to about 2.5°C below modern values. Figure 2 shows the mean annual total precipitation for the past 12,000 years at Kirchner Marsh, Minnesota, as shown by Webb (1981). There was a rise in precipitation after deglaciation beginning about 10,800 years BP, followed by a lengthy period of decreasing precipitation ending about 5600 years BP, and a steady rise towards modern values since then. Larsen (1985) argues in favour of a wet Optimum phase as evidenced by lake levels at much higher levels than are discernible in the short, 125-year historic record of measured lake level changes.

Historical Period

In order to obtain a better picture of climatic variations in the last 2000 years, one can use historical and archeological proxy sources—journals, diaries, explorers' journals, letters from settlers—and the beginnings of an instrumental record. Writings about bumper harvests and crop failures, untimely frosts and cold winters, and prolonged dry spells enable historians to piece together the early climate record.

Unfortunately, the pre-European settlement of the Great Lakes Basin is almost lost in antiquity, with only the skimpiest anthropological evidence available. The first inhabitants arrived about 10,000 years BP from Asia. By 6000 years BP, several hunting and fishing communities had sprung up throughout the Great Lakes Basin (Environment Canada *et al.*, 1987). Historical evidence from Europe and eastern North America points to a cool period spanning the Greek and Roman Empires from 1000 BC to AD 400 followed by a 500-year medieval mild phase during the Christian Centuries (AD 800-1300) about 1°C warmer than present—not as warm as the Optimum, but sufficiently mild to enable:

- Cultivation of grapes in England and possibly in Labrador
- Colonization of Iceland and Greenland
- The Inuit migration on Ellesmere Island and northern Greenland
- The Norse voyages across the ice-free Labrador Sea to North America

During this period, the Gulf Stream shifted northward in the North Atlantic, the Arctic pack ice retreated in summer to north of 80°N and the tree line was 100 km farther north than today. Near the end of the medieval warm period comes the first bit of evidence of European settlement in the Great Lakes, when a Viking expedition appeared to have traversed the length of the Great Lakes, leaving their mark on northeastern Minnesota (Swain, 1984).

In the 14th Century, the climate swung back towards progressively colder and wetter conditions marking the beginning of the Little Ice Age that lasted 300 years. In Europe,

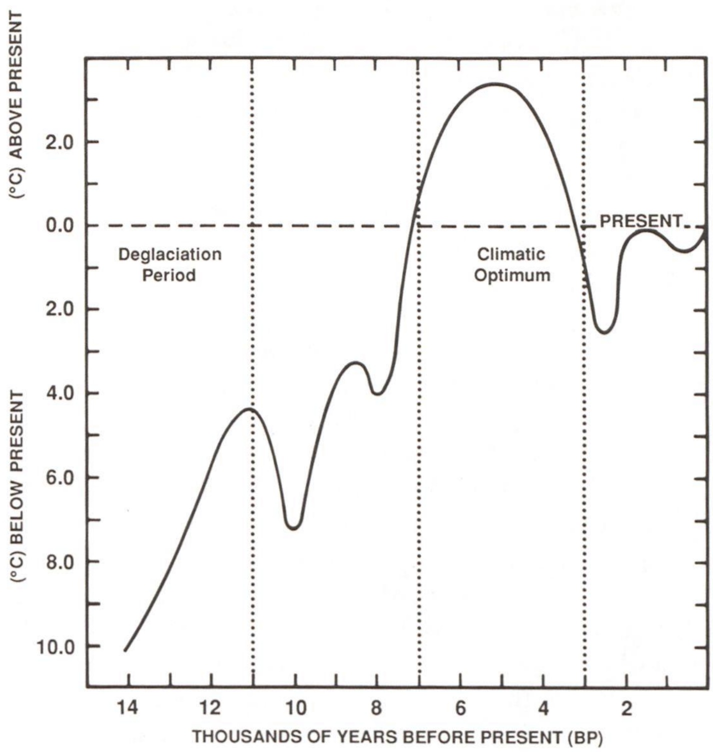

Figure 1. Mean annual paleotemperature (°C) for southeastern Canada (Terasmae, 1961)

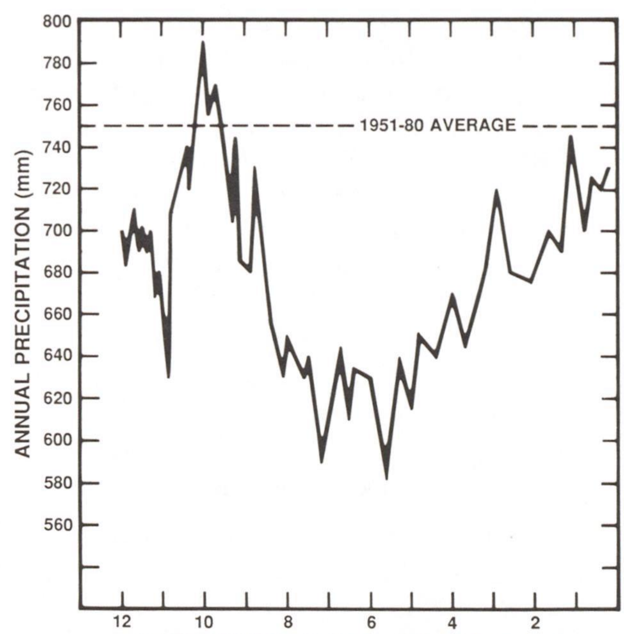

Figure 2. Precipitation estimates derived from pollen data at Kirchner Marsh in Minnesota (Webb, 1981)

mountain glaciers advanced, the coast of Iceland became ice-bound for several months of the year and the climate of Greenland became colder. The Viking colonies perished since agriculture was no longer feasible and famines were frequent. Rivers in Europe froze regularly when winters generally became colder and snowier. In northern Canada, the Inuit people retreated southward; off Labrador, ice choked the sea routes; and in eastern North America, cold air masses from northern Canada were more frequent. Early colonists suffered through harsh winters and shortened summers (McKay, 1978; McKay *et al.*, 1981).

Bernabo (1981) compared a sequence of temperatures based on instrumental and historical data from central England with temperatures reconstructed from pollen samples taken in Marion Lake, Michigan. Both reconstructions corroborate the general timing and temperatures of the medieval warm period and the Little Ice Age. The Marion Lake temperature series (Figure 3) reveals consistently warmer temperatures before AD 500 than the 2700-year average and a marked cold interval from AD 500 to AD 800. A warming trend began after AD 900. Temperatures peaked during the medieval warming when they were not unlike mid-20th century values. Temperatures declined about AD 1300 and by about AD 1750 fell 1.2°C below present values.

Reports and writings of early explorers and missionaries in Ontario indicate that the weather in the 17th and 18th centuries was much the same as it was in the 1950's (Thomas, 1957). Indeed, they apparently also had air quality problems in those years. An article published on Great Lakes climate in 1763 in the *Philosophical Transactions* discusses a particularly dark day at Fort Detroit when smoke from forest fires caused almost total darkness all day.

Settlement in the Great Lakes Basin by Europeans began appreciably by the middle of the 18th century. From diaries and newspaper reports we know that there were no excessively cold winters in the first quarter of the 19th century, but there were some extremely cool summers, in particular, 1816. The "year without a summer" following the tremendous volcanic eruption on Mount Tambora was the climax of the most remarkable depression of temperature in the northeastern United States since the beginning of thermometer records (Wilson, 1983). Excerpts from local newspapers reported that:

- Spring was promising, but in May ice formed an inch thick.
- Buds and flowers were frozen.
- In June snow fell to a depth of 3 to 4 inches in New York and in Ontario, levelling the fields of wheat as if they had been flattened by a roller.
- Corn and buckwheat crops were destroyed by snow and frost on July 6 and again on August 24.
- Within 12 days of the summer solstice, the countryside appeared like the middle of December.

Instrumental Record of Great Lakes Climate

Although instrumental observations of weather date back to the early 1800's in the Great Lakes Basin, the effective coverage of precipitation and surface temperature from an organized meteorological network began only a little more than a century ago.

The instrumental record in Ontario dates from 1840 when the British Government established a Magnetic and Meteorological Observatory at Toronto. There were some earlier records kept by individuals such as Reverend Charles Dade and Dr. Hodgin at Toronto, but the continuity of records was not maintained (Crowe, 1988). The Toronto record has continued for nearly 150 years within one kilometre of the original site. During

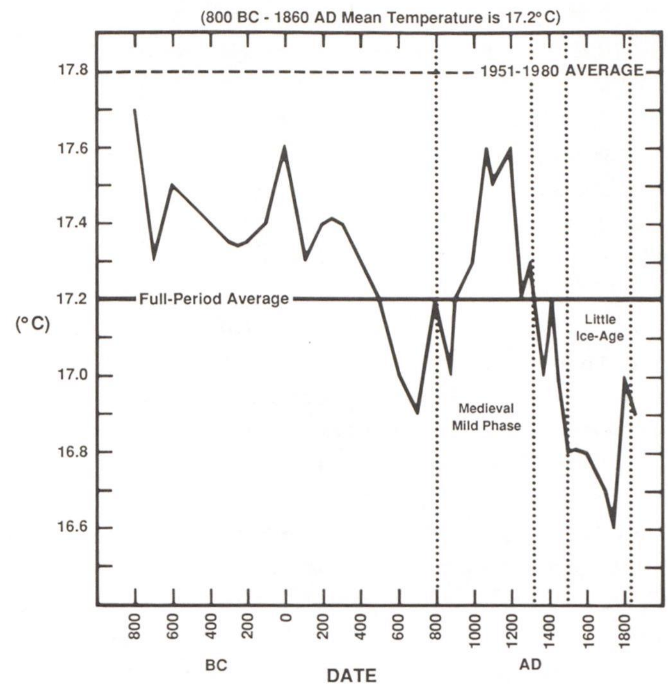

Figure 3. Growing season temperatures estimated from pollen data at Marion Lake, Michigan (Bernabo, 1981)

the 1870's, while the weather service in Canada was being organized, the weather network expanded to take in stations around Lake Huron and Georgian Bay and in the 1880's, around Lake Superior.

In the United States pre-1840 data are available from stations near the Great Lakes Basin at Minneapolis, Minnesota, and Cooperstown, New York. Long records for most of the latter half of the 19th century include those at Ann Arbor, Erie, and Rochester, among others. They were collected by a variety of agencies including the U.S. Patent Office, the U.S. Department of Agriculture, the Smithsonian Institution, the U.S. Signal Service, and the U.S. Weather Bureau (after 1892).

By the turn of the century there were 300 or more climate reporting stations in the basin; in the 1980's the number of climate stations had almost tripled and included many more specialized stations, such as those observing wind, sunshine, and radiation.

Precipitation Climatology

Precipitation has few surprises across the Great Lakes. Extremes are modulated, amounts are evened out, wet and dry spells are fairly rare, and there is a variety of precipitation types and sources. In one word, rain and snow in the Great Lakes region are about as "reliable" as one could find in a temperate continental climate.

Precipitation over the Great Lakes is fairly uniformly distributed throughout the year. It is this seasonal uniformity that chiefly distinguishes this climate type from others in North America. The contribution from the more vigourous and frequent storms of winter matches that from less developed cyclones and thunderstorms in the warm, moist air of summer. If anything, the growing season has a slight precipitation maximum. February is clearly the driest month in many areas, but in some instances this is only because it has two or three fewer days. Northwestern sections of the basin with a more continental climate have a definite summer precipitation maximum.

Precipitation reliability usually holds true from year to year. Periods of excessively dry or wet weather are infrequent, although there is a greater tendency for periods of drought in the late summer, in time for the final harvest, than at any other time. Dry periods of one month or longer are rare, but those of one week are not, occurring, on average, at least once a month during the growing season. Recent droughts have occurred in 1973, 1978, 1983, and 1988.

Individual stations within the Great Lakes Basin such as Alpena and Buffalo have a coefficient of variation of annual precipitation that is less than 15 percent—the lowest figure of the more than 30 representative stations sampled across the United States and Canada. Stations from diverse climatic regions, such as Bismarck, San Francisco, Miami, Houston, Los Angeles, and Portland, Maine, had double or triple the variation.

Precipitation Record. Quinn (1981) analysed annual precipitation totals over the entire Great Lakes Basin from the period 1854 to 1979. To that period was added data from 1980 to 1987 to make a 134-year record (Quinn, personal communication). The basic data are areally weighted totals for the five individual lake basins each comprising anywhere from 50 to 150 stations for at least the years since 1900.

Figure 4 shows composite annual precipitation departures from long-term average (1854 to 1987). The average yearly precipitation for the basin over the full period of record is 816.4 mm with a standard deviation of 70 mm and a coefficient of variation of 8.6 percent. It is easy to locate wet and dry years during the period. The wettest year on record, 1985, had an accumulation of 200 mm above the long-term average; the driest year in the modern era, 1930, received about 160 mm less than the 134-year average. These extreme annual totals represent a range of about 20 to 25 percent above and below the long-term average. Annual precipitation from 1890 to 1940 was almost entirely below the average. Except for a brief 5-year period in the early 1960's, annual precipitation since the mid-1930's has been predominantly at or above normal.

Figure 5 shows moving averages of annual Great Lakes precipitation for the 134-year record, filtered as Quinn did using 5-year weighted factors of 0.06, 0.25, 0.38, 0.25, and 0.06. The same apparent trends are evident in both series. There are two high precipitation regimes—from about the beginning to the early 1880's and from approximately 1940 to the present time. In between is a 55-year period of fairly low precipitation when the yearly average precipitation was 780 mm, 36 mm less than the long-term average and 80 mm less than what we have come to think of as normal for the basin.

The annual precipitation since World War II has been significantly higher than during the first 40 years of this century. Since 1937, 30 of 50 years have been wetter than the long-term average. The yearly increase of precipitation represents a tremendous amount of water being added to the system. Given a stable evaporation regime, the added precipitation amounts to a depth of 60 mm over the entire basin which translates into a water level rise of 0.2 to 0.3 m per year (Jim Robinson, Cornwall, personal communication).

Another way of displaying secular variation is to plot the cumulative departures from the long-term average. A string of wet years causes the curve to slope upwards while a string of dry years moves the curve downward. Changes can be gradual or abrupt and slopes steep or gradual depending on the magnitude of precipitation differences from the mean. Diaz and Quayle (1978) and Skinner (1984) have used cumulative departure curves to indicate out-of-phase fluctuation of temperature. For precipitation in the Great Lakes Basin the cumulative departure curve (Figure 6) confirms the earlier analysis of above-average precipitation in the early years, a long period of below-average precipitation from 1885 to 1940, 20 years of variable precipitation, and since 1965, a period of 20 wet years.

Quinn (1981) carried out a series of statistical tests to evaluate the significance of the distinct precipitation regimes and whether they depicted a linear trend. The dry period from 1900 to 1939 and the wet period from 1940 to 1979 were judged significantly different at the 4 percent level. Both regimes were declared stationary about their respective means with no linear trend present.

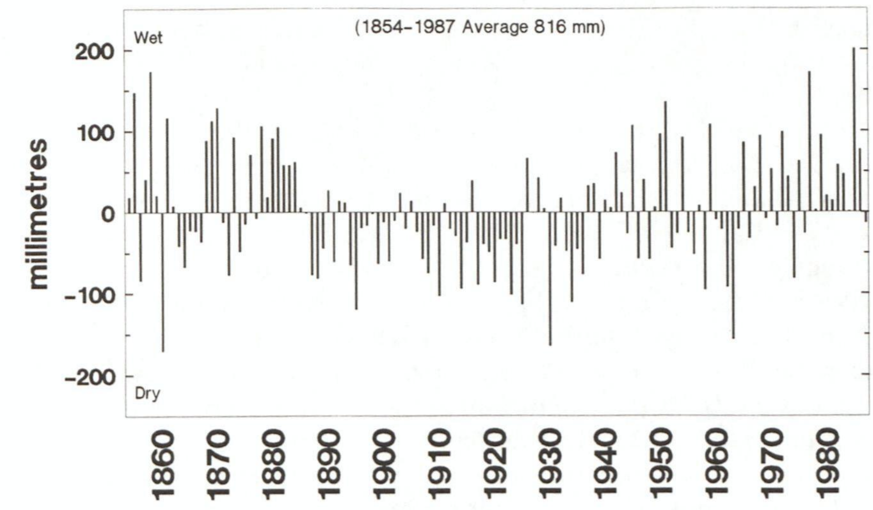

Figure 4. Departure from long-term average precipitation for the Great Lakes Basin 1854 to 1987

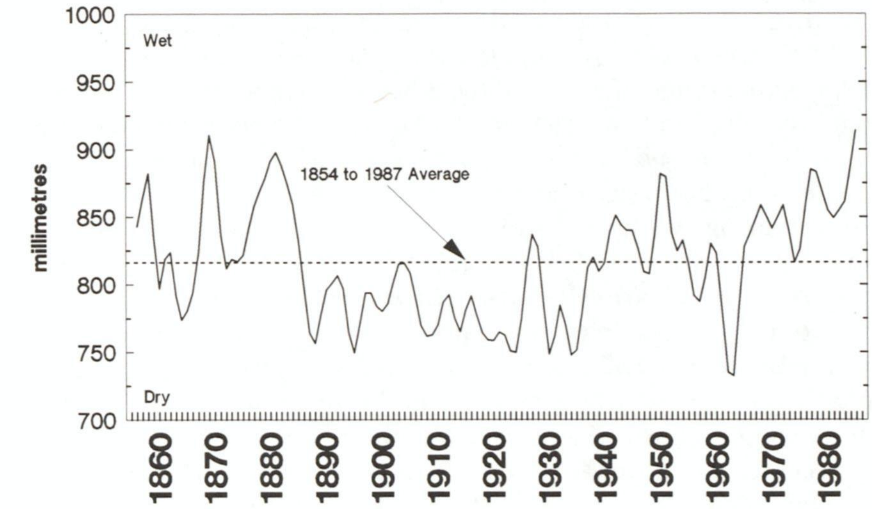

Figure 5. Great Lakes 5-year weighted moving average precipitation 1854 to 1987

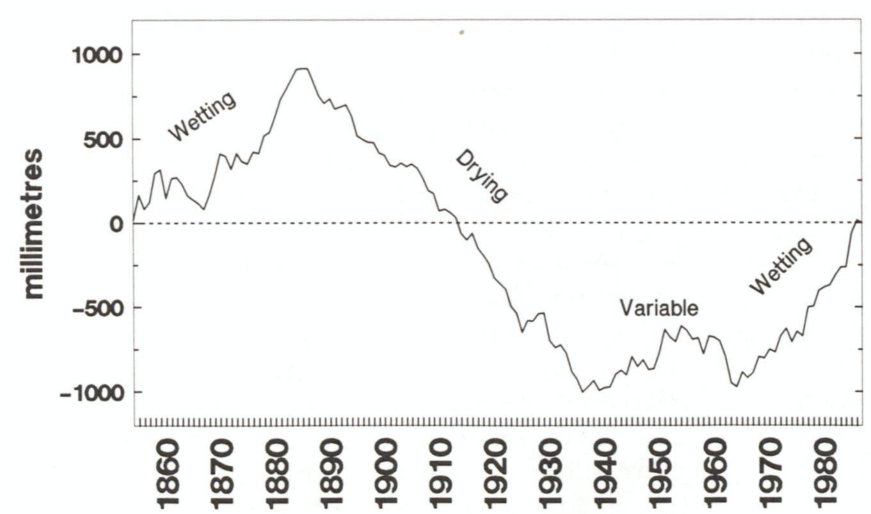

Figure 6. Cumulative departure from long-term average precipitation for the Great Lakes Basin 1854 to 1987

Spatial and Seasonal Precipitation Variation. While temperature variations have been shown to be fairly uniform across the basin, precipitation has shown major intrabasin variability. The 1930's was the warmest decade and also was the driest for the entire basin. However, Brinkmann (1983) identified separate precipitation regimes in the Great Lakes Basin. From the turn of the century until the 1930's and after about 1960, the southeast area of the basin received higher than normal precipitation, whereas during the period 1930 to 1960 the northwest portion received higher than normal precipitation.

Quinn (1981) separated the annual time series into seasonal components and applied a 5-year weighted filter. From the analysis he concluded the following:

1. Each season shows increased precipitation during the 1940-1979 period.
2. Differences between this century's wet and dry period can be accounted for primarily by the greater precipitation amounts in spring and summer.

Thomas (1957) also studied seasonal trends in the analyses of 100 years of precipitation totals in Ontario. He found that the spring season had the greatest variability, and the fall season had a remarkably smooth trend. Figure 7 shows the trend in the coefficient of variation of annual precipitation. It suggests that the precipitation variability for the basin as a whole decreased from 1860 to 1900, rose during the first 30 years of the century, fell during the 1930's, rose again from late 1940's to early 1960's, and stabilized since 1970.

Comparison with Other Regions. The coherence of Great Lakes precipitation trends with those in other regions or worldwide is difficult. In spite of the ease of measuring rainfall and the long history of observing rainfall that extends back over 2500 years in India and Israel, the crudity of measurement in small cans and the great potential for errors owing to exposure make comparisons difficult if not meaningless. Measurement problems dictate that only averages derived from a group of homogeneous, reliable, and well-distributed stations should be used. Quoting other studies, Hare (1979) found no clear trends in precipitation or prolonged wet or dry spells on a hemispheric or global basis. Subsequently, Bradley *et al.* (1987) analysed 150 years of large-scale precipitation change over the Northern Hemisphere and found significant increases in mid-latitude precipitation over the first 30 to 40 years with all seasons contributing (Figure 8). Their work corroborates what has occurred in recent decades over the United States (Wahl, 1968; Wahl and Lawson, 1970; and Diaz and Quayle, 1980), in southern Canada (Aston, personal communication), and in the Great Lakes Basin.

Individual station records show less spatial coherence owing to unavoidable local inhomogeneities. The record at Toronto, because of its urban effect, has been illustrated often and reveals two features found in other long precipitation records (Hare, 1979); namely, there is an abrupt decrease of mean precipitation of about 10 percent in the 1860's and early 1870's, and a decade-long drought in the 1930's.

Temperature Records in the Great Lakes Basin

Temperature Variations

For the Great Lakes, a basinwide annual temperature was calculated for each year from 1901 to 1984 and run through a series of statistical analyses to detect change and measure variability. Karl (personal communication) used 46 stations from the U. S. Historical Climatological Network to obtain representative temperatures for the U.S. side of the Great Lakes Basin. Six stations from the Canadian side, spaced to properly sample the five lake basins, were averaged to obtain a single average annual temperature for each year.

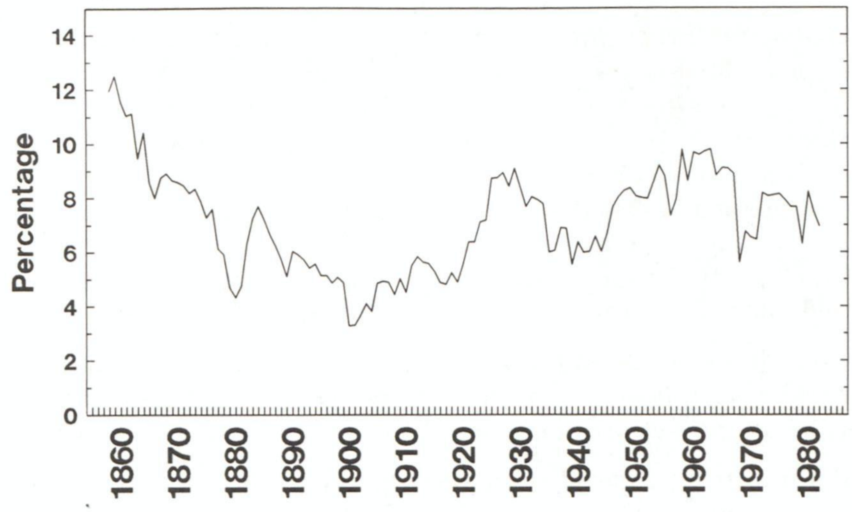

Figure 7. Moving average coefficient of variation of Great Lakes precipitation 1854 to 1987

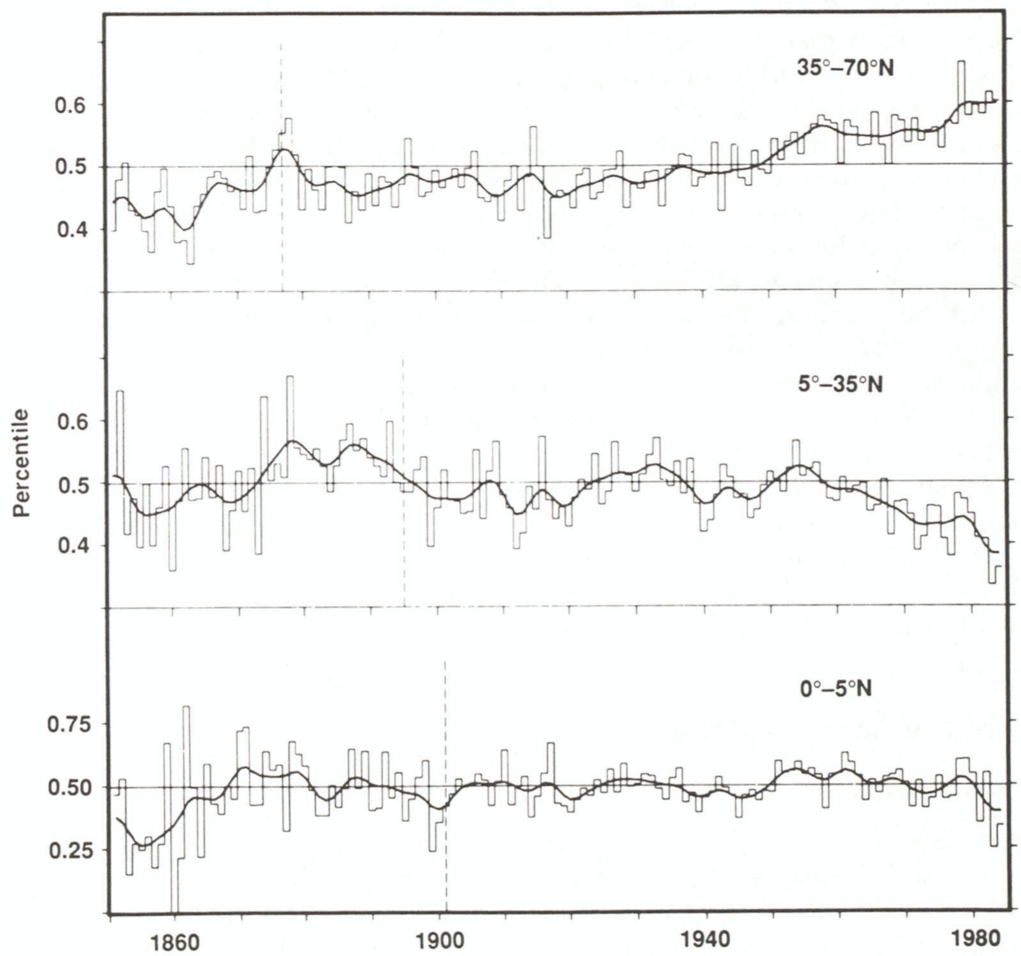

Figure 8. Percentiles of Northern Hemispheric precipitation (Bradley et al., 1987)

From the American and Canadian temperatures, each appropriately weighted by the land area of the basin, i.e., 0.57 in the U.S. and 0.43 in Canada, a single, basinwide temperature for each year was computed. Figures 9 and 10 show trends in 20th-century temperatures. Figure 10 uses a 5-year weighted smoother, identical to the filter used in the precipitation analysis, to remove the high-frequency oscillations and emphasize longer period trends.

Within the span of 84 years, three separate regimes can be identified. The period from 1901 to 1918 was colder than any other period this century with the general trend being upward. The warming continued in the 1920's and lasted until 1955—most years in this period were warmer than normal. The years 1921 and 1931 were the warmest with mean temperatures nearly 2°C above the long-term average. The warming was rather pronounced during the 1920's and 1930's, about 0.7°C. The warming trend levelled off during the 1940's, but most years had above-normal temperatures. The year 1953 was the warmest in 20 years but soon after, in line with a general hemispheric cool-off, there was a decided downturn in the average basin temperature by about 0.5°C in less than a decade. Temperatures stabilized near the long-term average of 5.9°C during the 1960's, but in the 1970's three exceptionally cold years, 1972, 1978, and 1979, kept the decade cool. Since 1979 a trend to warmer temperatures is evident. However, there is nothing in the first seven years of the 1980's to confirm what Gribbin (1985) and others have suggested about the 1980's having the four warmest years over the Northern Hemisphere since 1851. The year 1987 was warm, but at several stations sampled in the basin, it was only the fifth warmest year this century.

Another way of looking at temperature variation is to plot the cumulative departure of the annual average temperature from the long-term average. Such an analysis for the Great Lakes Basin (Figure 11) shows a lengthy period of negative anomalies to 1930 followed by an equally long period of positive anomalies. Since 1960 the annual temperature has remained close to the long-term average with no run of above- or below-normal temperatures.

Figure 12 shows 10-year moving average standard deviation of the annual temperature for the Great Lakes Basin. It suggests that the year-to-year variability has been decreasing since 1920, and has become especially small after about 1960, only to show some movement to slightly higher variability in the past 15 years.

Spatial and Seasonal Temperature Variations

In her study of the spatial patterns of surface temperature variability over the Great Lakes region, Brinkmann (1983) concluded that temperature variations have been relatively homogeneous. Eichenlaub (1979) found, however, that middle 20th century cooling has not been equally pronounced in all sections of the Great Lakes with the southern portions of the basin showing the most marked fluctuations during the past several decades.

When the annual mean temperature is desegregated by season not all the components share the same temperature tendency. Winter and summer seasons have been cooling in the basin since 1940, a decrease of 1 to 2°C in both seasons (Changnon, 1985); however, spring and fall have actually become warmer (Eichenlaub, 1979). The winter variation in temperature is consistent with those of Assel (1980) who identified temporal trends in maximum freezing degree days for the Great Lakes. Assel's analysis shows a cooling trend between 1898 and 1918, followed by a long warming climb until 1958 when a cooling trend began again. Assel also noted that a majority of severe winters occurred during the two cooling periods and a majority of mild winters occurred in the warming period.

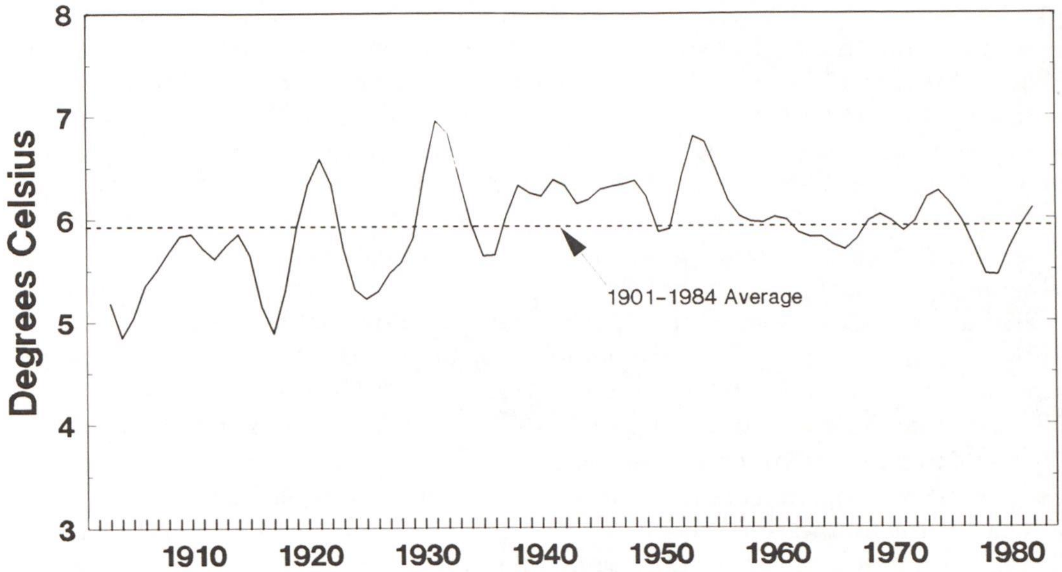

Figure 9. Average annual temperature for the Great Lakes Basin 1901 to 1984

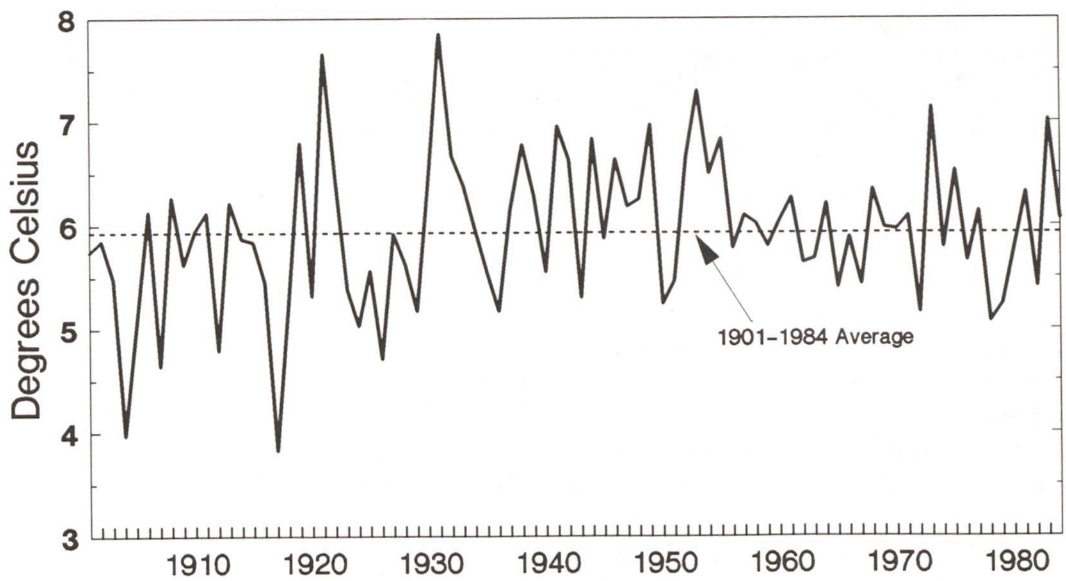

Figure 10. Five-year weighted average temperature for the Great Lakes Basin 1901 to 1984

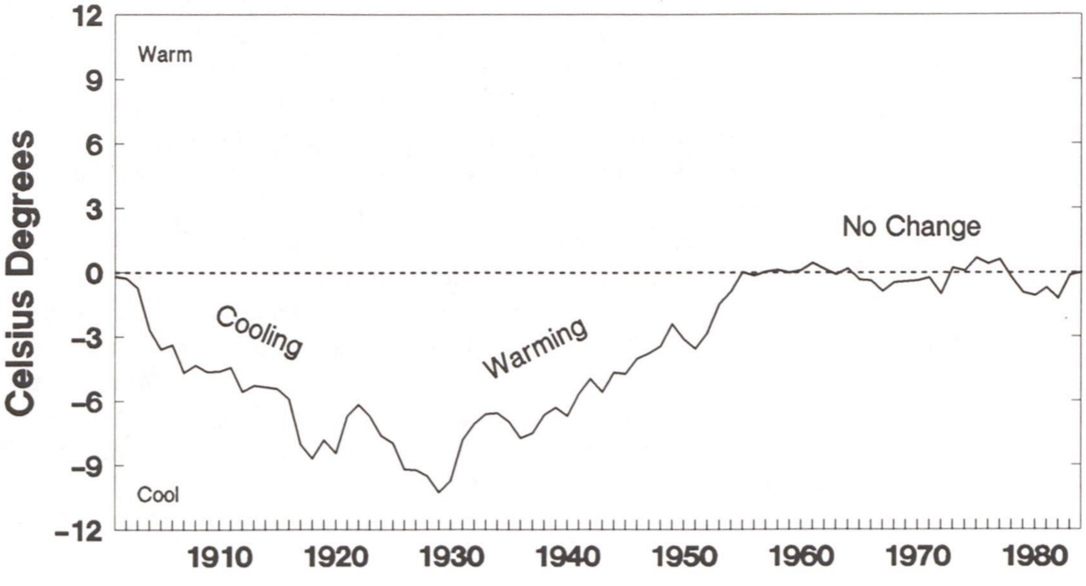

Figure 11. Cumulative departure from long-term average temperature

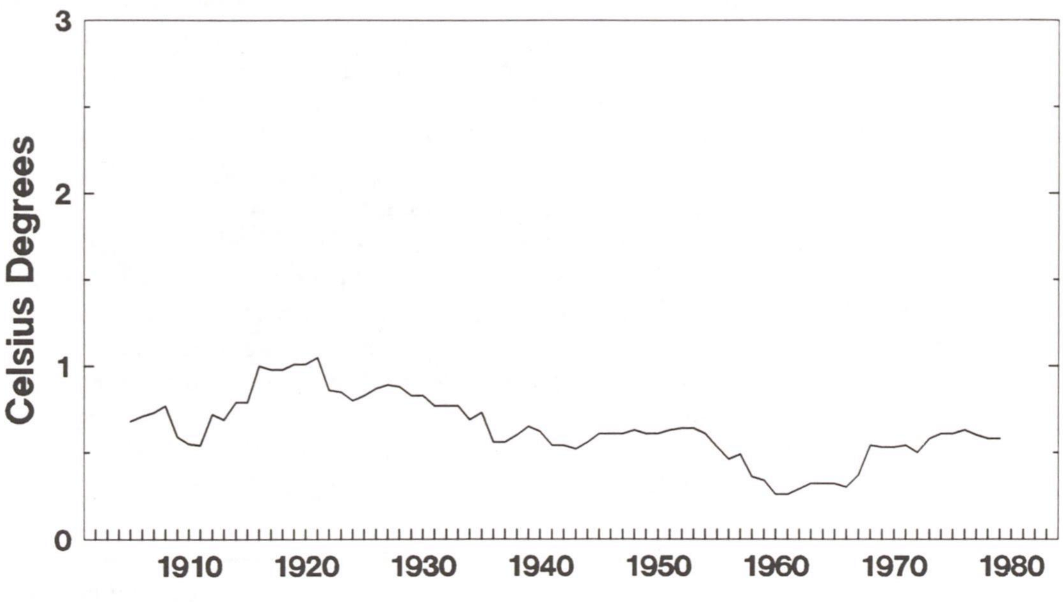

Figure 12. Moving average standard deviation of average annual temperature for the Great Lakes Basin 1901 to 1984

Comparison With Other Temperature Regimes

The variation of 20th century temperatures in the Great Lakes region appears to be generally in tune with Northern Hemispheric trends, with the eastern two thirds of the United States (Diaz and Quayle, 1978) and with Canada; namely, a cold period in the decades before and after the turn of the century, warming by 1.0°C to about 1940, remaining stable during the 1940's, cooling by 0.4°C in the 1950's and 1960's and some conflicting signals as to a trend in the 1970's. Analysis of data in the 1980's clearly indicates the beginning of a renewed upward trend, especially given the additional warming from 1987 and 1988, which should continue the segment of the curve upwards.

There is less consistency with global trends. Hansen's composite record of global mean annual temperature supports the first half century warming. His five-year trend analysis (Figure 13) points to 1940 as the turn-about year when a 25-year global cooling period of 0.3°C began. Such cooling was only evident in the Great Lakes beginning in the 1950's, lasting clearly until 1965 at which time the full cooling rate evident globally had been achieved. Further his analysis points to a rate of global warming in the past two decades higher than at any earlier time in the record. Further, four of the warmest years in the past century have occurred in the 1980's. The global temperature in 1988 up to June 1 is substantially warmer than the like period in any previous year in the record and he safely predicts that 1988, based on first half warming, will probably be the warmest year on record (Hansen, 1988).

Temperature Summary

I have succumbed to the temptation of displaying a composite record of relative temperature changes from several diverse data sources in the Great Lakes region. Figure 14 has a series of paleotemperature curves showing variations in the Great Lakes Basin's average annual temperature over the past 130,000 years derived from 100 years of instrumental records, from 1000 years of archeological and historical evidence, from 15,000 years of palynological evidence (pollen), and from 100,000 years of geological (fossil) evidence. The curves are highly generalized and admittedly tentative and may have to be modified as more information becomes available.

The data from the work of many researchers consulted in preparing this summary corroborate well, especially during the past 12,000 years. Values range 13°C above and below the present-day average. Temperatures at the end of the previous interglacial were slightly above present-day temperatures; as much as 10°C cooler than at present during the Wisconsin glacial advance; 3°C warmer than at present at 6000 years BP during the Climatic Optimum; and, following a drop in temperature at 5000 years BP, it stayed cooler than at present, until AD 1 when temperatures rose above present values. During the past 20 centuries, temperatures were generally warm for the first half and cool for settlement times. In the last century there has been a return to the warmer temperatures of the pre-Little Ice Age era. For the past 13,000 years, three fourths of the years had an annual average temperature cooler than the present-day average.

Table 1

Period	Percentage of time Below Present-Day Average
Instrumental	50
Historical	58
Post-Wisconsin	77
Wisconsin Glacial	95

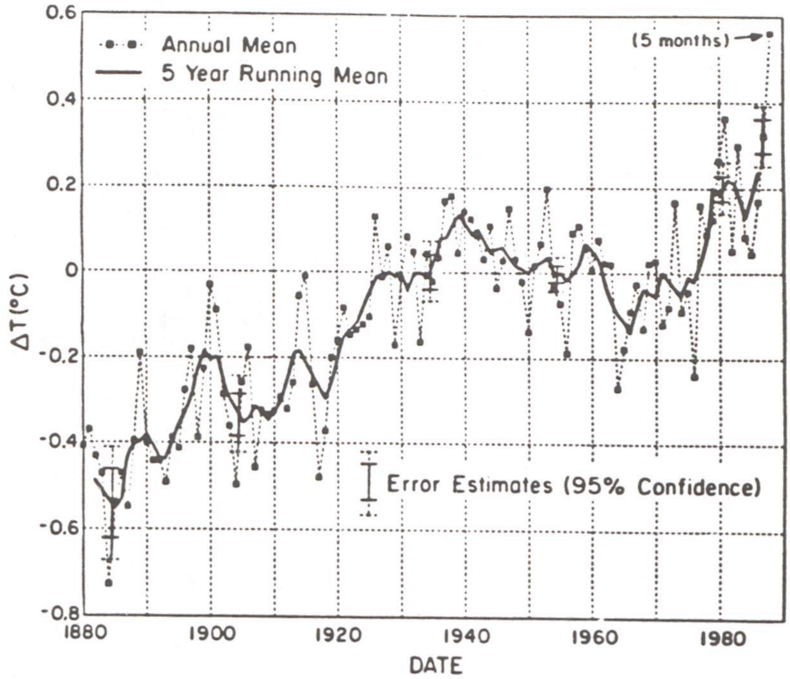

Figure 13. Global temperature trend (Hansen, 1988)

The Very Recent Wet Period

The 1970's and 1980's were a period of remarkable weather extremes with devastating consequences for people around the world. Television documentaries and news accounts presented the dramatic effects of unusual climate on the sea and on the land. The Great Lakes Basin had its share of climatic upsets and extremes. A seemingly endless parade of droughts, floods, strong winds, devastating storms, cold winters, wet years, and severe ice conditions seemed to make this period more memorable than any preceding decades. The impact of climate extremes was enormous in terms of losses in lives, property, and revenues.

There were many memorable climate happenings, but in recent years the three that stand out the most are:

- The cold winters of 1976-1977, 1977-1978, and 1978-1979
- The abnormal number of wet years
- The apparent increase in variability and the setting of an inordinate number of new climate records

The three winters at the end of the 1970's were extraordinarily cold. Agee (1982) commented that these winters probably rank along with the heat and drought of the 1930's as the two most significant climatic happenings this century in the United States. January 1977 was called the coldest month ever in the past 200 years in the eastern half of North America, and the winter set a new record for fuel demand (Diaz and Quayle, 1978). The cold winter of 1976-1977 cost Ontario over $200,000,000 (Allsopp *et al.*, 1981). The following winter had an even more profound effect in terms of suffering and disruption in the Great Lakes. Changnon (1979) found the economic impact of the severe 1977-1978 winter cost Illinois in excess of $1 billion in extra costs and lost revenue.

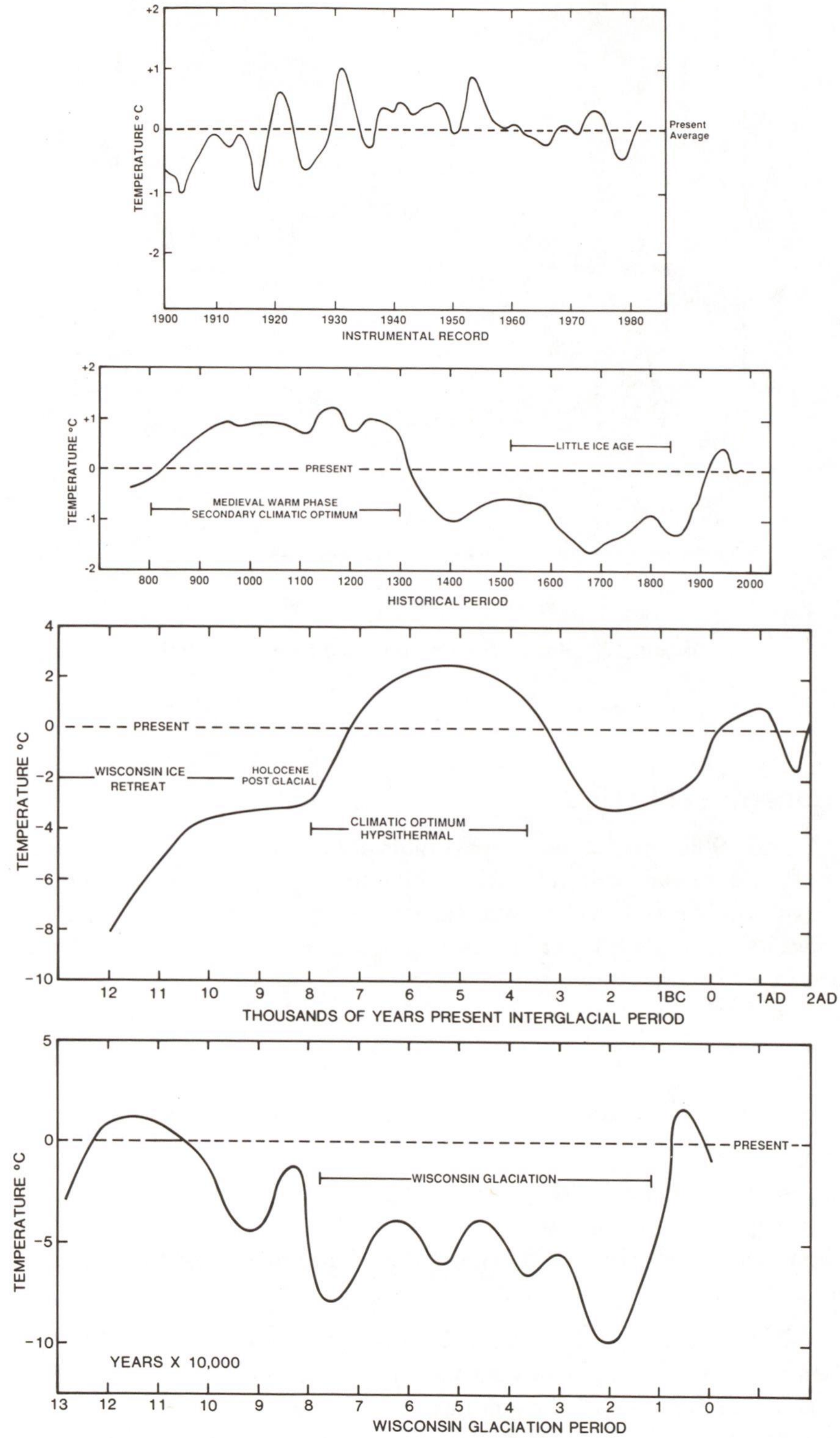

Figure 14. Variation of mean surface temperature (^{o}C) during past 130,000 years in the Great Lakes Basin

If anything, recent years in the Great Lakes region have been wet. Following the dry early sixties, the next 20 years were the wettest 20-year period since instrumental records began nearly 140 years ago. Only 6 years, 1966, 1969, 1971, 1974, 1976, and 1987, had below-normal precipitation. The recent 22-year wet period has an annual average yearly total of about 860 mm, 5 percent above the long-term average and 10 percent above the dry period of the first 30 years of the 20th century. Record high water levels in the Great Lakes occurred in 1973 and 1974 and were exceeded by water levels in 1985 and 1986. Also, Changnon (1987) discovered that the number of heavy rain events increased by 27 percent over an earlier decade, 1921-1930, and that 60 percent of the years were wet and only 20 percent were dry.

A statistical analysis of the various precipitation periods from 1854 to 1987 (Table 2) shows the recent wet period (1965-1987) to have 46 mm more precipitation per year on average above the century-wide (1901-1987) average but variability during the 23-year period was about 7 percent less than that for the century. Of course, this wet period was much wetter (by 81 mm) and more variable (by 17 percent) than the beginning dry years (1901-1936) of this century.

Table 2. Analysis of Precipitation Periods

Period	Maximum (mm)	Minimum (mm)	Mean (mm)	Standard Deviation (mm)	Coefficient of Variation (%)
1854-1987	1017	646	816.4	70.3	8.61
1854-1885	990	646	844.9	76.4	9.05
1886-1936	883	652	779.6	46.0	6.04
1937-1987	1017	660	836.0	69.1	8.27
1901-1987	1017	652	811.7	68.1	8.40
1901-1936	883	652	777.4	49.4	6.36
1937-1987	1017	660	836.0	69.1	8.27
1965-1987	1017	735	858.6	63.8	7.44

The Recent Dry and Warm Period

Beginning in November 1986 and lasting through the first half of 1987 and again during the first half of 1988, monthly precipitation has been only slightly below normal—1101 mm compared to a normal of 1138 mm. Months with above-normal precipitation numbered 10 in the past 18 months (November 1986 to April 1988). The declining lake levels only partially reflect this change, having dropped dramatically from record levels in 1986 to near-normal or below-normal values today. In June 1988, Lakes Ontario and Superior were below their long-term average levels, and by August 1988 the levels of Lakes Michigan-Huron and Erie had fallen below average, a situation that has not existed on Lakes Michigan-Huron since the summer of 1977 and on Lake Erie since 1968 (Ralph Moulton, Environment Canada, personal communication).

The recent dry 18 months were also warm. The year 1987 was especially warm, 1.5°C above the 20th-century average (Figure 15), and the third warmest year this century. The first two thirds of 1988 averaged 1.3°C above the long-term average, which, if the year continues warm, would make 1988 the fifth warmest year in the 20th century. Since 1983, the Great Lakes area has experienced three of its warmest seven years this century and compared to 80 years ago, temperatures are about 2.3°C warmer.

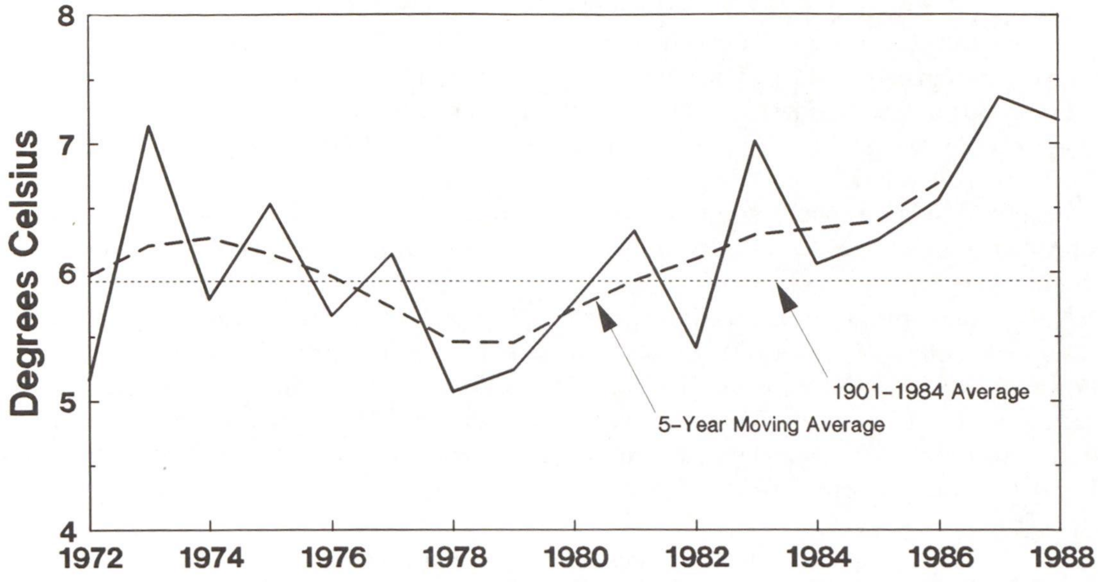

Figure 15. Average annual temperature and 5-year moving average 1972 to 1988

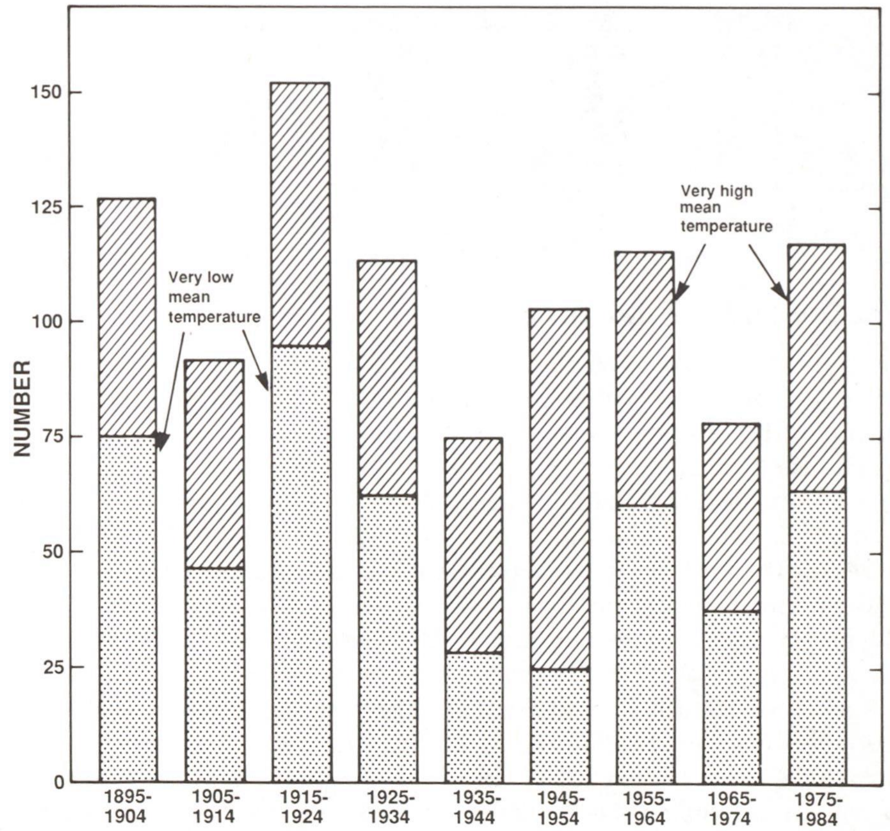

Figure 16. Number of extremes of mean monthly temperature observed from 1895 to 1984 at six stations in the Great Lakes Basin

More Variability?

The question of variability—whether more or less today than in the past—is one that everyone, farmers, grandparents, policy makers, scientists, and the media, is asking about and has an opinion on.

By many measures, variability has been high in the last two decades. But is it greater than in the past? Is the variability real or are we just more aware of the abnormalities? Could society be more vulnerable to weather extremes or have we been unlucky? Answering those questions is difficult. A substantial body of informed opinion contends that climate is becoming more variable; others have challenged this view.

A simple test of temperature variability using an analysis adopted by Asakura (cited by Mitchell, 1979) was tried for six widely spaced stations in the Great Lakes Basin. The number of temperature extremes beyond the 10th and 90th percentiles was tallied for each station for 10-year periods from 1895 to 1984. Figure 16 shows the total number of occurrences of very low (10 percent) and very high (90 percent) monthly mean temperatures. At the beginning of the first quarter of this century, the number of extremely low monthly mean temperatures exceeded the number of very high monthly means. In addition, the early years had generally a greater number of monthly very high and very low means. The middle years seemed less variable, although very high mean temperatures were more prevalent than the very low temperature means. In recent decades, the variability is moderate with about an equal number of very high (157) and very low (158) average temperatures.

A claim often made is that anomalies or abnormalities occur cyclically, at a 11-, 20-, or 30-year recurrence interval. As far as I can tell, major abnormalities occur in the Great Lakes region without any true periodicity. Few climatologists use anomaly recurrence as a basis for prediction of future occurrence.

To satisfy personal curiosity further, a nonstatistical comparison was made between the seemingly more variable 1972-1987 period and 1953-1968—a period described often as stable or benign. Climatologically, there were major differences in the amount of precipitation, as described earlier; however, the temperature was not dissimilar, and for some exotic categories, such as the number of days with clear skies, freezing rain, fog, smoke and haze at Toronto, there were no significant differences. Moreover, the earlier period had its share of severe ice (1962-1963) and early breakup (1953), heat waves (1953-1955); major storms (Hazel in 1954), droughts (1955, 1956, and 1963); early frosts (1956), flooding (1964); cold winters (1957, 1959, 1960, 1963, and 1969); and dire impacts, such as bad forest-fire season (1955), massive deer kill-off (1959), and poor recreation season (winter 1952-1953).

Climate variability and change have always existed, and I have not seen any convincing evidence that relatively abrupt shorter term fluctuations are greater today than in the past or that long-standing climate extremes are being exceeded with greater or lesser frequency today than in the past. Winters are not significantly colder and snowier, and summers are not warmer and drier than in years gone by. What I am willing to concede is that there is a greater interest in climate, and that society, as so many have suggested before, may be more vulnerable to the vagaries of climate. And to that I add that we may be unlucky today, have short memories, have constructed outmoded defenses against climate extremes, and have identified more vulnerabilities than ever before.

Conclusion

There are no simple, definite, or new conclusions that emerge from this descriptive review of climate change and variability in the Great Lakes.

- Although 90 percent of the earth's history has been recorded during warm periods, the past two million years were substantially cooler than has been usual in history and for the past 130,000 years, about 7000 years have had an annual temperature warmer than the present-day average.
- During the past 1000 years, the mean annual temperatures in the Great Lakes Basin have probably varied by less than 2.5°C.
- Major fluctuations in Great Lakes regional air temperatures are synchronous with fluctuations elsewhere in the Northern Hemisphere; precipitation variations are more difficult to associate in time and space.
- There has been an endless change of climate on all time scales in the basin and nothing to suggest that it is any more or less variable than elsewhere in the world.
- Three distinct precipitation and three distinct temperature regimes have been identified over the Great Lakes Basin during the recent period.
- The present-day (1988) temperature trend appears to be upward, the very recent (1960-1988) downward, the recent (1880-1988) upward, and the past (800 to 1988) downward.
- There is nothing in the climate record to suggest clearly what the trend will be in the next century.
- Climate happenings reoccur in the Great Lakes Basin without any true periodicity.
- The 1970's and 1980's were the wettest 20-year period ever in the Great Lakes Basin with records spanning nearly 150 years.
- The apparent high variability of climate since 1972 may not have been unusual or greater than in other periods.
- The physical geography of the basin and the characteristics of its modified continental climate—ample precipitation with a relatively low interannual variability, four distinct seasons, a location in the favoured path for North American weather systems, consistent and reliable precipitation, infrequent spells of unusually dry/wet and/or cold/warm years, and enormous water storage capacity with levels that are slow to change—give the Great Lakes region an important degree of protection and resilience to cushion the natural vagaries of climate.

Acknowledgements

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The views expressed herein are not necessarily those of Environment Canada.

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Scenarios for Future Climate Change:

Results of GCM Simulations

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Abstract: The continuing emissions of gases that are able to increase the efficiency with which the atmosphere traps infrared radiation are beginning to alter the global climate. During the next century, theoretical simulations project that global average temperatures will rise by several degrees Celsius above their pre-industrial baseline and that precipitation patterns may shift seasonally and spatially. Although research is being intensified so that detailed regional estimates can be provided, projected increases in summer temperatures and the accompanying increased evaporation, especially during natural warm excursions such as the summer of 1988, appear to pose troubling conditions for water supplies, agriculture, transport, and other activities dependent on water resources.

Introduction

With the expansion of industrial activity and mechanized agriculture in the 19th century, societal activities began having a noticeable impact on atmospheric composition. Since pre-industrial times, there have been significant increases in the concentrations of many species that control the radiative balance, and hence the climate, of the Earth. The concentration of carbon dioxide has gone up 25 percent, that of methane has doubled, and the concentrations of a new class of species called chlorocarbons have increased markedly. Observations indicate that concentrations are continuing to rise. Mankind is perturbing the composition of the atmosphere—and must now balance the consequences of this against the benefits gained by release of these species.

Projections of further emissions show a strongly upward trend that will not be easily moderated, given the importance of the energy, food, transportation, and space needs that lead to the emissions. With a 25 percent cutback in developed world emissions (which would require, for example, if done in one sector of the economy, switching all electric generation to nuclear or more than doubling fuel mileage), a policy of constant CO_2 emissions would allow less than a doubling of the developing world usage of fossil fuels (especially given population growth). Yet these nations now use only 10 percent of developed world energy levels on a per capita basis, so such a limit—which would continue rather than halt present concentration increases—would severely restrain improvements in the standard of living unless alternatives are found. While we may be able to slow the rate of increase of greenhouse gas concentrations, stopping or reversing the emission changes seems highly problematical.

The continuing increases in the concentrations of carbon dioxide and other greenhouse gases will induce environmental changes because they are essentially transparent to solar radiation, but absorb and re-radiate downward infrared radiation emitted by the surface. Such control of the global fluxes of atmospheric radiation will lead to a warming of the climate in a manner analogous to how a greenhouse becomes warmer than its surroundings.

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The great warmth of Venus, the cold of Mars and the Moon, and the moderate temperatures of the Earth all attest that the greenhouse effect is real—and that its intensification will lead to warming. The key questions concern how much the warming will be, where it will occur, what the other associated climatic changes will be, what the environmental significance of the changes may be, and whether there is enough certainty in our understanding to consider actions that move to moderate, ameliorate, or adapt to the changes.

How Much Will the Earth Warm?

Although the CO_2 and methane concentrations have varied significantly over the Earth's history (due, we believe, to causes not acting strongly today), there are no well understood or comparable analogues in the past record for the present situation. We know, however, that the Earth's climate has varied significantly due to other types of radiative forcings comparable to that which will be imposed by the increasing concentrations of greenhouse gases, but the time scales and patterns and types of forcing for these past changes were so different from the present forcing that we must rely on other methods for projecting future climatic change.

Because we cannot construct a physical model of the Earth's climate in the laboratory, scientists are using their knowledge about how fluids behave to construct theoretical models of the global climate system on computers. The most comprehensive of these models belong to a class called General Circulation Models (GCM's) that treat the full three dimensionality of the atmosphere and, in some cases, the ocean system. These models, although not necessarily containing many simplifications and shortcomings in comparison to the real world, are tested against climate changes such as the seasonal cycle and are then used in a series of numerical experiments in which the atmospheric composition is changed, sometimes by arbitrarily doubling the concentrations of carbon dioxide and sometimes other gases and, in some very recent experiments, by slowly increasing these greenhouse gas concentrations, as is occurring due to the continuing and increasing level of societal emissions. A particularly important limitation of the models is their limited horizontal resolution. For example, even the most finely gridded of the models has at most three grid points to describe California's climate—with one grid point covering central California from the Pacific to (and over) the Sierras. We cannot yet expect, nor do we yet have, model results to represent changes in the regional climate. For that, we must develop alternative techniques (e.g., as is now done in weather forecasting) for deriving local results from the large-scale model results.

In simulations to test the sensitivity of the climate to an arbitrary doubling of the carbon dioxide concentration (which is expected to have occurred over the period from roughly 1900 to 2075), the present versions of GCM's suggest that the global average temperatures would, once the oceans' temperatures have responded, rise by roughly 3-5°C (about 6-10°F), the result depending on the particular models. Model versions from earlier this decade had a broader range extending from about 1.5 to 4.5°C (e.g., see NRC, 1983; DOE 1985), so that the generally higher values of recent results have intensified scientific concern.

There are, however, processes omitted in the present versions of these models that may bring estimates down somewhat. There may also, of course, be other omitted processes that would push the values up, but the observed temperature trends over the past 130 years, during which time the global average temperature is estimated to have increased about 0.5°C (about 1°F), suggest that a much higher global temperature sensitivity would be consistent with the 25 percent increase in carbon dioxide that has occurred over this period.

In projecting how the actual temperatures will change over the next several decades, estimates must be made of the future emissions of not just CO_2, but of all the greenhouse gases. The role of the ocean's heat capacity in slowing the warming must also be taken into account. Both factors introduce uncertainties in addition to those in the GCM estimates of climate sensitivity. In the most complete time-dependent simulation yet published, Hansen *et al.* (1988) suggest that global average temperatures could warm (relatively steadily) by about 0.5 to 3°C by the year 2050, as compared to the present climate, depending on whether emissions are stringently controlled or allowed to increase unchecked at rates typical of the past few decades; their most plausible case—although projection of technological changes is inherently uncertain—suggests a warming of about 1.5°C (about 3°F) over the next 70 years. Although there is perhaps a factor of two uncertainty in this estimate, such a change, coupled with the approximately 0.5°C change from 1850 to 1980, will have moved the Earth (and its ecological system) to global warmth not experienced in 100,000 years. In addition, because the ocean slows the warming rate, even if all emissions were to be curtailed, some further warming is inevitable as the climate equilibrates to the already altered atmospheric composition.

Where Will the Changes Occur?

We are much less certain of the spatial distribution of the warming than we are that a warming will occur. The climate models generally suggest that the warming will be greatest in the polar regions as the sea ice and snow cover melts back, thereby reducing the surface reflectivity and allowing additional absorption of solar radiation to further warm these regions. In equatorial latitudes, the changes may be slightly less than the global average, but the balance between increased evaporation (which would moderate the warming) and increased high-level cloudiness (which would amplify the warming) is quite uncertain.

In mid-latitude continental regions, the warming appears to roughly agree with the global average changes. The models have, however, not yet shown significant skill in simulating the detailed regional distributions of the present climate (e.g., Grotch, 1988), so that little faith can be put in their ability to project the regional distributions of future climatic changes. (The four GCM's used by United States' scientists do not, for example, show good agreement on the regional distribution of future warming.) In addition, at least for the next few decades, the warming will not be evident everywhere and may often be submerged in the natural and so far unpredicted year-to-year variations. The extent to which this inability to project regional details is important, especially given the continuing expectation for climatic variability, may well depend on how detailed the estimates of potential impacts must be.

An important shortcoming of climate models, beyond their limitations in simulating monthly and seasonal averages, is their near inability to predict whether changes in the frequency of warm and cold climatic anomalies may occur. Very preliminary looks at this issue (Hansen *et al.*, 1988) suggest that future day-to-day variability may remain relatively steady, so that the large-scale warming can, to a first approximation, be added to the present day-to-day variability to develop an estimate of future conditions. This approach, however, deserves much more careful investigation, especially when applied in topographically complex regions, and there needs to be further efforts to consider changes in the frequency of intense storms (e.g., hurricanes), droughts, etc.

What Other Climatic Changes Are Projected?

Changes in precipitation will accompany the temperature changes, with increases in some locations and decreases in others. Not only is precipitation amount likely to change, but also its distribution, its seasonal pattern, and the fraction falling as snow. As significant for many societal activities, the evaporation rate will also increase as the surface temperature rises, which can, as the summer of 1988 demonstrated, lead to further warming when the soil moisture runs out and evaporative cooling is cut off.

The available climate models show less skill and agreement in projecting precipitation than in projecting temperature. While such large-scale features as the monsoons are reasonably represented, there is little agreement in estimates of regional precipitation changes. These discrepancies occur in part because the grid resolutions (i.e., the finest scales into which the models subdivide the world) are typically several hundred kilometers (a few hundred miles) so that clouds, thunderstorms, hurricanes, and even storm systems are not adequately treated. In addition, an approximation is made in some models to average the solar radiation over the 24-hour period, which limits the development of the convective precipitation systems that provide so much of the rainfall in the summer.

As a consequence of these model limitations, it is very difficult to quantify the hydrological changes that may impact water resources. The qualitative concerns are emerging, however; wintertime warming will lead to a larger fraction of the precipitation being rain, which has the potential, depending on the particular geographic situation, to intensify the winter/spring runoff period and reduce significantly the summertime runoff from melting snow in mountain areas. The earlier melting of winter snow and lengthening of the warm season seems likely to decrease soil moisture, leading to a lengthening of late summer dry conditions and possible concern over wind erosion of dry soils. However, the increased CO_2 levels improve the water use efficiency of some weeds and crop species, which may help reduce irrigation demands and sustain the vegetative cover. While it seems clear that water will become more precious, the extent to which climate-induced pressure will compete with other water resource considerations remains uncertain.

Climate change will also affect other variables. The rate of sea level rise is expected to increase to several times its current rate of about 15 cm/century (6 inches/century). Warmer ocean surface temperatures could increase tropical storm frequency, but this is not yet confirmed with adequate analyses. Ocean currents could change, altering fish migration rates. Warming will enhance formation of photochemical ozone near the surface, assuming emissions of reactive pollutants stay the same. For most of these, impacts on continental interiors are modest or indirect; for such regions, water resources and dependent activities will probably be most critically impacted.

What Will Be the Significance of Such Changes?

The emissions of CO_2 and the other greenhouse gases generally occur as an essential aspect of providing some beneficial results. This makes the greenhouse gas issue somewhat distinct from the acid rain issue, for which the sulfur and nitrogen oxide emissions are, or can be made to be, nonessential by-products. If society is to consider preventing the climatic changes by foregoing the benefits of the emissions of greenhouse gases (which would need to include foregoing expansion of our standard of living throughout the world with the technologies at hand), the costs of switching technologies must be less than the potential societal and climatic impacts; otherwise the options will be reduced to amelioration and adaptation.

Because the climate is a global phenomenon and international agreement will be needed if change is to be prevented or slowed, a broad-brush indication of potential effects on a global basis can serve as useful background for regional consideration. The types of potential impacts can be roughly categorized into a few major groups:

1. **Human health**: The direct effects of the emitted gases are believed to be small. In already warm areas, the warming would stress human health (depending on adaptation measures such as air conditioning), but in cold areas it might reduce stress. Diseases and pests may be more prevalent, but preventive or control measures may be possible.
2. **Food supplies**: A CO_2 increase enhances growth of some food crops and increases water use efficiency. Changing climatic patterns could require changes in cropping patterns and consequent infrastructure costs, perhaps bringing benefits to some regions while negatively impacting others. Unfortunately, weedy plants such as kudzo seem best prepared for the CO_2 increase.
3. **Water resources**: Rising snowlines, shifts in precipitation patterns, and increased evaporation will make water a more valuable resource.
4. **Habitat**: Rising sea levels will endanger coastal areas, initially most during storm surges, and lead to salt water intrusion into coastal estuaries and aquifers. Projections are for sea levels to rise by about 0.5 to 1.5 meters (about 1 to 5 feet) by 2100, which could inundate large low-lying areas. Permafrost areas may melt, making construction difficult.
5. **Ecosystems**: Shifting temperature and moisture patterns will induce competitive changes in ecosystems that will lead to shifts in composition and range of the various species at rates much more rapid than in the last 10,000 years as we warmed up from the last glacial maximum. The adaptability of natural systems to such conditions is poorly understood.

The projected changes in global average climate are unprecedented in historical times—at least for activities and systems living in particular locations and dependent on multiyear average conditions. (Of course, people moving from the northeastern to southwestern United States, for example, experience a much larger climatic change than will be induced by the increase in greenhouse gases.) If indeed current anomalous years become the new average state, and such a change happens relatively rapidly, the world's relatively steady climate of the past few thousand years will no longer be the baseline on which society can depend.

Does Scientific Understanding Justify Action?

That the greenhouse effect is real is certain—without it the Earth would be a frozen ball of ice. The rising concentrations of greenhouse gases have been definitely observed—and society's contributions to these changes are becoming quantitatively understood. The critical questions concern the extent and distribution of the expected climatic changes in response to the changes in atmospheric composition. That the magnitude could well be degrees rather than tenths of degrees over the next hundred years seems certain, but the details of the regional temperature, precipitation, and soil moisture changes remain uncertain. From the scientific results, it is clear, for example, that actions to reduce emissions (e.g., conservation, efficiency improvements, shifting fuels to natural gas, technology substitution, etc.) could slow the rate and ultimate magnitude of climate change. It is much less certain, however, whether new dams are needed to protect against winter flooding and to provide moisture for summer agriculture or whether we need to desalinate more water.

Intensified scientific efforts have begun to develop better estimates of future climatic changes. While this is in progress, an intensified effort is needed to identify the sensitive aspects of the environmental and economic domains, both as a step to begin consideration of potential ameliorative and adaptive actions and to provide a basis for focusing and directing the research program toward determining critical parameters and sufficiently reducing uncertainties.

Acknowledgement

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Climatic Sensitivity Of the Great Lakes System

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Introduction: The Great Lakes System

In this overview we attempt to identify points of climatic sensitivity of the Great Lakes, considered as a natural system that interacts strongly with human economic activity.

As many others have pointed out, the Great Lakes are an isolated system only in the hydrological sense, and only if that expression is taken to refer exclusively to surface runoff and basin discharge. In no other sense can one draw a meaningful line that encloses a Great Lakes system.

The human economic system at work within the Great Lakes Basin is, for example, in no way isolated from the rest of Canada and the United States, or indeed from the global economy. Secondly, there is free movement into and out of the basin of water vapour, contaminants, and biotic and genetic information, all borne by the free-flowing winds and their associated storm systems. There is an analogous but slower exchange below the surface within soil and ground water. And finally, the major terrestrial life-zones ignore the basin boundary. The Great Lakes St. Lawrence Forest, for example, extends across the basin from the Mississippi headwaters to Quebec and New England. Lakes Michigan, Erie, and Ontario project marginally into the Deciduous Forest formation, which extends far beyond the basin. And northern Lake Superior touches the great circumpolar Boreal Forest formation.

The remarkable economic advantages conferred by the Lakes and their connecting channels nevertheless give partial coherence to the human economic system within the basin. Few parts of this economic response are themselves confined to the basin. The specialised inland shipping fleet that plies their waters used to be confined to the Great Lakes-St. Lawrence Waterway, but modern vessels are increasingly designed to operate on the open seas. The Waterway is wide open to ocean shipping, and both fleets in any case serve markets external to the basin. In effect, the Great Lakes Basin acts as a gathering point for human initiative; as a site for heavy industry, and for prosperous agriculture and forestry; and for a diverse suite of recreational and residential opportunities. Only the surface waters themselves are obliged to stay with the basin boundary, until they reach the Gulf of St. Lawrence and the Atlantic Ocean.

There are many other inland waterways in the world, characterised, like the Great Lakes, by multiple economic uses. Many extend over more than one political jurisdiction. But in one particular there is no close parallel to the Great Lakes-St. Lawrence system: That two sovereign powers face one another across the waterway for most of its length, and have hence been forced to create effective joint systems of management, and joint agreements as to objectives—among them the International Joint Commission and the Great Lakes Water Quality Agreements. This symposium is itself yet another expression of the need for such bilateral accord (or multilateral, if allowance is made for the federal character of both national governments).

But we should clearly not ignore other situations. The Rhine is perhaps closest, France and the Federal Republic of Germany being the left and right bank parties for part of the way. But the headstreams lie in Switzerland (with minor contributions from Liechtenstein

***Climate Program Planning Board and Canadian Climate Centre**

and Austria), and the alluvial deltaic lower course lies in the Netherlands. The Danube traverses the territory of FRG, Austria, Hungary, Czechoslovakia, Yugoslavia, and Rumania, and touches those of Bulgaria and the Soviet Union. The river forms an international boundary in no less than four separate reaches. Maintaining water quality, quantity and levels, and sorting out the claims of competing users of these two rivers, have given every major European political body an unending headache, among the sufferers being the European Community, the Economic Commission for Europe, and even the North Atlantic Treaty Organisation. The Europeans have been much less successful than we have in sorting things out.

And there is no close physical comparison, either. The Great Lakes occupy almost one third of the basin's surface, and the St. Lawrence itself is comparatively short, merging below Trois Rivières into the Gulf of St. Lawrence, one of the world's largest marine estuaries. In effect the entire hydrological system consists of three parts: the Lakes, the St. Lawrence, and the Estuary. All Canadian provinces east of Ontario have a stake in the system—and if Canada has a legitimate interest in wholly-U.S. Lake Michigan, the U.S. has an equally legitimate interest in the Gulf of St. Lawrence, which is a gateway to the Midwest.

Other river systems exist, of course, in which large lakes form part of the course. The prime case is the Mackenzie, an even larger river than the St. Lawrence. The Saskatchewan-Nelson is another within Canada. Certain major rivers, such as the Volga, actually discharge into inland salt lakes, like the Caspian. But nowhere on the world map is there any real competition for the Laurentian Great Lakes, as they may be called.

Why do we put such emphasis on interbasin, intercontinental comparisons? Because climatic changes due to the greenhouse effect will themselves be felt in every other basin. Discussions like those we are holding here in Chicago are proceeding in many other places. One of us (FKH) just attended an excellent parallel event in New Zealand. Previous experience suggests that the worldwide effects of the greenhouse warming will be unequal as between regions, though the details cannot yet be predicted. It is important to be alert to the plans, conclusions, and innovations of other jurisdictions, as Canada and the U.S. prepare their own responses.

The Impending Change in Climate

The possible effects of the greenhouse warming on the Great Lakes region have been widely discussed elsewhere, and will be known to most people in this audience. Only a summary will be presented here. We have drawn extensively on Great Lakes studies by Cohen (1986, 1987), Quinn (1987), and others, and on the technical literature in meteorology and climatology, as cited below.

The buildup of certain trace gases in the atmosphere, primarily as the result of human interference, is increasing the resistance to the upward flow of energy from the earth's surface to space, while leaving largely undisturbed the incoming flow of solar energy. The result should be, according to theoretical analysis, a rise of temperature at the earth's surface, and a cooling of the middle and upper stratosphere (essentially the layer between 20 and 50 km above the surface).

In fact both trends have been observed on a global scale (see, e.g., Angell and Korshover, 1983). Jones *et al.* (1986, 1988) have shown that both hemispheres have undergone a surface warming of approximately 0.7°C since 1865. The effect in recent decades is, however, very unequal as between different places (Jones, 1988). In the Great Lakes region recent trends have been analysed at this conference by Phillips (1988). The observed global rise in temperature is consistent with predicted values from models of the greenhouse effect (Villach, 1985; Hansen, 1988). Nevertheless it remains highly controversial as to whether the warming has been so caused (see, e.g., Maddox, 1988; reply by Hare, 1988). Hare's view, which has been widely challenged, is that the best explanation for the warming is indeed the greenhouse effect, and that it is wise to assume that the warming will continue and accelerate—and show itself in regions where, as in the Great Lakes Basin, the signal is not yet prominent.

Estimates of the magnitude and pattern of the future warming must be based on predictive models. In the absence of any real evidence of regular periodicities (and we know of no significant truly periodic effects in the temperature or precipitation records), such models must be dynamical. The general circulation models summarised by MacCracken (1988) make it possible to simulate future changes in net basin water supply, as well as of surface temperatures and their spinoffs (such as length of growing season and period of freeze-up). Many uncertainties attach to such predictions.

Two such models in particular were used by Cohen (1986, 1987b) to estimate future net basin supply. These were due to Hansen *et al.* (1983) of the Goddard Institute for Space Science (the GISS model) and to Manabe and Stouffer (1980) of NOAA's Geophysical Fluid Dynamics Laboratory (the GFDL model). The latter is one of many variants due to Manabe's group. Cohen used a variety of scenarios based on these models to estimate hydrological impact on the Lakes.

It has become apparent that the augmented greenhouse effect is due as much to other trace gases (such as chlorofluorocarbons, nitrous oxide, and methane) as to carbon dioxide (Villach, 1985). Given the observed rate of buildup, an equivalent carbon dioxide doubling may occur by the year 2030, disregarding any delaying effect by the heat-absorbing capacity of the oceans. A doubled greenhouse effect by this date implies quite rapid changes of surface temperature, with associated precipitation changes. Cutting through the detail involved, such a doubling would imply (see Cohen, 1987b, for details):

- Strong rises in winter temperatures over the entire basin, with corresponding decrease in freeze-up period, and hence of the extent of winter ice
  [The GISS and GFDL models differ between themselves as to the magnitude of change. GISS in general calls for a rise of 4.5° to 6.0°C in monthly mean temperatures between October and March. GFDL predicts similar changes, but with a wider extent of uncertainty, and lower mean values of change, though the latter qualification does not apply to a more recent GFDL model (Manabe and Wetherald, 1986, 1987).]
- Warmer summers, of order 2° to 5°C warmer than today, with consequent increase in heat storage in the lake waters
  [The GISS and GFDL models again differ as to details and magnitudes for individual seasons.]
- Probable changes in monthly precipitation, evaporation, and runoff values, leading to decreased net basin supply
  [Table 1 (after Cohen, 1987b) shows an estimate of the potential impact on basin supply for the base case (N/N in Table 1) and for a variety of other possible scenarios identified in the legend.]
- Sharply increased soil moisture deficits during the growing season with some differences between the GISS and GFDL model estimates

Individual years occur in the present-day climate in which anomalies equal or exceed those predicted by the model calculations. Thus net basin supply in 1965 (including consumptive use of perhaps 2 percent) was 25 percent below the average value for the

Great Lakes Basin, a shortfall exceeding the base-case predictions based on either general circulation model. Similarly the temperature anomalies in 1982-1983 were comparable with predictions for a doubled greenhouse effect. Ice barely formed in the lakes, and winter navigation would have been largely unimpeded. It is thus possible to observe some of the physical and biotic responses to warmer and drier conditions, at least in single years. The same is true to a much less extent of human response, because foreknowledge of such anomalous years is lacking.

The GCM's do not permit a truly satisfactory treatment of the hydrological balance over the basin. Quite apart from the coarseness of the grid points for which predicted values are provided (e.g., 10 interpolated points within the basin for GISS, and 7 model points for GFDL), the models do not provide credible regional detail. Large differences exist for example between the temperature and especially the precipitation patterns over the basin between the two models cited by Cohen (1986; 1987b). Moreover it has been shown (Schlesinger and Mitchell, 1985; Grotch, 1988) that over such relatively small areas the detail differs not only between models, but also from the historical climatology; the models do not perform very well in relation to the modern climate, on the spatial scale of the Great Lakes. To quote Grotch (page 1), "The poor agreement between model simulations of the current climate on the regional scale calls into question the ability of these models to project the amplitude of future climatic change on anything approaching the scale of only a few ($\leq$10) gridpoints, which is essential if useful resource assessment studies are to be conducted."

These uncertainties led Cohen (1986, 1987b and c) to substitute contemporary climatic normals as the base to which model anomalies could be added, and to use indirect Thornthwaite-based estimates of evaporative losses in the calculation of future soil moisture deficits. He also utilized eight historical scenarios for comparative purposes (Cohen, 1987b). Six of these resulted in decreased net basin supply, the worst case being -26.5 percent. The remaining two indicated increases of 6 percent or less. Assumed changes in wind and humidity showed results similar to those in Table 1.

Notwithstanding these reservations, it is our opinion that a doubling of the greenhouse effect (including that due to gases other than carbon dioxide) is most likely to lead to:

- A reduction in annual net basin supply, probably in the range 15-25 percent below the current mean value
- Corresponding changes in lake levels and outflows (see below)
- Large increases in soil moisture deficit in the period May-September, the principal growing season, which will be several degrees warmer, and hence longer
- A decrease in the extent of winter ice-cover, to later freeze-up and earlier break-up (Sanderson, 1987) (By the time of effective doubling there will be little ice in most of the lakes at the height of winter in a normal season.)

We propose to leave these statements in their largely qualitative form. We doubt whether much more detailed estimates are justified in the present state of the general circulation modelling art.

Impact of Climate on Water Levels and Outflows

Intermediate between the changes of climate and human responses to those changes comes the question of how water levels and outflows in each lake's basin will be affected. Over the entire Great Lakes Basin, the net supply equates over a period of years to the discharge at Cornwall into the St. Lawrence system. But the gross changes foreseen for the entire basin—a sharp decrease of order 15 to 25 percent in net supply for a doubled

Table 1. Projected Percentage Changes in Net Basin Supply for the Great Lakes for a Doubled Greenhouse Effect (neglecting altered consumptive use).

Model	Scenarios			
	N/N	-20%/N	N/+10%	N/-10%
GISS	-23.6	-7.0	3.9	-51.1
GFDL	-16.9	-2.7	8.5	-42.3

Key: Scenarios are for various assumptions as regards windspeed (numerator) and vapour pressure (denominator)

N/N: base case, using present normal winds and vapour pressures, plus model temperature and precipitation changes

-20%/N: windspeeds 20% reduced

N/+10%: vapour pressure raised by 10%

N/-10%: vapour pressure reduced by 10%

The high sensitivity of net basin supply to assumed values of wind and vapour pressure is made very clear.

Source: Simplified from Cohen (1987b)

Table 2. Equilibrium Effect of Reduced Net Basin Supply (NBS) on Lake Levels.

Lake	NBS Reduced 15%	NBS Reduced 30%
	Change in lake levels (cm)	
Michigan-Huron	-77	-156
St. Clair	-60	-125
Erie	-51	-106

Source: Quinn (1987)

greenhouse effect at equilibrium—must be translated into more detailed estimates for the individual basins. Moreover there will be large interannual and even interdecadal variations in levels and outflows, since the variability of climate over the basin is very high even in the absence of actual change to a new equilibrium.

Noting, as we have done, the uncertainties involved in the climatic models available, Quinn (1987) calculated (using the period 1962-1980) the lake level lowering corresponding to 15 and 30 percent reductions in net basin supply for Lakes Michigan-Huron (which are interconnected), St. Clair, and Erie. Superior and Ontario are regulated lakes, and were not calculated. Quinn's result is in Table 2.

Quinn points out that present-day mean seasonal variation of lake levels is in the range of 0.3 to 0.4 m, with the range between mean annual maxima and minima about 1.5 m. Hence the changes projected in Table 2 are highly significant. Quinn's earlier estimates are now being supplemented by a more detailed sub-basin by sub-basin estimate of the change (Croley and Hartmann, to be published).

A similar but more detailed basin-by-basin analysis was carried out (but also unfortunately not published) by Southam and Dumont (1985), using the 1984 version of the GISS model. Lake Ontario was again omitted, the lake being regulated. The authors note that the system of regulation will be unable "to address the large decrease in water supplies projected..." Table 3 summarizes their results.

The Southam-Dumont analysis does not suggest that a doubled greenhouse effect will reduce the annual *range* of lake levels, but it does confirm a general decrease in these levels except in regulated Lake Superior. In the unregulated middle lakes (Michigan, Huron, St. Clair, and Erie) mean levels will drop by 45-60 cm, and extreme low levels by comparable amounts. These results are like those reported by Quinn. Southam and Dumont estimate a diminished annual outflow of the middle lakes of 12-13 percent, and of the entire Great Lakes Basin of 15 percent, at the lower end of the range of reduced net basin supply suggested in this paper.

Another relevant issue full of uncertainties is future consumptive use of Great Lakes water. In 1981, the International Joint Commission (IJC, 1981) predicted much increased use (to about 10 percent of net basin supply) in the next few decades, mainly as new thermal-electric plants come on stream. Increased demand for municipal and agricultural purposes can also be expected (Cohen, 1987b; Quinn, 1987; Smit, 1987). A revised estimate (IJC, 1985) taking into account lowered expected demand for electric power puts consumptive use in the year 2000 at 238 $m^3 s^{-1}$, or 3.4 percent of present day net basin supply (as against the present level of 2 percent).

Rising consumptive use—in effect, water evaporated by human industrial, municipal, and agricultural use, and hence lost to net basin supply—is thus small by comparison with projected losses arising from climatic change. But it is far from negligible, especially if there are demands for increased diversions out of the basin at Chicago or elsewhere.

We conclude that there is likely to be a sharp drop in water levels and outflow as the result of projected climatic change, and that increased consumptive use of the water, though a smaller potential loss, will act in the same direction.

Economic and Social Impact

The above results, if physically realised, will have significant and mounting effects on the human economy within the Great Lakes Basin. Several effects have already been identified, and some effort has been devoted to attaching numbers to them. A summary here will be useful to those not regularly involved in climatic impact analysis.

The sectoral impacts identified include at least the following cases:

- Use of the Great Lakes waters for navigation by inland and sea-going shipping (negative in impact as regards lake levels, positive as regards effect of ice on navigation)
- Use of the waters for fresh-water fisheries
- Recreational use of the waters and shorelines, including the welfare of shoreline communities
- Use of waters for hydroelectric power production, and for supply of cooling waters to nuclear and thermal generating stations

Table 3. Calculated Great Lakes Water Levels (Above Sea-Level) and Outflows.

Lake	Assumed Recent Values (as basis of comparison)		Values Resulting From GISS Model, Doubled Greenhouse		Percentage Change In Outflow
	Levels (m)	Outflows ($m^3 s^{-1}$)	Levels (m)	Outflows ($m^3 s^{-1}$)	
Superior					
Mean	183.01	2,204	182.80	2,209	+2
Annual Range	1.04	1,926	1.19	1,926	
Michigan-Huron					
Mean	176.26	5,236	175.67	4,599	-12
Annual Range	1.74	3,398	1.79	2,577	
St. Clair					
Mean	174.83	5,347	174.35	4,689	-12
Annual Range	1.84	3,341	1.73	2,690	
Erie					
Mean	173.97	5,867	173.53	5,086	-13
Annual Range	1.68	3,341	1.76	3,200	

Source: Southam & Dumont (1985)

- Use of the waters by municipal water supply authorities, and for agricultural irrigation systems
- Water quality implications of altered flows, ice regimes, and water temperatures
- Altered opportunities for agriculture and forestry
- Altered costs and physical requirements for municipal sewerage operations

These sectoral impacts will, of course, be interconnected. We reproduce here Cohen's (1986) attempt (Figure 1) to explain how climatic variation leads to *direct* effects on the human ecosystems in the basin, and hence (via new lake levels and outflows, additional withdrawals, consumption of water, and altered diversions) to specific sectoral impacts. These combine to influence the regional economy, as measured by income, investment levels, employment, and input-output relationships.

The analysis of this complex system has barely started, largely because of the uncertainties attached to the climatic scenarios, but also because climatic impact assessment is a new and challenging art (see, for example, Kales *et al.*, 1985; Parry *et al.*, 1988). Among the preliminary studies already published, we note particularly the following:

1. An analysis by Smit (1987) and colleagues at the University of Guelph of the implications of climatic change for agriculture within Ontario. Using the GISS and GFDL doubling models as a basis for this study, Smit found that:
   - The raised temperatures may permit corn, soybean, and other corn-belt crops to become viable in northern Ontario, but to become risky in southern Ontario, where drought conditions will impair production
   - Horticultural crops (fruits, vines, vegetables) may replace ordinary field crops in much of southern Ontario
   - Profit levels, but also risks, may increase for many farmers

- Without adjustment to the new conditions, a greenhouse doubling will cost Ontario farmers over $100 million per annum in lost production

2. Analysis by Wall (1988) and others at the University of Waterloo of the implications of the impending changes for tourism and recreation in Ontario. Proceeding via case studies, the group found no simple picture of gain or loss from either the GISS or the GFDL scenarios. But significant changes would affect wetlands and wetland-based recreation, largely because of disturbance from falling water levels. The ski season would be reduced. In northern Ontario this would not affect the key holiday seasons, and hence revenues; but in Georgian Bay, and by implication further south, the effect of shortening the season would be critical. Summer opportunities, by contrast, might well benefit.

3. Studies by Sanderson (1987) and others at the University of Windsor concerning the implications of the GISS and GFDL doubling scenarios for navigation and hydroelectric power production. Sanderson took note of the probable reductions in water levels and outflows, finding that, in eight years out of ten under the doubling scenario, low levels comparable with those of the 1930's and 1960's would occur. She concluded that:
   - An eleven-month ice free shipping season would become the norm, only Lake Erie retaining a significant ice problem
   - Increases in cost to the Canadian Great Lakes shipping companies for the chief cargoes (iron ore, grain, coal, and limestone) may be roughly 30 percent, with costs equalling or exceeding 1963-1965 levels nine years in every ten (in constant dollars)
   - Decreased flow at the Canadian generating stations on the Niagara River and elsewhere would lead to a loss of 4165 gWh of energy (equivalent to about 2.7 percent of predicted total energy production in 1993) (Replacement costs for this lost energy would be of the order of $111 million 1984 Canadian dollars per annum.)
   - On the Canadian side of the Great Lakes, the predicted temperature changes will lead to a significant decrease in winter power consumption, partly offset by a small rise in summer demand (mainly because of air conditioning increase)

4. A study by Linder and Gibbs (1987) of the potential impacts of a doubled greenhouse effect on electric utilities in New York State, as compared with a southeastern U.S. utility. They found that:
   - The effects of climatic change, as predicted by the available suite of models, will significantly affect demand as well as supply of electricity, at least on the U.S. side of the Lakes
   - The impacts arising from demand changes are likely to be largest for large utilities with heavy weather-sensitive air conditioning loads. In the northern U.S., presumably including the Great Lakes region, there is still scope for a higher level of saturation of air conditioning. The effect is likely to be greater on *peak* demand (capacity requirements) than on energy consumption (generation requirements)
   - The temperature changes predicted by the models will not seriously affect the efficiency of power generation by any mode, but decreased flow in hydroelectric stations will obviously have a large negative impact

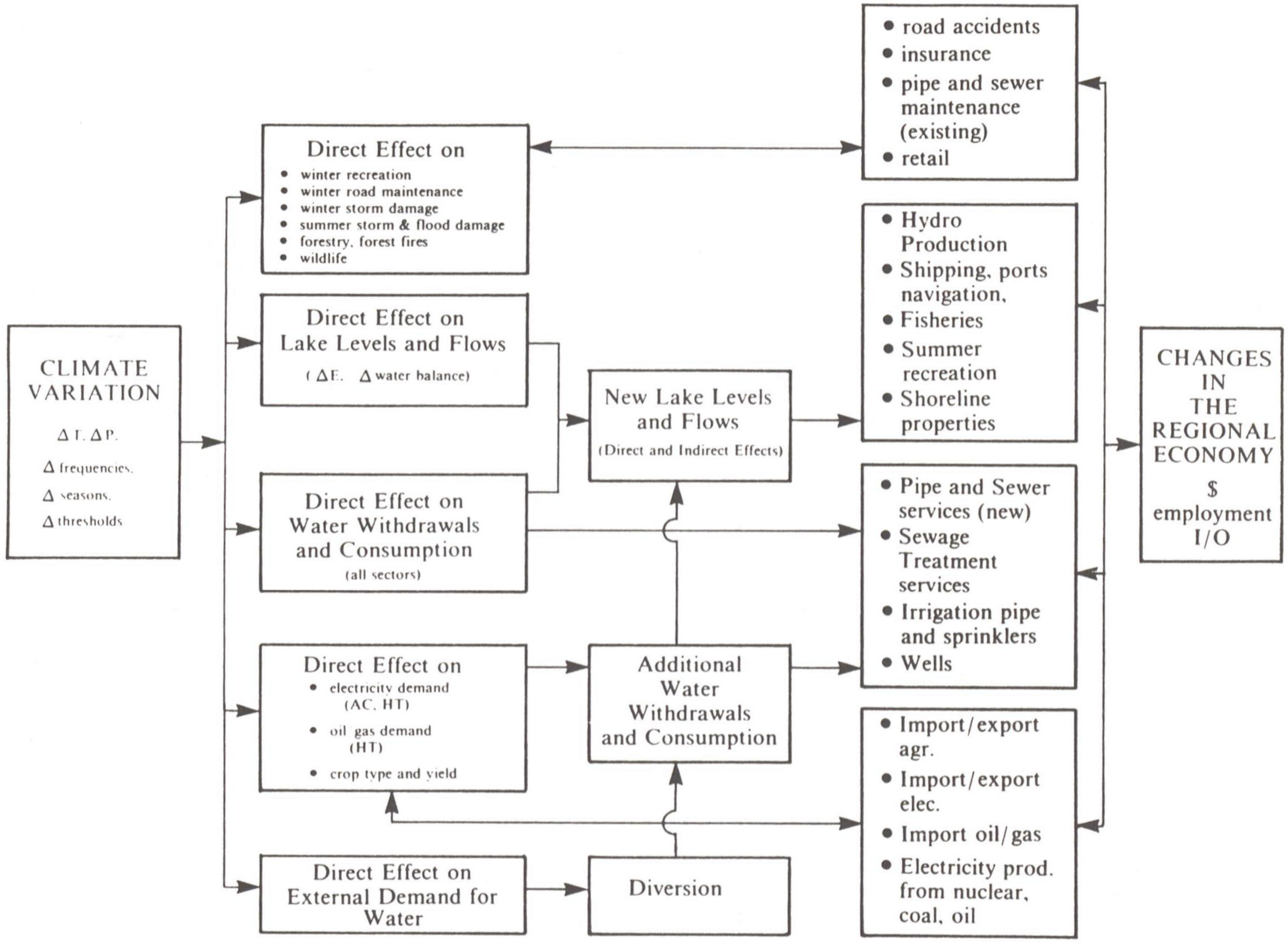

Figure 1. Interconnected components of climate impacts and societal responses within the Great Lakes region
Δ = change; T = temperature; P = precipitation; E = evaporation; AC = air conditioning; HT = space heating; I/O = inputs/outputs. Source: Cohen (1986).

These studies are obviously tentative and will need to be pushed much further. But they do suggest that a doubled greenhouse effect (possibly by the year 2030) will have a significant impact on the regional economy, and that the results will be mainly unwelcome. They also suggest, however, that their negative impact can be lessened by forethought and planning, especially in the realms of current long-term capital investment and technological research.

Conclusion

Our first conclusion is that there is enough evidence of an impending warming to justify immediate attention.

We qualify this by remarking that the firm evidence is actually of a global warming over the *past* century. This has not shown itself unequivocally in the Great Lakes region itself. There is no evidence of which we have knowledge of any equivalent change in precipitation. The very striking interannual variations of the past three years, and the much longer term variations in lake levels are not evidence of lasting climatic change. But the best available theory is consistent with the observed changes of temperature since 1865. Hence it is reasonable to assume that the predictions of these models will indeed be realised.

We agree with Schlesinger and Mitchell (1985) and Grotch (1988), however, that the GCM's used in most quantitative approaches to the prediction of future changes are unsatisfactory on the geographical scale of the Great Lakes region. Nevertheless, the warmer and in general drier conditions predicted by the models are consistent with derived scenarios based on historical evidence. We therefore conclude that planning should allow for possible reductions of net basin supply in the next few decades in the range of 15 to 25 percent of present-day values. Such reduction, if realised, will have significant and largely negative results for the human economy—which should be allowed for in contemporary planning and impact research.

What we have ignored, and what cannot be ignored much longer, is a whole suite of complex changes in the natural environment. These include, for example, the impact on the forests and wetlands of the basin, and on the limnology and fresh-water ecology of the lakes.

We are conscious, in closing, of the limitation of our understanding of how such impacts will be absorbed by the economic and social systems within the basin. The impact studies reported in this paper have concentrated on readily measured direct impacts and their putative costs. In practice, a market economy of the kind both countries practice adapts continually to perceived changes; it does not wait for official action or sanctions before taking precautionary measures. Once it becomes the received wisdom that the greenhouse effect is really in progress, the task of governments will be to keep up with the adaptive measures that will be taken spontaneously. Individual institutions and consumers will then make the pace—as the individual voter will do on election days.

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Everything Else Will Not Remain Equal: The Challenge of Social Research In the Face of a Global Climate Warming

Peter Timmerman*[1]

"The future state of society would be perfectly known only in a perfectly static society—a society whose structure would always be identical and whose map of the present would remain valid for all time!....But as soon as a society is in movement, its familiar traits are perishable: they disappear, some more rapidly than others....To say the movement is accelerating is to say that the length of time for which our Map of the Present remains more or less valid grows shorter. Thus our knowledge of the future is inversely proportional to the rate of progress."

—Bertrand de Jouvenal, *The Art of the Conjecture*

"No bears have come because there is no ice, and there is no ice because there is no wind, and there is no wind because we have offended against the powers...."

—An eskimo, cited in Godfrey Lienhardt, *Social Anthropology*

Introduction

My presentation is, in the first instance, a warning. It is a warning to both policy makers and researchers about what can be expected from the social sciences in the way of useful and applicable results from climate impact studies. It is perhaps particularly relevant as a warning for a conference devoted to possible regional impacts from climate change; but it may also be timely in light of the recent summer's events. The rapidity—almost desperation—with which the climate bandwagon is being mounted suggests that the time has come to speak a few blunt home truths about climate impact research in the social sciences, before the whole subject becomes discredited by some of the claims and expectations now proliferating. I am deeply concerned that if some of these claims become the basis of public policy, and they falter, other attempts to cope seriously with the climate issue will lose credibility with policy makers and the public, thereby delaying us further at this already late hour.

My title, "Everything else will not remain equal," is also designed as a challenge, since it reveals the weakness at the heart of much of what has passed for research in this area. We have all read, and in some cases been party to, slightly hedged predictions of how much the climate warming is going to cost. If we take a sector such as transportation for example, this usually begins with the assumption that temperatures and lake levels will go up or down over the next 50 years, which will then translate into increased or decreased transportation costs based on seasonal opening and closing times or the shallowness and depth of ship draught; all finally calculated into future dollar costs. Having thus piled these uncertainties one atop the other, there is then added some version of a saving clause: *if* technology stays

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[1]Superscript numbers refer to the endnotes of this paper

the same as in 1988, *if* the economic system remains the same, *if* international trade competition is ignored, or, as a blanket saving clause, ***if everything else remains equal.*** I refer to this as the EERE clause.

I submit that the only thing we can predict with 100 percent accuracy is that everything else will not remain equal.

Therefore, much of what is being said cannot survive close scrutiny. Why then, honestly, is it being said? First of all, on the supply side, we put large numbers forward so as to get attention. Second, on the demand side, the system demands numbers however inadequate, since politics, as someone once said, is often a version of that art form known as "crayoning by numbers." Third, and less venally, we put forward these numbers in order to give people a sense of the magnitude of the issue—a "ballpark figure" as the phrase has it. Fourth, and here we begin to move into the gray area, there are some things that we can say with some confidence are likely to still be with us in 30 years time, unless there is a nuclear war. Fifth, and perhaps most important for the charge to this conference, is the way in which social science research in this area has been channeled, modelled, and conceptualized until very recently.

The model of social impacts due to climate which is commonly used is based on 1) a tendency to focus on impacts as first-order, second-order, etc., causal chains working through a basically frozen social system; 2) a tendency to focus on simple extrapolations from current conditions; and 3) a tendency to focus on dividing the world up into sectors. This is supposed, in turn, eventually to match up to regional climate impact information derived from physical global models, information which cannot currently—or perhaps ever—be made on the detailed scale required. By operating within this model (or variants), policy makers find themselves unable to use their own expertise, since they are hamstrung by the vagueness of what they are given to work with. Inevitably, they are led into cost extrapolations and EERE clauses.

This, I would argue, is a bad way to think about social policy in this area; and my presentation is in part an attempt to argue that there are other alternatives available which can assist in helping us break the strangle hold of these linear and mechanical models of social processes.

To make this point more forcefully, I want to begin the first part of my substantive presentation by sketching very briefly the recent history of climate impact research in the social sciences, so as to give you some background as to what got us into this fix, the current state of the art, and an idea of how conceptually naive much of the work being done really is. Then I want, in the second part of my presentation, to try to show some of the hard issues at stake for the progress of understanding and the internal development of the social sciences. Having then dug this deep pit, I want finally to try to clamber back out again by pointing out ways in which future research in this area might be improved, and how social thinking might actually contribute more usefully to the climate issue. All this, I hope, will give researchers a more useful context within which to deliberate upon our future social options with regard to long-term climate changes.

"Three Generations of Research"

The history of climate impact research in the social sciences can be characterised as an oscillation between overly vague notions of climate-society interactions, and very specific physical cause-effect analyses which become more sophisticated as time passes. If we look at the recent research history, we can discern roughly "three generations" of impacts work.

SELECTIVE HISTORY: CLIMATE SOCIO-IMPACT ASSESSMENT

PRELIMINARY:

HIPPOCRATES
MONTESQUIEU
HUNTINGDON

FIRST GENERATION
(1945-1965)

CONCEPTUALISING CLIMATE

ASSIMILATING BASIC "WEATHER" DATA

LOCAL, ACUTE EVENTS

SECOND GENERATION
(1965-1985)

Phase 1:

INITIAL DATA LINKS (e.g. AGRICULTURAL IMPACTS)

NATURAL HAZARDS WORK

HISTORICAL/SOCIAL THEORY (e.g. CLARK UNIVERSITY)

Phase 2:

INTERDISCIPLINARY

INITIAL COMPUTER MODELS FOR SOCIAL PROCESSES

MAJOR STUDIES

INITIAL POLICY FRAMEWORKS (e.g. VILLACH)

THIRD GENERATION
(1986 +)

DETAILED COMPUTER MODELLING

STRATEGIC PERSPECTIVE

POLICY ISSUES BECOME PART OF PUBLIC AGENDA

Figure 1. Three generations of research

The first generation (Figure 1) operated roughly between 1945 and 1965. Various theories of how climate shaped human society had been put forward before this, by a range of geographically or anthropologically minded scholars. With the rise of serious scientific meteorology and initial attempts to conceptualise the science of climatology, this kind of broad speculation disappeared from serious scholarship for awhile, under the avalanche of the new data and discoveries in meteorology in the 1930's and after. In the "first generation" of impacts research, the only area in which data collection and interpretation could be made rigorous according to the canons of the time was in those climate impacts that were localised, acute, single events and therefore susceptible to quantification (e.g., costs of hailstorms on orchards).

It was out of this research area, it can now be seen with hindsight, that natural hazards researchers (mainly geographers) developed the main line into the "second generation" of research. By the middle and late 1970's there were struggles to try to expand from short, sharp shocks towards the understanding of such large sustained events as drought; and also to return to the broader questions of climate-society interactions by eclectic searches through various disciplines (e.g., social anthropology, general systems theory, archaeology) for appropriate theory. In particular, efforts were made to examine previous historical epochs for analogies and insights (e.g., the 1970's Clark University comparative study of Ancient Iraq, the colonial Sahel, and the American West). It should be emphasized that much of this research continued primarily to reflect a quantitative impacts approach based on physical geography, trying to relate social responses to "drought indices," etc., although attempts were made to formulate some more general hypotheses.[2] The overall mental picture, however, can be characterised by examining a well-known impacts diagram from Warrick and Bowden (1981), where we find pictured a domino or "pinball effect," as drought is injected at the entry point to the system and then bounces through the society, having impacts and causing stresses (Figure 2).

The spectacular climate anomalies of 1972-1973 (and related sociopolitical events) gave a new impetus to impacts research, which began to emphasize global "teleconnections" between disparate events linked perhaps to longer-term changing climate patterns, and also began to explore new elements of the social dynamics involved in climate-related activities (e.g., Glantz and Thompson's 1981 work on the El Nino phenomenon off the Peruvian coast, and subsequently Glantz *et al.*, 1987) (Figure 3). The climate events and their sociopolitical linkages, combined with the oil price rises, suddenly made Western society conscious of the potential fragility of elements of the vast industrial superstructure that kept it going. In addition, the controversy over the possible impacts of supersonic airplane transport (SST's) resulted in the first official climate impact assessment project in the U.S.A., thereby drawing economists and others into the field, and also thereby bringing them face to face with the problem of teasing out climate impact information from the vast array of information and social dynamics characteristics of any complex society (Climate Impact Committee, 1975).

Among the new range of disciplines now reconsidering climate as an issue, historians (especially economic historians) perhaps wrestled most directly with the question of the complex relations between climate and society. New efforts were made to collect and interpret detailed data such as dates of harvests and glacial advances and retreats in modern times; as well as to try to extend the historical record through re-evaluation of prescientific diaries and journals. These were then tentatively applied to historical events such as the bread riots in the years before the French Revolution. Speculation about the historical role of the deterioration of the climate in the late Middle Ages and the Renaissance (The Little Ice Age) found its way into journals of interdisciplinary history (Rotberg and Rabb, 1981) and new general histories of these periods (Parker, 1979). The

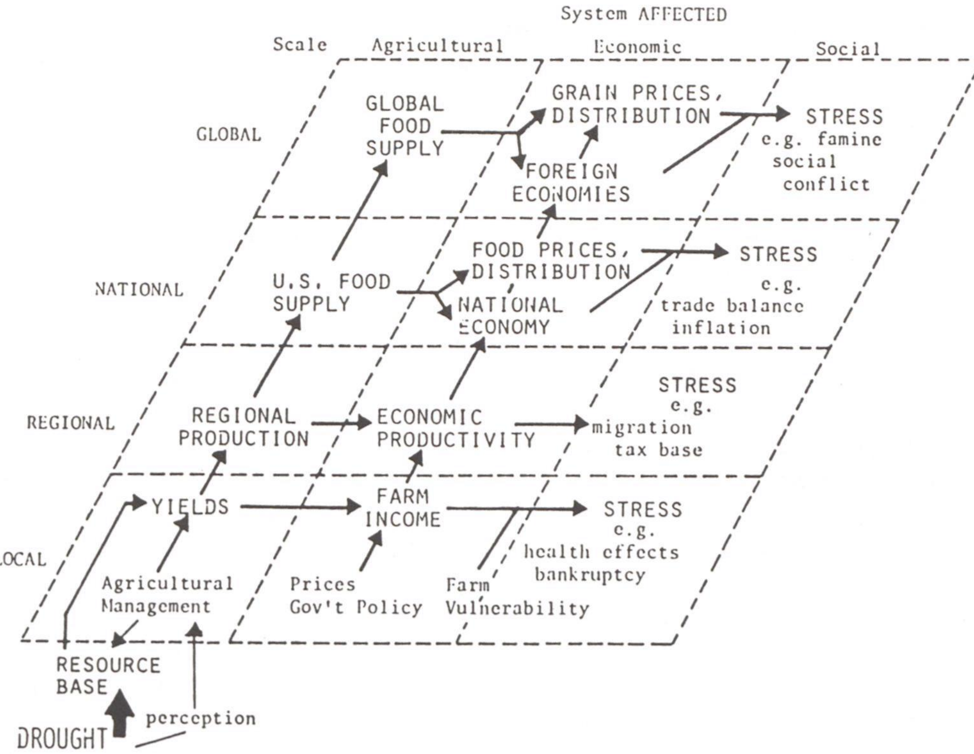
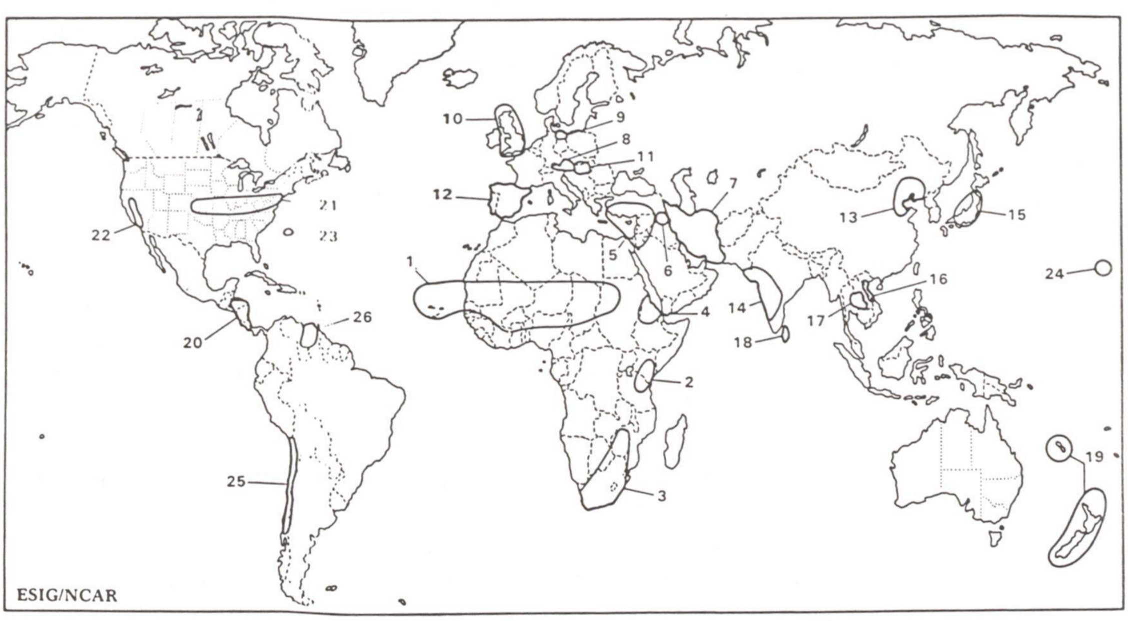


Figure 2. Pathways of drought impact (from Warrick and Bowden, 1981)



Africa & Mid East

1. African Sahel: Mali, Mauritania, Senegal, Chad, Niger, Cape Verde Islands, Upper Volta, w Sudan - Jan thru mid Aug*
   a. Continuation of 5-yr drought, intensified in 1972-73
   b. Crop failures, famine, livestock deaths, forest and brush fires, water shortages
   c. Niger & Mali most severely affected
      (i) June 1973: Lake Chad at lowest level in over 10 yrs, Niger River in Mali at lowest level in living memory
   d. Sahel-like areas in W African countries also affected esp. n Ghana, n Cameroon, ne Nigeria (10% normal harvest)

Europe & USSR

8. Austria - Jan thru mid Feb
   a. Deficient snows, reduced hydropower, financial losses in winter tourist industry
9. n E Germany - Jan thru Mar; June thru Aug
   a. Persistent below-normal precip causing decreased crop yields
10. United Kingdom: Britain - Jan thru Mar*
   a. July 1972 thru Mar 1973 driest period since 1749 for England & Wales, esp. eastern areas, very dry winter, water shortages, crop damage

Australia & Oceania

19. New Zealand & New Caledonia - dates not known
   a. "Extended droughts" during 1973 caused severe damage to agriculture & livestock

US, Canada, Latin America, & the Caribbean

20. Central America: Honduras, Nicaragua, Costa Rica - Jan thru May*
   a. Worst drought in 50 yrs, began in 1972
   b. Abnormally light rains during last year's rainy season created acute drought situation in dry season lasting until May, water rationing in Apr. heavy crop damage

Figure 3. 1973 droughts, January-August (from Glantz et al., 1987)

basic question—could climate be held responsible for this or that historical event or process?—was (and is) the historians' version of the dilemma of the EERE clause. Given the multiplicity of factors (chance, individual decisions, broad economic changes, social and religious forces, etc.) influencing historical evolution, could climate be singled out in any plausible sense as a resource, a constraint, or a prod?

Much of this "second generation" impacts work has been conveniently summarized by Climate Impact Assessment, a SCOPE volume published in 1985 (Kates *et al.*, 1985). In the late second phase of this development, the growing unhappiness with the static nature of impacts work led to tentative steps in new directions (also conveniently summarized in Chen *et al.*, 1983), the impetus of which assisted in the development of a new set of interdisciplinary initiatives on a global scale. These initiatives were rooted in the growing sophistication of global modelling efforts and also the need to begin consideration of how to manage the planet as a whole into the uncertain future (Nanda, 1983; Clark and Munn, 1986). In addition, as the prospects for a global climate warming began to become clearer, a number of major government studies of "The Changing Climate" were undertaken (e.g., the American NRC reports of 1979 and 1983). All these in turn set the stage for a "third generation" of research which is now beginning to emerge.

This "third generation" is characterised first, and most obviously, by its rapidly growing involvement in the policy implications of climate change, due to the unprecedented popular visibility of the climate issue, an involvement perhaps datable from the 1985 Villach Conference (World Meteorological Organization, 1986). Secondly, the sophistication of the modelling and the interpretation of the physical and first-order impacts of climate variability and change are qualitatively new. The recent release (March 1988) of the first volume of the extensive work of Martin Parry and his colleagues in possible worldwide agricultural impacts, is a long-awaited and welcome symbol of the kind of serious applied integrated research that is now possible in this area (Figure 4).

Yet this new generation of research, perhaps even more deeply than its two predecessors, has to struggle with the problems associated with moving away from the EERE saving clause. Parry's graph, for example, has unprecedented sophistication in its use of feedback loops and interactive capacities; but I believe that Parry and his colleagues would be the first to admit that what these loops entail, and how the shape of social trends and the forces of policy formation alter impacts, are largely unexamined (Figure 5). To cope with this, various research projects are applying assorted techniques, such as arguing in a more rigorous fashion from historical analogy, sensitivity analyses, focusing on marginal areas,[3] and others. But these techniques remain ultimately unsatisfactory when dealing with a subject as complex as the rapidity of change in an already complex world (cf. the quotation from Jouvenal (1967) at the outset of this presentation). In the last analysis, one is still dealing, albeit now on a very sophisticated level, with a physical world "out there" which **impacts** (a revealing word) on a social world "over here," and one then proceeds to try to trace out the effects of those impacts through the social system. Finally, to assuage one's guilt, rhetorical feedback loops are added onto the diagrams, representing "societal structures," "policy responses," "cultural constraints," etc.

To summarize this first part of my presentation, climate impact research in the social sciences has been characterised to date by, on one track, an increasing sophistication in the modelling and prediction of direct physical impacts and first-order social impacts, given the EERE saving clause. This has obviously been a technically difficult task; but far more frustrating has been the inadequacy of the conceptual tools which have hitherto been brought to bear on the central issue of dismantling the EERE clause. With regard to society beyond first-order impacts, and how the targets of those impacts came to be where they are and why, thinking has clearly reached something of an impasse. This is

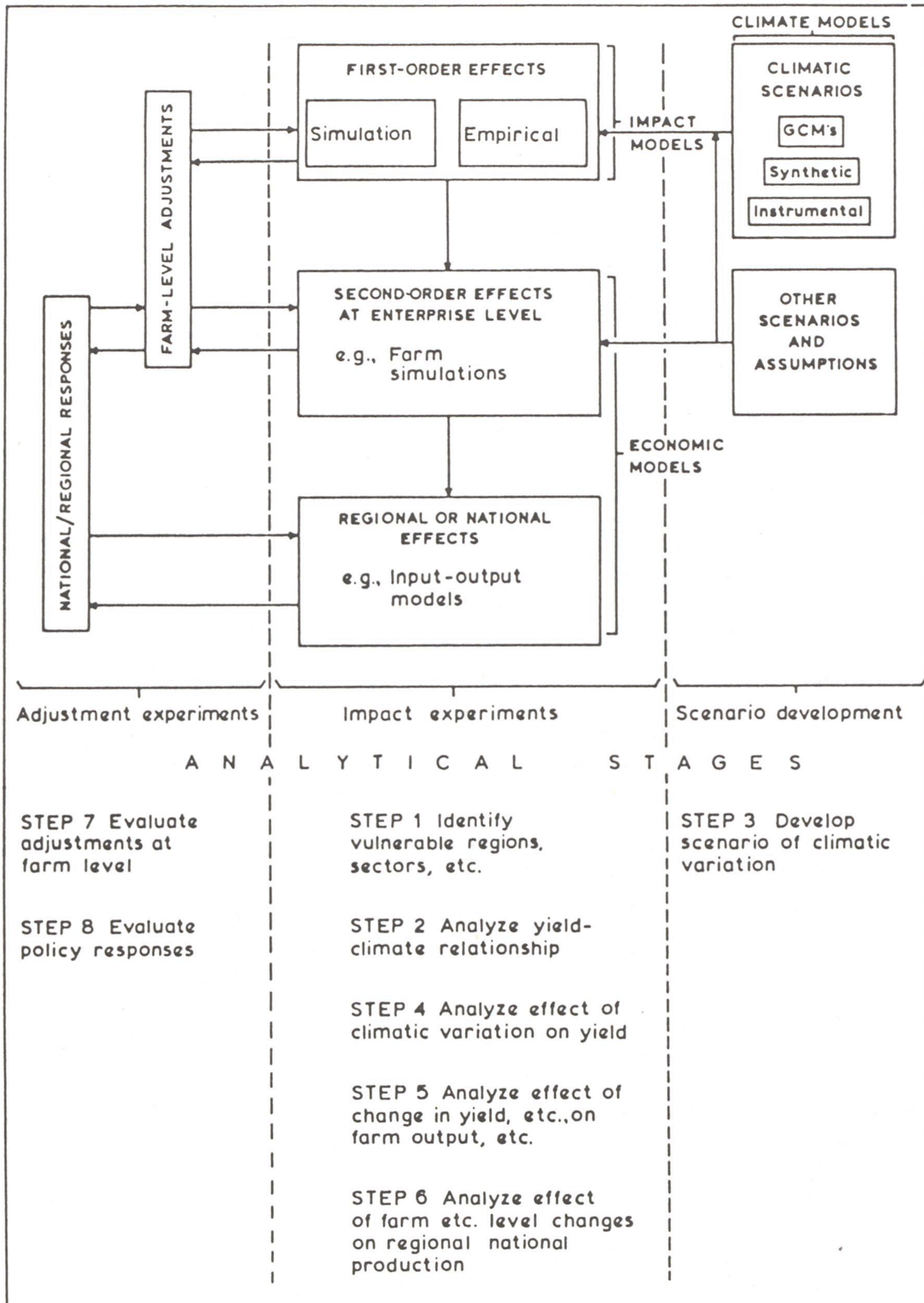


Figure 4. Types of models used and stages of analysis adopted in the HASA/UNEP project (from Parry et al., 1988)

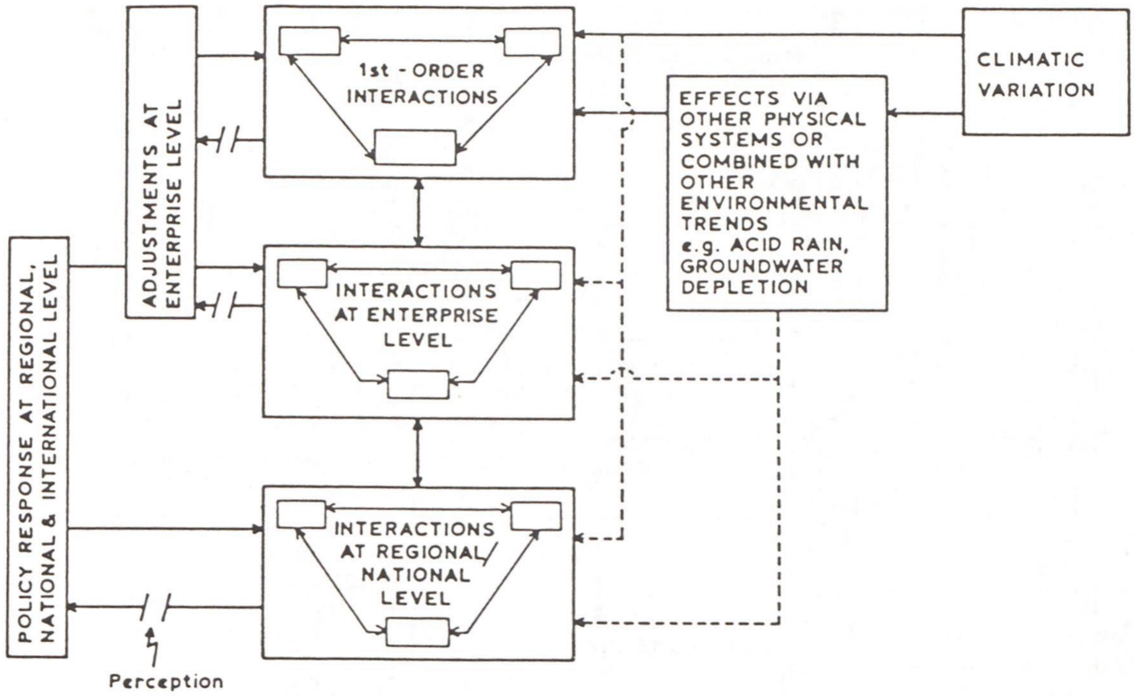


Figure 5. Schema of the HASA/UNEP project's approach: an interactive approach to climate impact assessment with ordered interactions, interactions at each level, and some social and physical feedbacks. (from Parry et al., 1988)

because, on the other main track of development in social impacts research, attempts to provide a framework for social dynamics and policy functions have come up against fundamental difficulties in the description or prescription of how societies operate, evaluate, and evolve. The frameworks that are used instead, often by default, are thus patchy, ad hoc, and characteristically driven by a physical science agenda.

Other Things Not Being Equal

In the second part of my discussion, I want to focus as briefly as possible on some of the major reasons why this is the case.

Because of the strong, not to say overwhelming, physical science input into the climate impacts issue, it is often assumed unconsciously by all researchers in this area that what is required of social scientists is that they present a model of social systems which will be analogous to models of physical systems, only more complicated and somewhat more mysterious, involving such magic properties as decisions, culture, and values. It cannot be stressed enough that this unconscious model is itself deeply biased, since by its very nature it gives primacy to physical facts and has buried in it linear and mechanical assumptions of human behaviour and interaction. By working within this model, social scientists are driven towards pseudo-physical thinking, which results in the pervasive problem of social research in the climate impacts area, namely the generation of numbers that bear no relationship to the real dynamics of social processes. Thus—to make up a research project—social scientists are asked to come up with cost figures about climate impacts on Toronto in the year 2030. To be blunt, this is a consummate waste of time. Yet as we know, the pressures to undertake this type of research are almost insurmountable—and part of that pressure does not come from the outside, but from the internal inability of social impact researchers to come up with solid, coherent, rigorous alternative research programmes.

Perhaps much more insidious is the fact that, by invoking the EERE clause so as to generate numbers, one is committing oneself in a profound way to the present order of things. By freezing the system, today's physical and social structures become the basis for making projections of impact estimates, thereby reinforcing the status quo. The present becomes the template which is subject to risk, vulnerable to attack, in need of protection, subsidy, etc., since the various parties to the impact assessments are naturally concerned to project (and protect) their own part of the world into the future. So one then becomes faced with the recurring absurdity of sectoral estimates with overlapping EERE clauses (everyone freezing everyone else), thereby cancelling out the mutually synergistic social transformations which will necessarily occur. These sectoral estimates are then added up into impressive billions of dollars of potential climate impact costs.

Let me make the general point about the dynamics of change more strongly by pointing out just one social force at work, which is perhaps central to any contemporary discussion, and that is modern economic trends. It is clear that when one takes away the EERE clause, most of the climate impacts work in first or higher order social dynamics is swamped by potential economic changes. In his recent study on the "Effects of Climatic Change on World Industry, Trade, and Investment" for the Industry, Trade and Investment workshop at the Changing Atmosphere Conference in Toronto (1988), Derek Ireland makes some bold claims about world GNP losses in the next century due to climate change; but one can also find the following paragraph:

> Comparative advantage and international competitiveness among countries are changing all the time, the consequence of shifts in exchange rates, changes in technology, establishment of new production facilities, and discoveries of new resource supplies. Changes brought about through the greenhouse effect will be more gradual than, for example, the alterations resulting from the major realignment of developed countries exchange rates which have taken place over the last decade.

In her magisterial paper reviewing two decades of social science research into population dynamics, resource availability, and technological transformation, Nazli Choucri (1984) points out that the new interdependent world order has produced large-scale flows washing over the world, eroding old systems, and creating new ones. She cites five "macro-flows": investment flows; goods and services flows; technology flows; information flows; and population flows (One could parenthetically remark that immigration policy may well be the single most important social issue raised by global climate warming). With our current state of social understanding, we cannot predict these flows, nor what they will engender. (It might also be noted parenthetically that we are now being asked to engage in "integrated regional assessments" at a time when in a broad social perspective regions are disintegrating.)

We are not helped in this situation by the inadequacy of contemporary economic theory, which has an inherent bias towards the shorter and shorter term (in fact, towards "instantaneous clearing"), and presumptions of equilibrium. This makes economic theory crucial for those aspects of the response to climate that do approximate to instantaneous perfect markets, such as commodity tradings. But because it focusses so completely on market information (prices), and assumes such concepts as infinite substitutability, economic theory as it now stands becomes less and less useful the further away one gets from these kinds of markets; and in particular it cannot tell us whether or not the physical systems upon which we rely are ecologically sustainable, and for how long. At the same time, the single most obvious cultural trend in the world today is the gradual reduction of all other forms of social diagnosis and explanation to economic paradigms. This is a grim paradox.[4]

The case of economics is only one example of the issues we face in trying to grapple seriously with the real forces involved in rapidly changing social dynamics. The "tragedy of the commons" exemplifies another. The "tragedy" is a situation where in using a commons area, it is in everyone's locally rational self-interest irrationally to destroy that commons through overuse. We have many social systems whose subsystems are all locally rational, but which act irrationally as a whole. The "tragedy of the commodities" is a situation where local farm subsidies are rational, but globally irrational (or in another variation, when all farmers are doing well, no farmers are doing well). What therefore constitutes rational conduct, and on what level it should be evaluated, is a key issue in describing social dynamics.

Other issues involve such obvious facts as that there are many different competing theories of why and how societies function the way they do. Indeed, politics is (or ought to be) primarily a debate between different models of what is central to human and social development. Thus, rather than despairing over methodological disagreement in the social and political sciences, perhaps one ought to be pleased that there is competition between different explanations of social reality, since if there was only one such model it would likely be totalitarian. Yet how do we incorporate competition between explanatory theories into impact assessment?

Nevertheless, having said all this, I do not believe that we are ultimately left in a chaos of infinitely proliferating theories and completely groundless predictions. One of the reasons we are able to do any social research at all is that people are often predictable in the mass, that human beings use up measurable amounts of physical resources, and that there are major, long-lasting social and demographic trends upon which planning is necessarily based. We can learn from the past, we can do some forms of extrapolation, we can build upon our current intuitive understanding of how society operates; and perhaps most important, if the environmental change is big enough, catastrophic enough, then the social impacts do become predictable.

Yet, it cannot be stressed enough, as soon as one says this one is almost irresistibly led back into all the biases already outlined. Just to take one more instance, as can be seen in discussing the development of climate impact assessment through hazards research, there was a tendency to focus on margins and extreme catastrophic events, because that is where the numbers could be found. What was not often asked in this context was: How did these areas become marginalised in the first place? or How prone was the society to having a climate catastrophe happen here? or Was the society's overall choice of trajectory at fault?

Where Now?

These questions (and others) suggest that to make the most of what we can do in social research, and to work against our biases as best we can, in the Great Lakes Basin as elsewhere, we urgently need new ways of conceptualizing our way out of the "bear hug of the linear, the momentary, and the contemporary."

Some examples of this type of thinking include:

—cross-sectoral thinking, based on new integrative concepts

One example might be the role of information as a political, economic, and social tool. This role involves a range of issues, from the use of information to create a broad "climate of opinion," all the way to the microeconomic ways in which people make their individual decisions based on the provision or absence of climate information.

Another example—and at least as important—is the cross-sectoral role of time. Let me discuss this in more detail. Modifying climate impacts, or adapting to them is primarily a function of time, but we do not have a good sense of such questions as what decisions we will have to make, in what sequence, and what research results will we need, not now, but in 5, 10, or 15 years, when we will have to make major decisions. We do not know very much about societal lag-times, about how long certain trends take to become pervasive, how long they last after their usefulness is exhausted, etc.[5]

Time also relates natural and social systems. As an instance of a difficult managerial issue related to time, natural systems can adjust to a range of climate changes by migration over time, but our social systems have locked them into contemporary land use patterns. We want our parks and beaches to stay put. One might say that we have arrived at a point where we can't have the countryside wandering all over the countryside.

The study of the temporal factor in many social and natural systems could serve as a bridge between them, and would of course be automatically relevant to the timetable for preventing or adapting to climate change.[6]

—qualitative systemic thinking

Over the past 15 years or so, a number of terms have come into existence which attempt to describe the overall qualities of systems or subsystems. These terms are often terms which carry with them the connotation of quantitative approaches, but which are also qualitative. *Vulnerability, resilience,* and now *sustainability* are part of this new descriptive lexicon. We are very far from having credible indicators of the presence or absence of these qualities, but they are conceptual growth points, simply because of their integrative possibilities. Because they relate to the quality of a social system's performance over time, as well as its subsystems, these quantitative/qualitative terms begin to allow us to relax the EERE clause. They also allow us to think about what is critical and most sensitive to change in a society, much of which operates either below or above sectoral divides.

—strategic thinking

Another way of relaxing the EERE clause is by approaching societies from a strategic perspective. There has been some work on strategic options for dealing with the climate warming (Beijer Institute, 1988), based on preventive, limitation, and adaptive strategies. But there has been little or no work on relating these strategies to the current overall strategies that societies use to cope with uncertainties. These strategies, which may be called risk strategies, are the ways in which societies mediate future uncertainties, and different societies have different strategies to which they have recourse (Timmerman, 1981).

Until modern times in the developed world, and still continuing in many parts of the developing world, these strategies were very closely tailored to the environmental context within which each society lived and developed, and by far the vast majority of these strategies were designed to minimize potential losses, rather than maximise potential returns. Over the past few hundred years, however, due to technological advances, there has been a gradual uncoupling of developed societies from the immediate environment, and also a gradual insulation of ourselves from the incidental vagaries of climate. It is this uncoupling which complicates climate impact research, especially with regard to historical analogues.

The same uncoupling also complicates the provision of information about what is occurring: If it can be put this way, our local uncoupling blinds us to the continuing larger coupling. So that, for example, we now have the phenomenon of people buying air conditioners in light of the increasingly warm weather, which is in turn helping to make the climate warmer by increased electrical power generation and chlorofluorocarbon production. Also worth noting is the problem that our gradual uncoupling desensitizes us to the signals of potential trouble emanating from the natural world: When we replace a lake with a swimming pool, we lose an information connection to the outside. This means that as a technological society, we depend more and more on technical monitoring, data collection, and the interpretative warnings delivered by public or private agencies. It thus becomes important not just to support thinking globally, but also to foster seeing and hearing globally as well.

To generalise, the overall system becomes dependent on a strategy of recourse to technological solutions which, if they become inadequate, may actually make the society more vulnerable and fragile in the long run (Dotto, 1988).[7] What we lack is an understanding or serious assessment of whether or not this particular strategy within which we are so deeply embedded is the only strategy available, whether it is worth the risk, or whether there are benign alternatives. There has been some research in this area, but, again, it has not been on a high enough level to generate an integrated strategic overview.

—globally strategic thinking also needed

There needs to be developed a perspective within which national and regional strategies can be embedded and developed. These evaluative perspectives—they can be called scenarios—would provide the social and political context within which the broad social trends that must be incorporated into more specific impact studies can be placed, thus allowing for some coherent evaluation to occur. Some work has already begun on such strategic perspectives. This includes the work of UNEP through the Beijer Institute and others; the World Resources Institute effort; and others. A new initiative, with which I am associated, the Human Dimensions of Global Change Programme, completed in late September 1988 its first major planning meeting in Tokyo, Japan, during which it called for the establishment of a global research programme in the social sciences, to complement the forthcoming International Geosphere-Biosphere Programme (IGBP) of ICSU, and made special reference to research into the social and policy implications of the global climate warming. This may provide one global platform upon which the natural and social scientists can meet.

—environmental perception

The whole question of environmental perception needs to be readdressed. Apart from one or two exceptions (Whyte, 1977; ACNS, 1986), the study of environmental perception has been the psychological equivalent of the linear and mechanical impact models already discussed. The very term "perception" indicates that we are dealing with an 18th century epistemology, where individuals respond to "percepts" that impact on their sensory organs. We should rather be considering ***concepts*** rather than ***percepts***, environmental ***con***ceptions rather than ***per***ceptions.

It is these conceptions, mental patterns, social constructs within which percepts are sorted and given coherent sense that are the ultimate carriers of power in society. The information people respond to, the strategies they develop, and the hopes, fears, and values they consciously or unconsciously use to shape past, present, and future meanings—these are all mediated by cultural concepts. The analysis of these concepts, and what holding them entails, is surely a major task for the social sciences (and the humanities), and one which only they can carry out properly.[8]

—thinking beyond "climate"

The interrelationships among cross-sectoral thinking, strategic thinking, information, and environmental concepts with regard to "climate change" are constituted in part by the definition of the problem itself. Thomas Schelling once remarked that one critical aspect of any problem is what the problem is seen to be. If we define what we are dealing with as the "climate change" problem, a whole array of concerns, players, and agencies orient themselves accordingly. If we defined it some other way—as a carrying capacity issue, as an energy issue, or as a new stage in the growing human governance of the planet—then the arrangement of players would alter. It is, I think, fairly obvious that the "climate change" issue is being laden down with a number of other agenda items which it probably cannot bear. Until recently (perhaps the Toronto "Changing Atmosphere" Conference marked the end of this phase), one of the virtues of the "climate change" issue was that it was new enough to be able to stay clear of already established and polarized constituencies (e.g., the energy debate; but also see Lovins *et al.*, 1981, and Jaeger, 1983).[9] It may be that some way can be found to keep this issue from being completely captured by one of these constituencies, but at some not too distant point, the "climate change" issue is going to be redefined, and its agenda rearranged. The strategic (and tactical) point is: How should this transition "beyond *climate*" be managed?

In addition to the above, let me take the opportunity provided by this conference to make three more specific research proposals, which flow out of my remarks here today.

1. The first research proposal is a study of 1988. I believe that we are already in the middle of society's response to the global climate warming. The events of this year—including this conference—are part of the ways in which a modern postindustrial society responds to environmental change, with all that that entails. It may be frightening, but there it is. A study of the social dynamics of 1988 would be both a baseline case for future social research, and also relatively accessible.

2. Another major study that should be undertaken immediately is a study of international economic trade flows and "teleconnections" due to climate impacts. This should be a through-time study, utilizing the years 1972-1973, 1983-1984, and 1988. This would enable us to explore the changes in the world economy over the past 15 years, and integrate them into climate impact studies. A contribution could thus be made on the role of global environmental changes to the development of international political economy (for which, now see Gilpin, 1987).

3. Lastly, we have, in the Great Lakes Basin, a chance to do comparative research between social systems that are slightly different, but which occupy similar ecosystems. Because of the unique collection of public, private, and other institutional arrangements in the Great Lakes Basin, there is surely room to begin a bi-national set of studies, using some of the thinking outlined here today.

Conclusion: "Degrees of Freedom"

I would like then to conclude, not by summarizing the three parts of my presentation, but by going slightly further. I would like to stress here that at all levels, from the global to the local, the impacts of climate change will largely depend on what attitudes and strategies are adopted to deal with climatic and other changes. We are not stones, but human beings; and can therefore change our minds when faced with predictions. Much of our present way of talking about impacts is like asking how many lung machines we will need in 2050, and what the effects will be for health policy. But will people still be smoking or not? And would it be a good idea if they were?

This is not just pious rhetoric. If the peoples of the Great Lakes Basin and the surrounding regions determined on doing as much as possible to develop a strategy for a sustainable society in the region, everything else would not remain equal. Such a decision would alter the rules of practically all the social trends now predicted, and would rewrite the equations upon which the impact predictions are based. The Great Lakes Basin and surroundings still contain within themselves major forces for influencing the activities of the modern world, whether by political power, media outlets, or, in the case of climate change, eliminating major sources of the problem.

I believe that for policy makers and the rest of us it is folly to try to make detailed social forecasts for any period beyond twenty years or so. What we should rather be embarking upon together as a global society is what is occasionally called "backcasting"—that is, we should be deciding what kind of a world we would like to live in in the year 2050, and backcasting from then to now, so as to decide the best ways of getting there from here.[10]

One of the ways in which human beings can be made predictable is if they are forced into a situation in which they have no alternative. An underlying problem we face as a society is a widespread assumption that planning is somehow inimical to freedom. We seem to have forgotten the principle that we can voluntarily give up some freedom at one stage in order to gain larger, and richer, kinds of freedom at other stages. Planning and putting in place a social and physical infrastructure for society frees us as individuals to engage in more interesting tasks than worrying (for example) about foraging for food and fuel. The key word, of course, in all this is *voluntary*.

Rapid environmental degradation, overpopulation, and other stresses place a growing burden on society which can lead to the necessity for a "command and control" system of government just to keep things together. In his 1987 policy study, *A Matter of Degrees*, Mintzer makes this point succinctly:

> The longer the delay before preventive policies are identified, agreed upon, and implemented, the more extreme the policies imposed to stay within prudent bounds will have to be.

This is what is now happening in a number of Third World countries faced with extreme environmental degradation. It is imperative that we retain our (to use a deep pun) "degrees of freedom" with regard to action, before we find ourselves constrained by a series of diminishing choices. Backcasting allows us as a society to debate openly what kinds of future we value, and allows us to exercise the human dignity of deliberate choice. Alternatively, if we continue to abdicate our growing responsibility for the future of the earth, we will eventually be predictable according to the best canons of physical science, since we will plummet like a stone.

I close on this note, and urge the delegates to this conference to keep in mind that perhaps the best way to predict the future is to create it.

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Endnotes

1. This paper has been slightly revised from that presented at the Symposium, so as to take into account some of the discussions and questions put forward at that time. The footnotes are designed to carry that dialogue a bit further.

Due to circumstances, I have been unable to take account here, except in very minor ways, of the very recent, still unpublished work of M. Glantz, "Politics and the Air Around Us", and "An Essay on the Interactions between Climate and Society" (prepared for the XVI International Political

Science Association World Congress, 1988); nor of W. Riebsame's "Brief Report on the First Two UNEP 'Roving Seminars' on Climate Impact Assessment," and his report "Assessing the Social Implications of Climate Fluctuations" prepared for UNEP under the auspices of the World Climate Impacts Programme. These sensitive analysts of the current situation have come to conclusions similar to some of those put forward here, though from different directions and with different emphases.

2. The Clark University Study (cf. *The Effects of Climate Fluctuations on Human Populations: Two Hypotheses*, Progress Report #2, August 1979, from the Center for Technology, Environment, and Development, Climate and Society Research Group) put forward two hypotheses: one, that persistent and adaptive societies through their technology and social organization, lessen the impacts of recurring climate fluctuations; and, two, something akin to a counter-hypothesis, that this success may actually make these societies more prone to a "worsening" or "catastrophic" situation. It is, I think, fair to say that there were too many variables in the chosen cases to make the study anything more than exploratory.

3. Sea level rise as an increased burden on already threatened areas is clearly a touchstone for this kind of research. G. Pl. Hekstra in "Will Climatic Changes Flood the Netherlands? Effects on Agriculture, Land Use and Well-Being", *Ambio*, Vol. XV, NO. 6, 1986, describes the Health Council of the Netherlands' 1986 report on possible impacts to that country.

4. In discussion, it was argued that through the use of "externalities" and other techniques, neo-classical economic theory was able to cope with the issues raised in this paragraph. It might also be argued that "expectations theory" and "theoretical future markets" can cope with the issues raised by the uncertainties and long time-frames associated with climate warming. The counter-argument is that "externalities" and the rest remind this reader of what was happening to astronomy just before Copernicus: a series of attempts to patch together, with even more complicated methodologies, an increasingly implausible theory of reality.

5. The work of the great French historian Fernand Braudel does not seem to have been mentioned in the context of the Great Lakes. In the 1950's, he produced an integrated study of the natural, economic, and political history of the Mediterranean, based on time. Braudel used 3 time scales: the long scale of geographical change, the somewhat faster scale of social change, and the practically instantaneous scale of political change. His hypothesis was that when these three scales came into conjunction, *conjoncture*, major historical leaps and phase changes occurred (see *The Mediterranean and the mediterranean world in the Age of Philip II* (1972), trans by S. Reynolds, Harper and Row).

6. For the strategist, there is a distinction between "chronological time"—the time when things happen according to timetables—and "kairological time"—the time when things are ripe to happen, the appropriate time, the *moment juste.*

7. This remains an intuitively appealing hypothesis (cf. Timmerman, 1981), but it could also be argued that a technological society may be so successful that it can afford to spend some of its surplus in protecting its stocks of resilience and cultivating a range of alternative strategies of survival.

8. It is worth citing, in this context, the following words of Northrop Frye, from his essay, "Expanding Eyes" in *Spiritus Mundi* (Indiana: University Press, 1976): "The real trouble is ...that social scientists do not yet understand that their subjects, besides being sciences, are also the applied humanities."

9. Glantz, in his recent paper, makes a different but related point, suggesting that in some cases it is better to get agreement on action before those involved find out which of them is going to be the winners and which the losers ("Politics and the Air Around Us" (forthcoming)).

10. I owe the term and related ideas out of the energy literature to John Robinson of the University of Waterloo.

Climate Change and Hydrologic and Atmospheric Issues: Lessons of the Past

Stanley A. Changnon*

Introduction

What are some of the key issues relating to the atmosphere and hydrosphere that future climate change in the Great Lakes Basin will produce? I refer here to effects, possible responses, and then adjustment to likely future climate changes equalling or exceeding anything experienced in the basin during the past 200 years.

One fundamental way to prepare for such issues is to consider past experiences. What has happened during major past climate fluctuations that gives insight as to what might happen again? or, What in the past provides guidance as to what **should** happen? There are at least **four** major lessons to be learned from past impacts and responses to air and water issues in the Great Lakes Basin. Awareness of these will help us plan for such issues in the future.

Lessons from the Past

Lesson One. **We lack understanding of climate's interactions with society.** Recent assessments about how the climate interacts with the environment and affects the economic fabric of our society have pointed to an enormously important lesson—we lack adequate understanding of climate impacts, particularly of the complex interactions between the physical effects and resulting socio-economic impacts and policy responses (Institute for Environmental Sciences, 1985). If this is true, and I believe the record supports this position, we are **not able** to understand, with sufficient certainty, how a major change in the climate of the region would impact the physical environment, and in turn, how this would relate to the socio-economic conditions that will exist 50 years from now (Changnon, 1987a).

Some initial studies have estimated possible effects of future severe climate changes on Great Lakes Basin water supplies and water use (Cohen, 1986a, 1987); on lake fisheries (Goodier *et al.*, 1985); on lake levels; and on resulting economic outcomes to shipping on the lakes (Marchand *et al.*, 1988). These are useful initial studies but they are limited to single sector investigations.

A major facet of this issue, and one we know embarrassingly little about, is the absolute "interdependence" between the environment, the social fabric of the basin, and the weather conditions over time, or climate. Furthermore, there are many signals that, due to population growth, the socio-economic structure in the Great Lakes region has become ever more sensitive to climate fluctuations (Cohen, 1986b). The enormous impacts from the lake level fluctuations during the past 25 years prove to us that even relatively small climate oscillations around the "average condition" create major losses and gains, and furthermore that serious impacts can develop rapidly (Bruce, 1984).

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In the past, we have operated with only limited information about how the climate affects us. As a result, we have often made incorrect economic, environmental, and policy decisions. For example, this lack of knowledge about relationships such as how the multi-year dry periods of the early 1960's affected water quality, or how the recent wet periods affected the atmospheric transport and deposition of pollutants, has plagued decision making.

Let me illustrate this lesson further by reviewing certain events during the recent shift from the basin's wettest 5 years on record, those during 1982-1986, to a regionwide drought with precipitous falls in the lake levels during the 20 months since January 1987 (the second most rapid declines in the levels of Superior and Michigan-Huron on record). Responses involving adjustments in the diversion of lake waters during the record high lake levels served as examples of what to do, whereas those proposed during the rapidly falling levels have served as dramatic illustrations of what not to do. The point is: one cannot widely plan nor make meaningful responses **without understanding the current and likely future climatic conditions.** This also illustrates that better long-range predictions of the climate conditions for months, seasons, and years ahead are desperately needed, as well as better near real-time climatic information.

Now, let us consider how inadequate climate information, or its misuse, could cause a major problem in the future. We continue to make in-depth assessments to find ways to sustain lake levels near the "average" (IJC Reference Study, 1986). This seemingly worthwhile goal remains illusive unless major structural changes are made in the system. Even if both nations agreed to manage the lakes differently (i.e., alter the diversions) and to make some extremely costly investments in major engineering solutions (lower connecting channels, changes in locks, etc.) to help remove some of the lake level fluctuations, some of these changes could become useless in a vastly changed climate. We will likely find in 30 to 40 years that we are dealing with a climate that is so different from today's as to make most such solutions for today's climate regime of doubtful utility in the future! Major investments **now** to deal with current climate extremes could be inappropriate until we better understand the complexity of climate impacts and what the future very altered climate will be like. For example, the climate models all predict serious reductions in average lake levels, and it appears unlikely that associated "wet period" extremes 50 years from now will bring high lake levels comparable to those of the past 100 years. Hence, why design or expend funds now to avert losses for such high level conditions?

This lack of information about the characteristics of this sizable future climate change and how these would affect the Great Lakes Basin is the **key reason** for this, the first of a series of U. S.-Canada symposia. Our nations need to begin to obtain a first approximation of the troubles and advantages that future climate conditions will produce, and in turn begin to consider what could be done about them. The outcome of this conference should be information that can help serve as a platform for designing the research on climate effects and the planning for adjustments, including policy, in the basin. There is still time to do it, but we need to begin **now**.

Lesson Two. **Climate has changed due to natural and man-made forces: attempting to hit a moving target.** A second important lesson is to realize that the climate does change, has always changed, and is changing now due to natural causes. Further, human influences on the atmosphere have already produced sizable climate changes in the past 100 years.

A major recent fluctuation in the basin's climate is an interesting example of change and its influence on basin water management. The extremely wet period of the early 1980's was "basinwide," and now the 1987-1988 drought is also "basinwide." The basinwide nature of both events is very interesting because climatologists who have studied the region's climate over the past 100 years will tell you that this represents a very different climatic regime from what commonly had prevailed before. The precipitation regime over the lakes has typically been divided geographically; that is, what happened with the precipitation over a given period in the southeastern basin was different from the conditions in the northwestern basin (Brinkmann, 1983). This allowed for water management planning involving certain strategies, but these strategies have not been realistic in the current, very different basinwide weather conditions. If what has been happening in the past few years, that is, more uniformity of precipitation extremes across the basin, is a precursor of the future climate, then it illustrates how managers can suddenly have a new "ball game" to address. Gaining understanding of climate fluctuations and future changes in climate at the management and policy levels becomes critical to more effective planning.

A second aspect of past climate and fluctuations relates to inadvertent effects due to man's activities. Detecting climate change is made difficult by "urban effects" on climate that systematically affect temperature records over time. Conversely, 75 percent of all North Americans have lived since 1920 in urban areas, locales where ***all*** climate conditions have been sizably modified by urban influences on the atmosphere (Changnon, 1976). Studies of the basin's large metropolitan areas including Chicago, Detroit, and Toronto reveal they are not only much warmer than surrounding rural locales, but they have very different winds and lower humidities. Further, they and their surrounding areas experience more clouds, more precipitation, and increased storms due to urban influences. In addition, in our heavy jet aircraft travel corridors there has been 10 to 30 percent increases in cloud cover since about 1960, and the "quality" of the climate has been altered for many years as witnessed 30 to 50 percent decreases in visibility and altered precipitation chemistry throughout the basin. The ***point*** is that the basin's population has lived in a man-altered climate for the past 70 years, and thus has functioned and adjusted essentially unknowingly to sizable man-imposed climate changes. Thus, the postulated future global change is not a totally ***new*** condition to adjust to. This condition and the consideration of past climatic fluctuations in the basin provide three conclusions and recommendations.

A. Study of the historical adjustments to man-induced climate changes in urban and rural areas since about 1920 should provide useful lessons about what can and should be done to adjust in the future.

B. Estimations of future climate effects will be attempting to assess an uncertain climate outcome (i.e., How fast will it change? How much will it change? What will change? etc.), and an equally uncertain societal structure. The environment and the socio-economic systems will greatly change over the next 30 to 60 years **without** any change in climate, and this difficult-to-estimate change must be factored into meaningful "estimates of how future climate changes will impact the basin." Indeed, we are attempting to "hit a moving target"!

C. Analysis of how weather-impacted sectors react to climate change (Changnon, 1987a) reveals that atmospheric scientists must do a better job of describing climate 'change' and 'fluctuations' to nonscientists. Confusion exists over the issue because explanations have varied and have often been too simplistic. We need more concise, yet definitive descriptions of the postulated future climate changes and scenarios, coupled with accurate definitions of the uncertainty levels so that information users can better assess the risks.

Lesson Three. **The issues are transboundary and will need new approaches for their resolution.** Another critically important lesson found in the history of the atmospheric and hydrospheric issues of the Great Lakes Basin is the fact that these issues automatically become **international** issues, not just national issues. Although this may seem obvious, how the U. S. and Canada have collectively handled transboundary air and water problems in the past is a key to understanding better what to do in the future.

Great Lakes policies have traditionally developed in an ad hoc manner as specific problems appeared. These often arose as a result of unknowns in the physical sciences, and up to a point, the ad hoc approach worked well. However, the recent transboundary air and water pollution problems have caused the ad hoc approach to become **inadequate**. The acid rain issue is one example of where physical measurements of atmospheric effects and environmental effects were considered by some as too scanty and thus economic impacts were not on a solid foundation (Carroll, 1982). Nevertheless, real or perceived damages have led to specific policies on acid rain in Canada and in certain eastern states. The U.S. policy of "more research before we act" is seen by many as valid, yet also viewed as a delaying tactic. The lack of scientific certainty over the impacts of acid rain was a central factor in the U. S. policy.

Regardless, the two nations have yet to demonstrate a capability to carry policy actions through, especially when: a) a long period of time is involved, b) changing governments are involved, and c) major scientific uncertainties exist (Changnon, 1987b). We must seek **informed** regional and planning-oriented policy making. It is not difficult to speculate that problems emanating from future climate change will require new thinking, new policy approaches, and new policy-making institutions. However, we will continue to be plagued with problems of understanding how changed climatic conditions will impact our **physical and socio-economic systems**! Responses to problems with inadequate information generally always compound the problem. Thus, we return to the absolute need for research to better understand how climate affects the environment and society.

Lesson Four. **The need for credibility and specificity in predictions of future climate conditions.** The fourth major lesson to be learned from the recent past, and one that greatly affects what our nations, provinces, states, municipalities, and private sector entities could and should do to adjust to the future change in climate, is the degree of **credibility and specificity** about the future climate changes (Changnon, 1987a). We need more research to better describe the future climate change.

The greenhouse effect has raised international concern because 1) clear evidence of increasing CO_2 and other trace gases exists, and 2) all global climate models (GCM's) have estimated that, as a result, the future global temperature will change rapidly and be warmer. They all predict warming but of varying magnitudes. Concern exists, as it should, but the immediate and related question is, "What will it mean in my city, state, or region of interest?" Will the effects of a given future climate scenario be small or large, and can we adjust to them? One Canadian group (Marchand *et al.*, 1988) investigated how future climate changes would impact shipping on the Great Lakes, and they obtained a wide range of economic outcomes depending on the climate scenario used. The GCM's are limited by their assumptions about clouds and the radiative changes due to the gases, and also by the large space scales that are necessarily inherent in their calculations. The **net** of these limitations is that what the climate models predict for the Great Lakes Basin in 20, 30, or 50 years in the future varies considerably. The future climate conditions for the Great Lakes Basin calculated from three of these models were used by GLERL scientists as input to lake basin hydrologic models. They estimated future lake levels, and for Lake Michigan, all models predicted levels well below the 1951-1980 average level, but the future levels **differed greatly**. One model's values led to a level down 2 feet, another was for a level down 4 feet, and the third down nearly 9 feet.

We then studied what happened along the Illinois portion of the lake during the record low levels of the early 1960's and used these results to speculate about the impacts and adjustments apt to occur with levels from these three different climate scenarios (Changnon *et al.*, 1988). Four important facts emerged in that many adjustments to address the future change could be made in a rational, cost effective manner

1. **If** atmospheric scientists were highly certain about what the future climate conditions would produce as average values. (That is, "Will future mean lake levels be down 2 feet or 9 feet?")
2. **If** there was more certainty about the types and magnitude of the climate effects. (Again, we lack definitive studies of climate-water-social effects)
3. **If** the GCM's could reliably predict how the change will occur. (That is, will they consist of a few sudden jolts in climate like the drought of 1988, or will they occur very gradually)
4. **If** the global climate models could also predict—with greater confidence—the magnitudes of the spatial and temporal variability in the various conditions of the future climate.

To have a permanently lowered lake level is one thing, but from an impact and management view, it is equally important to know **how** we will get there and **whether** the future climate regime will produce lake level fluctuations that will be plus or minus 1 foot, 2 feet, or 5 feet around the **new** average level. The models' certainty levels and the specificity needed to bring **basinwide** planning and action on adjustments are insufficient at this time. Most lake experts we interviewed believe that given greater certainty and specificity about the future climate state, many costly adjustments **required** can be made over the next 50 years as part of normal replacement costs of structures like docks and lockages, water intakes, and storm outfalls.

The message from this case study of effects at Chicago is not to use a "wait-and-see" policy, but rather to call for **wide awareness** of the coming problem, and **attention** to four needs:

1. Further development of climate models to gain greater certainty and specificity
2. Development of alternative climate scenarios based on the sensitivities in the environmental and socio-economic systems
3. Intensive research on climate impacts and adjustments
4. Planning and development for new approaches for developing policy relating to the basin

Summary and Recommendations

Future climate change is a certainty for the Great Lakes Basin. Consideration of the atmospheric and water issues points to two **fundamental questions**. Will the problems be big or small, and how can we best deal with them?

A review of the impacts and responses to past climatic fluctuations identified four lessons. These, in turn, lead to several recommendations. It appears that we must simultaneously and vigorously pursue three tracks.

First, we need to better define the climate impacts and importantly discern the *sensitivity levels* in the myriad impacted areas to varying levels of climate change (Institute for Environmental Studies, 1985). For instance, we need to know with certainty, and for each impact sector, that a 1-degree change in the summer temperature might have little effect but that a 2-degree change would be devastating. Much greater attention to applied climate research is needed. Further, the complexity of the impacts from climate change means we need interdisciplinary research. It must involve the physical scientists, the social scientists, and the policy experts (Rind *et al.*, 1988).

I recommend we consider establishing a U.S.-Canadian joint research center (or centers) for this purpose. Past failures to accomplish long-term quality interdisciplinary research within our educational institutions supports my belief that an institution charged with such a mission is the correct solution. Such an international commitment and effort in the basin should also bring greater unanimity about the status of scientific knowledge on controversial issues, and hence will help eliminate unilateral decision making.

Second, we must have more definitive information about the dimensions of the future climate regime. As more definitive results emerge from the recommended atmospheric research, the findings must be integrated and effectively translated to those who will be impacted and those making decisions. Then, plans can be developed for responding to predicted changes that make environmental and economic sense.

Third, if the past is any kind of predictor of the future, it appears that our current response mechanisms to transboundary problems are inadequate to address effectively what will happen with sizable climate changes. New institutions and better policy-setting approaches will be needed (Changnon, 1987c), and I recommend immediate attention to this issue. However, no planning or policy-making approach will be adequate if we do not have better information on future climate conditions and in turn, how they will interact with the environment and how these physical changes translate through possible future socio-economic structures.

The bottom line to these recommendations is, "let us get prepared." We must act in these areas or we will be sentenced to an unbelievably expensive crisis management response to climate change.

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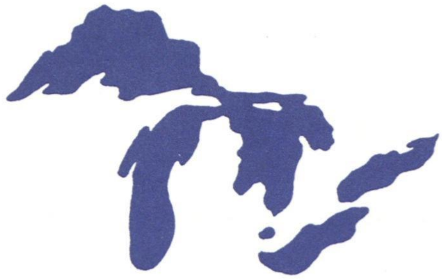

Potential Economic and Political Problems of Climate Change

Panelists:
Donald Totten
Elizabeth Dowdeswell
Lee Botts

Presentation by Donald Totten*

The charge to this panel is to discuss potential economic and political problems of climate change in the Great Lakes Basin. I intend to focus on the facet with which I am most familiar—the political aspect. To do this, I will open with some words that you have probably heard elsewhere but met the proper context for my brief remarks here. I quote:

> **"Humanity is conducting an uncontrolled, globally pervasive experiment whose ultimate consequences could be second only to a global nuclear war. The earth's atmosphere is being changed at an unprecedented rate by pollutants resulting from human activities, inefficient and wasteful fossil fuel and the effects of rapid population growth in many regions. These changes represent a major threat to international security and are already having harmful consequences over many parts of the globe.**
>
> **"Far-reaching impacts will be caused by global warming and sea level rise, which are becoming increasingly evident as a result of continued growth in atmospheric concentrations of carbon dioxide and other greenhouse gases. Other major impacts are occurring from ozone-layer depletion resulting in increased damage from ultra-violet radiation. The best predictions available indicate potentially severe economic and social dislocation for present and future generations, which will worsen international tensions and increase the risk of conflicts among and within nations. It is imperative to act now."**
>
> —Conference on "The Changing Atmosphere: Implications for Global Security," Toronto, June 1988

This dramatic language, arising out of the conference on climate change held in Toronto just three months ago, serves to remind us that this problem is global and potentially severely disruptive. Yet this worldwide event is linked to the Great Lakes region in several ways. Let me give you two examples.

First, higher mean and annual temperatures, increased evapotranspiration, and reduced rainfall are predicted for arid and semi-arid areas such as the sub-Sahara. These are precisely the locations that can least cope with such changes and, therefore, will be the most severely affected. In considering the implications of these conditions, the Commission recognized in 1985 that the need for exports of food and fiber from both Canada and the United States might well increase for either humanitarian or economic reasons [*Great Lakes Diversions and Consumptive Uses*, IJC, 1985]. If this production required new irrigation water, then the Great Lakes might be considered a suitable source. Second, because of the

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region's considerable industrial production, it is a major user of fossil fuels—the primary causal factor in global warming. Any unified effort to curb their use could impact the region's current economic and social structure. Thus we come to Totten's first political rule on climate change, that is:

Rule 1: Decision makers in the Great Lakes Basin must be accurately informed as to what is occurring in the rest of the world.

Now, let's look at a second perspective on global climate change. Both Canada and the United States are fully industrialized countries with major roles in the world's environmental, economic and political structures. Consequently, they will be a principal participant in any effort to influence the direction of or adapt to the impacts from the projected climate change scenarios. Hence, Totten's second political rule:

Rule 2: Decision makers in the Great Lakes Basin must be accurately informed as to the options and plans under consideration by their respective government.

A third perspective focuses on interactions taking place directly between the two countries, while, simultaneously, attempting to resolve what may well be impossible domestic conflicts and survive the global competitions. You can easily imagine a state of mutual anxiety if Great Lakes levels were to decline to the 20 to 100 inches estimated by current models.

However, global climate change would also impact the volume and uses of other boundary waters such as the St. John and St. Croix Rivers, Rainy Lake and River, and numerous transboundary waters such as the Columbia, Flathead, Milk, Red, and Souris Rivers. We've now arrived at Totten's third political rule:

Rule 3: Climate change issues between the United States and Canada will probably extend along the entire common border, although they may be most acutely felt within the Great Lakes-St. Lawrence Basin.

Now with these three rules combined with my seven plus years of experience as a Commissioner, I'm going to quickly draw some conclusions:

1. Global negotiations will be multilateral starting from a given position, and impose a tremendous work load on the governments.
2. Resolution of issues between Canada and the United States are more readily and satisfactorily achieved by collectively seeking joint solutions.
3. Some institutional changes should be expected such as the recently created Canadian roundtable to integrate economic and environment decisions. These changes will probably be designed to improve the coordination and consultation among agencies, interests, and levels of government.
4. Governments will likely increase their utilization of the IJC in boundary water issues since—
   a) There is no real or perceived threat to the sovereignty of either country
   b) Solutions to problems are traditionally approached in a collegial manner
   c) A fact-finding reputation has been established
   d) Under Article X of the Boundary Waters Treaty the governments can agree to refer disputes to the IJC for decision (However, this provision has not been used to date)

Earlier I indicated that the IJC had for several years been aware of the potential for severe climate change impacts, both globally and in the Great Lakes Basin. Consequently, when we received the August 1, 1986, request from governments for a comprehensive examination of ways to alleviate the adverse effects of fluctuating water levels, we included the climate change scenarios.

The Canadian co-chair of our ongoing study of this complicated issue is on this panel: Ms. Elizabeth Dowdeswell.

In closing, I would like to leave you with this political question: Do you believe the scenarios?

Presentation by E. Dowdeswell*

There is a quotation by Albert Einstein, of which I am particularly fond. He is reported to have said, "It would be possible to describe everything scientifically, but it would make no sense; it would be without meaning, as if you described a Beethoven symphony as a variation of wave pressure."

Increasingly, those of us involved in developing and implementing environmental public policy are learning that lesson. We understand that science must be the underpinning of the decisions we take. We know that we must encourage and support efforts to expand the frontiers of knowledge. Sometimes we even take comfort in, or hide behind, the wisdom of scientists. But the challenges we face today—such as what to do about climate change—require additional skills and understandings. The fact that there is a relationship between human activity and environmental response means that our policy judgments must take into account economic, social, and political factors as well as scientific and technological knowledge. This symposium of scientists, planners, and decision makers is evidence of that awareness. We must continue to create opportunities of this kind so that we are not two solitudes. Good science and good management need each other. They must go hand in hand.

Both scientists and the public are very quick to give up on our institutions. We cannot afford that. Public policy makers and decision makers will continue to make choices and shape our future. And the policy choices that will exercise us in the years ahead do not have "correct" answers. Appropriate and responsive policies can be developed. The perceptions of the public must be weighed and our governmental process must accommodate the will of the people and recognize and respect its wisdom.

I suspect that every one of you in this room has felt directly, at one time or another, an inability to solve environmental problems. Some have described this frustration as environmental gridlock. Visualize an intersection in which cars are trapped as the light changes, and no one can move in any direction. That's gridlock!

We seem to be forever debating, often with no conclusion, the best way to reduce toxic substances, or the best place to site new waste disposal facilities, or the pros and cons of development rather than preservation of wetlands.

Harry S. Truman was noted for the sign on his desk saying, "The buck stops here." There are times when our decision-making process results in the buck stopping nowhere—rather, bouncing around as we undertake more studies, or declare the problem to really be the mandate of another level of government, or taking a landfill decision that ultimately becomes a water quality problem, then substituting air pollution through incineration because there are no more sites for landfill—and so it goes, round and round.

Environmental gridlock is not only jeopardizing the protection of our air, water, and land—it is also expensive. It is expensive in terms of dollars, but also in terms of public and

***Regional Director General, Conservation & Protection, Environment Canada**

environmental health—and in an erosion of public confidence. The stage is set for escalating confrontation unless there is a greater understanding of respective interests and of political and technical capabilities, so that we can design a process that will lead to cooperative political action. To help break the gridlock we need to understand the causes:

Public distrust
Industry short sightedness
Scientific and technical uncertainty
Political grandstanding
Faulty decision making

Incorporating ecological principles into regulatory frameworks is not easy. I start by talking about problems and challenges not to conclude that solution is impossible, but rather to convince you that we have to change our approach.

In fact, if some of our local, day-to-day challenges appear insurmountable—the global ones will require uncommon wisdom and persistence.

And climate change is just such a challenge. Yesterday, you spoke of the scientific understanding of greenhouse gases and the global climate response. You looked at projections for the Great Lakes Basin. You heard of uncertain futures and of far-reaching consequences. You began the analysis. The question that interests me is—can this challenge be responded to differently—to take advantage of what we've learned about how *not* to develop policy responses to environmental problems.

By way of illustration I would like to take a few moments this morning to talk about the "Reference" on fluctuating lake levels. The International Joint Commission has been enthusiastically portraying this Reference as a major comprehensive reference, broader in scale than any before, unprecedented in scope, requiring new approaches, innovation, and creativity. Whether or not this is what governments intended when they gave this Reference to the IJC matters little. The IJC has seized an opportunity.

At first glance, the Reference appears simple and straightforward—"to examine and report upon methods of alleviating the adverse consequences of fluctuating water levels in the Great Lakes-St. Lawrence River basin."

Upon closer examination, the unprecedented scope and complexity become apparent. For example, an exploration of the full range of possible factors involved in those fluctuating levels of necessity involves looking at:

- Climate change
- Land use and shoreline management
- Costs and benefits of lake regulation schemes
- Engineering solutions
- Environmental, economic, social, and political impacts

As well, reference is made to effects within and outside the basin. The problem has to be looked at in differing time dimensions (from emergency measures to long-term solutions). Add to this list the inevitable complication of jurisdictional responsibility—and the scope becomes clear.

But perhaps an even more daunting feature of this Reference is its complexity. The Great Lakes-St. Lawrence River Basin is a complex interdependent system—not only in geographic and hydraulic terms. The natural and human systems each with different dynamics and time horizons add to the complexity of problem solving. There are uncertainty and risk, limits to technology, and many diverse stakeholders demanding solutions with a local flavour—and demanding to be involved in the process.

Environmental concerns, the economy, political relations, social and heritage values are inextricably interwoven. Solutions that are environmentally sound, socially acceptable, politically viable, and economically feasible will not be arrived at easily.

This is a work in progress. But I think I can point to some lessons we've learned.

From the outset it was apparent to us that this Reference would require a change in *mind set.* That said, we have to continually remind ourselves. The first law of wing-walking states, "Never let go of what you've got until you've got hold of something else." It is understandable that we cling to old but familiar ways of doing things. It may be understandable, but not appropriate for this study. It's time to expand and rethink the way things have been done in the past—to set aside current constraints and go beyond what might be considered politically and economically feasible today. We encourage divergent thinking.

We wanted the study to be future-oriented and anticipatory—not simply more of the past—or fundamentally like today. We are trying to ask different questions. For example, if we were studying health care, instead of asking how to combat the high cost of medical treatment (which conjures up images of hospitals, drugs, doctors, and laboratories) perhaps the question would be, What is the nature of wellness? For us the question—How can we mitigate damages of fluctuating lake levels—might become, "How can we help man adapt?

The reference dictated that we take a *broad systemic view* of the interaction among the physical, biological, and chemical components in the Great Lakes Basin. We are slowly coming to understand that we don't yet understand the phenomenon that is the Great Lakes. We still see it in bits and pieces rather than holistically. But we are trying, not just to be multidisciplinary, but to be interdisciplinary.

An integrated whole system approach is essential because of the many interdependent aspects of the reference. Economic policy problems and social policy concerns cannot be separated into prior questions of efficiency and subsequent questions of equity—or cast into terms of simple "trade-offs." They require balanced and integrated treatment.

We have been wary of a segmented approach which encourages specialist biases and political conflicts. Instead, the integrative approach should encourage a free flow of ideas. The participative mechanisms, teams of peer cooperation and coalition formation, are designed to effect real synergy—a bonus of energy from cooperation. We have set aside our conventional jurisdictions. Our task is not to develop an Environment Canada policy, a Corps of Engineers or EPA policy—not even an IJC policy—rather an integrated set of solutions.

But it's not easy. The constraints of time and the discomfort of ambiguity are continual pressures to return to the known approaches.

A true systemic approach includes humans as a central factor in the well-being of the system—recognizing the social, economic, political, and technical variables that affect how humans use and live with natural resources. To some of us it has become clear that the crux of the solutions to this policy dilemma are not scientific or technical. The heart of the issue is conflicting human values. What is beneficial to one vested interest can have adverse consequences for another. The desires of the recreational boater and the demands for hydroelectric power may be in conflict. The challenge will be to develop policy proposals that can encompass uncertainty and respect the values of all the different groups living and working around the Great Lakes. The time is past for government decisions to be spontaneous knee-jerk reactions and quick-fix schemes for those who lobby loudly—what is required is a tool for value clarification and environmental mediation.

We aim for *broad participation* in this Reference. Involving people is administratively untidy, and in an issue as controversial as this, somewhat risky. Any public process creates expectations from which one cannot back down. But the potential rewards clearly outweigh the risks.

Participation of key stakeholders (including institutions, experts, and the public) is critical in creating awareness and in arriving at some consensus about the design of workable solutions. The best written plans, impressive on paper, ultimately will not succeed if those who are affected are not convinced—do not "own" the solution. (I like Etzioni's concept of leadership—he says it's 50 percent followership and followership grows out of a sense of commitment to the community.) In the end, we can't police people—we have to make them think things are "unthinkable."

Broad participation is also helpful in ensuring that there is a link between science and policy—ensuring that this is a study designed to be used. This cannot be an academic exercise alone. We must link the best science (both natural and social) with the needs of public policy makers. To do less will render the study impotent.

And finally, we're trying to be flexible. The process has to be flexible enough to evolve, as creativity and innovation are not only acknowledged but encouraged. Our study plan is a dynamic document. It is highly unlikely that one single solution will be effective. If the mix of solutions is to be mutually reinforcing, our approach must remain flexible. We are trying to develop a "what if" capability in recognition of the real uncertainty this problem poses. In short we are trying to develop a consensus about the major uncertainties and the range of possibilities for management to deal with the uncertainties. There is a real question as to the adequacy of our social and political institutions to deal with change. What is required is a willingness to move beyond conventional wisdom, to combine ideas from unconnected sources, to embrace change, and to see problems integratively.

The work and learning of the IJC Reference can be a prototype for problems of similar scale around the world. There are many global dilemmas, including global climate change, that exhibit a similar interrelationship of issues of technology, economics, ecology, multiple jurisdiction, and quality of life. Problems of such magnitude ought not to limit our vision.

At the risk of reaching to the converted—the message I want to leave is that environmental decision making becomes much more complex when modern science and advanced technologies come face to face with the human element—human needs and human politics. But there can be no turning back. Challenges such as climate change cannot and will not be tackled effectively with the single perspective of science. A colleague of mine talks about making planetary survival politically popular. Our challenge is to engage the imaginations and the energies of all.

Presentation by Mrs. Lee Botts*

I am very glad to be here this morning with friends who share concerns about regional issues of the Great Lakes and who have helped develop the idea that what happens in the Great Lakes is significant globally.

The Great Lakes act as a kind of global warning system for the rest of the world. Yet no one has mentioned the possibility that the ability of the Great Lakes region to respond to the prospective global warming could help the rest of the world understand how to respond.

***Deputy Commissioner for Environmental Protection, Center for the Great Lakes**

I have been so busy acting locally these days that I have relied on work done really by the Center for the Great Lakes for my presentation this morning.

Great Lakes politicians continually boast about the economic advantage of the abundance of water in the region. But residents have tended to take that abundance for granted. The demands for increased diversion during the recent high water levels demonstrate how shoreline property owners who live closest to the lake decry the very abundance that the rest of us enjoy.

Yet, the threat that global warming will reduce these water supplies means that government and citizens alike in the Great Lakes area must consider how the changes will affect the region's economy, and that's the subject that I am discussing this morning.

As we all know, scientists now suggest that, in spite of likely increased precipitation in the region, global warming will lead to enough increase in evaporation to lower the levels of the Great Lakes and diminish other water resources in the region.

The Center for the Great Lakes carried out their work as part of the study that the U.S. Environmental Protection Agency will report to Congress later this year. The Center examined current and past regional studies, and the work was carried out by Daniel Ray, Curt Newman, and Bill Brock of the Center's staff.

Effects of Climate Change

Overall, the Center found that climatic changes due to global warming could bring both economic advantage and potential economic loss to the Great Lakes region. The climatic change would include higher average temperatures, changes in growing seasons, and changes in vegetation. Surface water resources would be affected by reduced runoff and declines in snow and ice cover, as well as the increased evaporation.

In addition to lowering of the levels of the Great Lakes, the streamflows in the rivers and streams would be reduced. Greater use of ground water supplies and less replenishment could lead to faster depletion of ground water.

Some economic responses would result from the lower levels of the Great Lakes, others from the climatic changes affecting other water resources.

The waterways shaped the development of the region. They provided transportation from the East Coast to the interior for settlers, and later the way that agricultural products were carried to market. Still later industrial centers grew near the water supply sources, and these same waterways provided the least expensive transportation of raw materials.

Today the regional economy still benefits from all the availability of water but is less dependent on water resources now than in the past. The question now is whether the abundance of water will give the region new advantages with global warming.

The 1980's have brought major changes in the regional economy. The largest change has been the decline in basic industry. This region has also lost population to other regions. Its growth in population is expected to remain slower than the growth in the rest of the country, 4 percent in this region compared to 11 percent in the nation as a whole.

Even with this decline in basic industry in both Canada and the United States, the Great Lakes area is still the industrial heartland of the continent. According to the Federal Reserve Board, in 1982, 42 percent of the value of manufactured goods was produced in the Great Lakes states.

In 1984, mostly automobiles, steel, and chemical productions still provided 23 percent of jobs. The manufacturing is related to other water dependent sectors of the economy such as power production, which Don Totten mentioned, and transportation. But the manufacturing itself does not require huge water supplies.

While producing almost half of the industrial products, the region used only 15 percent of the self-supplied water used by all the nation's industries. Surface sources supply all but 2 percent of the water that's used.

Gains in service employment recently have partially offset the loss in manufacturing jobs, but the rates of pay are lower for the service related jobs on the average. Some of the new jobs depend on tourism. In many communities, especially on the shorelines of the Great Lakes, there is much hope that expansion of tourism in the future can continue to help offset the loss of some industrial jobs.

Most of the Great Lakes states are now actively promoting tourism for economic growth which would then lead to still more service employment. A lot of the increased tourism is expected to be related to the Great Lakes. Tourism has been important in the region for at least 100 years, but the customers have come from the region itself. We do not know whether the Great Lakes will be able to develop a tourism industry that attracts people from other parts of the country.

It's not just the Great Lakes that support tourism. It's also the many small lakes and the many rivers that we have in the region. To date, models of the effects of the global warming all agree that tributary flows will decline and also contribute to the lower levels of the Great Lakes.

Effects on Navigation

The Center identified three kinds of economic activity that are sensitive to lower levels. They are navigation, power production, and tourism. The navigation system is both a regional system and an international system, but the greater part of the area served is the region itself, that is, there is more transportation between the lakes than from the lakes out through the ocean. The hopes that developed with the construction of the St. Lawrence Seaway for growth and international trade have not been realized to the extent that was projected at that time.

This use of the Great Lakes for transportation serves a much larger area than just the basin itself. Nineteen states contribute to the commerce that takes place on the Great Lakes.

There was a discussion yesterday about the fact that the lower lake levels anticipated with global warming will have major effects on the navigation system. The navigation interests have felt for some time that the controlling depth of 26 feet in the connecting channels and the harbors is too shallow.

But in 1968 the cost of deepening the system to 32 feet was estimated to be $4 billion. Neither in Canada nor the United States does anyone except the people involved in shipping contemplate the kind of investment that would be needed.

The ships that are used for interlake traffic have shallower drafts, but in recent years these ships have been becoming larger. Thousand-foot-long vessels are now the norm for new construction, which means that they can carry larger loads and decrease the cost per ton.

Time is also a big factor in the use of the Great Lakes system. Today's overseas customers are seldom willing to wait for manufactured goods while the ship travels out of the Great Lakes through the seaway and across an ocean.

Finally, closure of the system in winter limits navigation in the Great Lakes. If warming occurs, shorter winters will be one positive effect.

The system now has operated routinely as much as 11 months of the year, but it still can be closed down between December and March in a cold winter. The Center concluded that the benefits of global warming for shipping and navigation would be offset by the increased costs due to lower lake levels.

The longer shipping season would not increase the overall capacity if the ships have to carry smaller loads because of the lower water levels. Traffic backups in locks and connecting channels would also increase costs unless harbors and channels could be dredged deeper and more often. Then there is another complication.

Dredging in the Great Lakes is limited not only by direct costs but also by the high cost of disposal of contaminated sediments. Since open lake disposal of sediments has been banned, almost every dredging project throughout the lakes has been delayed or cancelled because of controversy about disposal on land.

The Corps of Engineers program for so-called confined disposal has allowed some dredging projects to proceed. Many others have not. In general, the controversy is greatest in commercial harbors that serve heavy industry where pollution levels in sediments are highest.

With lower lake levels, either ships would have to be smaller or they would have to carry smaller loads. The Center found that with a drop of 0.45 meters in Lake Superior, cargo capacity would be decreased by 5 percent. Cost would be increased by 6 percent, and it would take 15 days longer to transport cargo out of Lake Superior.

In shallow Lake Erie, water level changes are likely to be more extreme, and a 1-meter drop would decrease cargo capacity 14 percent, increase cost by the same percentage, and require 50 days longer for cargo delivery.

Effects on Power Production

Lower water levels would obviously also affect power production in the Great Lakes. More Great Lakes water is used for generation of electricity than for any other purpose. This availability of power, of course, is a keystone of the industrial strength of the region, and most of the electricity now and in the past has been used in the region.

According to studies examined by the Center, the Great Lakes states produced almost 700,000 giga-watts of electric power in 1984, and power production accounted for over 82 percent of the self-supplied water used by industry. If decreased water results in decreased power production, the Center suggests that the region could become more dependent on outside sources of power. This would happen because while power production decreased, the need for electricity in the region would increase. The experience in the summer of 1988 confirmed the Center's conclusion that higher temperatures would lead to increased use of electricity for air conditioning.

In Chicago this past summer, peak load records were broken repeatedly in the hottest summer since 1935. The Center estimates that the climate change predicted with global warming would require from 11.5 percent to 14 percent more electricity and concurrently more power production capacity because of the temperature increases.

The costs to meet the necessary increases in peak capacity are estimated to be in the order of $5 to $10 billion per year. These costs could be reduced by use of new technology such as solar power. Hydropower production would be decreased with lower levels.

Power generation is already the most consumptive use of water from the lakes. Should more nuclear plants or even coal- or oil-fired plants be built to meet the new demands, the increased consumptive use would lower the levels of the lakes still further.

Not discussed in the Center's paper, but a factor brought to my attention at a meeting I just attended in Tucson, is the fact that the nuclear industry is gearing up on the assumption that global warming will bring a revival of nuclear power.

In the 1960's the Atomic Energy Commission believed that nuclear electrical generating capacity would be concentrated in the Great Lakes. As recently as the early 1970's, the AEC was planning to build between 20 and 24 nuclear plants on Lake Michigan. Fortunately, this did not come to pass.

In Tucson where I was attending a meeting of local and state officials concerned with air quality, there was also a meeting of people in the uranium industry that was like a rally. They think their future is looking very bright, which has made me think again about increased use of nuclear power as another possible side effect of global warming.

Effects on Tourism

Tourism is the third area that would be affected by the warming effects on water resources. The Center's estimate of 1984 revenues from tourism were based on the value of business by restaurants, sport fishing, boat operators, marinas, and boat builders with travel costs and motel and hotel expenditures also covered. They estimated that the benefit to the regional economy in 1984 was from $8 billion to $50 billion based on different sources.

Much of the promotion of tourism since 1970 has focused on the income generated by avid anglers. The Great Lakes Fishery Commission estimated that anglers spent $766 million in 1981, and the Center estimated that they spent $133 million on Lake Erie alone in 1984.

Tourism is the major industry in many areas of the northern part of the region. Family vacations and visits to rural and natural areas are the chief reasons for tourism in these rural areas. Recreational boating, sport fishing, and conventions are the base in urban areas.

Again, the Center found that there could be both advantages and disadvantages to tourism with global warming. Longer summers could mean better use of public parks and boating facilities.

Shorter winters could mean less skiing and ice fishing. But all forms of water recreation would be affected by changes, not only in the quantity of water, but also the quality. Higher temperatures could lead to greater production of algae and concentration of contaminants.

Increased biological activities would increase possibilities for oxygen depletion. Some have even suggested that the annual turnover of lakes which now mixes oxygen with deep waters could not occur. Turnover would be least likely to occur in shallow bays and harbors and in the shallow areas of Lake Erie.

Receding waters could also expose contaminated sediments which are a major issue in the Great Lakes, but they could reduce the possibilities of flooding of hazardous waste disposal sites, especially in the industrialized areas. What to do about these old hazardous waste disposal sites is one of our major questions.

Loss of wetlands could diminish the ability of natural systems to cope with the pollution as well as reduce habitat for wildlife. New shoreline areas would be exposed with lower lake levels. In some cases increases in the shorelines might offset losses to erosion in the past.

It is also possible that the loss of ice cover in winter could expose shorelines to more erosion. We had experience in Chicago with how important the ice cover can be in the famous storm in February 1987 where lack of ice cover enhanced the threat of extensive flooding in Chicago. No flooding would have occurred and the damage would not have been nearly so great had we had a normal ice cover for February.

Even with increased evaporation and significantly lower levels, the Great Lakes would still remain the largest source of fresh surface water on North America.

While it would seem on the face of it that this relative abundance would be a great advantage to the Great Lakes, the Center also suggests that population growth, greater use for power production, and pressures for diversion to replenish ground waters or to augment water in the Mississippi River, which was demanded in the summer of 1988, could increase water consumption and pressures on the Great Lakes. Other regional resources besides the Great Lakes and the water resources would also be affected.

Other Resources Affected

Agriculture and forestry are the other major resources that would obviously be affected by the climatic changes. Agriculture is actually the largest industry in the region with $16 billion in direct cash receipts for agriculture in 1983. Carrying of grain for export is one of the major uses of the Great Lakes transportation system.

In the past, surplus production has depressed agricultural prices which rose somewhat this year with the drought. Although use of irrigation has been increasing in the region, it is still quite small compared to other places such as the Great Plains.

The increase in temperature and changes in the growing season would, of course, affect crop yields. The Center's analysis speculates that the southern parts of the region may have to consider changing crop to perennials or to annuals that can yield two crops per season where the soil is good.

For forestry, the effects would be to cause changes in species and in some places to cause forests to disappear and to be replaced by prairies or savannas or grasslands. The forests in the region are used for furniture production and other purposes. In general it would be expected that the species that replace existing species will have less value than those that are now present.

In conclusion, the Center's analysis suggests that features in the region that would promote adaptability include extensive public lands, vast aquifer recharge areas, many prime farmlands, and many natural shorelines (in spite of many urban shorelines). Also, a good land transportation system could be developed. Features of the region that would diminish the ability to adapt to global warming include implacable infrastructure such as the Great Lakes navigation system and extensive shoreline development that wants to have a fixed level of the lake. These features would be less adaptable to change.

Finally, the Center suggests that "flexibility in responding to climate change should be a more important criterion to those investing in new infrastructure or making decisions which may be affected by climate modification. This flexibility can assure the region's flexibility to maintain the public services which support economic development."

In closing, I would like to add that I disagree with the people this morning who say that the issue is <u>how to be certain</u>. I contend we will never be certain and that the issue is <u>how to adapt</u>.

I was reminded of this even more when Stan Changnon was talking about this year's drought and the lower precipitation. Yesterday I received the Corps of Engineers' most recent bulletin on lake levels which reported the record-breaking rains on Lake Superior that resulted in a 5-inch rise in level. Even with the drought and heat of last summer, precipitation in the Lake Michigan Basin in 1988 is only 2.5 inches below the annual average precipitation.

I do not believe we will ever be able to predict with absolute certainty. And I think to try to make certainty rather than adaptability the goal could do us in. Thank you.

Report of the Panel On Energy and Transportation*

Introduction

This group assessed the possible impacts of climate change on energy and transportation, and in turn identified key issues. These endeavors led to the identification of recommendations for research, policy actions, and future studies.

There were six papers presented to this group, three concerning power generation, two on transportation, and one which addressed both topics. These papers were discussed and served as the basis for identification of key issues.

The energy papers each described changes in demand which would be likely in response to future warming. While warming of the climate of the basin was found to benefit society by reducing the need for power in winter months, it was noted this apparent benefit could be offset by other factors. For instance, negative factors include a higher peak demand in summer due to increased air conditioning, lower water levels decreasing available hydropower capacity, and the possibility, under extreme conditions, that there might be inadequate supplies of cooling water in some locations within the basins of the Great Lakes. The hydroelectric losses described in the energy presentations, although seen as a small portion of the gross revenues involved in power generation, are estimated to be $1.5 billion annually.

Transportation papers considered potential effects to the industry as a result of climate change. Consequences of the warming were envisioned to include reductions in cargo size, higher operating costs, restricted access to ports, and increased dredging on a recurring basis.

The highlights of the ensuing discussion noted that very conservative assumptions were used in developing the impact assessments. The risks associated with actions that accept or reject the climate scenarios need investigation. The panel discussed the fact that extreme events were not considered in the climate scenarios. This omission was considered important in assessing impacts on the transportation and energy fields where changes in extremes rather than the mean condition are apt to be more serious. Sensitivities and resiliency within each sector are important. The panel concluded that these must be precisely identified.

One of the main problems identified was conflicting multiple uses of the lakes. This fact needs to be recognized and considered in transportation and energy impact research. The diversion of waters from the Great Lakes is a very sensitive subject, especially in view of the diverse reactions to proposed diversions of Great Lakes water during the 1988 drought.

In the discussions, five common issues were identified in concert with other groups, and three more were identified specific to this group. The issues which follow include specific recommendations based on these issues and our discussions.

***Presented by Andre Saulesleja, Panel Rapporteur**

Issues

Our first issue concerned ***research opportunities.*** Energy and transportation impacts differ between the lakes; hence, lake-by-lake studies need to be conducted. A range of probabilities for future Great Lakes levels is needed, along with extreme bounds for risk analysis. Climate impacts research should be interactive and as accurate as possible in defining the physical effects to assure that their outputs meet the informational requirements of policy and decision makers. Research must be convincing to the transportation and hydropower sectors if they are to become supportive of reducing fossil fuel combustion or other options (conservation, increased efficiency). Research must also address conservation and resiliency measures as means of adapting to future climate changes.

Our second issue focused on ***potential sources of friction*** between Canada and the United States. In the energy and transportation sectors, we found there were potential social, economic, and political frictions; for instance, within the transportation sector, we concluded that there are different interests not only between countries, but also between modes of transportation. Water diversions for transportation and consumptive uses represent a potential for major conflicts. Potential conflicts also involve hydropower generation. That is, unilateral actions by one country to constrain an energy mix or energy strategies would have impacts on pricing and cause disagreements. These impacts and conflicts need to be investigated.

A third issue includes ***actions required of the private sector.*** We also included public utilities, entities not completely private nor completely public. A major issue concerns information; that is, sectors which are vulnerable to climate change should be alerted to the issue and be involved in developing the research agenda.

The fourth issue was ***how Canada and the U.S. collaborate on Great Lakes issues.*** For the energy and transportation sectors, there already exist sufficient institutional structures to collaborate on major climate impacts issues. The key to making these work is in developing and maintaining good information networks. A good example of this is a Great Lakes Directory published in 1985; it should be updated.

The fifth issue identified involved the implications of use of ***alternatives to fossil fuels*** as part of the solution to other environmental problems. Conservation, which is already under way, is a desirable goal. There are some alternatives to fossil fuels but their development as a practical technology must occur.

The sixth issue is the need to ***investigate more than just future changes in temperature and precipitation.*** Impact studies must address other climate conditions (such as the potential for severe storms, more intensive precipitation, and strong winds).

The seventh issue concerned ***the global climate models*** and their outputs. Concerns exist about whether they are to be viewed as forecasts or just a possibility of future conditions. We need to have a measure of the degree of certainty and to improve the consistency of present day models. Accuracy in precipitation is crucial to defining transportation and energy impacts. Predictions of possible climate changes with a higher spatial resolution are also needed.

The eighth issue identified concerned the need to ***conduct multiobjective interdisciplinary climate impact studies.*** Assessment of the potential effects of climate change cannot succeed without such endeavors. Acid rain, the emission of other gases, and risks of other energy alternatives must be considered, even in a short list of concerns.

Recommendations

Many specific recommendations for research, institutional development and adjustments, and policy development are implicit in the above eight issues. We also identified two broad recommendations.

One is the need to improve the quality of outputs of the global climate models. This involves a better understanding of atmospheric processes and also improving the computer modeling capabilities and enhancing the spatial resolution.

Second is the need to conduct multiobjective, multidisciplinary climate impact studies. Historically, the kind of research that meteorologists, climatologists, and those from the other physical sciences pursue involves things which can be linearized, separated in terms of functions, and thought of mathematically. But, we must go beyond the numerical methods. We need to develop a framework for these studies which would incorporate energy, transportation, and other sectors in the decision-making processes. We have to develop a framework for developing policy, and that is a very difficult challenge.

Responses to Climate Change: A Challenge to the Energy and Transportation Sectors

Stewart J. Cohen*

The Need to Know

Atmospheric change issues, including climate change, are now receiving considerable attention throughout the world. At the global level, proposals for new international agreements to reduce pollution are being seriously considered. However, there is concern that our planet is already committed to a certain amount of change because of the historical accumulation of various trace gases in our atmosphere. If that is the case, it becomes appropriate, indeed necessary, for people at the regional and local levels to assess how global climate change may affect them, and to consider possible responses.

This panel has been asked to consider climate change as it pertains to the energy and transportation sectors within the Great Lakes region. We are most fortunate to have a number of experts from these sectors participating in the discussion.

Let me preface my remarks by pointing out that I am not an expert in energy or transportation systems. I am a consumer of their products and services, as we all are, and I'm concerned about how climate change may affect these activities under a "business as usual" scenario. My purpose here is to attempt to articulate these concerns, building a bridge of information between the atmospheric sciences and regional resource users. I do this with the hope that others in this group, who are experienced in energy and transportation matters, can suggest appropriate responses to climate change that will allow consumers to continue to enjoy the benefits of these services at a reasonable cost and with minimum interruption.

Impacts of Water Resources

Hydrology

Global warming scenarios, obtained from either General Circulation Models (GCM) of the atmosphere or hypothetical cases, have been used in a number of Great Lakes studies, including Cohen (1986a; 1987a), Quinn (1987), Quinn and Croley (1983), Southam and Dumont (1985), Sanderson (1987), Marchand *et al.* (1988), and work in progress at the Great Lakes Environmental Research Lab, Ann Arbor, Michigan. Although there is agreement regarding projected global temperature changes, the above scenarios exhibit a considerable range of projected changes in monthly temperature, precipitation, and other elements at the regional scale. As a result, it is difficult to be precise about the magnitude and timing of hydrologic changes. However, there appears to be census on the direction of change (Table 1).

Reduced net basin supply occurs because the projected warming leads to increased evaporation from land and water surfaces, which is only partially offset by projected in-

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Table 1. Impacts of Global Warming Scenarios on Great Lakes Hydrology.

Overland Evapotransporation	Increase
Snowmelt	Decrease with earlier peak
Runoff	Decrease with earlier peak
Soil Moisture	Decrease
Lake Evaporation	Increase
Overlake Precipitation	Increase
Lake Surface Temperatures	Increase
Ice Cover	Decrease
Net Basin Supply	Decrease with earlier peak
Lake Levels	Decrease with earlier peak

creases in precipitation. If changes in wind speed and humidity would be large enough, these could play important roles, but for now, uncertainties regarding their projections at the regional scale make it difficult to reach consensus on their hydrologic impact.

Water Demand

Projected changes in regional water demand (i.e., consumptive use) require consideration of both climatic and nonclimatic elements, including population growth, economic concerns, technological change, and changes in the energy supply mix. Estimates of present and future demand and supply for the basin as a whole are listed in Table 2. Had estimates been made for individual lakes, the demand/supply ratio would probably be higher for Lakes Michigan and Erie, and lower for the other lakes.

Demand estimates obtained from IJC (1981, 1985) did not consider climate change, so an additional "warmer climate" column has been added to provide a "best guess." More research and monitoring is needed so that a clearer picture of water demand trends can be obtained. For now, this "best guess" is that demand, as a percentage of supply, will increase, thereby creating additional force on the projected downward trend in lake levels, with negative side effects on resource users including the energy and transportation sectors.

Impacts on Energy and Transportation

Energy Supply

Hydroelectricity is produced by utilities in both Canada and the United States. A number of facilities are located along the main connecting channels within the Great Lakes watershed. Reduced net basin supply and lower lake levels would tend to reduce production at these facilities.

Recent studies of utilities in Ontario and New York are summarized in Table 3. Under a "business as usual" scenario, reduced production of hydroelectricity would necessitate increased production by other modes, notably coal and/or nuclear power, or increased imports from other regions (e.g., Quebec), hence the rise in costs. Greater use of coal would also exacerbate the atmospheric change problem.

Projected changes in production of hydroelectricity may be offset by improved production efficiency and changes in demand. The latter could be induced by economic considerations, government policy initiatives (e.g., conservation incentives), and warmer temperatures.

Energy Demand

Scenarios of global warming would affect demand for heating and air conditioning. Assuming "business as usual," warmer winters should lead to reduced demand per customer, while the opposite would occur during warmer summers. Annual demand would decrease in Ontario (Table 3), where winter heating is the dominant seasonal requirement. In New York, annual demand would *increase* (Table 3) because of the higher demand for air conditioning in the "downstate" or southern region. This increase would overshadow the reduced demand in "upstate" or northern New York, where historical and projected demand patterns are similar to Ontario's.

There are many uncertainties associated with projections of summer demand, including future growth in the number of homes with air conditioners (room units or central systems). The Ontario study assumed no change in the percentage of customers with air conditioners, so these projections should be treated as conservative. The New York study indicated that in a warming scenario of sufficient magnitude, increases in the number of air conditioned homes would contribute to further increases in demand.

Commercial Shipping

Projected changes in lake levels would create a shipping environment not seen since the low level period of 1963-1965. In fact, it is estimated that a 15 percent decrease in net basin supply at all lakes would reduce levels to below recorded minimum levels for this century (Quinn, 1987). Such a decrease is well within the range of results produced by various studies listed above and in Table 2. There would also be significant reductions in ice cover permitting almost year-round shipping.

In a "business as usual" scenario, lower lake levels and reduced drafts at interlake connecting channels would lead to increased navigation costs, since less cargo could be carried per trip. This is illustrated in Table 4. Projected cost increases for a scenario of global warming are listed in Table 5. The supply decrease for the middle column is approximately 15 percent. Results indicate that losses associated with lower lake levels would overshadow the benefits of a longer ice-free shipping season (Sanderson, 1987; Marchand *et al.*, 1988).

Future shipping activity could also be affected by changes in regional energy production. It is estimated that in a scenario of increased coal shipments (a possible side effect of reduced hydroelectricity production), net losses would be greater since these shipments would be interlake (Table 5).

It should also be noted that climate changes in other regions could have a significant influence on demand for Great Lakes shipping services. These include changes in agricultural export patterns, and availability of competitive services, such as shipping via Churchill at Hudson's Bay.

Possible Responses?

Having reviewed the potential impacts of global warming scenarios on the energy and lake transportation sectors within the Great Lakes region, it is appropriate to address the question of responses. Fortunately, we are not faced with a scenario of gloom, doom, and devastation. However, a cautionary "yellow alert" has been sounded. The potential problems appear to be significant within the region and could lead to disruptions of service and increased real costs unless appropriate actions are taken. But what should they be? What are the alternatives for responding to global climate change at the regional and sectoral level?

Table 2. Projected Water Supply and Demand in the Great Lakes Region due to Global Warming Scenarios.

	1985	2000	2035	
Supply (m^3/sec)	8200	7300-7700	5900-7100	
			Present Climate	Warmer Climate
Demand (m^3/sec)	106-180	161-280	300-720	350-770
Demand/Supply (%)	1.3-2.2	2.1-3.8	4.2-12.2	4.9-13.1

Notes: Supply is represented by streamflow at Cornwall, including natural flow and assumed constant net diversion of +68 m^3/sec; demand not included.

Demand represents <15% of withdrawal for various sectors; does not include in situ demands by hydroelectric utilities, shipping, recreation, etc.

Assume +10 m^3/sec for municipal and +40 m^3/sec for agriculture in warmer climate scenario.

Sources: Cohen (1986a, b; 1987b); IJC (1981; 1985).

Table 3. Projected Changes in Electricity Supply and Demand Due to Global Warming Scenarios.

	Supply		Demand	
	%	Costs ($ mill)	(%)	Costs ($ mill)
Ontario (2035)	-4 to -7	up to 111 (1984 $C)	-2 to -3	Down to -204
New York (2015)	-10 to -19	up to 126 (1985 $US)	0.13 to 0.45	Up to 115

Notes: Supply change due to loss of hydroelectricity. Change in supply costs due to substitution of fossil and nuclear fuels for lost hydroelectric power
Demand change compared with forecasts.
Change in demand costs due to increased or decreased use of substitute fuels. New York study includes increased number of air conditioners.

Sources: Ontario; Adapted from Sanderson (1987), 4 Ontario Hydro facilities.
New York; Adapted from Linder and Gibbs (1987), Upstate and downstate facilities.

Table 4. Projected Lake Levels (cm) and Loss of Carrying Capacity (1000 tons).

Changes in Levels (cm)	Size of Vessel (1000 tons) 21	27	45	60
Hypothetical				
-7.5	.3	.4	.5	.6
-15	.6	.7	1.1	1.3
-22.5	.9	1.1	1.6	1.9
-30	1.2	1.5	2.2	2.5
Scenario of 15% Decrease in Supply				
Erie:				
-51	2.0?	2.6?	3.7?	4.3?
St. Clair:				
-60	2.4?	3.0?	4.4?	5.0?
Michigan-Huron:				
-77	3.1?	3.8?	5.6?	6.4?

Note: "?" values are extrapolated by author.

Sources: Adapted from Raoul and Goodwin (1987) using supply scenario from Quinn (1987).

Table 5. Estimates and Projections of Annual Navigation Costs (1979 US$ million).

	1900-1977 Climate	Warmer Climate	Warmer Climate +
Iron Ore	78.8	84.0	86.6
Grain	77.3	80.0	75.7
Coal	31.4	33.2	91.6
Limestone	9.6	9.7	8.3
Total: Mean	197.0	206.9	262.2
Max	207.1	227.0	299.6
Min	193.5	196.8	239.8

Notes: "+" includes increased consumptive use obtained from IJC (1981) and "forecasted" economy, including 2% annual growth in coal shipments over 50 years.

Source: Sanderson (1987); Marchand *et al.* (1988).

I do not know what specific actions the energy and transportation sectors should take, but I would like to complete this "information bridge" by providing a general list of response types that may be appropriate for different planning horizons. These are: a) prevention, b) anticipation, c) mitigation, and d) adaptation.

Prevention strategies are designed to slow or stop the changes taking place in our atmosphere, including the greenhouse effect. Such strategies include global reductions in trace gas emissions, afforestation in the tropics, and other changes in resource uses. Although changes within the Great Lakes region will not by themselves solve this problem, they could serve as an example for other regions to follow.

Anticipation includes monitoring and research activities that would provide planners and decision makers with a clearer, more detailed look at the future. No one has a perfect crystal ball, but given that the time horizons of projected impacts are not much longer than the lifetimes of major capital works, such as dams and freighters, there would be benefits associated with better anticipation of future conditions. It is no longer safe to assume that the future climate will be similar to historical climate experience.

Mitigation measures to reduce damage may include short-term responses to extreme events, such as temporary changes to lake regulation plans. In a future climate, however, it may become expensive to protect infrastructure that had been designed for the present climate. Consequently, there may be situations where adaptation would be more appropriate. This could include a system of water allocation, new designs for ships, or changes in location and operation of facilities. In addition, we must not forget the diversion and dredging options, both of which are controversial.

How will we know what strategies would be the best to use in the Great Lakes region during the next 2 years, 10 years, or 50 years? By what criteria should "best" be defined? Must we wait for more accurate climate projections before action is taken? What are the costs of doing nothing?

If there can be consensus within the energy and transportation sectors that the Great Lakes region should now be on "yellow alert," then the information bridge will have been completed. This bridge has been built largely by a few impacts researchers funded by or working for federal government agencies in both countries. However, the design of the road that leads from this bridge will require the active participation of a broader base of expertise, *especially the resource users themselves*. This symposium represents another step in facilitating collaboration between scientists and policy makers in the private and public sectors. I hope that it will be able to send a clear message to the region's industries and governments (state, provincial, regional, local) that there is recognition of the potential problems, and *active support* for finding solutions.

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Impacts on Electricity Generation in New York State

Randy D. Crissman*

Abstract: An overview of the potential climate change impacts on electricity generation in New York State is presented. The impacts are based on the economic costs of replacing low cost hydroelectric generation from the New York Power Authority's plants on the Niagara and St. Lawrence Rivers with nuclear and fossil fuel generation. For climate change scenarios predicting a lowering of Lake Erie and Lake Ontario levels by 2 feet, the long run average annual costs to New York's economy may be on the order of 160 million 1988 U.S. dollars. In addition, projected efforts by the industry to reduce or compensate for capacity additions through demand side management may be offset and eventually exceeded by the impacts of such a change in climate.

Introduction

The purpose of this paper is to present an overview of the potential impacts of climate change on the generation of electricity in New York State. It does not represent an exhaustive analysis of the potential impacts, but focuses on those impacts that would be most noticeable from a statewide economic viewpoint. For example, the effects of climate change on generation from mall hydroelectric projects, which only account for about 3 percent of the state's total annual electricity usage (NYPP, 1988), are not considered. On the other hand, climate change impacts on hydroelectric generation by the New York Power Authority (NYPA) at its generating plants on the Niagara River and the St. Lawrence River, which accounts for about 19 percent of the state's annual electricity usage (NYPP, 1988) could be significant. As a result, the interrelationships between Great Lakes levels, flows in the Niagara and St. Lawrence Rivers, and hydroelectric generation by the New York Power Authority are used as the basis for assessing the impacts of climate change on the demand, supply, and cost of energy in the state.

This paper does not necessarily endorse the concept of climate change, since the technological, environmental, social, and economic factors affecting such change are quite complex. The change in the state's mix of generation and the attendant avoided costs resulting from predicted changes in climate due to a doubling of the carbon dioxide concentration in the atmosphere is used as the basis for assessing the economic impacts. Avoided costs in the context of the analysis presented herein are the costs associated with replacing nuclear or fossil fuel generation with less expensive hydroelectric generation. Positive avoided costs represent a benefit to the state's economy and negative avoided costs represent a cost. Such benefits or costs result whenever hydroelectric generation offsets or is replaced by nuclear or fossil fuel generation, due to changes in the relationship between the demand and supply of energy.

Although climate change might affect electricity generation in the entire Great Lakes Basin, the impacts discussed here apply only to New York State. Impacts of climate change on electricity generation in Canada are discussed in a report prepared by Environment Canada in 1987 (Environment Canada, 1987).

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New York Power Authority

The New York Power Authority's primary objective is to provide lower cost energy for the benefit of the people of New York State (NYPA, 1988). This is done by constructing, owning, and safely operating electric generation and transmission facilities, purchasing lower cost out-of-state energy, and promoting conservation. As a state-owned energy corporation, the NYPA sells energy to industry, to utilities for resale to their customers, and to authorized public bodies.

The generation and transmission facilities of the NYPA are spread throughout New York State as shown in Figure 1. The generation facilities include the hydroelectric projects on the Niagara and the St. Lawrence Rivers, a pumped storage project, two nuclear stations, an oil/natural gas station, and five small hydro projects. These stations, which have a combined peak capacity of 6,816 megawatts, generated 38,320 gigawatt-hours (GWH) of electricity in 1987. The mix of the NYPA's 1987 generation is illustrated in Figure 2, where Great Lakes hydro refers to power generated from the Niagara and St. Lawrence Rivers. The NYPA's 1987 generation accounted for about 29 percent of the total electricity consumed in New York State.

New York Power Pool

The New York Power Pool (NYPP) was established in 1966 by the seven major investor-owned utilities in New York State. The New York Power Authority became a participating member one year later. The basic purpose of the NYPP is to coordinate the development and operation of the members' electric production and transmission facilities in order to obtain maximum reliability of service and efficiency of operation from the interconnected systems of the NYPP members.

Electric Power Outlook for New York State

Each year the New York Power Pool issues a planning document entitled "Electric Power Outlook." These documents present forecasts of the demand for and supply of electricity in New York State over a 17-year planning horizon. For example, the April 1988 report (NYPP, 1988) covers the period from 1988 to 2004. To keep the analysis presented in this paper in perspective, the impacts of climate change are assessed over this 17-year period. The potential impacts in the long run, say 25 to 50 years hence, are also briefly discussed.

Historical and forecasted annual energy requirements in the period between 1978 and 2004 are presented in Figure 3. The values in Figure 3 don't reflect the potential reduction in energy requirements through new industry-sponsored demand-side management programs. In general, demand-side management, in the absence of climate change is forecasted to reduce total demand by about 1 percent by the year 2004. Demand-side management is not considered to be a strategy for offsetting the economic impacts of climate change. The relative economic impacts would be similar whether or not such programs are implemented (Ontario Hydro, 1987). However, the effect of climate change on the industry's projected energy supply savings through demand-side management are discussed, since it is relevant to the industry's plans for adding to the generation capacity.

The NYPP projections of future energy requirements do not explicitly reflect the possible effects of climate change. Based on the results of the 1987 Environment Canada study, use of projections that don't consider climate change should not be a major limitation on the analysis presented herein. That study concluded that climate change

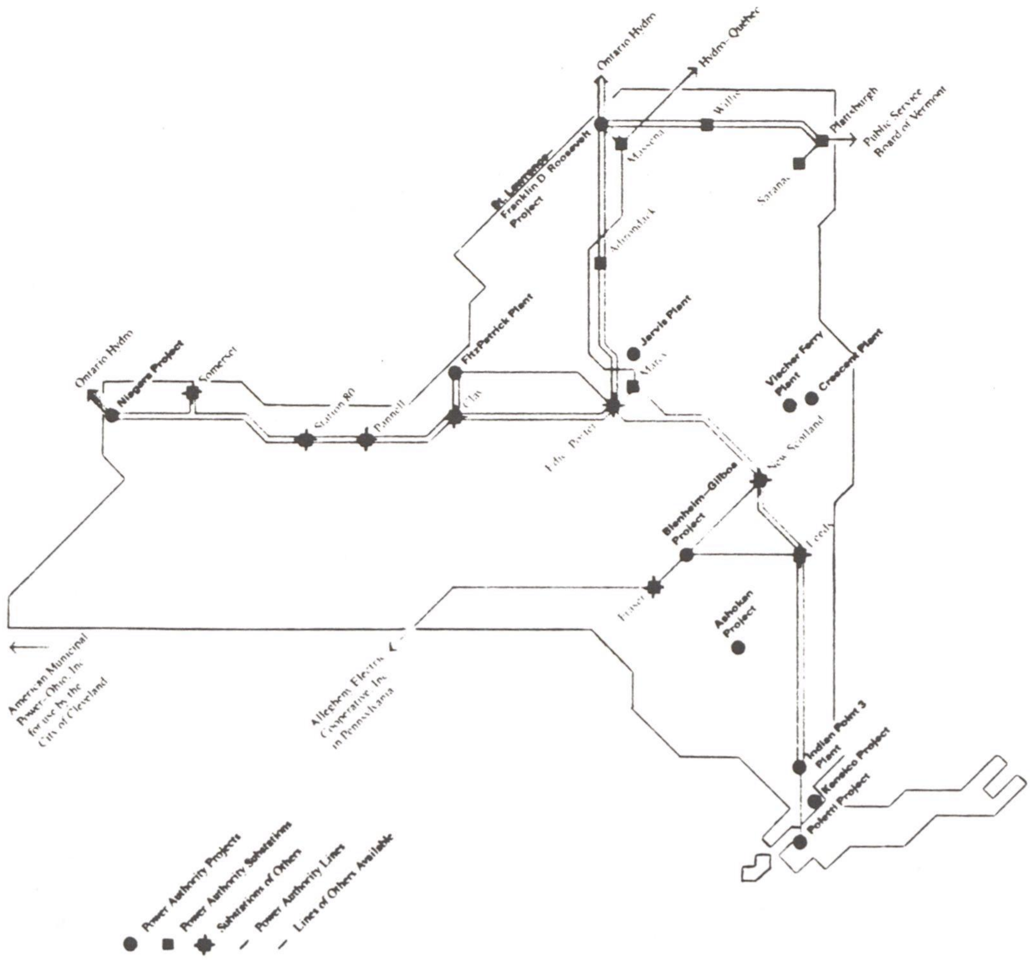

Figure 1. New York Power Authority network

may actually produce energy savings due to reduced demand in the summer and winter in Canada. In this paper, it is assumed that climate change would equally increase summer demand and reduce winter demand in New York State, resulting in a zero net change in annual energy requirements.

Note that the analysis presented here is based on the NYPP's base forecasts for average annual energy requirements (average annual growth rate of 1.4 percent) and not peak summer or winter load requirements. As a result, impacts associated with climate change induced increases in peak summer loads, which may be higher than those forecast by the NYPP, are not explicitly accounted for. Such impacts might include capital costs for building more generating capacity than is currently planned and/or impacts due to forced reductions in supply due to capacity constraints. The effects of climate change on peaking requirements might be more closely aligned with the high (global warming, average annual growth rate of 2.4 percent) or low (global cooling, average annual growth rate of 0.8 percent) growth rate cases evaluated by the NYPP. For the high growth rate case, the NYPP estimates that additional capacity to handle peak demand, beyond currently planned additions, would be required by 1999.

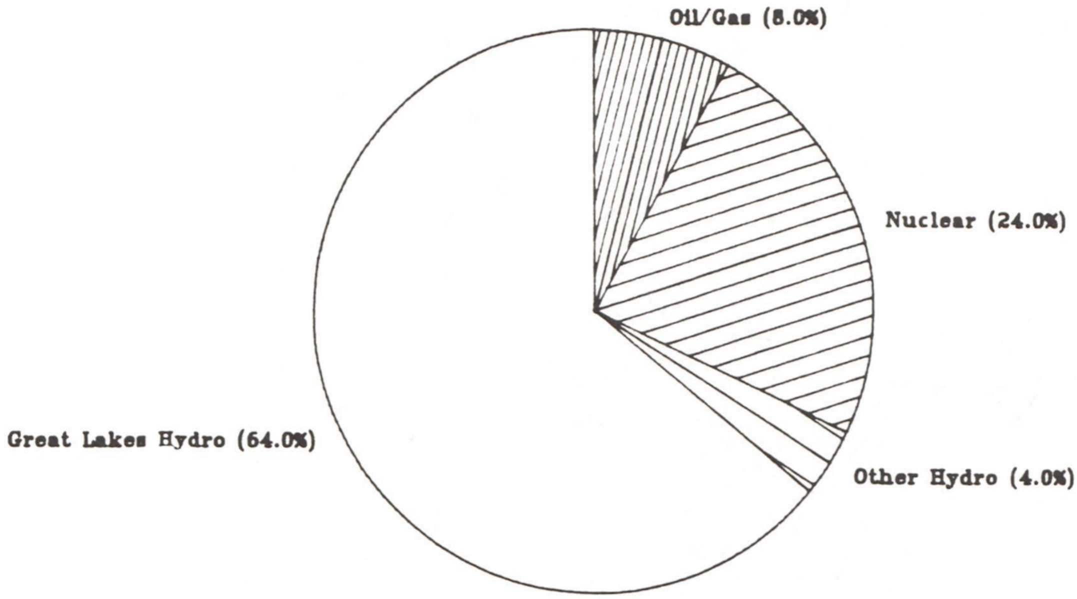

Figure 2. New York Power Authority's mix of electricity generation in 1987

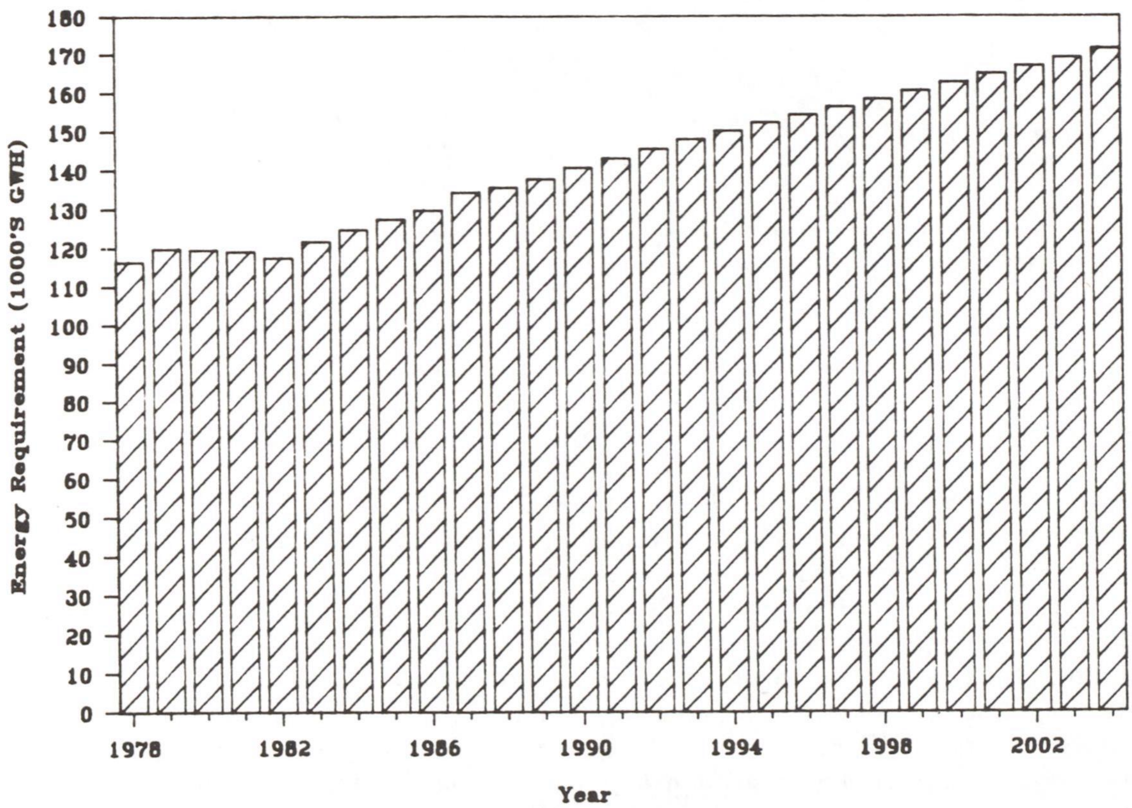

Figure 3. Annual energy requirements for New York State
[Actual: 1978-1987; projected by NYPP: 1988-2004]

Great Lakes Hydropower Generation in New York State

The New York Power Authority generates hydroelectric power at its Niagara Power Project on the Niagara River and its St. Lawrence-Franklin D. Roosevelt (FDR) Project on the St. Lawrence River. The generating capacities of the plants are 2400 megawatts and 800 megawatts, respectively. In 1987, these plants generated 17,130 GWH and 7,370 GWH, respectively, of electricity. A major upgrade and expansion of the Niagara Power Project, scheduled for completion in 1988, will add about 330 megawatts of peak generating capability to meet summer and winter demand. However, annual generation should not change significantly.

The impacts of climate change on electricity generation in New York State are derived from relationships between average annual Niagara River flow and annual generation at the Niagara Power Project and the St. Lawrence-FDR Project. St. Lawrence-FDR Project generation is correlated to Niagara River flow, because over 80 percent of the total inflow into Lake Ontario is from the Niagara River. These relationships were developed from actual generation and river flow data in the years since 1962, the first full year of operation for the Niagara Power Project. In this period, average annual Niagara River flows varied from 161,800 cubic feet per second (cfs) to 253,300 cfs; the minimum and maximum recorded annual flows since records began to be kept in 1860 (Figure 4). Net annual generation at the Niagara Power Project and the St. Lawrence-FDR Project varied from 9,550 to 18,000 GWH and from 5,430 to 7,790 GWH, respectively. The correlation coefficients (R^2) between average annual Niagara River flow and generation at the two projects were 99 percent and 97 percent, respectively. Figure 5 illustrates the relationships between average annual Niagara River flow and generation at the Niagara Power Project and the St. Lawrence-FDR Project for flows between 150,000 cfs and 270,000 cfs.

Impact of Climate Change on Electricity Generation

The NYPA's firm commitment for power from the Niagara Power Project and the St. Lawrence-FDR Project, on an annual basis, is 19,750 GWH. The average annual Niagara River flow required to meet this commitment is about 200,000 cfs (Figure 5). Generation in excess of this commitment is an added benefit to the state's economy, since it replaces other and more expensive sources that would otherwise have to be used (e.g., oil). Generation below this commitment results in additional costs, since the shortage must be made up from other sources. Based on this, a relationship between avoided costs (in 1988 U.S. dollars) and average annual Niagara River flow was developed (Figure 6). Note that Figure 6 is plotted relative to the long-term benefit of approximately 1,000 GWH derived from the long-term average Niagara River flow, which is about 208,000 cfs. In other words, relative to conditions without climate change, there are essentially zero annual avoided costs at average annual Niagara River flows around 208,000 cfs.

The unit cost for replacement of Niagara Power Project and St. Lawrence-FDR Project generation used herein is $30,000/GWH (PSC, 1987). This value approximates a statewide average, avoided cost for nuclear and fossil fuel generation in 1988. It includes costs for capacity, transmission, and energy. The capacity and transmission costs, which are the per unit annualized fixed costs for capital, account for about 10 percent of the total unit cost. The remainder includes variable costs attributable to costs for fuel, operation, and maintenance.

For purposes of this analysis, costs are expressed in terms of 1988 U.S. dollars. Thus impacts in future years are related to current price levels. This was done to provide a consistent basis for comparison.

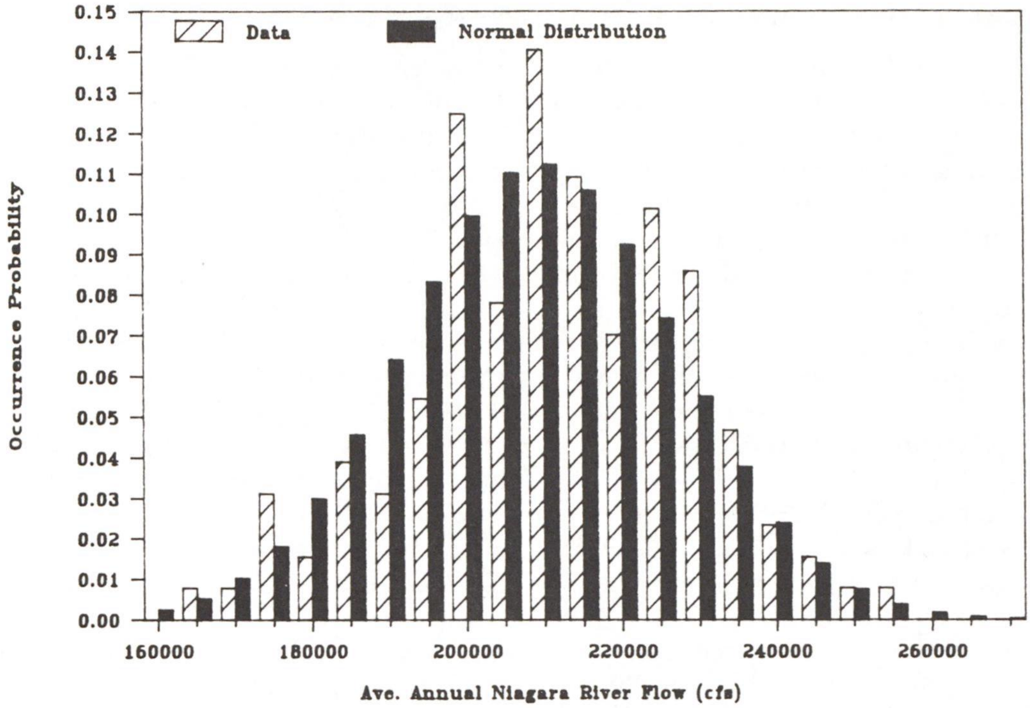

Figure 4. Distribution of average annual Niagara River flow for 1860 to 1987 (Normal distribution passes the Chi-square test at the 5% significance level)

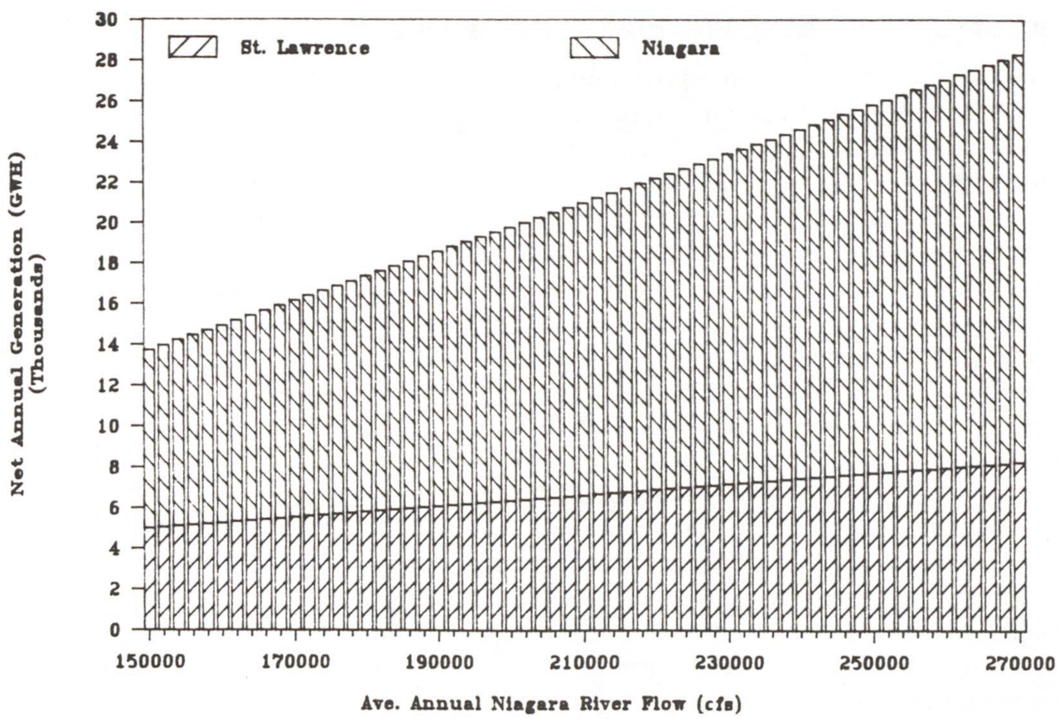

Figure 5. Relationship between average annual Niagara River flow and net annual generation at the Niagara Power Project and the St. Lawrence-FDR Project

The most uncertain aspect of the assessment of climate change impacts on electricity generation is the climate change itself. There are many scenarios for climate change, which would suggest that a probabilistic approach ought to be used. However, such an approach is beyond the scope of this paper, particularly since so few data are available to work with. Instead, a climate change scenario for the Great Lakes Basin derived from global climate modeling of a doubling of the concentration of carbon dioxide, which is predicted to induce global warming, is used. Since this scenario has been used previously by others, it provides another basis for comparison in the assessment of impacts on electricity generation.

The predicted effects of climate change resulting from a doubling of carbon dioxide on the Great Lakes will be to lower long-term average Lake Erie levels by up to 2 feet. A lowering of the long-term average level of Lake Erie by 2 feet is the "climate change" scenario referred to in the remainder of this paper. This change would lower the long-term average flow of the Niagara River from about 208,000 cfs to about 165,000 cfs. The predicted time required for this to occur varies significantly. In this paper, it is assumed the change will occur over a period of 25 years.

Both short run and long run impacts of this lake level lowering are assessed. The short run impacts are assessed over the 17-year planning horizon of the New York Power Pool. The long run impacts are assessed for years in which the long-term average Niagara River flow is reduced to 165,000 cfs.

Both the short and long run impact assessments assume that average annual Niagara River flow will decrease linearly over a 25-year period starting in 1988. Based on measurements through August 1988 and forecasts for September to December 1988, the average Niagara River flow in 1988 will be about 207,000 cfs. This flow, which is close to the long-term average flow, is used as the starting point for applying the flow reductions associated with the predicted lowering of the level of Lake Erie. The effects of these flow reductions on hydroelectric generation are used to estimate average annual economic impacts.

The annual energy requirements for New York State, without the new industry-sponsored demand-side management supply savings forecasted by the NYPP, are shown in Figure 7 for the period between 1988 and 2004. Values for 1978 to 1987 in Figure 7 are actual values. Also shown in Figure 7 are the annual generation values for the Niagara Power Project and the St. Lawrence-FDR Project in the same period. The generation values for 1988 to 2004 reflect the predicted effects of the lowering of the long-term average level of Lake Erie by 0.08 feet per year.

Combining the information in Figure 7 with that in Figure 6 produces a chart (Figure 8) showing the actual and forecasted avoided costs of hydropower generated at the Niagara Power Project and the St. Lawrence-FDR Project in the period from 1978 to 2004. The chart shows the impacts of lowering the long-term average level of Lake Erie by 2 feet. The costs in Figure 8 are relative to the generation benefits derived from current long-term average Niagara River flows, which are about 1,000 GWH per year. The average annual cost of a change in the climate that lowers the level of Lake Erie by 2 feet in the period from 1988 to 2004 would be about 55 million 1988 U.S. dollars.

The long run impacts of the simulated climate change scenario are assessed by looking at the new long-term equilibrium condition in 2012. In this year, annual generation from the Niagara Power Project and the St. Lawrence-FDR Project would be about 15,500 GWH. This translates to an annual cost, relative to current conditions, in 2012 of 160 million 1988 U.S. dollars. These costs would approximate the average annual costs to New York State in subsequent years, if the long-term average Niagara River flow were to become 165,000 cfs.

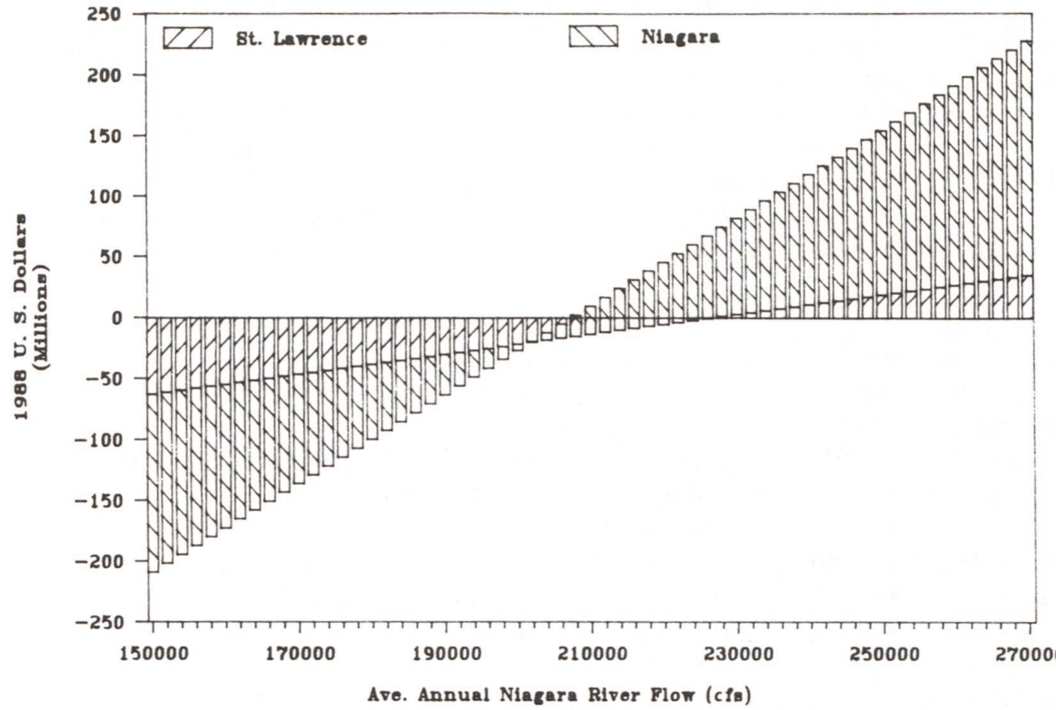

Figure 6. Relationship between average annual Niagara River flow and annual avoided costs

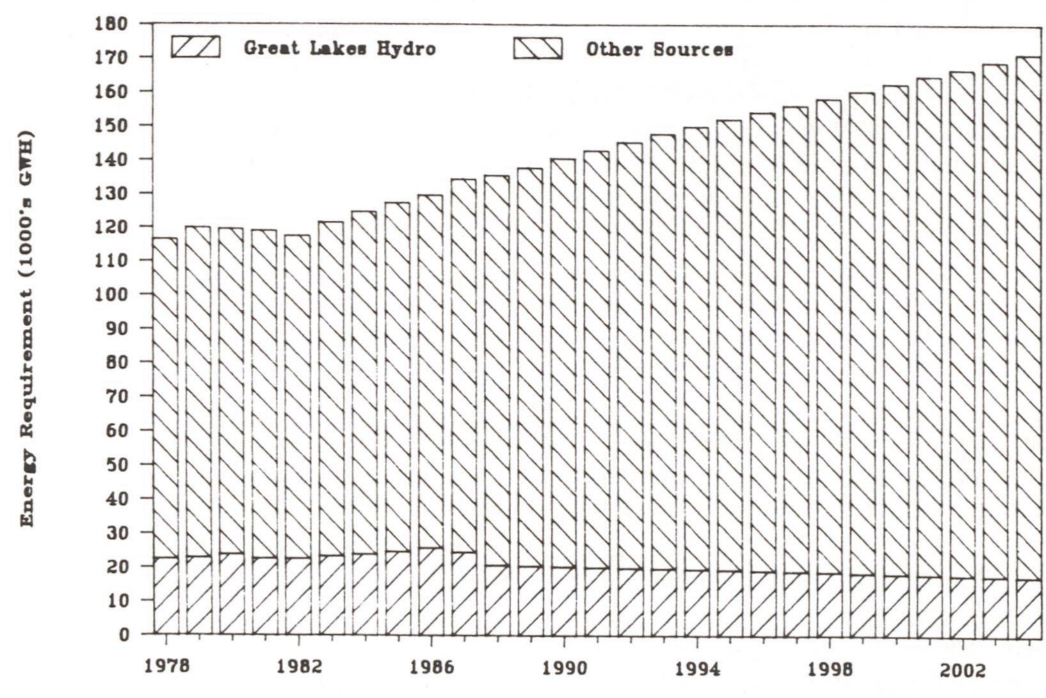

Figure 7. Estimated contributions of Great Lakes Hydropower to New York State's annual energy requirements due to predicted climate change

The impacts of climate change on the industry's projected energy supply savings from demand-side management programs are shown in Figure 9. Figure 9 shows that the anticipated savings could be entirely offset in the years up to the year 1999 and be exceeded thereafter by the predicted climate change impacts on lake levels. As a result, planned capacity additions may not be adequate to meet future requirements.

Conclusions

The major conclusions that can be deduced from the information and discussion presented in this paper are:

- Climate changes that cause a lowering of the levels of the Great Lakes could have a significant impact on the generation mix of the New York Power Authority and New York State. Great Lakes hydroelectric generation would need to be replaced by more expensive nuclear and/or fossil fuel generation, which may adversely affect the economy of New York State.
- For climate changes that result in a lowering of Lake Erie water levels by 2 feet, the short run average annual costs to the economy of New York State could be on the order of 55 million U.S. dollars. The long run average annual costs could be on the order of 160 million 1988 U.S. dollars.
- Projected demand-side management energy savings by the industry may be offset and eventually exceeded by climate changes that cause a lowering of the levels of the Great Lakes. As a result, capacity additions may be required sooner than anticipated.
- Climate change impacts on the state's capacity to meet peak demands were not explicitly assessed. Such impacts should be assessed and combined with the impacts on annual energy requirements.
- More comprehensive assessments of the impacts of climate change on the electric generation should adopt a probabilistic approach to account for the uncertainties in predicting 1) climate change and its effects on the Great Lakes, 2) future energy demands, 3) future reductions in demand attainable through demand-side management, and 4) the ability to add generating capacity.

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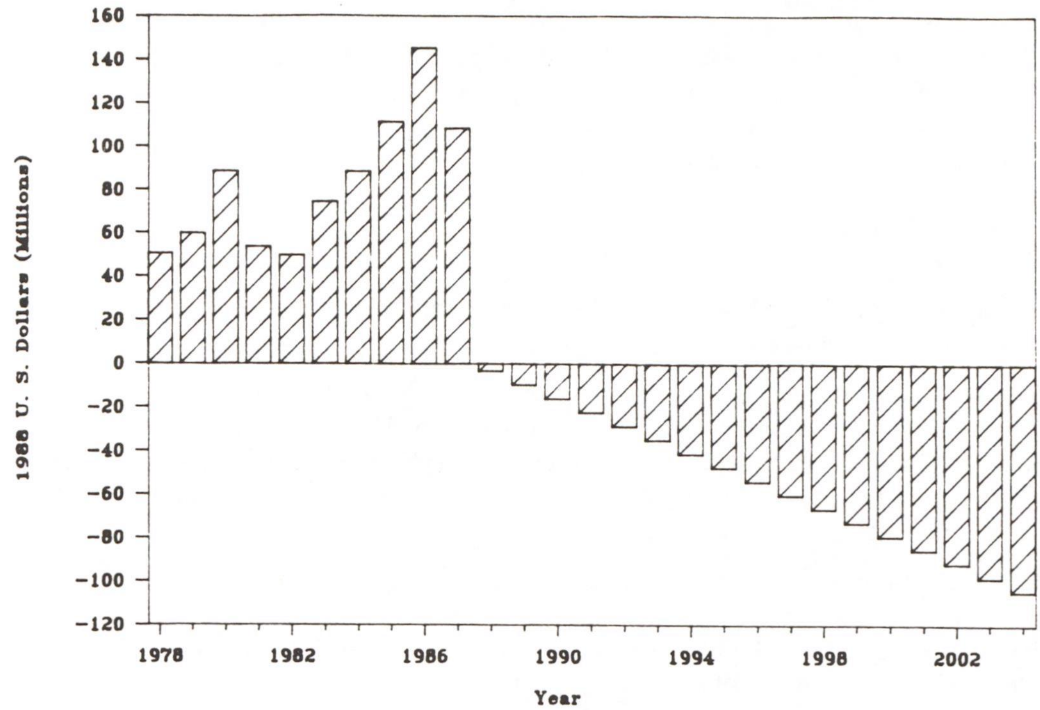

Figure 8. Estimated annual avoided New York State electricity generation costs, relative to current benefits, due to predicted climate change

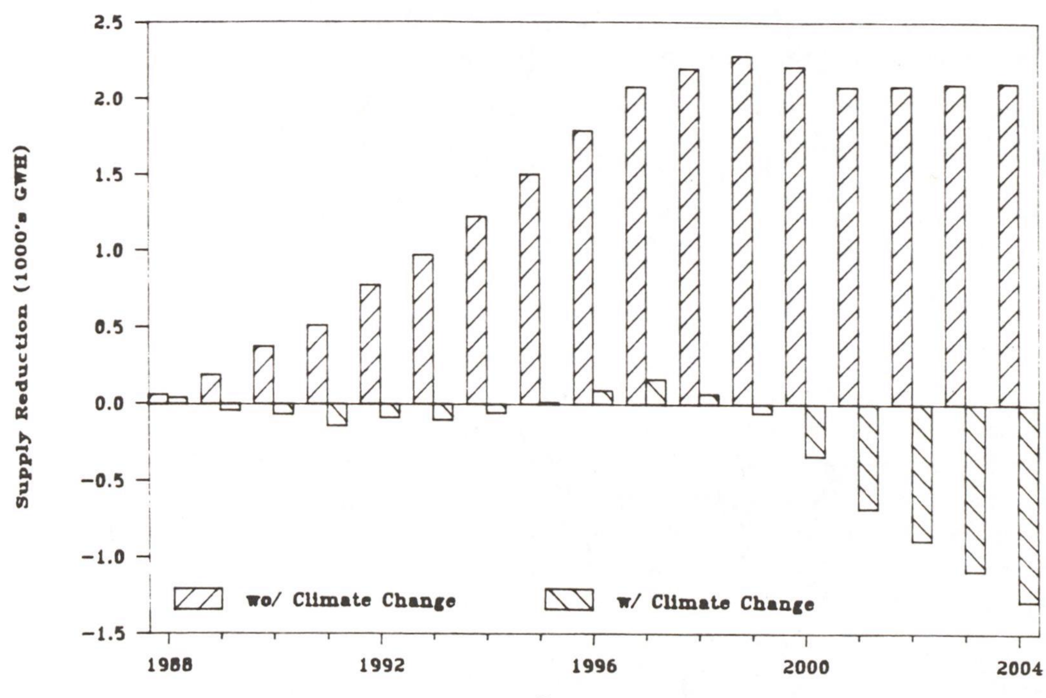

Figure 9. Potential impacts of climate change on energy supply savings through demand side management

Notes on Climate Impacts on Transportation

Angus Laidlaw*

When I was asked to represent the Dominion Marine Association at this conference some months ago, I felt a certain ambivalence. The subject, I thought, was undoubtedly a worthy one, and one in which I had a personal interest. But I wondered at that time what kind of a meaningful contribution I might make, other than to offer support for the efforts of some to forecast in a quantitative manner the implications of climatic change on this multiple use resource.

Perhaps I was suffering a little from the influence of what I might call industrial apathy. Some months ago, an item crossed my desk: It was a newspaper clipping on this very subject of long-term climatic effects, one of which was loss of water in our lakes and channels. A member of the marine community had annotated the headline with a note to me which read something to the effect, "A good issue for DMA ... in 100 years." The remark was reflective of a lack of appreciation for a looming but—to the layman at least—not yet palpable problem. Since that item crossed my desk, we've experienced the summer of 1988 and a lot of laymen have begun thinking about the weather.

Ask a Canadian Great Lakes shipowner about the weather this summer and he'll tell you bleakly about prairie drought, desiccated wheat fields, and putative calamitous reductions in grain exports this navigation and next. He is not to be faulted for such a reaction. In truth, although it may be beyond the scope of this conference, climatic changes may affect transportation by affecting trading patterns of primary commodities. How much more (or less) grain will Canada and the U.S. produce as a result of climatic change? Who will our competitors be, and who will be net importers? These may be valid questions for further analysis within an economic framework.

For the moment, you must indulge us if we have been tardy in exhibiting the requisite concern. Business is used to, or tries to get used to, the business cycle. One can prepare for, or at least not be surprised by, the peaks and troughs of economic activity. But we are now facing up to something quite different. This is not a cyclical phenomenon with "eventually back-to-normal implications."

For me, it is reminiscent of a seminal paper written in 1968 and entitled "The Tragedy of the Commons." In the early part of the paper, the author refers to a conclusion which he and others cited by him have reached; namely, "There is an implicit and universal assumption of discussions published in scientific journals in that the problem under discussion has a technical solution, i.e., a change in technique of the natural science demanding no change in human morality or values." However, he concludes there is a class of problems for which desired technical solutions are not possible. You might guess the rest. His thesis continues, in the context of the population problem and with a "sidebar" on pollution, that a change in behaviour backed by "mutual coercion, mutually agreed upon" is the only viable alternative to ruination.

Please indulge me for this reference. I make it because the author's argument struck me at the time as a compelling one, and as I said, our particular problem does not strike me as having any overtly obvious technical solutions.

***Dominion Marine Association**

This leaves us, I suppose, with effects observed and accommodations to be made, and I will at this point step away from prior pronouncements and do what I'm supposed to, which is to give a perspective on the marine transportation dimension of the problem.

A cursory look invites a straightforward analysis. One has been performed, in admirably blunt and straightforward summary fashion in the *Climate Change Digest* published by authority of the Ministry of Environment. It suggests that under three different scenarios plugged into an appropriate mode, there will be a range of incremental transportation costs associated with hauling bulk commodities through traditional trade patterns. These incremental costs will arise from extra voyages required to move assumed tonnages through lakes and channels whose levels and flows have been reduced by climate change and consumptive use. One scenario properly employs an assumption of an 11-month navigation season occasioned by significant reduction or complete elimination of ice cover, and this consideration acts as a partial mitigating influence, not to total transportation costs of course, but to presumed economic performance over the course of the navigation year.

Our home-grown analysis, which we have had occasion to trot out when there are discussions of marginal and temporary reductions in levels and flows, is rough but demonstrative. Our dry bulk fleet comprises 100 ships of various sizes, but predominantly in the 20,000 to 25,000 dead weight tonne range. Sixty-five of these are straight deck bulk vessels with holds capable of carrying by turns grain, ore, coal, salt potash, stone, cement, and any other dry bulk commodity for which a high volume to value ratio militates a water movement. The balance of the dry bulk fleet is composed of self-discharging vessels which, as the term suggests, obviates the need for shore-based unloading equipment and greatly speeds up the process (up to 6,000 tonnes per hour may be lifted out of this type of ship by its boom-conveyor system). Together with the tanker fleet, Canadian lake vessels hauled around 76 million tonnes of cargo last year, the bulk of it around the Great Lakes and through the St. Lawrence Seaway.

As a transportation artery, the waterway has been and will continue to offer important benefits to Canadian and American shippers and exporters, benefits that in any reasonable environment, free of economic distortion, cannot be matched by any other mode. Nonetheless, while some Great Lakes shipping trades remain buoyant, overall activity in the 1980's falls short of that of the late 1970's when 95 million tonne per year haul was the norm.

Wholly as a result of this decline, shipowners have been keenly interested in developing better technology for greater efficiency of design and improved flexibility of operations. One notable manifestation of this effort has been the development of the ocean laker, a ship of the familiar laker design but which can operate on the seas at any time. This type of vessel design will almost certainly prevail in the future because, for a relatively marginal higher capital cost, it operates in any market at any time.

Despite such new developments, there remains the fundamental constraint of operating ships in the system. There is not much margin in draft in a waterway whose limiting depth is 27.5 feet. In laker vessels of 25,000 tonnes, the approximate carrying capacity per inch of draft is about 110 tonnes. In the rough analysis to which I alluded a moment ago, the loss of an inch of water could translate into between 200,000 tonnes and 1 million tonnes of cargo foregone over the course of an 8.5-month navigation season. To a limited extent, this calculation can be applied in a more than academic manner. Just this past spring, several of our ships reported groundings in Lake Superior due to a relatively short-lived condition of lower-than-anticipated levels.

Nor is that situation new or unique. There have been a number of occasions when variations in levels have posed difficulties, but thanks to the minor nature of the variations and the management practices of IJC, they have been short-lived and of little commercial significance.

What we could be facing, I gather from the projections, are reduced cargoes, higher operating costs, restricted access to ports, more dredging on a recurring basis. In addition, these will be secondary environmental impacts attending our attempts to "normalize" the situation.

Are we prepared for relatively radical changes to levels and flows of the kind envisioned in the worst case scenarios? The answer is of course, "No." Changes in climate and associated implications have not up to now been included in the capital planning calculus of ship operators.

You may, however, rely on the assumption that in an industry as competitive as shipping, they will figure, implicitly or explicitly.

From a time when shipping had a measure of environmental notoriety, I would venture to say it is regarded as a relatively benign resource user, particularly in the inland waterway. The industry is highly regulated in the area of emissions. It is, relatively speaking, nonconsumptive in the sense we are using the word today. It is at the same time trivially obvious that shipping is highly dependent on the maintenance of optimum water levels in navigation channels. We don't know at this stage the extent of the problem we face, nor the degree to which a menu of technical solutions (redesign of ships, dredging) will redress the problem. One thing is clear: As an industry, we will be looking to the successions of gatherings such as this for intelligence and direction, if not solutions, in the future.

Impacts on Great Lakes Shipping

George J. Ryan*

As President of the Lake Carriers' Association, I am here to represent fleets who carried more than 100 million tons of cargo on the Lakes last year. This year's float should top more than 110 million tons, so if you get the idea that water levels are important to us, you're right!

Water levels and their impacts on commercial navigation are a subject easily misunderstood. When diverting Lake Michigan water to the Mississippi River was suggested a few months ago, we objected strongly, in part because the increased outflow would have lowered Lakes Michigan and Huron by roughly 1 inch. To the non-mariner, we might have seemed overly protective of our water. But even just 1 inch of water is critical to shipping. The 63 U.S.-flag lakers in service this year would have surrendered 360,000 tons of their annual hauling power had we volunteered that inch for the last half of 1988. Had all those tons been iron ore, the American steel industry would have been shortchanged enough product to make the steel used in 225,000 automobiles.

When the diversion issue first arose, we prepared the attached illustration of the impact of water levels on the major vessel classes working the Lakes. Our 1000-foot "supercarriers," of which there are 13, lose about 270 tons of carrying capacity for each inch of reduced draft. Obviously, hauling power decreases with vessel length, but even a 500-foot cement carrier surrenders 70 tons of cargo for each inch of draft lost.

The question of diverting Lake Michigan water was generated by a climate change causing a multiregion drought. But while the public was being told that declining water levels on the Mississippi were forcing barges to lighten their loads, no one mentioned that below-normal precipitation and record-high temperatures in the Great Lakes Basin had cost the larger Lakes freighters 4500 tons of cargo per trip. Proponents of the Lake Michigan diversion weren't saying that Lake levels have been declining since the latter half of 1986. A comparison of loaded draft at the Soo Locks (they connect Lake Superior to Lake Huron) between June of 1986 and 1988 showed a loss of 17 inches. Can anyone then wonder why we didn't want to forfeit another inch of water? The 17-inch drop at the Soo Locks had already cost us 6.1 million tons of annual carrying capacity. We didn't have an inch to spare.

All these facts aside, our most strenuous objection to the Lake Michigan diversion was the precedent it would have set. We all know that several western and southern states have eyed the Great Lakes as a solution for their water woes. How could we have said "Yes" to the Mississippi River and then said "No" to Arizona or some other state? To date, we have fended off any major diversion of water outside the Great Lakes Basin, but the first diversion would surely lead to the second, the third. . . . If the list gets too long, the "Great Lakes" could become "Great Ponds."

The question may now arise, "Why did Lake Carriers' Association wait until the diversion proposal to publicize the impacts of falling water levels on Great Lakes shipping?" The answer is quite simple—there's nothing we can do to correct fluctuating water levels caused by natural phenomena. To have bemoaned current conditions would have been like complaining when it rains on a holiday. While there's some value in venting frustration, you've changed nothing.

***President, Lake Carriers' Association**

IMPACT OF LAKE LEVELS ON VESSEL CARRYING CAPACITY
(net tons)

Great Lakes Bulk Carriers	Vessel Length (feet)	Per-Trip Carrying Capacity	Capacity Per Inch Of Draft*
	1,000	69,664	267
	806	34,720	146
	767	28,336	127
	635	22,064	107
	501	13,776	71

*Capacity per inch of draft reflects the incremental tonnage carried at normal loaded draft.

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When it comes to water levels, carriers have learned to adapt to what Nature offers. In times of high water, we carry more cargo. When water levels decline, we lighten our loads and make the best of the situation.

On the other hand, our opposition to increased diversions outside the Great Lakes Basin is no secret. For the past three years, LCA's Annual Report has highlighted our opposition to any siphoning of the Lakes.

That then is LCA's position on water levels and their impacts on Great Lakes shipping. As charged, I'll direct the remainder of my comments to the impacts of more drastic climatic changes on waterborne commerce on the Lakes.

However, before addressing the future, I must make it clear that what follows is pure speculation. And with all due respect to this symposium and the forecasts my fellow speakers may make, I could never recommend that my members base their long-term planning on weather and climate forecasts for 1995 or 2005. In fact, I'm glad no one made economic decisions based on Lake level forecasts of two years ago. For if I may remind you, just two years ago we were being warned that the record-high water levels could very well prove to be just a prelude of what was to come. There were those who believed that 1986's peaks were just the foothills of an even higher plateau.

Thank goodness those predictions weren't taken as gospel. Had they been, it might have made economic sense to scrap even more vessels in the stand-by fleet. Had a vessel operator based his future plans on his 1000-footers always loading at 28-plus feet for years to come, more of the smaller ships might have been deemed expendable.

And yet, despite all the best efforts of forecasters, those projections proved incorrect. As a result, the 1000-footers are now loading to less than 27 feet and many of the ships that were idle in 1986 have been in service since April of this year.

That said, let's assume the weather gets significantly warmer in the years to come. (I could also speculate about a colder climate but that is not in vogue today.) The most probable impact on Great Lakes shipping would be an extension of the navigation season. A 10-, 11-month shipping season would be feasible if ice formed later and broke-up earlier.

There have already been studies to lengthen the Lakes shipping season because the benefits are so dramatic. Vessel operators should better utilize their vessels and carry the same amount of cargo with fewer ships. Our customers would be spared the stockpiling costs associated with the current mid-January close of navigation.

In terms of business opportunities, a longer shipping season might enable the Lakes fleet to regain some cargo lost to railroads because of the long winter closing. More probable, however, would be an increase in the export grain trade. Warmer temperatures would lengthen the growing season in the U.S. and Canada and generate more grain cargos.

Shippers of general cargo also might be attracted to the system if near year-round navigation was possible. A U.S.-flag carrier in the overseas trade might well consider building or committing a ship to an 11-month trade route in the assumption that the idle month could be used for the spot market or ship maintenance.

Warmer temperatures could produce a kind of "toss up" for the coal trade. A lessened demand for power to heat in the winter would be offset by more demand from summer air conditioning.

Warmer temperatures would certainly lead to a downturn in the salt trade—there would be less need to de-ice roads and highways. With less corrosion from salt, there would be an attendant fall-off in the need for cement, aggregate, and steel to repair these structures. A minimal increase in automobiles' life span would only slightly impact steel demand.

And what of water levels themselves? Warmer temperatures would, of course, bring higher evaporation rates and lower Lake levels. A long-term drop in Lake levels would require extensive dredging to maintain channels and harbors at Federal project depth. Private docks and terminals likewise would have to increase their dredging efforts. All this would heighten an already-existing need for new confined disposal facilities and, when environmentally sound, open Lake disposal.

If water levels fall below the point where dredging can maintain current project depth, a real fear would be a weakening of dock foundations. Loading and unloading equipment might have to be lowered or vessel structures raised.

Should warmer temperatures reduce snow accumulation, the lack of spring runoff would retard the Lakes seasonal rise. If milder temperatures make the ground softer, melting snow would seep down to the water table instead of flowing to the Lakes. Lake levels might decline until a balance was reached.

All that I have mentioned is within the realm of conjecture. But the probability is an unanswerable question, at least given the current level of our knowledge about future climatic changes. Given this uncertainty, I cannot make any concrete recommendations other than continuing research so that we may someday be able to accurately predict future weather patterns. When our knowledge produces that kind of expertise, then appropriate economic decisions can be made by industry.

Thank you.

Effects on Electric Utilities

Mark R. Inglis*

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

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

National Electricity Demand Will Rise

Global warming would cause an increase in the demand for electricity and generating capacity requirements in the United States. The demand for electricity in summer cooling would increase, and the demand for electricity for winter heating would decrease; annual electricity generation in 2055 was estimated under the scenarios to be 4 to 5 percent greater than without climate change. The annual costs of meeting this demand would be $33-$73 billion (in 1986 dollars). These results differ on a regional basis and are shown in the attached illustrations. States along the northern tier of the United States might have net reductions in annual demand of up to 5 percent. Decreased heating demand would exceed increased demand for air conditioning. In the south, where heating needs are already low, net demand was estimated to rise by 7 to 11 percent by 2055.

More Power Plants Will be Needed to Meet Peak Demands

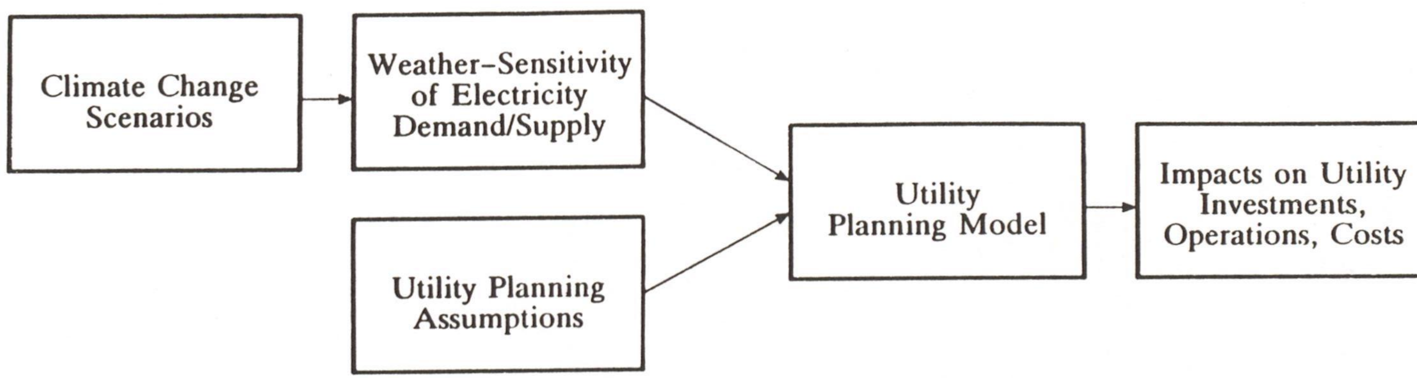
Generating capacity is determined by peak demand, which occurs in the summer in most areas of the country. By 2010, generating requirements to meet increased demand could rise by 25 to 55 gigawatts (GW) or by 6 to 15 percent above new capacity requirements, assuming no climate change. By 2055, generating requirements could be up by 200 to 400 GW or 14 to 23 percent above non-climate-related growth. The cumulative cost of such an increase in capacity would be between $175 and $325 billion. The south would have a greater need than the north for additional capacity as shown in the attached figures. Additional capacity requirements would range from 0 to 10 percent in the north to 20 to 30 percent in the south and southwest. U.S. emissions of greenhouse gases such as CO_2 could increase substantially if these power plants are built, and especially if they burn coal.

*ICF Incorporated

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

Acknowledgment. The study conducted by ICF Incorporated was sponsored by the Edison Electric Institute, the Electric Power Research Institute, the New York State Energy Research and Development Authority, and the U.S. Environmental Protection Agency.

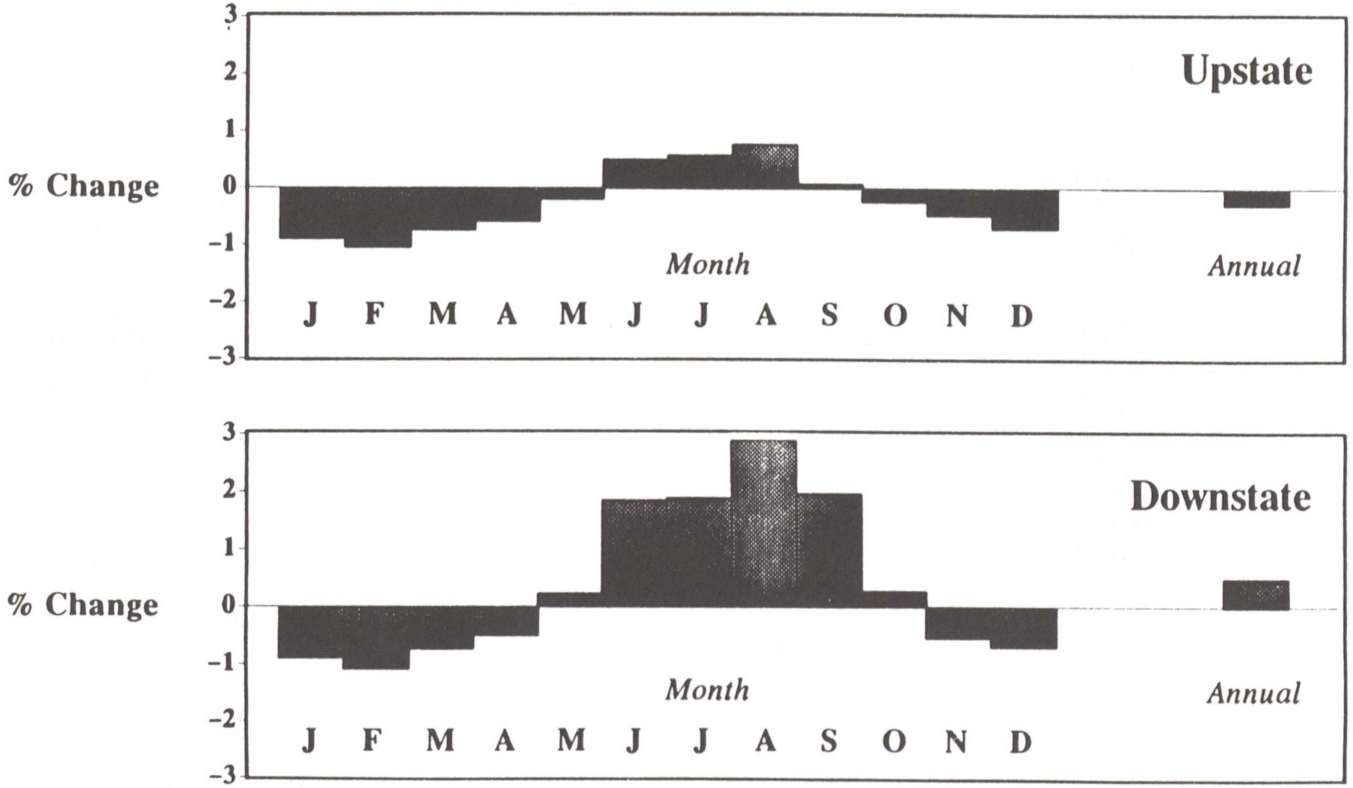
Analytical Approach



- **Study Period: 1985–2015**
- **Case study analyses: New York (Upstate and Downstate)**
  Southeastern U.S. Utility
- **Have not addressed secondary effects and interactions**

ICF Incorporated

Impact of Temperature Change on Energy Demand by Month in 2015*



*Estimated for temperature scenario C, using Statistical Approach

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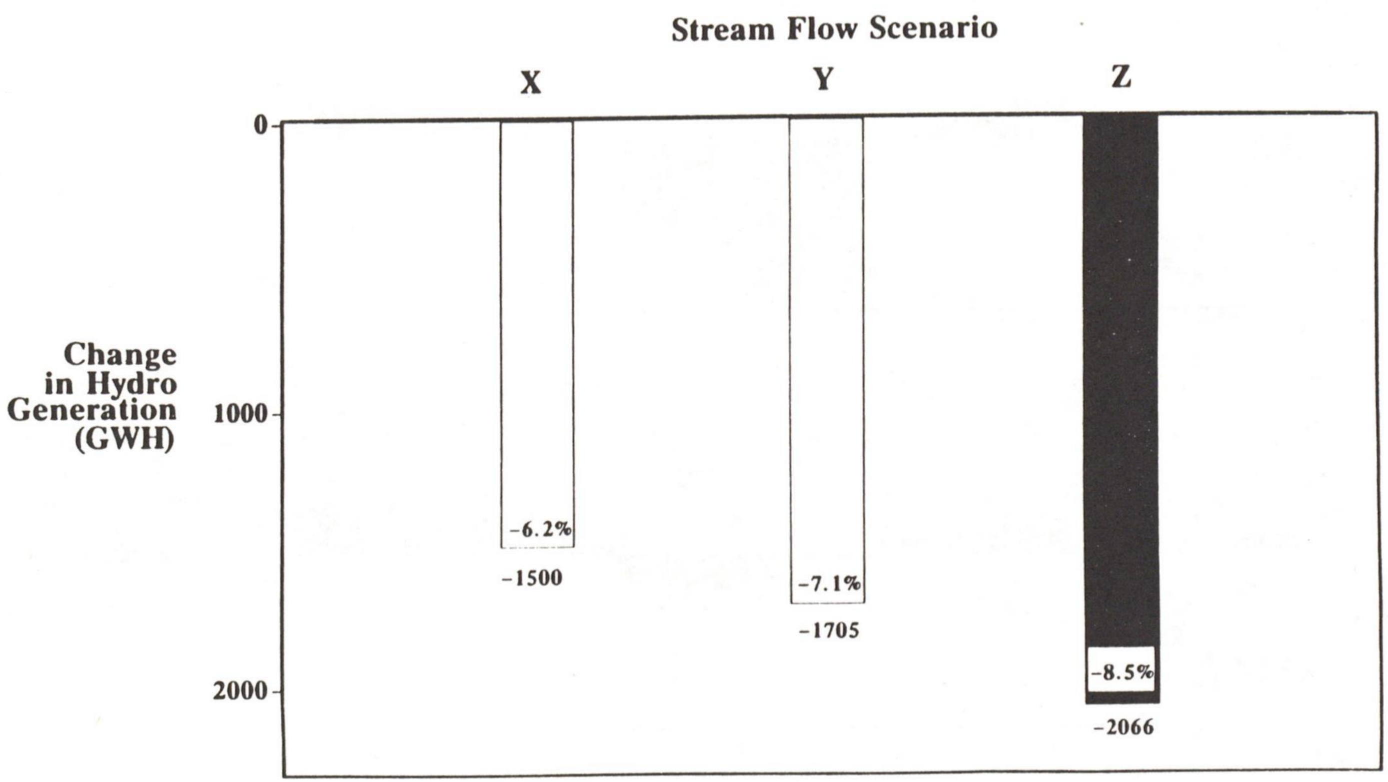
Impact of Changes in Stream Flow on Hydro Generation in 2015



ICF Incorporated

Comparison of New York and Southeastern Utility Case Studies

Impact on Total Costs in 2015
(MM $1986 per year)

New York	*Temp. Scenario C Stream Flow Base*	*Temp. Scenario C Stream Flow Z*	*"High Impact"*
Upstate	+22	+79	+91
Downstate	+26	+95	+150
System	+48	+174	+241
Southeastern Utility	+262		

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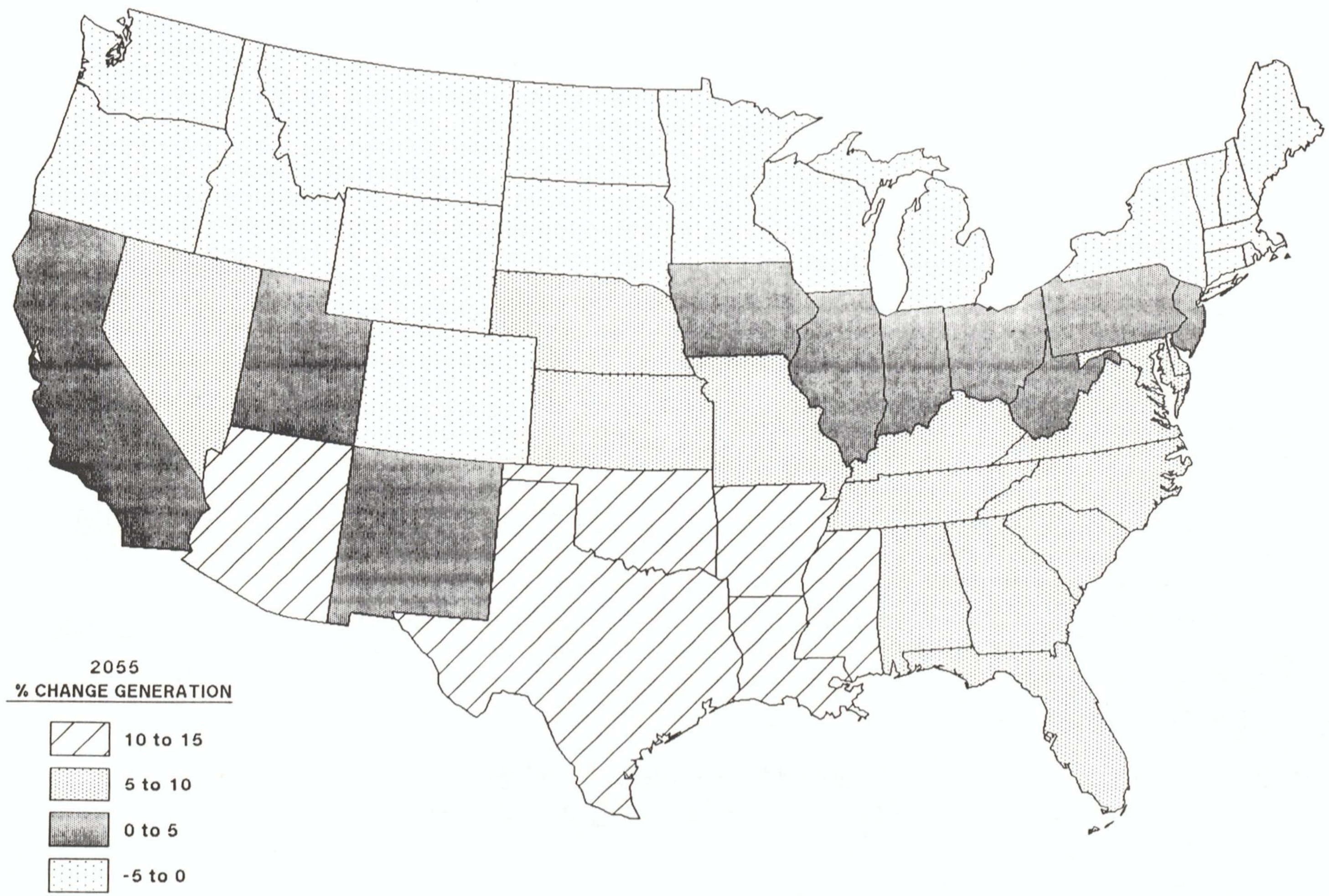
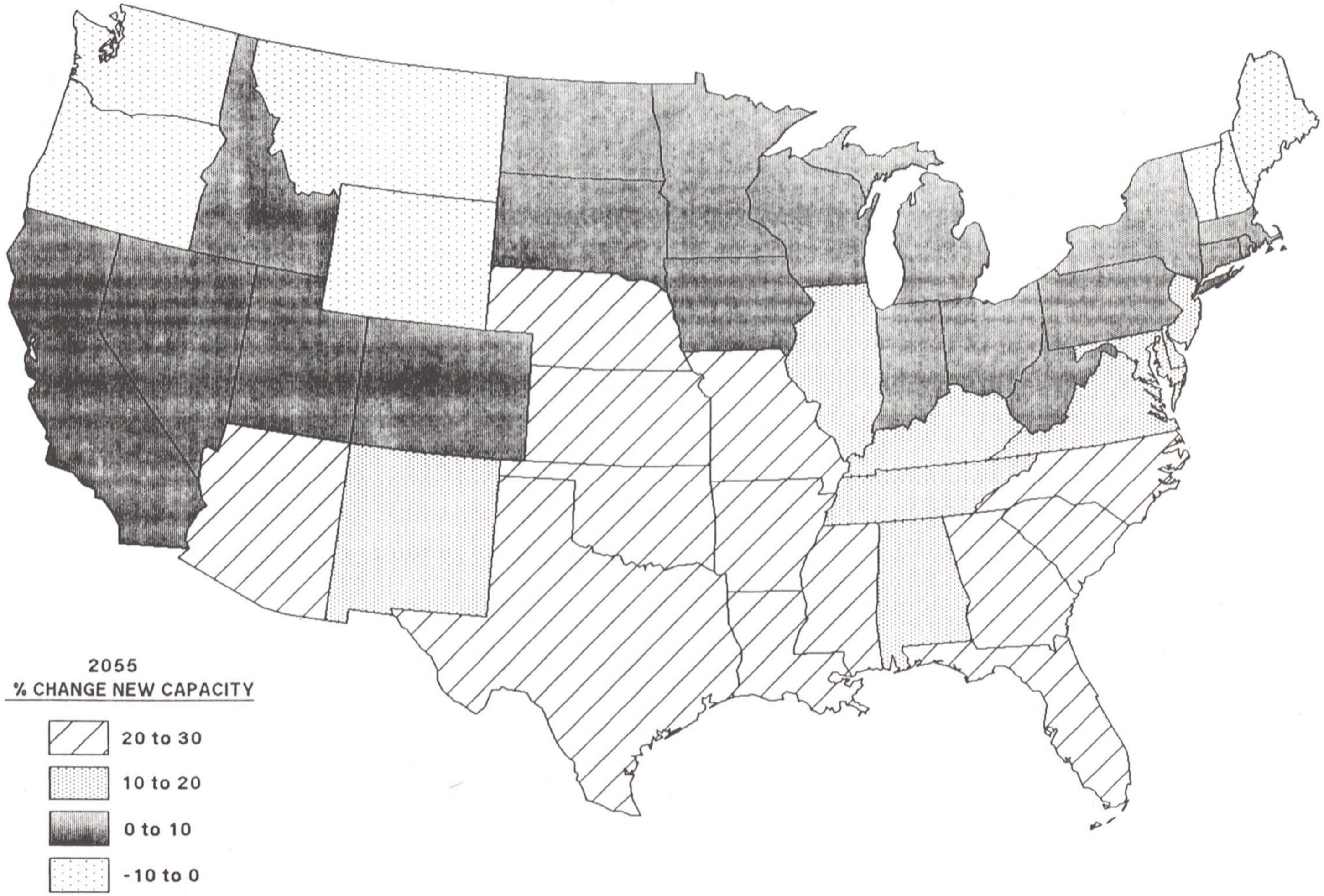

2055
% CHANGE GENERATION
10 to 15
5 to 10
0 to 5
-5 to 0


2055
% CHANGE NEW CAPACITY
20 to 30
10 to 20
0 to 10
-10 to 0

Electricity Supply and Demand in Ontario

O. T. Melo*

Abstract: The hydroelectric stations on the Niagara and St. Lawrence Rivers are a key component of Ontario Hydro's electricity generating system. They provide a secure, economic supply of electricity with an estimated replacement cost of about $1 billion per year. Further development of the Niagara energy potential is contemplated. The value of the existing stations and the economic viability of the proposed new station would be undermined by long-term climatic change. Climatic change can also alter the demand patterns in Ontario. The greenhouse effect should thus be studied further, and the implications of global climate change to electricity generation and demand should be quantified better. Facilities with a long in-service life should be designed for a range of future climatic conditions.

Ontario Hydro

Ontario Hydro is a self-sustaining corporation created in 1906 by special statute of the Province of Ontario. Under the Power Corporation Act, it has broad powers to generate, supply, and deliver electricity throughout the province (Figure 1).

In size, capability, and organizational strength, Ontario Hydro is comparable to the Tennessee Valley Authority in the United States and the Central Electricity Generating Board in the UK. Ontario Hydro's capital investment in plant, stations, and other equipments is about $32.7 billion, while its annual revenue is of the order of $5.3 billion (Ontario Hydro, 1987).

Electricity is generated using hydroelectric, nuclear, and fossil-fuelled plants (see Table 1 and Ontario Hydro, 1987). Total installed capacity is 30.3 million kW with another 3.6 million kW under construction.

A network of just over 27,000 km of transmission lines ranging in voltage from 69 to 500 kV connects the generating stations to the load centres and neighboring utilities. The majority of customers are served through the 316 Municipal Utilities which buy electricity in bulk from Ontario Hydro. The remaining retail customers and a number of large industrial customers are served directly by Ontario Hydro.

In 1987, about half of the electricity generated came from CANDU nuclear stations, and the rest from electric and fossil-fuelled stations (Table 2). Total generation was 120.2 billion kWh while the primary peak was 20.5 million kWh.

The Greenhouse Effect

A number of trace gases in the earth's atmosphere are transparent to incoming solar radiation but absorb and re-emit downward the long-wave infrared radiation emitted by the earth's surface. This, the greenhouse effect, maintains the temperature at the earth's surface more than 30°C above what it would be otherwise.

Carbon dioxide, chlorofluorocarbons, methane, nitrous oxide, and tropospheric ozone are the major greenhouse gases. Human activities since the start of the industrial revolution have increased the rates at which these trace gases are emitted to the atmo-

*Ontario Hydro Research

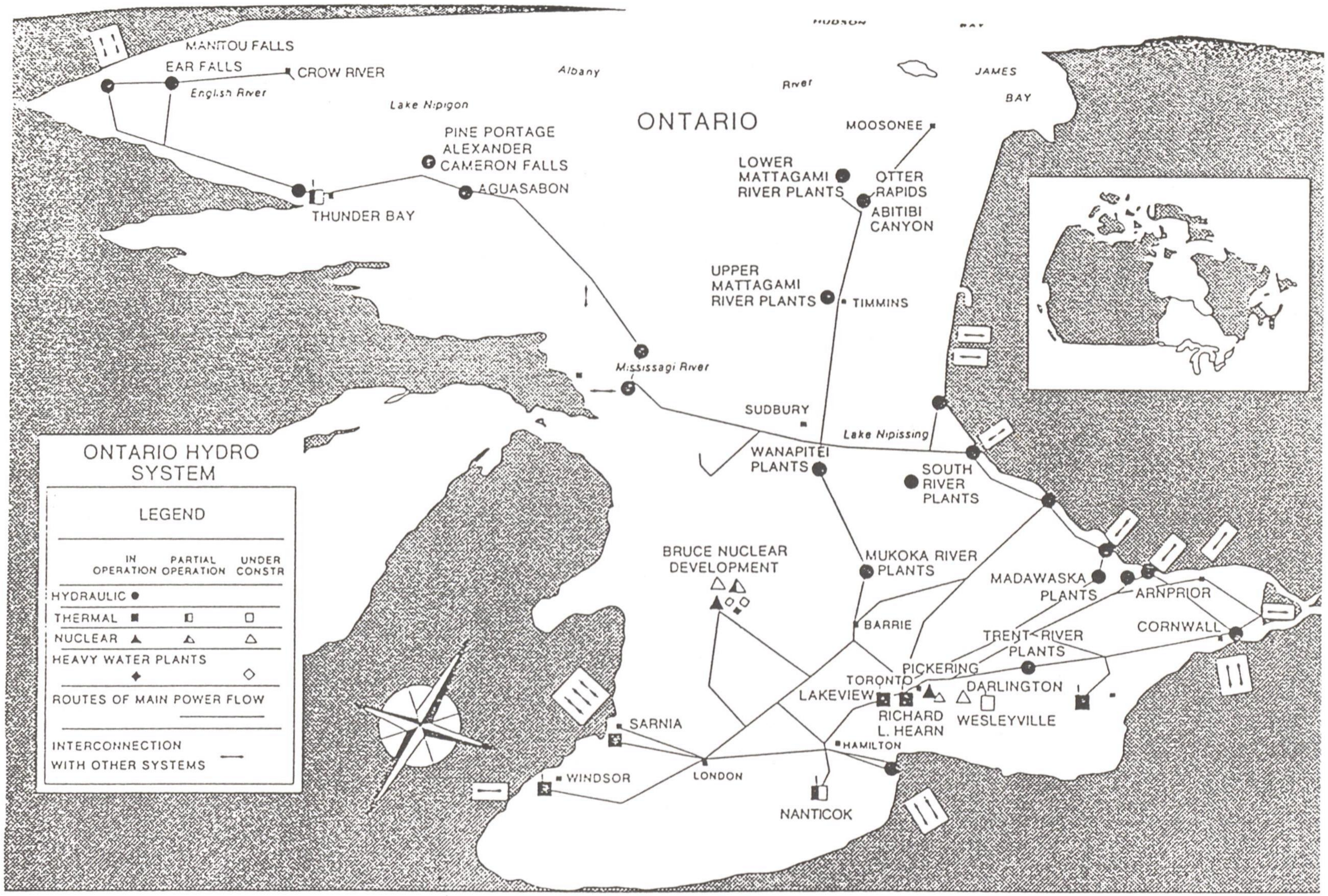


Figure 1. The Ontario Hydro system

Table 1. Ontario Hydro 1987 Statistical Data.

Installed Capacity (million kW)		
Hydroelectric		6.5
Nuclear		10.7 + (3.6)
Fossil-Fuelled		13.2
	Total	30.4 = (3.6)
Transmission Lines		27,330 km
Customers		
316 Municipal Utilities		2,508,000
Direct Retail		835,900
Direct Industrial		116
Staff		32,150

Table 2. Ontario Hydro 1987 Energy Sources and Markets.

Energy Sources (billion kWh)		
Hydroelectric		30.2
CANDU Nuclear		60.0
Fossil-Fuelled		30.2
	Total	120.2
Electricity Markets (billion kWh)		
Municipal Utilities		84.1
Direct Retail		16.6
Direct Industrial		19.5
	Total	120.2
December Primary Peak Demand		
(Million kWh)		20.5

sphere and have reduced the ability of the earth to assimilate the additional burden (e.g., through deforestation). As a result, the concentrations of most greenhouse gases have been increasing, and the outlook for the future is that this trend will continue.

Glacial records indicate that global mean temperature and carbon dioxide concentrations in the atmosphere have been well correlated in the past. This should be expected to hold in the future. Another tool that has been used to assess future climatic conditions is the use of general circulation models. These models, while still primitive in some respects, invariably suggest that mean global warming of 1.5-4.5°C should be expected around the middle of the next century if current emission rates continue. These models further suggest that global warming will be most severe in the winter and at northern latitudes. Predictions of changes in precipitation are less certain but appear to indicate enhanced winter snowfall at high latitudes and possible decreases of summer rainfall at mid-latitudes.

The greenhouse effect and climate change may affect Ontario Hydro in several ways. Firstly, the ability to generate electricity from hydroelectric facilities will be impaired by permanent decreases in precipitation, increases in evaporation, increases in other water uses, etc. Secondly, the demand for electricity will be strongly influenced by climatic variables such as temperature, humidity, etc., making the forecast of future demand and the decisions on how to meet that demand (e.g., hydroelectric vs. nuclear) dependent on future climatic conditions. Finally, as a user of fossil fuels for the generation of electricity, Ontario Hydro will come under pressure to reduce its emissions of greenhouse gases.

Hydroelectric Generation in Ontario

Ontario Hydro's electricity generating system of 6.5 million kW includes 68 hydroelectric stations with a total of 264 units (McIntyre, 1984). In addition to these publicly owned stations, there are about 100 privately owned stations which have a combined additional capacity of near 0.65 million kW. The total available hydroelectric capacity in the province is, therefore, close to 7.15 billion kW.

The hydroelectric generating system, see Figure 2, is made up of two major subsystems, namely the Great Lakes subsystem and the rest of the system or the Non-Great Lakes subsystem. The Great Lakes subsystem, see Table 3, is made up of two major components, the Niagara complex (including the Welland Canal) and the Robert A. Saunders installation located in the St. Lawrence River (Law, 1988; Vilar *et al.*, 1988). The Great Lakes subsystem represents about 40 percent of the total hydroelectric generating capacity, while its energy contribution is nearly 50 percent of the hydroelectric total (Law, 1988).

Ontario's neighbours, the Province of Quebec and New York State, share the Great Lakes hydroelectric generating sources. The Province of Quebec has an installed capacity of 1.74 million kW on the St. Lawrence River while New York State has developed 3.1 million kW on the Niagara and St. Lawrence Rivers (McIntyre, 1984; Law, 1988).

Inflows to the Niagara complex are essentially unregulated (Vilar *et al.*, 1988). The flow in the Niagara River is naturally dependent on a ridge of shoals that constrain it at the Buffalo/Fort Erie end. The flow over these shoals depends on the instantaneous level of Lake Erie at Buffalo/Fort Erie. This level is the algebraic sum of a steady state (or calm) level that results from the lake's inflow from the upper lakes, and of the wind seiches, a natural oscillating phenomenon tied to the shallow nature of the lake.

The operation of the St. Lawrence facilities is very rigidly controlled by an international agreement (McIntyre, 1984; Law, 1988; Vilar *et al.*, 1988; Sanderson, 1987). The aim of these controls is first to balance the inflow and outflow of Lake Ontario while observing

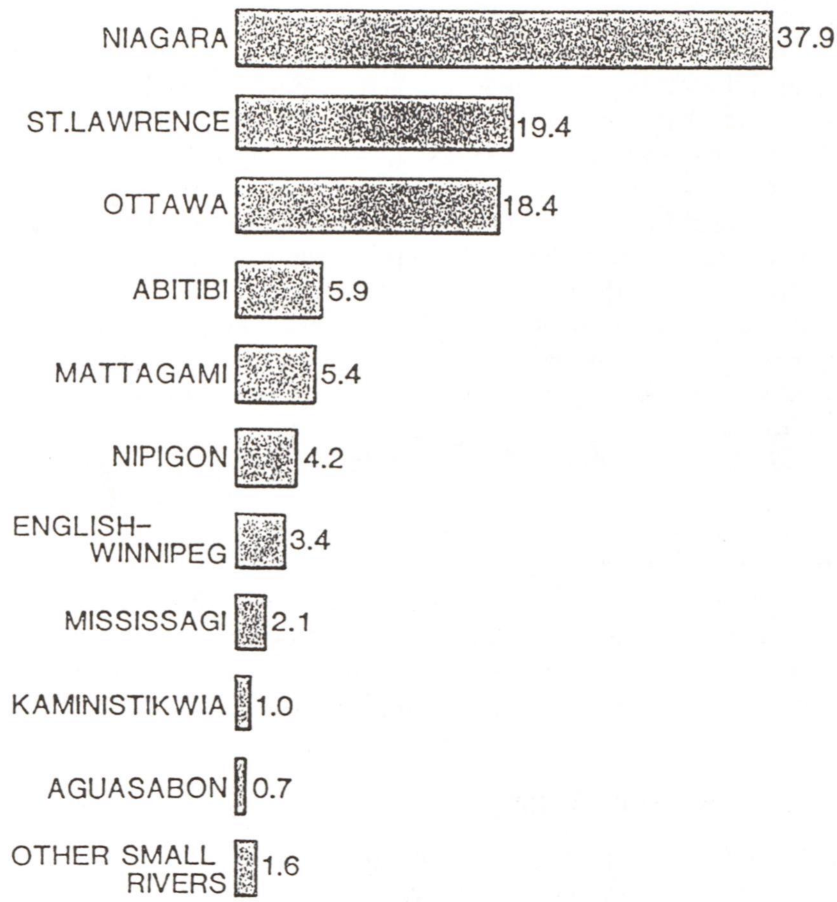


Figure 2. Energy generated by each river basin as a percentage of total Ontario Hydro hydraulic generation (1977-1981)

navigational limits, and second to dampen as much as possible natural variations of level. Application of these controls leads to a high degree of correlation between the Niagara and St. Lawrence River systems (Vilar *et al.*, 1988).

$$F_{StL} = 1.315\ F_{Nia} - 0.634 \qquad (1)$$

where F_{StL} and F_{Nia} are the St. Lawrence and Niagara River flows, respectively, in 10^3 m^3/s.

The yearly energy production from the Great Lakes subsystem is of course determined by the amount of water flowing through the Niagara and St. Lawrence Rivers. Flow through these rivers, and energy production, fluctuate from year to year in response to weather and lake level control actions, see Figure 3 (Vilar *et al.*, 1988). During the period 1959-1986, the yearly energy production has varied between extremes of 15 and 21.5 billion kWh. The difference between high and low production years, 6.5 billion kWh, represents a value of $260 million if the energy were produced by fossil-fuelled stations and $207 million if the energy were produced by nuclear stations (Ontario Hydro, 1987).

Influence of Climate on the Demand for Electricity

The demand for electricity is made up of two components—a base demand and a seasonal demand. The base demand is determined by the size of the consuming population

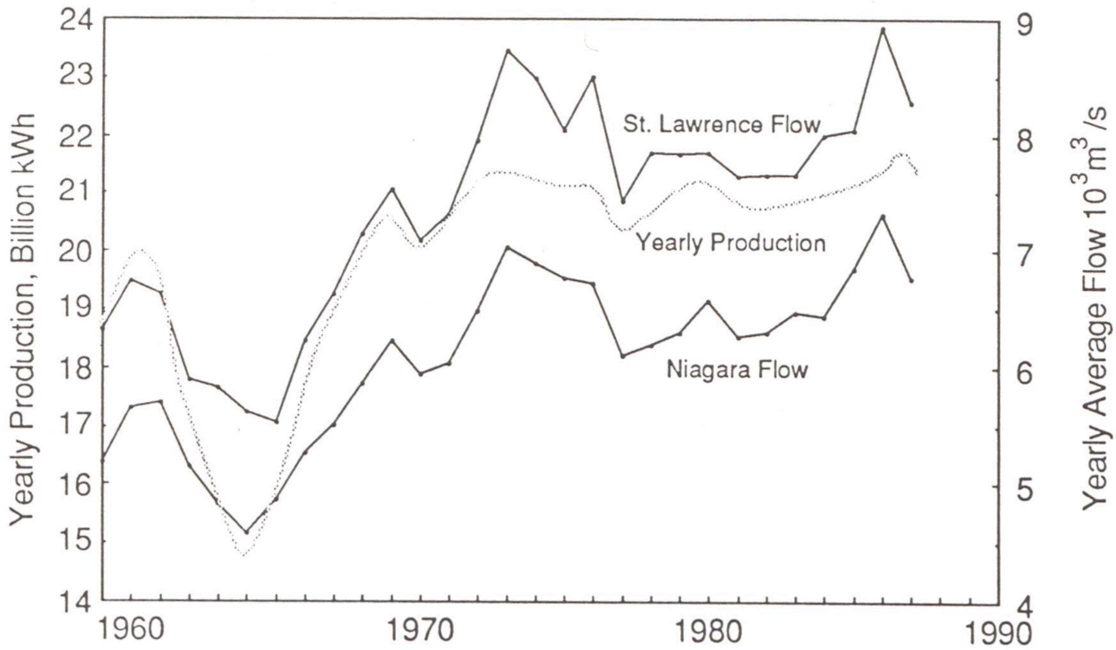


Figure 3. Niagara/St. Lawrence yearly average flows and energy production

Table 3. Niagara/St. Lawrence River Hydroelectric Installations.

Development	I/S Date	No. of Units	Generating Capacity (Thousand kW)
DeCew No. 1	1901	6	35
Rankine (CNP)	1904	11	75
Ontario Power	1905	12	104
SAB No. 1	1922	10	488
DeCew No. 2	1943	2	144
SAB No. 2	1954	16	1312
SAB PGS	1958	6	122
Saunders GS	1958	16	842

Heating

$$\Delta L = 80.5\ T_h + 41.7\ T_h' + 3.3\ T_h'' + 13.7\ T_h''' + 12.9\ W_s - 0.18\ I \qquad (2)$$

where

ΔL = weather effect, thousand kW

$T_h = 15 - T_{av}$, °C, if $T_{av} \leq 15$°C

T_h', T_h'', T_h''' = T_h for the previous 1,2 and 3 days, °C

T_{av} = average temperature for the day, °C

W_s = mean wind speed for the day, km/h

I = average illumination for the day, foot-candle

Cooling

$$\Delta L = 117.3\ T_c + 40.9\ T_c' - 10.1\ T_d - 0.0048\ I \qquad (3)$$

where

$T_c = T_{av} - 17$, °C, if $T_{av} \geq 17$°C

T_c' = T_c for the previous day, °C

T_d = dew point depression for the day, °C (defined as the difference between the mean temperature and the mean dew point.)

Figure 4. Equations for the influence of climate on demand

and the level of economic activity. Long-term changes in demand occur as a result of changes in economic and demographic factors. The seasonal demand is driven largely by climatic factors. The influence of climate on demand is captured in the equations shown as Figure 4 (Schaedlich and Keng, 1985).

Equation (2) indicates that the Provincial load changes by 700 thousand kW when winter temperatures vary by 5°C over extended periods of time. A permanent climate warming of this magnitude would amount to a load reduction of about 3 billion kWh during a six-month heating season. This represents a saving of $120 million if fossil-fuelled generation were avoided.

Equation (3) is more difficult to use in order to explore the effect of climate warming on the demand for electricity. This is because a permanent increase in summer temperatures would likely lead to a permanent change in the base load, through a greater penetration of air conditioning into the domestic and industrial sectors. Equation (3), which only accounts for the day-to-day effect of climate on load, is not able to describe the long-term changes in demand. All we can say at this time is that a 2.5°C change in summer temperatures would lead to a daily average load increase of at least 400 thousand kW. Over a three-month cooling season, this would amount to 0.9 billion kWh and an added cost of $36 million.

Outlook for the Future

The Great Lakes hydroelectric subsystem is a key component of Ontario Hydro's generating system. It provides a secure supply of economically priced electricity. Its value to the residents of Ontario is of the order of $1 billion per year, see Figure 5 (McIntyre, 1984). This estimate is the total cost (fuel, operation and maintenance, plus interest and depreciation on capital) of replacing the Great Lakes stations with coal-fired stations.

Some of the Niagara stations were built in the early 1900's. These stations are old and were designed to use water at about 30-50 percent of the efficiency of the newer Sir Adam Beck plant. Ontario Hydro is therefore proceeding with plans to build a new plant at Niagara to make more efficient use of the hydroelectric potential available to Canada. The new plant, which would have a useful service life of well over 50 years, would have a capacity of 700 MW and cost $1.45 billion. In-service date is expected to be 1998.

The value of the Great Lakes hydroelectric stations and the viability of the proposed new station can be undermined by long-term climatic change such as global warming due to the greenhouse effect. A study carried out by Marie Sanderson (1987) of the Great Lakes Institute examines, through the use of climate, hydrologic, and economic models, the effect of a doubling of the CO_2 concentration in the atmosphere. The analysis suggested that the levels of the Great Lakes would decrease and the flow through the interconnecting channels would be reduced. This could result in an annual loss of about 4 billion kWh, a value of about $110 million (1984 dollars). The 4 billion kWh has a current value of $160 million.

Sanderson's study further suggested that the demand for electricity would decrease significantly in the winter and increase slightly in the summer. The net effect was estimated to be an annual saving of the order of $175 million (1984 dollars). However, as we've seen, this effect, which is very difficult to quantify, may amount to a smaller annual saving of $84 million.

Climate change would affect Ontario Hydro in other ways. For example, the load-carrying capacity of the vast transmission system would be reduced under higher ambient temperatures in the summer. In the winter, temperatures around 0°C could become more frequent leading to an increased frequency of occurrence of freezing rain storms. These storms already pose serious threats to the transmission and distribution system. Finally, pressures to reduce emissions of greenhouse gases would likely be felt. Through its use of hydroelectric and nuclear plants, Ontario Hydro already has avoided vast amounts of emissions, relative to the use of fossil-fuels, see Figure 6. Energy conservation, currently a corporate priority, along with nuclear generation would provide the means to avoid future emissions.

It is obvious that the greenhouse effect needs to be studied further and that the implications of global climate change to electricity generation and demand need to be refined. In particular, the unusually warm summer of 1988 provides an excellent opportunity to examine how society may respond to global climate change. Such studies are encouraged. At the same time, projects which have a long in-service life, such as power plants and transmission lines, should be designed for a range of future climatic conditions.

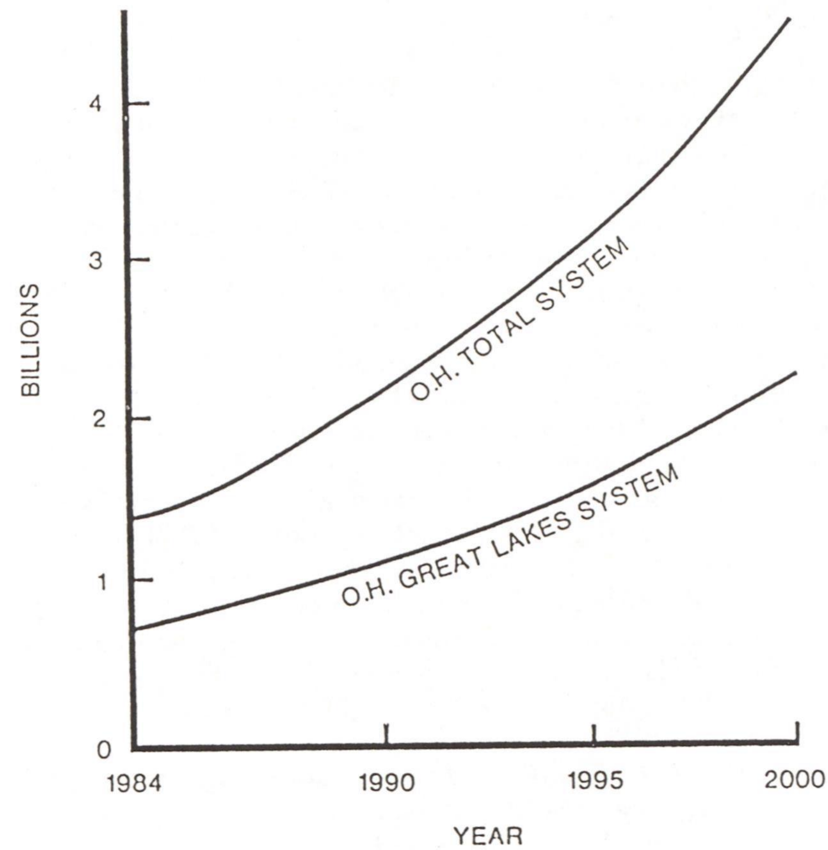


Figure 5. Annual replacement cost of hydraulic resources

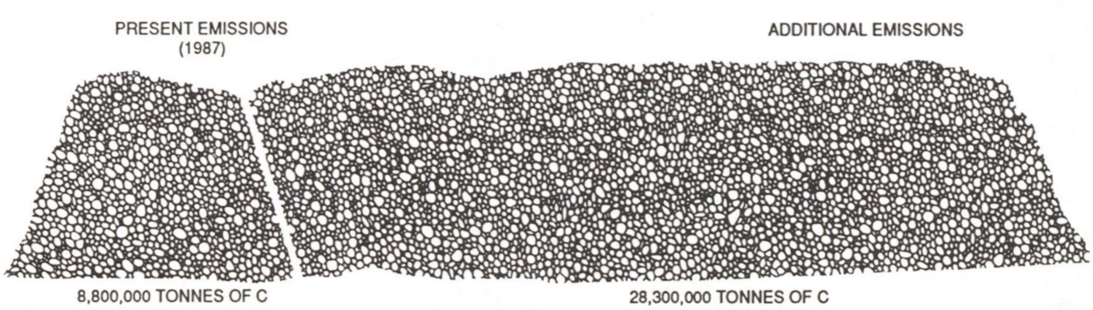


Figure 6. Effect of loss of hydroelectric and nuclear resources on CO_2 emissions

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Schaedlich, I.H., and C.W. Keng, 1985: *Weather-Load Analysis.* Ontario Hydro Power System Operations Division Report, January.

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Comments on Report of Panel A Findings

MR. HECHT: I have one point to seek clarity. You said the panel identified the need for lake-by-lake studies since each lake was different. Lake-by-lake studies appear necessary, but another panel emphasized the need for an integrated analysis of the whole lake system. Are we in conflict here? Please comment or just elaborate about the lake-by-lake studies.

MR . SAULESLJA: We agree that understanding is needed about effects over the basin as a whole. We also must realize that each lake responds physically differently, and probably in terms of the impacts as well. The transportation issue is likely to be different from lake-to-lake, as well as those issues that have to do with power generation. In fact, in terms of expanding the interest, we noted that we could not consider the Great Lakes themselves as an entity; we need to consider activities that will be occurring outside the basin.

MR. HECHT: Another comment concerns the conclusion that sufficient institutional structures exist to collaborate on major climate impact issues. Specifically, are you talking about governmental structures?

MR. SAULESLJA: We are talking about institutional structures like the Great Lakes Carriers Associations, Institutes for Climate Study, places where some of these problems can be studied.

MR. HECHT: All right. Are there additional comments from anybody in this group, or any of the other groups?

AUDIENCE MEMBER: What other climate elements do you think need to be looked at besides temperature, precipitation, and wind?

MR. SAULESLJA: Wind shear extremes form virtually one of many indicators. We need to develop a large list. In fact, within the Canadian Climate Program, such a list has been prepared by those involved in climate impact studies, working together with the group doing the numerical modeling. This is one of the main recommendations of this panel in that these scientists should get together.

AUDIENCE MEMBER: Who is the contact person at AES [Atmospheric Environment Service]?

MR. SAULESLJA: On that list I think Alan Malinauskas is probably the best contact person.

AUDIENCE MEMBER: Whenever one considers projects involving energy use in the future, an effective method is to conduct an energy analysis of projects and programs as though there were an alternative. Did your group address this approach at all? I feel strongly this should be an underlying recommendation from this conference.

MR. SAULESLJA: I cannot say our group addressed that, but it sounds like a good recommendation. I could say the group did not, and it probably should have.

MR. HARE: I think that the net energy is an excellent principle and is not done very much. It needs to be done. It does cast considerable light on whether the change of climate is going to alter the net energy balance including the use of fossil fuels in support of agricultural technology; for example, in relationship to the net yield conceivable, the net yield of mechanical energy. It ought to be done.

Report of the Panel on Recreation, Conservation, And Wetlands*

Introduction

Our panel discussion began with two invited papers. We then discussed these papers and identified issues for discussion including conservation, recreation, wetlands, fisheries, water quality and supply, and climate information. Under each issue, we identified major impacts or questions, stated recommendations, and noted any policy issues. One paper addressed climate impacts on recreation, and the other paper addressed environmental issues relevant to our subjects.

Issues/Findings/Recommendations

Conservation. In the conservation sector, three major questions were identified. First, how will the designation and management of our wilderness and heritage areas respond to climate change? Given that climatic change will alter the ecology of the Great Lakes Basin, how will we ensure that on any scale (regionally, continentally, or even globally) significant rare or endangered wildlife species are maintained? Does society want to do this? As to habitats for wildlife, vegetation, fish species, and movements and shifts in them due to climatic change, how will these species migrate to find refuges elsewhere?

We identified a number of research opportunities for conservation. Vulnerable and critical habitats and species must be identified. We need to designate new areas to conserve; for example, if agriculture moves into new areas or new agricultural practices develop, land use competition will increase. We need to analyze what areas should be conserved, or perhaps we could anticipate and acquire some areas now in northern Canada. We definitely need to quantify wildlife, fisheries, and vegetation impacts to climate and their possible responses to climate change.

Some policy issues that need to be examined include how we designate and manage parks, nature preserves, and recreation areas. Policy needs to address the question, How much human intervention should there be in this process of change? We should also enhance and stress flexibility in our policies to adjust to the climate change. We should continue to conserve areas, and we also must develop a policy for transplanting species to new areas.

Recreation. In the Great Lakes Basin, there will be both positive and negative impacts in recreation. For example, winter activities will be vulnerable. As a result, research should identify the opportunities and also our vulnerabilities to this change. We should be aware of what methods capitalized or minimized those impacts. We also should undertake more winter recreation studies.

Wetlands. The changing hydrology of the Great Lakes Basin will certainly be reflected in alterations to water levels, and since wetlands are along the land/water interface, they are going to be impacted. Will there be a decrease or increase in wetlands? Where will they migrate, and what will be the impacts on the wetland ecosystem? How do we protect wetlands or create new wetlands?

***Presented by Linda Mortsch, Panel Rapporteur**

One research requirement is improved bathymetric measurements of near shore areas. In addition, we need an understanding of how various components of the wetland ecosystem are linked and the processes between the different components. Then we might be able to estimate wetland ecosystem changes, and through this identify vulnerable areas.

Policies should give priority to wetland creation and protection, and advanced planning is needed for wetland augmentation and creation. The issue of shoreline management is very important, and policy must address issues such as who owns the land of exposed shorelines, and how to define zoning and setbacks. Wetlands represent an excellent opportunity to pursue joint Canada/U.S. studies. The Northern American Waterflow Management Plan is an excellent start for these types of endeavors.

Fisheries. Climatic change will cause the extension of ranges of various species of fish. There will be a greater productivity in the fisheries, but will there be enough food in the food chain to support it? We can expect an invasion of warm water exotics, and with the greater productivity, there may be more fishing opportunities. Research requirements include small lakes in the basin and how they may be severely impacted. We should study the physical and chemical limnology, alterations in the food web relationships, predator and prey relationships, and how the changing winter thermal structure might affect ecology.

Policy initiatives should recognize the necessity for more intensive management of the fisheries resources, and we should deal with food webs and predator/prey relationships. We should plan for dealing with more exotics. Policies should also continue to rehabilitate certain species; for example, the Lake Trout.

Water Quality. Our panel identified eutrophication, nutrients, toxins, and acidification as important water quality issues. Policy should develop better water resource management and planning for conflicting uses. Our panel thought policies must develop to limit withdrawals of ground and surface water. There should be policy to establish minimum flows and minimum levels to maintain ecological viability. We also should evaluate our current water quality criteria. We need to develop policies to deal with dredging and the resultant toxins that might be resuspended, and how we can dispose of these toxic sediments.

Water Supply. Water supply in the Great Lakes Basin will likely be decreased because of increased evaporation and decreased precipitation. We will likely experience an increased consumption of water. With water shortages in other areas of North America, there will be a greater demand for water diversions. Obviously, the response of the hydrologic system to a changing climate must be studied. In policy formulation, we should recognize that any regulation of flows and levels within the basin will have impacts outside the basin; for example, the Gulf of St. Lawrence.

Climate Information. Because of the severe effects of climate change, we must acquire more climatic data than currently available, and provide the kinds of climate information needed by recreational interests, ecologists, conservationists, and fisheries interests. We need more information on how the winds will change, on shifts in storm frequency and tracks, and on types of changes in temperatures, cloudiness, and precipitation. We also need to undertake sensitivity studies; that is, how certain environmental areas are affected by climate.

Policy should support long-term climate studies and monitoring, research, and assessment at present long-term ecological sites. We need to identify the climate change signal and establish ecological relationships.

Potential Effects on Great Lakes Fishes

J. J. Magnuson*

As part of an exploration by the Office of Policy Analysis of the U.S. EPA, we have exercised a set of biological models on fish distribution, growth, and production in the Great Lakes (Magnuson *et al.*, MS). Climate scenarios for $2XCO_2$ warming generated with the OSU, GISS, and GFDL global climate models were compared with the base climate conditions. The response of fishes which do best in warm, cool, or cold waters was compared for warmer, cool, and colder regions of the Great Lakes. Output of the climate scenarios were used to simulate thermal changes in the lakes, and these water temperature scenarios were used to estimate changes in the size of fish thermal habitat as well as changes in body growth and prey consumption using bioenergetic models. (The main assumptions were that fish could behaviorally thermoregulate by moving to deeper waters in the heat of summer and that sufficient prey were available to fuel their greater appetites.) For one species, the smallmouth bass, a reproduction model was combined with a bioenergetic model. Finally, a "Q-10" model was used to explore the general response of primary production zooplankton biomass, and fishery yields.

Potential positive effects on fishes noted through the exercise are increases in thermal habitat for warm, cool, and coldwater fishes; increases in productivity of primary producers, zooplankton, and fisheries; increases in body growth of warm, cool, and coldwater fishes; increases in recruitment of some species; and an increase in prey consumption of warm, cool, and coldwater fishes. Potential negative effects are an increase in species interactions; an increase in anoxia of deep waters; decreases in spawning areas in streams and wetlands; and increases in warmwater exotic biota.

Policy implications are that the potential increase in fish production could provide greater recreational, commercial, and artisanal fisheries in the basin, that the importance of reducing toxic and nutrient pollutants would continue, and that fishery management agencies would need to pay even closer attention to management of food webs, prey-predator interactions, and disturbances from invasion of exotic species.

Reference

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***Center for Limnology, University of Wisconsin-Madison**

Potential Effects for Tourism and Recreation in Ontario

Geoffrey Wall*

Preface

This document has considerable similarity to that published as an issue of *Climate Change Digest* (CCD-88-05). The maps and diagrams referred to in this paper can be found in that document. More detailed information is available in the original reports submitted to Environment Canada and in a number of other publications (McBoyle and Wall, 1987; Wall *et al.*, 1986a-d). Some of the highlights of the study are indicated below. However, this paper differs from its predecessors in that additional comments are made concerning research needs and policy implications.

Study Highlights

- A warmer climate may mean declining lake levels with associated changes in the ecological interest and recreational potential of wetlands.
- Impacts will vary considerably with the physiography of the littoral.
- The length of ski seasons will be reduced at the Lakehead, but the key holiday periods, when a larger proportion of business is conducted, will still fall within the reliable ski season.
- Diversification of activities is a suggested management response.
- The downhill ski season in the South Georgian Bay region could be eliminated with an associated loss of $36.55 million per annum in skier spending at the resorts and a $12.8 million reduction in the trade of Collingwood (figures in 1985 dollars).
- Summer recreational activities are likely to have extended seasons, and the viability of summer recreational enterprises may increase with associated positive benefits to neighbouring economies. However, the magnitude of potential gains varies throughout the province.

Introduction

The purpose of this document is to present the findings of an investigation of the possible implications of climatic change for tourism and recreation in Ontario. The study was conducted in two phases. The initial phase defined terms and assessed the literature directed at furthering our understanding of the relationsips between climate, weather, and outdoor recreation. A variety of research strategies with the potential to shed light on the implications of climatic change was assessed and a number of these were recommended for implementation. The application of these methodologies was undertaken in phase two of the study and the results of these investigations are presented here.

As in previous research reported in *Climate Change Digest*, two scenarios for climatic change associated with an increase in atmospheric concentrations of CO_2 were employed

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and their implications assessed. Scenario A was based upon a model developed by the Geophysical Fluid Dynamics Laboratory at Princeton, whereas Scenario B used output from a similar analysis undertaken by the Goddard Institute for Space Studies.

Because recreation and tourism comprise a multitude of different activities which take place in a diversity of environmental settings, it was not possible to undertake a comprehensive investigation, and a case study approach was adopted to make the research more manageable and to provide examples of possible impacts. Much recreation takes place at or near shorelines and other investigators had previously suggested that future changes in climate could have considerable implications for water levels in the Great Lakes. These circumstances provided justification for an investigation of wetlands on the edge of Lake Ontario as an example of the implications of climatic change for recreation resources. In addition, downhill skiing was chosen for examination as an example of a winter activity, and camping was selected to illustrate the nature of impacts upon summer recreations.

Even should the scenarios evolve as projected, they are unlikely to be experienced in a world which has not also changed in other ways. Given that we are unable to predict the future, in order to proceed the assumption was made that, other than the changes in climate, all other things will remain as they are. Thus, no allowances were made for technological changes or policy initiatives which could modify climatic change. Furthermore, it was assumed that future recreationists will respond to the new climates in a fashion similar to their responses to weather and climate at present. It was further assumed that variability about future climatic norms will be similar to that which is now experienced.

The Natural Resources Base

Wetlands

The consensus among climatologists is that the future climate of Canada may be warmer and drier than at present. One of the consequences of this is likely to be a lowering of lake levels with implications for the character and recreational potential of shoreline ecosystems. Some of the greatest impacts of lake level changes will occur along the margins of the Great Lakes where wetlands constitute important waterfowl habitat and a source of recreation for many people.

Point Pelee National Park and Presqu'ile Provincial Park were selected as study sites. Both contain large areas of marsh which are of considerable significance for wildlife and recreation. However, they also constitute two different types of wetland systems with the potential to respond differently to changes in water level. Point Pelee is a closed, protected marsh which is separated from the lake by natural barrier beaches. In contrast, the marsh of Presqu'ile is an open wetland system. In both cases the marshes are not influenced to any great degree by runoff from the mainland, and water levels in Lake Ontario are a primary determinant of the vegetational composition and functioning of the marsh.

Impacts

Water levels in Lake Ontario are expected to drop 30 to 83 cm as a result of mean annual temperature increases in the neighbourhood of 4 to 6°C. Precipitation may increase but increased evaporation is expected to more than offset this. In naturally confined marshes such as Pelee, lowered lake levels will cause the marsh to revert to marsh meadow and eventually succeed to dry land. Because of the protective sand spits, the marsh will be prevented from moving lakewards, and vegetation will tend to shift from hydric to mesic conditions. Some plant species may change growth form to accommodate drier conditions, but vegetation will change dramatically as species intolerant of drying die and are replaced by species emerging from buried seeds. The trees which mark the landward edge of the marsh may advance due to a lowering of the flood line.

Wetland species diversity will decline, and the suitability of the marshes as a habitat for recreationally and commercially valued species, such as migrating waterfowl and muskrats, will be reduced. Sport fishing may also be affected by the reduced quality of shoreline marshes where fish feed and spawn. Other nonconsumptive activities, such as canoeing and ice skating, will also decline due to the lack of open water. In time, the marsh may lose its wetland character and, under extreme conditions, the waterfowl migration route may change resulting in the collapse of hunting and, more importantly, birdwatching.

In open shoreline marshes such as Presqu'ile, the effects of lowered lake levels are unlikely to be as severe. Instead of a draining of the marsh and a trend towards dry land, there will probably be a shift in the vegetation in a lakeward direction. The extent of this shift depends upon the magnitude of the lake level change, the slope of the bottom profile, and the suitability of the substrate. Some new shoreline areas may actually develop wetland characteristics.

Conclusions

Point Pelee is a closed marsh and a decline in water levels may lead to a drying out of the marsh with an associated loss of ecological diversity and a consequent decline in the recreational interest of the area. On the other hand, Presqu'ile is an open marsh and it may be able to migrate with changing water levels leaving its ecological interest largely intact. It is evident that the impacts of climatic change on shoreline ecosystems will vary considerably with the physiography of the littoral.

Discussion

Presumably, should water levels in the Great Lakes fall, then, other things being equal, and given sufficient time, a new equilibrium will develop which will include the establishment of new wetlands in locations where the physiography of the littoral is suitable. However, unfortunately, other things are unlikely to be equal. Many of the major wetlands are currently under protection in national or provincial parks or some other heritage designation. There is no guarantee that locations with wetland potential will be under public jurisdiction, and existing users may discourage the development of new areas adjacent to their property. The requirements of other users, such as navigation and power generation, which may encourage dredging and filling or stabilization of water levels, will also militate against the formation of new wetlands. What are managers of existing wetlands to do if their holdings become less interesting ecologically and the reasons for their designation are removed?

Wetlands are only one environment with potential for recreation. Modifications in the ecosystem, including increased water temperatures, may increase the growth rates of fish but lead to the decline of highly favoured, cold water species. Decreased water to dilute pollutants may lead to degraded environments for many species. Thus, the implications of climate change for recreation are far-reaching.

The points which have been made with respect to wetlands are applicable in a more general form to other ecosystems. A warming trend should lead to the northward movement of biomes. However, in many parts of the Great Lakes Basin, natural areas are islands embedded in vast areas of modified landscapes, and in the absence of obvious routes for the spread of species or assemblages, it is unclear how the relocation of ecosystems will occur. Furthermore, little is known concerning the speed at which ecosystems respond to external stimuli: such information is vital for understanding the implications of climate change. It is unlikely that different ecosystems will respond at the same rate. This is a topic requiring further investigation with competition in ecotones appearing to offer one potential point of entry for examination of the problem.

To date, research on the impacts of climate change has concentrated upon man-modified environments, such as agricultural lands and forests, and there appears to have been little attention devoted to relatively natural ecosystems, particularly in the Great Lakes Basin, although Vetsch (1986) has undertaken some work of this type in Saskatchewan.

There are likely to be considerable implications of climate change for park agencies and others responsible for the preservation of natural ecosystems. Many parks, including the Canadian national and Ontario provincial parks, are established partly on ecological criteria. In some cases they are designated as being representative of existing natural regions and, in others, in an attempt to preserve particular species. What is natural in an era of change? This is not an entirely new question, and agencies have evolved policies to deal with man-induced and natural agencies of change, such as fire. However, the magnitude of the changes which are contemplated, particularly when coupled with other environmental modifications such as ozone depletion and acid rain, raise the question to a new level. Plant succession may be arrested at a particular seral stage to protect the habitat of a particular species, but such a strategy may be complicated, if not frustrated, by climate change. Climate change thus poses fundamental questions concerning both the designation and management of natural areas which have yet to receive attention.

Downhill Skiing

Introduction

Many recreational activities are seasonal and there are strict climatic requirements for them to be possible or enjoyed. It follows that anything which alters the length of the seasons is likely to have repercussions for participation in outdoor recreation and for the businesses which cater to recreationists. Downhill skiing is one such activity.

Two areas of Ontario were selected for detailed study. The South Georgian Bay area was selected as a southern ski area and the Lakehead was chosen from northern Ontario. Together these two areas constitute the major downhill ski areas in the province. For each of the three areas the following three procedures were carried out:

1. Snow cover periods suitable for skiing were determined for present day conditions as well as for conditions suggested by Scenarios A and B using a method suggested by Crowe *et al.* (1977).
2. Data on current skier visits and expenditures were used in conjunction with estimated future season lengths to calculate changes in the number of skier visits and the economic consequences of the climate scenarios.
3. Sensitivity analyses were conducted to determine the likely impacts of various small changes in temperature and precipitation combinations.

Results

Changes in the average monthly values for precipitation and temperature for the months of November to April inclusive, the winter season, were calculated. Both scenarios suggest that winter temperatures will increase while precipitation totals will vary from normal to 115 percent of normal, depending on location. Even if precipitation increases, because of the rise in temperatures, snowfall will be reduced.

The procedure developed by Crowe *et al.* (1977) was used to calculate snow cover suitability percentiles for both study areas for present day conditions and for future climates as suggested by the scenarios. The ski seasons were divided into two major categories:

1. The "reliable snow cover season" (hereafter called the reliable season) in which there is a 75 percent or greater probability of there being suitable snow cover for skiing
2. The "marginally reliable or better snow cover season" (hereafter called the marginally reliable season) in which there is a probability of between 50 and 74 percent of there being snow cover suitable for skiing.

For the Lakehead under Scenario A, the present marginally reliable season will be reduced from 131 days to 91 days, a reduction of 30.5 percent. The present reliable season will be shortened from 111 days to 72 days, a reduction of 34.5 percent. Further reductions in both the reliable and marginally reliable seasons occur under Scenario B. Although the reductions in the ski seasons are large, the key Christmas break when 20 percent of the year's business is done, and the university/college mid-February break, still fall within the reliable skiing season. The elimination of skiing in March, when 20 percent of skier visits currently occur, is the major loss and will give rise to a reduction of skier expenditures annually of $1.9 million in 1985 dollars at the resorts under Scenario A. However, it may not be necessary to endure all of this loss because of the possibility of an enhanced ability to draw upon the southern Ontario market.

The South Georgian Bay region, which is climatically marginal for skiing at present, does not fare as well as the Lakehead. The present day marginally reliable ski season of 70 days will be reduced to 40 days under Scenario A and will disappear altogether under Scenario B. There will be no reliable ski season under either Scenario A or B. It is questionable if skiers will continue to be attracted to an area with, at most, a 40-day marginally reliable ski season that excludes the Christmas and tertiary education mid-February break. The calculations associated with both scenarios suggest the virtual elimination of the ski industry in the South Georgian Bay area with a loss to the resorts in 1985 dollars of $36.55 million per annum in skier spending and a reduction of $12.8 million per annum in the retail trade of Collingwood. This is in addition to the millions of dollars invested in infrastructure by the ski industry.

The conclusions, particularly with respect to the South Georgian Bay area, may appear to be extreme. However, an analysis of climatic variability indicates that this is not the case and average conditions as indicated by the scenarios are experienced occasionally under the present climatic regime. Furthermore, it is not necessary for climatic change to be as great as that suggested in the scenarios for there to be a marked decrease in the length of the ski season in the South Georgian Bay area.

Conclusions

The analyses suggest that, under both Scenario A and B, the ski areas in the south will be more adversely affected than those in the north. Unsuitable conditions occur in present-day, mild winters such as 1979 to 1980 and they will occur at temperature values lower than those indicated in the scenarios. Two observations are in order. Lakehead resorts may be able to take advantage of the reduced skiing opportunities in southern Ontario by catering to residents of the south. Diversification of activities is suggested as a management response, for the summer season will be lengthened and in this way it may be possible to defray winter losses through summer gains.

Discussion

The materials on downhill skiing demonstrate that methodologies for the examination of the implications of climate change for skiing have been developed and have been applied with some success. These methodologies link climatic variables with information on human behavior to enable making tentative estimates of economic implications and assessment of their significance. With some modifications similar methodologies could be applied to other activities. Such studies should include sensitivity analyses, for in some cases, smaller changes than those projected for the greenhouse effect may have considerable implications.

Participants in outdoor recreation are extremely mobile, and they may be able to divert their patronage from one facility to another with relative ease. Furthermore, residents of the Great Lakes Basin currently travel outside of this area to meet their recreational desires. It follows that the evaluation of specific sites, in the absence of a consideration of the broader context of recreational opportunities, may lead to misleading results. Detailed results have been presented above for two ski areas in Ontario, but results of analyses of other areas are beginning to emerge. For example, research on the Laurentians is indicating that skiing may also be curtailed in that location (McBoyle and Wall, 1987; *Climate Change Digest* CCD-88-03). Unpublished results for Michigan suggest similar results for Ontario, i.e., that the downhill ski resorts in the south of the state will struggle, whereas resorts in the north may continue to operate successfully but with slightly diminished operating seasons. There is a need to undertake similar studies in Vermont and New York in order to get a more complete picture. The potential also exists to undertake a continentwide study of downhill skiing for, as has been demonstrated, methods of analysis exist and the data base is quite strong; however, the complexities of mountain climates may pose some challenges. It is always dangerous to take a place or a region out of context and, even though the Great Lakes Basin is very large, it is influenced by activities beyond its borders. A continentwide study of the ski industry could serve as a demonstration project leading directly to implications for policy based upon more than parochial concerns.

Camping

Introduction

Camping is both a recreational activity and a means to participate in many other forms of outdoor recreation. As such one might expect there to be a relationship between participation in camping and participation in other summer recreational activities, such as hiking. For this reason, camping is likely to be a good indicator of participation in summer outdoor recreations.

It is possible that the warming and drying trends suggested by the scenarios will lengthen the period of the year which is conducive to camping. Much as was done in the preceding section on skiing, it is possible to employ temperature satisfaction criteria developed by Crowe *et al.* (1977) to calculate a lengthened camping season based upon user satisfaction. Once the lengthened season is established, the economic implications of the increased potential can be assessed. However, camping is influenced by many other factors in addition to climate and weather, and participation in camping exhibits considerable peaking on both a seasonal and a weekly basis. For the purposes of this study it is assumed that any elongated season will provide the campgrounds with the same amount of activity in the additional weeks as is present at the margins of the current normal season.

Study Sites and Research Procedures

Camping opportunities are provided both by the public and private sectors, but because of data availability, the analyses are confined to camping in provincial parks. Eight parks were selected for analysis. No claim is made that they are representative of Ontario: rather, they constitute parks of a diversity of sizes and types from a variety of locations scattered across the province. Temperature frequencies were divided into three groups representing the 0, 50 and 100 percent satisfaction percentiles found in Crowe *et al.* (1977). The data were divided into 10-day periods and 18°C was taken as the lower limit for 100 percent satisfaction (the lower limit for reliable camping); 11°C was taken as the temperature at which 50 percent satisfaction occurs (11°C to 18°C was termed the marginally reliable season); and below 11°C it was assumed that conditions would be unsuitable for camping. Note that the temperatures being considered here are the average daily maximum temperature. Satisfaction percentiles were calculated for each 10-day period from April to October, excluding July and August. Many of the parks are at peak capacity during July and August so that a warming trend will not cause more people to visit the parks at these times. It seemed to be more appropriate to concentrate attention on the shoulder seasons.

Changes in Camping Seasons

There are considerable regional differences in season length with parks in the south generally experiencing a longer season climatically (although not necessarily administratively) than those farther north. In all cases the reliable camping season is extended under both scenarios, sometimes by as much as 40 days. The marginally reliable seasons always occur earlier in the spring and later in the fall.

Differences in the length of extended seasons, from no change in the fall in Fitzroy under Scenario A to a considerably extended fall season at Pinery and Fitzroy under Scenario B, indicate the magnitude of climatic change on a regional basis. There does not appear to be a clear north-south or east-west pattern. However, Scenario B permits the greatest extension of the season in all cases.

Economic Implications

Information on numbers of campers, their length of stay, and expenditures incurred within 40 kilometers of the parks was obtained from the statistical summary of the Ontario provincial parks (Ministry of Natural Resources, 1984). The average expenditure per camper per night was calculated for each park and multiplied by the number of camper-nights to give total camper expenditures within 40 kilometers of each park.

The impact of the extended seasons of the scenarios was found by calculating the number of 10-day periods suitable for camping (with the marginally reliable periods receiving a weighting of two-thirds that of reliable periods) for normal and scenario conditions. If the number of 10-day periods in the normal camping season is divided into total camper expenditures, then we can find the expenditure per 10-day period at present. If it is assumed that expenditures per capita will remain the same, then total camper expenditures for Scenario A and B are gained by multiplying this figure by the number of weighted 10-day periods.

Under Scenario A conditions, expenditures increase from a low of 9 percent at Fitzroy to 31 percent at Sibley and Quetico. The magnitude of increases depends upon park size, the number of visitors, and opportunities to spend money in the surrounding region, as well as climatic variables. Thus, for example, Pinery Provincial Park has the largest number of campsites, camper-nights, and the greatest volume of expenditures so that the implications of an extended season are relatively large.

Conclusions

Both Scenario A and Scenario B suggest that there may be a potential for camping seasons to be extended. Should campers take advantage of this there would be positive economic implications which vary in magnitude in different parts of the province. However, these economic benefits may accrue at the risk of increased environmental deterioration as the parks experience more users for longer periods of time.

Discussion

It is important to acknowledge that impacts are not always negative, that change need not necessarily be bad, and that climate change may create opportunities as well as problems. The outlook for enterprises providing summer recreation opportunities is rosy provided that they are not likely to be adversely affected by declining water levels or the reduced availability of water. Perhaps, if winters are shorter, there will be less desire to undertake winter vacations in warmer climates, particularly if the tropical coasts which currently attract the majority of this business are experiencing their own environmental problems resulting from rising sea levels.

Summary

This presentation has examined some of the implications of climatic change for tourism and recreation in Ontario. A case study approach has been adopted in which selected recreational resources, and a winter and summer activity, have been the focus of attention. Where possible, economic estimates of the magnitude of impacts have been made.

The study of the wetlands of two parks indicates that, in addition to the magnitude of climatic change, the physiography of the shoreline is a major factor influencing the response of wetlands to water level modifications induced by climatic change. In some cases there may be a reduction in species diversity and recreational attraction as water levels recede, but in others the marsh may be able to migrate with the water levels.

The studies show that the implications of climatic change will be mixed. The climatic changes of the scenarios will place increased stress on businesses catering to winter activities, particularly in southern Ontario, as operating seasons will be reduced. The downhill ski season in the South Georgian Bay region could be eliminated unless technological measures are able to overcome the climatic difficulties. The climatic data suggest that investments in winter activities should be undertaken with caution and that it is in the interest of winter recreational complexes and the communities in which they are located to diversify their activities.

Summer activities are likely to have extended seasons, and the viability of summer recreational enterprises may increase with associated positive benefits to neighbouring local economies. At least there will be the potential to extend summer business into what at present are shoulder seasons if institutional arrangements permit. However, this potential varies spatially. It may also place increased pressures on the resource base. This will require careful management.

Recommendations

The following recommendations are made as a result of the analyses and discussions which have been presented:

- Research on man-modified systems, such as farmlands and forests, should be complemented by additional studies of the implications of climate change for natural systems.
- Investigations should be undertaken of a wide variety of natural ecosystems in addition to wetlands, with particular attention being devoted to the time required for different ecosystems to adjust to environmental perturbations, and mechanisms for the migration of species and assemblages.
- An assessment should be made of the implications of climate change for the designation and management of protected areas.
- Additional studies should be undertaken of the implications of climate change for downhill skiing, leading to a continentwide examination of this phenomenon and an assessment of policy implications.

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Report of the Panel on Water Supply, Lake Pollution, and Lake Levels

Introduction

This panel heard five presentations, and then identified key issues and concerns. The issues became the basis for identifying a series of recommendations dealing with research, institutions, and policy changes. Two presentations dealt with hydrological issues, two dealt with water quality, and one dealt with broad policy implications. Contents of the presentations were discussed and served as a basis for issue delineation.

Issues

Lake Levels. The first issue identified concerned effects of climate change on the Great Lakes water levels. Given the climate scenarios described by the climate modelers, it was concluded that lake levels will decline, although uncertainty exists about the ranges of decreases. Ability to conceive of this outcome, given the current experience of record high levels, revealed a need for education and communication, certainly to gain wider understanding of the climate change problem. The panel envisioned serious impacts to water quality (hypolimnion anoxia), restriction of aquatic habitats in wetlands, hydropower generation, navigation, disposal of dredged sediments, shoreline infrastructure, and recreation. Some possible positive impacts of climate change and water level declines, such as broader beaches and reduced beach maintenance, were identified. If water levels decline, delta formation will increase and river inlets will be affected.

Regulations. The second issue concerned the effects of changes in the regulation of the two Great Lakes already regulated, Lakes Ontario and Superior. There was a strong concern in the panel that, as a result of climate change, the existing regulation plans may not be able to meet the objectives of various users. One of the important policy issues is how one might be able to reconcile the various objectives that different users of the system have.

Consumptive Usage of Water. The third issue relates to the conclusion that consumptive uses will likely increase due to changing requirements from a warmer climate. Consumptive uses are increasing and the rate of increase might be even greater if the climate changes envisioned occur.

Water Quality. The panel dealt extensively with the degradation of water quality as a function of lake pollution. Anticipated changes in the hydrometeorological components of the Great Lakes system (i.e., decreases in flows and water levels as well as potential changes in the air/water interaction components) will likely impact on water quality issues especially in susceptible lakes and embayments. Changes in the climate are expected to alter the surface radiation balance, increase water temperatures, alter the seasonal thermal structure and length of the stratification season, and alter water residence times—all components that affect the lake water quality and trophic status. Alterations in runoff have the potential to affect loadings of nutrients and deleterious chemicals to the lakes, and there is concern over the influence of ground water responses to altered climate for the migration of agricultural chemicals (pesticides) to the lake system.

***Presented by Murray Clamen, Panel Rapporteur**

One of the serious concerns was the effect of decreased dilution resulting from decreases in flows and water levels especially for shallow lakes such as Lake Erie. Decreased water levels and shallow hypolimnia may result in the increased prevalence of hypolimnetic anoxia leading to mobilization of metals, nutrients, and other toxic chemicals from the sediments to the overlying water and decreases in suitable habitat space for affected fish species. Lower water levels may also affect water quality through an indirect route as navigation difficulties may increase the frequency of ship 'grounding' especially in connecting channels, with potentially increased spills of toxic chemicals. Areas currently identified by the IJC as areas of concern for pollution may be at greater risk under the influence of climate change, and under a general climate warming, more areas may be considered as being at risk.

Ice Cover and Snow. Effects due to reduced ice cover and changed snow from climate change will seriously affect the hydrologic cycle. Ice retardation in the connecting channels, which plays a large role in the natural regulation of the inflows and outflows of lakes, could change and affect the levels and entire flow regime of the Great Lakes system, as well as lengthening the navigation season. Alteration of regional snowfall could seriously affect the annual cycle in lake levels. This could have profound effects on the general hydrologic conditions of the basin.

Conflicts Between Users. Even under normal supplies, we now have conflicts between the various users of the system. This panel felt these would be exacerbated and would increase under climate change, making it much more difficult to reach a consensus amongst the various users of the systems.

Demands for Increased Supplies and Diversions. Climate change which reduces water supplies will likely lead to pressures to agument supplies within the basin. This will include lobbying for diversions into the system, searches for new supplies, and conflicts over proposed reductions in the amount of current diversions from the basin.

Conservation and Ground Water. Increased pressures for water conservation would develop. Shortages would impact ground water due to increased demands on the ground water resource for both municipal and industrial water needs. These could exacerbate some local problems and could possibly affect the migration of pollutants from waste disposal sites.

Monitoring. With respect to biological systems, monitoring is essential for all parts of the basin, the big lakes and the thousands of other lakes and the streams in the system. Measurement programs will require standardization between U.S. and Canada in order to observe changes in the physical, chemical, and biological components.

Land Use. Land use policies and regulations will be more difficult to implement. If lake levels decline, policies will need to be changed.

The panel derived eight general recommendations that stemmed from these issues.

Recommendations

Modifications to current Great Lakes regulation plans, and perhaps even additional regulatory works and regulations need to be considered. This first recommendation is being done as part of the current IJC Lake Level Regulation Study of fluctuating lake levels.

The second recommendation concerns the need to develop Canada/U.S. agreement on long-range goals for monitoring and policy on water use in the Great Lakes. This would help alleviate, or resolve, the conflicting uses that are likely to happen in the future.

Third, the notion of new principles or agreements should be considered. Specific examples include: 1) identification of some of the in-stream, in-lake uses; and 2) protection of these uses as a first priority. There are a number of ways in which this could be done, one being Canada's national water policy which includes diversion and implementation of a hierarchy of uses.

The fourth recommendation concerns the need for increased research of past and present climate in the Great Lakes. Efforts should include study of the past 3,000 years including development of new hydrologies that might have existed as a result of many climate changes. There needs to be a better framework for dealing with climate change by developing a better understanding of the current climate and its effects on the system and its users.

The fifth recommendation concerns the development and implementation of techniques, laws, and policies to prevent detrimental effects of climate changes. Besides adaptation to climate changes, there also should be efforts to try to prevent it, e.g., encourage reduction of those factors causing climate change.

The sixth recommendation is the need to develop an improved and integrated data base. Separate data bases serve some sectorial needs, but not on an ecosystem approach. We also need a real-time hydrometeorological data network and modeling capability, as recommended by the IJC in a recently completed report to the U.S. and Canadian governments.

The seventh recommendation concerns the development of a process for all interests to be included in any water use allocation and determination. This is related to developing agreements. It would involve the energy, transportation, shoreline riparian, and recreation interests. Compromise will be needed to address impacts of climate change.

The eighth recommendation relates to improvements needed in climate change models. Research must be done to improve these models, and specifically to provide better definitions of change in terms of spatial and temporal distribution of the climate variables.

Abstract: Effects On Water Resources

Douglas R. Cuthbert*

The focus of this presentation is on the effects of climate change on the region's hydrologic cycle, on water supply and on other water resource related impacts. The views and ideas in this presentation are based on assumptions that the greenhouse effect and climate change will cause a general increase in air temperatures and an increase in regional evaporation rates. Also that these temperatures and evaporation changes will result in an overall net reduction in water supplies to the Great Lakes region according to the various estimates from global circulation models.

Great Lakes Water Levels Will Decrease

Previous and current modelling of water level conditions by the Great Lakes Environmental Research Laboratory of NOAA, the Army Corps of Engineers, and Environment Canada indicates that we are looking at a possible reduction in lake levels in the range of up to a metre under the two times CO_2 scenario. This effect varies by lake and depends on whether one refers to average water levels, maximum levels, minimums, or ranges of levels. For example, the current estimates produced by GLERL suggest a decrease in Lake Erie mean levels of 2 to 6 feet and an expansion in the range of Erie levels by 1 to 2 feet. These estimates of lake level effect are, however, predicted on the assumption that all other factors affecting lake levels will remain the same, and they won't!

The lake regulation plans for Lakes Superior and Ontario will fail to meet their objectives under these changing water supply conditions. Long before this "failure," we can expect that a requirement for changes in these regulation plans will be identified and changes made. In fact, under the current IJC Great Lakes water level reference study, these regulation plans are being reviewed with one objective being to define how and when these plans might be modified as a result of changing water supply conditions to the lakes.

As far as the unregulated Lakes Michigan-Huron, St. Clair, and Erie go, the effects of falling water levels might be handled in a number of ways. From a purely structural lake level modification viewpoint, the construction of lake outlet control works of complex or simple form would serve to reduce lake outflows and prop up water levels in these middle lakes. For example, simple flow-restricting underwater dikes or weirs in the St. Clair, Detroit, and Niagara Rivers could be constructed at minimal cost to reduce lake outflows and raise lake levels.

Consumptive Water Use Demands Will Increase

Consumptive uses of water throughout the Great Lakes Basin are currently estimated to be about 6,500 cubic feet per second. Under existing climate conditions this consumptive use is expected to increase to about 8,400 cfs by the year 2000. Under two times CO_2 conditions, consumptive uses can be expected to rise considerably further. The following quote from a September 22, 1988, *Toronto Globe and Mail* newspaper article entitled "ENLARGE THE PIPE" provides an example of this projection.

***Inland Waters Directorate, Environment Canada**

> The possibility that the greenhouse effect will dry up creeks in the Halton municipal region within 50 years has prompted planners to recommend the region spend an extra \$7 to \$10 million to enlarge a proposed pipeline to Lake Ontario. The consultants suggest making the water intake larger than needed as insurance against the possibility that some or all of the existing stream and well-based water supply sources might no longer be viable within 50 years.

The point is that in the face of rising demand for water and diminishing local supplies, one reaction of municipal water supply agencies is to build more and larger pipelines to access Great Lakes water supplies. Under expected climate change conditions this activity will proliferate. These actions will in turn exacerbate falling water level conditions on the lakes.

Water Quality Problems Will Become Worse

Many may feel that lower water levels and reduced through-flow in the system will lead to increased water quality problems in the lakes. However, reduced water supplies may not be the major source of water quality problems. Certainly interbasin and through-basin flows will decrease and there will be less dilution. But considering the vast amount of water in the lakes themselves this may pose a problem only in the interconnecting channels.

Residence time for water in the lakes based on plug flow, ranges from 2.6 years for Lake Erie to about 190 years for Lake Superior. As a result, pollutants entering the lakes tend to be retained in the system and become more concentrated with time rather than being flushed through the system. This feature will not be changed significantly under two times CO_2 conditions, but neither may it be a major concern.

What may be of considerable concern from a water quality viewpoint is increasing water temperatures and the higher prevalence of thermal stratification in the lakes. As other researchers have stated, seasonal turnover or destratification of the four deep lakes will not occur or not occur very often under two times CO_2 conditions. Currently this turnover and vertical mixing of the water column occurs twice a year on all lakes. If continuous temperature-based stratification of the lakes were to occur, then oxygen deficient conditions below the thermocline and related water quality problems of the deep lakes will be of considerable concern.

Other Related Lake Impacts

- Reduced winter ice cover on the lakes.
- Reduced winter-time ice retardation to flows in the interconnecting channels resulting in additional lake outflows, which will add to the lowering effect on water levels.
- Regional snowpack will be reduced leading to reduced spring runoff which in turn will affect to some degree the annual cycle of lake level variation. This effect will not be significant from a Great Lakes record high or low level perspective, as the large size of the lake system tends to buffer these annual supply variations. Some related environmental/ecological effects can, however, be expected.
- Decreased lake levels and flows will affect other interests such as commercial shipping, recreational boating, hydropower production, etc. Many of these topics are addressed by other symposium panels.
- Greater variations in the hydrologic cycle may result, such as those that caused record high precipitation over the basin in 1983 and 1986 followed by the very low precipitation conditions in 1987 and 1988.
- Greater variations in storm frequency and storm magnitudes over the lakes may be experienced.

Policy Implications of Climate Change

Eugene Z. Stakhiv and James R. Hanchey*

Abstract: Large uncertainties are a ssociated with climate change forecasts, enough so that policy analysts, planners, and decision makers are reluctant to explicitly incorporate these considerations in their strategies, plans, and specific actions. Nevertheless, many water resources planning studies and analyses have indirectly integrated a large proportion of the anticipated range of the physical consequences of anticipated climate change (precipitation, runoff, lake level fluctuations). This has been done through the normal multiobjective comprehensive approach to river/lake basin planning and the reliance on hydrologic extremes for the design of specific projects to mitigate the adverse consequences of natural hazards.

The Great Lakes have been subjected to near-record low lake levels in the mid-1960's and record high lake levels in the mid-1980's. These conditions are likely to encompass the statistically defined boundaries for lake-level fluctuations in the foreseeable future. Water resource management strategies have been formulated, debated, and analyzed within the context of these historical and probabilistically extended bounds. Policy analysis and strategic planning evaluation does not require explicit, accurate predictions of climate change and its physical, social, and economic consequences. Rather, the assessment and relative appraisal of the social, environmental, and economic consequences of several plausibly formulated climate scenarios serves as the necessary first step in the development of adaptive and mitigative strategies that would be common to and effective across all scenarios.

On the other hand, specific actions and projects that evolve from adaptive strategies and resource allocation priorities would require a more detailed understanding of the physical consequences of climate change. The sizing of water supply systems, determination of the level of flood protection, or the size of a navigation lock would be enhanced by the application of risk-cost analysis principles. Given that approach, however, the rather high discount rate (nearly 9 percent in the U.S.), which is used in evaluating the economic (not financial) viability of a water resources project, discounts most benefits beyond 10-12 years. Thus, one of the major impediments for *anticipating* and ameliorating the consequences of a slowly evolving and long-term phenomenon such as climate change is the manner in which present economic decision rules in use by the U.S. Federal agencies (benefit-cost analysis, the discount rate) inhibit the consideration of future, potentially catastrophic consequences. Nevertheless, many of the feasible societal responses, which can be implemented as near-term first steps, are adaptive in nature (conservation, pricing, land use regulations, etc.) and do not require structural solutions nor depend directly on the discount rate as part of an economically driven benefit-cost calculation.

Introduction

Climate changes that are expected to be induced by global warming are uncertain phenomena, not so much in the direction of change, but in the expression of the changes in terms of regional weather anomalies, the magnitude and variability of storm events, duration and intensity of droughts, and of course, the resultant fluctuations of Great Lakes

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levels. We have seen, over the past two decades, Great Lakes levels moving from near-record lows in the mid-1960's to record highs in the mid-1980's. Numerous studies have been conducted specifically with the intent of physically regulating the levels to stabilize mean lake elevations and dampen the fluctuations. The underlying societal objectives tied to regulation were primarily to maximize navigation uses and hydropower outputs, while minimizing flood, storm, and erosion damage to shoreline properties at higher lake levels and ensuring that recreational opportunities were not diminished as a consequence of extreme fluctuations.

During the past two decades of extreme fluctuations, climate change, i.e., the transition from one permanent state to another, was not considered a significant issue. Cyclical lake fluctuations were most often tied to sunspot cycles that somehow affected the decadal precipitation variability. The more important considerations during this period were how the natural resources of the Great Lakes could be most effectively managed in the face of increasing population growth and demands for water-dependent services, such as municipal and industrial water supply, power cooling water, navigation, hydropower production, recreation, and the improvement of fish and wildlife and water quality. This was the epoch of multiobjective, comprehensive river basin planning and management, one result of which was the Great Lakes Basin Framework Study published in 1976 by the U.S. Great Lakes Basin Commission (1976). Although the massive 25-volume study covered only the United States portion of the Great Lakes, many, if not most of the salient issues considered were common to both the U.S. and Canada, and comprise the core of issues that are yet to be resolved through U.S.-Canadian agreements and actions.

Currently, a joint U.S.-Canada comprehensive study is being conducted through the International Joint Commission to propose alternative solutions or measures that would aid the management (mitigation) of the adverse effects of fluctuating lake levels. This study is being carried out within the context of the many anticipated future demands on the natural resources of the Great Lakes. In between the two studies, there have been numerous Coastal Zone Management planning efforts by the eight states in the U.S. that border the Great Lakes and comparable efforts by the Canadian government. Also, an extensive study on the feasibility of an extended winter navigation season was undertaken by the U.S. Army Corps of Engineers, along with countless site- and project-specific studies for a variety of shore erosion, waste disposal, navigation improvement projects, and extensive water quality studies of the Great Lakes.

Thus, over the years, numerous comprehensive studies and countless volumes of data, analyses, plans, and impacts of alternative water resources management schemes that deal with the complex interactions of water resource uses have been conducted. The addition of one more factor, that of climate change uncertainty, should not cause unwarranted concern among planners and decision makers. Most water resources planning efforts inherently deal with the uncertainty of supply and demand. Clearly, if the worst possible climate change scenario were to materialize, according to the latest modeling results (Cohen, 1988); Croley and Hartmann, 1988; and Assel, 1988), current problems and resource use conflicts would be seriously exacerbated. However, the same mix and range of issues and consequences of not doing anything or failing to initiate sensible adaptive mechanisms would increase dramatically. The concern with recent historic fluctuating lake levels has prompted the resource management institutions and interest groups of the Great Lakes to move beyond "business as usual."

The populace and users of the Great Lakes natural resources have inherently contended with a broad range of resource use impacts in the past 20 years. These impacts could logically be expected to occur with greater frequency and certainty in the next 50 years, again, with or without climate change. The public has experienced the two extremes that are likely to define the context and constraints within which, at least most near-term adaptive strategies should fall. Uncertainties about climate change will, in all likelihood, not change the range of solutions and resource allocation tradeoffs that need to be made for careful management of those resources under the current variable climate regime. Thus, while an accurate projection of physical climate change consequences, in terms of precipitation, evaporation, temperature, and runoff, is not likely to materialize for at least 20 years, it is not essential for the purposes of policy analysis and resource management planning. We need only to be convinced of the certainty of this change and its direction. There are very few, if any, long-term climate consequences of resource uses that have not been encountered and considered in the contemporaneous cyclical lake fluctuations.

Evaluating the Consequences of Climate Change

Although the GCM models that are currently in use produce highly aggregated and gross predictions of precipitation and runoff, there is reason to believe that lake levels will continue to fluctuate in roughly the same cyclical fashion with a general slow decrease in mean lake levels. The variability may also increase, exceeding both the high and low record levels recorded to date. The GCM models show that under a global warming scenario some river basins draining into the Great Lakes receive much higher precipitation than under the current climate regime. This situation, then, may comprise the most likely scenario, along with several other reasonably likely climatic regimes. These alternative future scenarios constitute the "with" climate change future. Future social, economic, and environmental demands must also be forecast that are compatible with the physical consequences of those scenarios. For example, energy demands should not be projected to increase substantially with a scenario calling for increased warming in the Great Lakes region.

Similarly, a stable climate scenario, reflecting the historical record of fluctuations and extremes in temperature, precipitation, runoff, and lake levels must be developed to represent the "without" climate change conditions or status quo. Again, all the complementary future social, economic, and environmental needs must also be forecast to establish a comparative baseline. As a first step in the comparative evaluation process, the future "with" and "without" climate change scenarios should be compared pair-wise for each of the selected social, economic, and environmental indicators selected to represent the human-environmental interactions.

The establishment of a proper baseline or "without" climate change scenario is a key step in the evaluation of anticipated impacts. Impacts are measured as changes or differences between a benchmark state and some alternative state. In addition, we must realize that the baseline itself changes over time because so many factors are at work simultaneously. For example, while water quality standards for dissolved oxygen (DO) may be fixed, biochemical oxygen demand (BOD) loading is a function of recycling technologies, wastewater treatment practices, and water conservation measures. Water quality regulations and measures taken to reduce wastewater effluent can be expected to substantially improve the water quality of receiving water bodies, over an extended period of time. The impacts or consequences of climate change can be skewed or artificially magnified by assuming a "worst case" baseline, i.e., choosing a historical series of events or conditions that are extreme, and then simulating a "worst case" climate change scenario that will produce large impacts.

Figure 1 schematically portrays the difference in both the relative and absolute measures of a perturbation or effect and that of the impact. An effect can be measured as the relative difference (decrement) between the "with" and "without" climate change

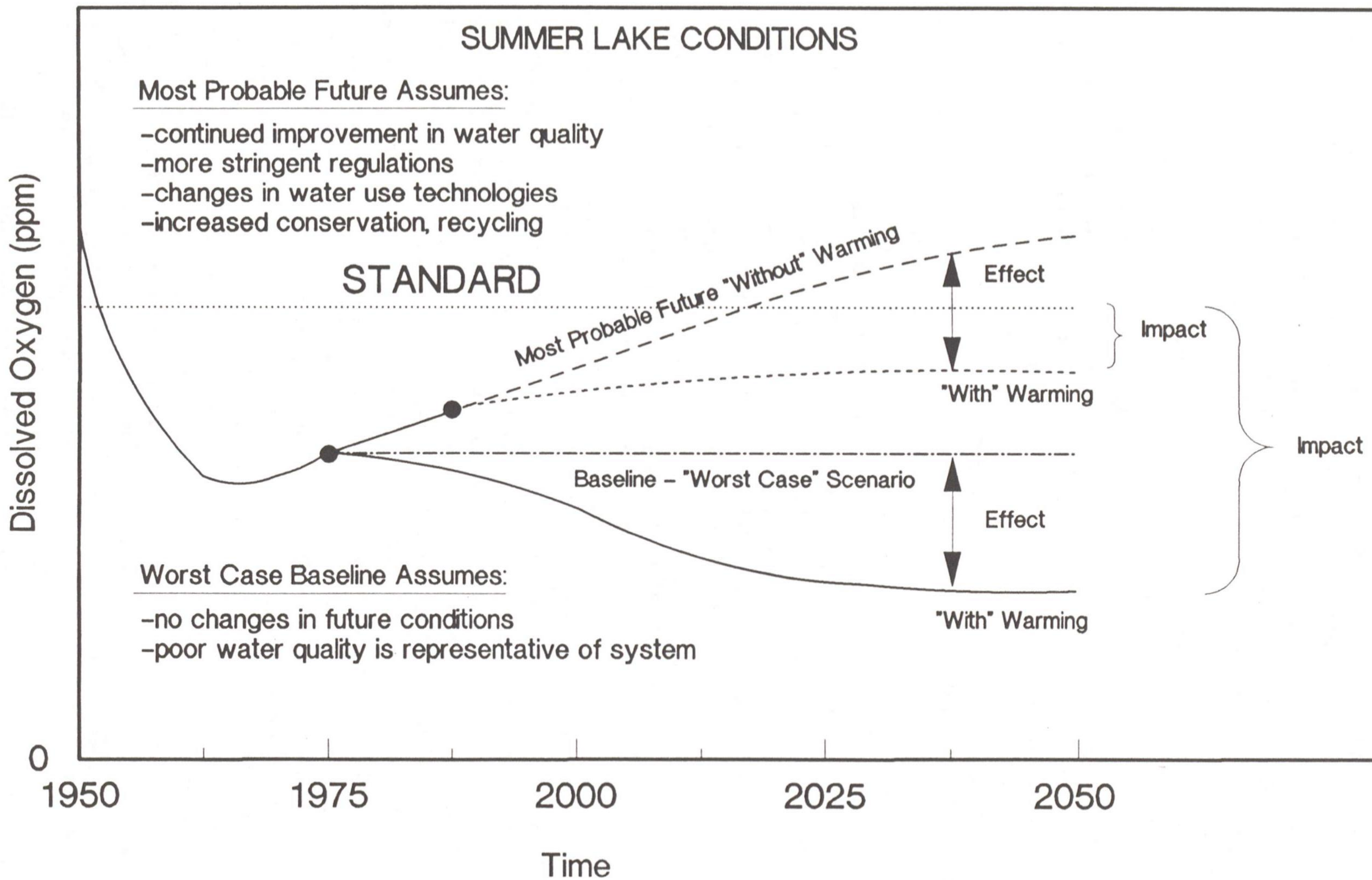

Figure 1. Alternative evaluation premises for predicting water quality consequences of global warming

scenario or as the absolute difference with respect to the common baseline, i.e., the water quality standard. In the case portrayed here, the effect or relative difference is equal for both approaches, but the absolute difference, or impact, can be very large. This simple figure shows how climate change analyses can be inadvertently skewed if care is not taken to correctly represent social adaptations that are continuously occurring, and are likely to continue into the foreseeable future as a consequence of the impetus generated by the current set of regulatory constraints and economic forces.

There are two basic causative climate factors that will separately affect different categories of resource use. First, global warming will cause mean seasonal temperature increases that are likely to reduce current energy demands. However, temperature increases will also result in greater water use and may result in lake thermal stratification regimes that slow down the long-term turnover rates, exacerbating water quality problems. Also, global warming is likely to increase precipitation and evaporation simultaneously, resulting in a long-term net decrease in runoff. However, the immediate ephemeral impacts of precipitation increases could result in increases in riverine flooding, and extreme storm events that exacerbate shoreline erosion. Therein lies the real quandary of adapting to the uncertainty in climate change. General policy and strategy development for human adaptation to climate change may be conducted with a relatively vague knowledge of the direction and consequences of climate change. These include priorities for resource allocation, emergency water management measures, water pricing, conservation measures, flood warning and evacuation, flood plain and coastal zoning, etc.

However, site-specific actions, such as designing flood protection levees, or reservoirs, or sizing an electric utility or water supply pumping station, require specific information about the likelihood, magnitude, and variability of both the resource availability under the selected climate scenarios as well as the future demand for the resources. The consideration of the sources of uncertainty is the essence of risk analysis. There are many accepted procedures for such project specific analysis under climate uncertainty.

In the past, the most difficult analysis in planning had to do with forecasting future demands on each of the resources rather than with uncertainties in supply. Climate change uncertainty merely adds another complex dimension to project scaling, i.e., picking the most efficient size. The choice of the effective alternative course of action (plan, project, site) should be less affected by climate uncertainty. Most demand forecasts are simple extrapolations of historical trends, without regard for resource constraints, prices, and technological innovation. Water supply is a classical example, where forecasted demands were uniformly and dramatically overestimated (Osborn *et al.*, 1986; U.S. Congress, 1980). The reality is that there exists, continuously in progress, a whole series of adaptive market-driven mechanisms along with policy and legislative mechanisms that allows society to adapt in an orderly manner. In fact, on a comparative basis, climate change and lake fluctuations allow for much more deliberate and thoughtful social adaptation than do sporadic tax and trade policies or monopolistic energy disruptions.

In fact, Figure 2 demonstrates how much variability there has been in numerous water use projections that were generated by respected water policy commissions and research institutions. Contemporary estimates for 1980 and 1985 by the U.S. Geological Survey (Foxworthy and Moody, 1985) are superimposed onto Figure 2 to show that current water use appears to be closely matching the rather conservative projection of the U.S. Water Resources Council (1978). Foxworthy and Moody (1985) show that water quality regulations were the most important factor in reducing industrial water use, accounting for the largest portion of the reduction in water withdrawals. This reduction was accomplished despite a doubling of manufacturing income between 1970 and 1980. "Many industries that used large amounts of process water simply increased the recycling of water in their plants to reduce the volume of waste discharges and the associated costs of treating the discharges."

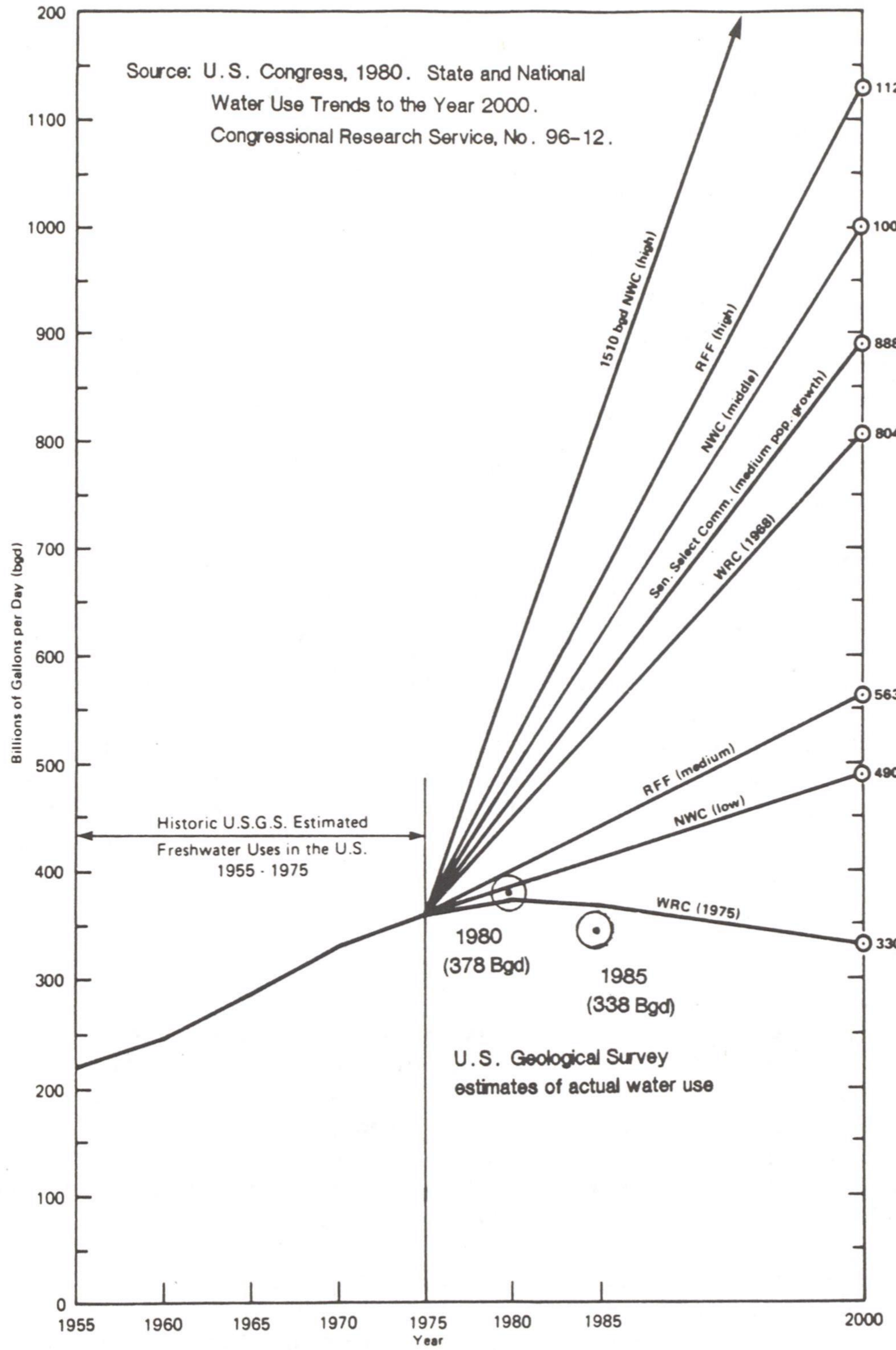

Figure 2. Historic and projected fresh water withdrawals, 1955-2000

Water resources management has been undergoing major changes and these changes will continue into the foreseeable future. In addition to the effect of Federal water quality regulations, Foxworthy and Moody (1985) summarize these changes as follows:

> These changes are driven by several factors: increasing water demands; a fixed but renewable resource base whose physical limit is being approached in some river basins; increased costs of expanding water-supply capacity; and a changing view of the Federal role in water-resources development. Several strategies appear to be emerging as a means of coping with these factors.
>
> - *Demand management*—use of water-conservation measures, water pricing, and withdrawal permits to match demands to available supplies.
> - *Supply management*—use of recycling and reuse of existing supplies, conjunctive use of surface and ground water, and the joint operation of individual water projects in a river basin as a system in order to increase the beneficial use of existing supplies.
> - *Water reallocation*—use of water markets, negotiated water transfers, and other voluntary transfers to set priorities for meeting competing water demands.

Once the supply and demand uncertainty and variability under each of the scenarios is plausibly projected to include the likely range of adaptive market mechanisms and regulatory controls, and the comparative evaluations are made, only then can alternative resource allocation and management strategies be examined with respect to their feasibility in mitigating the adverse consequences of climate change. The viability of each strategy, represented by selected indicators, is expressed as the difference between the "with" and "without" climate change scenarios. The purpose and challenge of planning and policy analysis is to formulate strategies, plans, and policies that are effective, efficient, and operationally robust, and resilient enough to fulfill all or most objectives across a broad range of circumstances (alternative scenarios). The key, however, in all planning and policy analysis is the necessity and ability to make the hard tradeoffs and resource allocation decisions under conditions of uncertainty. No interest group is willing to give up its share of the status quo under the presumption of future changes.

Implications

The perception of decision makers and water resource planners and managers about climate change and its potential adverse consequences is still a very cautious one (Riebsame, 1988; Ingram *et al.*, 1988). While concern is expressed, the predictions are too diffuse and ambiguous, and the impacts are too far off in the future for managers to commit their limited resources to solving future problems today. Nevertheless, substantial progress has been made in dealing with what are very similar problems to those that may be encountered under even the very worst postulated climate scenarios. This is accomplished through the normal approach of comprehensive planning studies and resolution of complex institutional issues.

The most effective studies and solutions to global warming and climate change are those that deal with *preventive measures* such as that which led to the international agreement on the control of ozone depletion. Other regulatory mechanisms in Canada and the United States that deal with emissions and air quality have been put in place in a more deliberate manner. Slower yet is the development of a comprehensive national energy use policy that could have the greatest beneficial impact on retarding global warming and its predicted adverse consequences on climate change and hydrologic deficiencies.

All that regional and local resource managers can do effectively is to develop *adaptive* and *mitigative* strategies that consist of minimizing social, economic, and environmental losses. Again, these adaptive strategies have been developed, analyzed, and evaluated repeatedly in the context of the "normal" climate regime, which by itself comprises a highly variable and hazardous state in terms of floods and droughts. From the perspective of an operating Federal water resources agency, such as the Corps of Engineers, there are other considerations that evolve from dealing with climate change uncertainty on a project-specific basis.

The U.S. Army Corps of Engineers is responsible for various aspects of a diverse water resources and coastal shoreline protection program. The Corps recognizes that its activities are likely to be affected by the hydrologic, meteorologic, and oceanographic consequences of global warming and expected climate changes. While the Corps has not taken a lead role in responding to this increasingly important hazard, it has been delving into the ramifications of these changes for some time now. Most of the Corps incremental modifications so far have dealt with its planning and design procedures which address the manner in which the Corps computes physical (hydrologic and hydraulic) changes and forecasts economic conditions. A primary change has been in the explicit introduction of risk analysis for the selection of an appropriate design basis for the various alternative plans and component projects whose primary purposes are to ameliorate hydrologic extremes and mitigate their social and economic consequences.

As yet, the Corps has not developed a focused and direct policy statement that emphasizes the importance of considering climate change either for existing water resources management projects or for the planning and design of new ones. Part of the reason resides in the comforting notion that many of the engineering profession's design criteria are already based on meteorologic and hydrologic *extremes* that are continuously being revised (generally upwards, towards more extreme events) as new data are recorded. This has been the case with the National Weather Service's periodic upward revisions of the Probable Maximum Precipitation (PMP) that, in turn, engenders updates of the design floods for flood control structures. Thus, a case can be made that a good deal of the anticipated climatic variability for the near-term has already been taken into account for existing projects through the Corps traditional, but highly reductionist and incremental approach to reality analysis.

Another reason for the absence of a clear policy is that the Corps is reluctant and indeed, unable, to use the relatively unrefined climate change predictions (especially on an intra-continental regional basis) as a justification for changing project design features or adjusting design standards. Furthermore, the Corps faces substantial difficulties in explaining and supporting those future probable events that comprise a climate change scenario as part of the series of forecasting activities that serve as the basis for evaluating alternative projects before a skeptical public influenced by stringent budgetary constraints. It may seem ironic that the very procedures which call for generating future scenarios and forecasts of population, economic growth, land use, and ecological trends often generate the most public controversy in water resources planning. The development of future scenarios called for by the U.S. Water Resources Council's *Principles and Guidelines* (WRC, 1983) often hold the key to whether a flood control project or shoreline protection is economically justified, by influencing how large it should be.

Finally, a policy directed at anticipating changes 50 years hence must take into account the reality of the effect that Federal economic decision rules have on public investment choices. Although the Corps generally plans for a 50-year project life, the effective economic return on a water resources project is heavily influenced by the discount rate. The Federal discount rate for water project economic analysis is nearly 9 percent, and is fixed by law. This means that most project benefits are realized within 10 years, and the

Corps effective project evaluation and decision horizon is less than 15 years. Thus, the discount rate has a far greater bearing on the choice and scale of an alternative project designed to mitigate the hazards of climate change than does the uncertainty surrounding supply and demand forecasts.

In summary, global climate change implications for quantifying meteorologic and consequent hydrologic changes have not been developed well enough for use by practicing water resources engineers. Consequently, the Corps of Engineers, like other Federal and state water resources agencies, is not in a position yet to develop a unified response to the threat of climate change and its water resources management implications. Nevertheless, the Corps has undertaken a series of changes and modest initiatives to some of the more important component parts of its planning, design, and management responsibilities.

First, both planning procedures and environmental impact statement guidelines call for the consideration of reasonably foreseeable future events as part of developing forecasting scenarios. Second, planning procedures require the development of alternative solutions to water resources problems that fulfill the forecasted needs in an economically efficient manner. Alternative solutions that are typically proposed consist of structural and nonstructural measures. These alternative measures undergo risk-cost analysis that could explicitly consider impacts of climate uncertainty, both for the magnitude and frequency of the hazard and for project benefits and costs. Nonstructural measures include emergency warning and evacuation plans, water conservation measures, reallocation of water, trading and selling water rights, floodplain management, and other nontraditional solutions.

Design standards also undergo risk analysis as part of structural project performance reliability analysis. Management of existing water resources projects calls for a system analysis approach and changes in operating rules, as decision making moves ever closer toward real-time operation. Traditionally, the focus of the Corps concerns has been on the high flow, flood control end of the hydrologic spectrum. Nevertheless, Corps flood control reservoir projects also provide a capability for dealing with low flow drought conditions, increasing the robustness and resiliency of the entire operating system. These systemic properties should continue to be exploited as future demands shift under climate uncertainty, particularly in meeting future urban water needs. The most threatening climate change scenario, which is quite likely to occur, is one where extreme flood events are more frequent and drought events are more persistent.

Matalas and Fiering (1977) concluded, and subsequently reinforced in a number of other papers on the subject, that "... it is comforting to recognize that most large systems contain so much buffering and redundancy that resilient design can be operationally achieved without resort to sophisticated or elaborate projections about climate." Several other comparative studies have shown that there is little discernible statistical difference in hydrologic models that reflect a stationary climate hypothesis versus those of a nonstationary climate, at least for long-term changes of the mean in precipitation and runoff of less than 20 percent (Klemes, 1985). Thus, public water resources agencies have effectively been conducting the design of large hydraulic structures and water control systems as if anticipating climate change. The design of smaller structures, such as urban drainage culverts and sewers, and local flood protection projects are more susceptible to changes in the variability of events, however.

Risk-Cost Effectiveness Analysis

Society cannot afford to build "*fail-safe*" projects anymore. It isn't economically efficient, either for water supply, flood control, or hurricane storm protection on coastal shorelines. Notwithstanding the Corps past history of a reliability-based analysis for extreme events, their design concept has increasingly become "*safe-fail.*" It is a strategy of designing flood protection for less than the extreme event of record. A structural measure (levee, channel) is complemented by emergency management plans that mitigate the damages of designed (i.e., safe-fail) failure of structural solutions. In other words, local and flood protection could conceivably be designed for a 20- to 50-year level of protection, as long as there is a complementary flood warning and evacuation plan. The complementary mechanisms represent an important contributing factor to the robustness and resiliency of water resources management systems, and are specially relevant to adaptation under climate uncertainty. The dichotomy between structural and nonstructural measures also serves to emphasize functional and conceptual differences between risk assessment and prediction of climate consequences from that of risk management. While hydrologists may not be able to explicitly factor in the anticipated variability of climate change, especially if they rely on empirical rather than causal models, water resources planners and engineers can implement a wide range of management measures that increase the robustness and resiliency of solutions that can operate under an anticipated range of climate uncertainty. Adaptive risk management includes measures for floods and droughts.

Among the measures that are actively considered by water resources planners (including engineers, economists, and social and environmental scientists) are the previously mentioned hazard mitigation measures that are employed when the hazard prevention measures (dams, levees, sea walls) fail. Also, many solutions address longer term and more permanent adjustments in the way in which society uses its water resources. Changes in water pricing will redistribute the demand toward more efficient uses of water and will induce the various sectors (e.g., agriculture, municipal, and industrial) to develop more efficient water-using methods. Water can also be reallocated by changes in water laws and reservoir operating criteria. Water resources management is becoming more efficient and effective, with greater reliance on a range of water conservation measures and a systemic water resources operations approach. All these changes increase the buffering capacity of the existing systems, i.e., its robustness (ability to absorb surprises) and resiliency (ability to recover from failure).

Anticipated Water Resources Problems

Notwithstanding this admittedly benign assessment of the near-term (10-20 years) ability of a regional water resources infrastructure to absorb most consequences of anticipated climate uncertainty, there are many user-specific and site-specific water resources needs that are currently stressed and where substantial shortfalls already exist. Little has been said also about the possible effects of climatic marginality (Wigley, 1985). This is the physical reality that a climate change scenario, i.e., a shift in the mean, would also be accompanied by extreme events that may occur more frequently and where the frequency might change substantially even from a rather small change in the mean. Areas that are currently in marginally productive agricultural zones would be most affected by the amplified cumulative impact of successive extremes (Wigley, 1985).

The Corps (Stockton and Boggess, 1979) study of the sensitivity of 18 river basins to climate change focused on water shortages rather than on floods. Stockton's work showed that even today, several river basins are operating near the upper limit of their potential yield (Table 1). The information in this table also shows that the estimates for total water supply requirements (withdrawals for industrial and municipal uses, including power cooling) can easily be met by the water resources of the Great Lakes Basin watersheds (United States drainage) for a warmer and drier climate scenario. These estimates are based on the U.S. Water Resources Council's forecasts for projected water withdrawals

TABLE 1

	Present Climatic State					Scenario 1 (warmer and drier)			Scenario 2 (cooler and wetter)		
Region	Estimated mean annual supply (bgd)[a]	Estimated mean annual requirement (bgd)[c]	requirement / supply	total storage / mean annual flow	Q_{05}/Q_{95} (streamflow)	Estimated mean annual supply (bgd)	total storage / mean annual flow	requirement[e] / supply	Estimated mean annual supply (bgd)	total storage / mean annual flow	requirement / supply
. New England	78.6	1.03	0.01	0.38	2.2	56.6	0.54	0.02	108.5	0.28	0.009
. Mid-Atlantic	81.0	3.54	0.04	0.48	2.4	53.5	0.73	0.07	115.0	0.34	0.03
. South Atlantic Gulf	232.5	10.05	0.04	0.39	2.9	148.8	0.42	0.07	339.5	0.19	0.03
. Great Lakes	75.3	4.69	0.06	0.27	2.3	50.5	0.41	0.09	103.2	0.20	0.04
. Ohio	179.0[b]	4.33	0.02	0.29	2.4	111.0	0.47	0.04	256.0	0.21	0.02
. Tennessee	41.1	1.11	0.03	0.75	1.9	25.9	1.20	0.04	56.7	0.55	0.02
. Upper Mississippi	114.0[b]	2.66	0.02	0.27	2.9	70.7	0.51	0.04	166.4	0.18	0.02
. Lower Mississippi	416.8[b]	5.51	0.01	0.05	3.7	291.8	0.09	0.02	571.0	0.03	0.009
. Souris-Red-Rainy	6.1	0.47	0.07	1.72	1.4	3.4	3.11	0.14	10.2	1.03	0.05
. Missouri	61.5	26.14	0.42	2.92	4.1	22.1	8.12	1.18	100.9	1.77	0.26
. Arkansas-White-Red	67.7	12.03	0.18	1.32	5.5	31.1	2.41	0.39	138.8	0.66	0.09
. Texas-Gulf	35.6	12.52	0.34	1.97	10.3	17.8	3.94	0.70	71.2	1.05	0.18
. Rio Grande	5.3	4.80	0.87	3.58	22.0	1.3	14.2	3.69	9.5	1.99	0.51
. Upper Colorado	13.9	11.75[d]	0.84	1.38	4.0	9.3	2.21	1.26	27.0	0.72	0.44
. Lower Colorado	8.3[b]	9.87	1.18	12.66	1.4	3.6	18.99	2.74	14.1	4.83	0.70
. Great Basin	13.9	4.37	0.31	0.51	3.8	7.6	0.93	0.57	25.3	0.29	0.17
. Pacific Northwest	286.5	17.28	0.06	0.40	1.9	171.8	0.62	0.10	386.6	0.28	0.04
. California	73.4	30.39	0.42	1.08	4.0	41.1	2.15	0.74	119.6	0.63	0.25

(a) assumes zero ground water overdraft
(b) inflow from upstream region included
(c) projected through the year 2000
(d) includes 6.70 bgd for downstream obligations
(e) assumes no increase in evapotranspiration rate from present climatic state

Source: Stockton, C. and Boggess, 1979. Geohydrological Implications of Climate Change on Water Resources Development. U.S. Army Institute for Water Resources. Unpublished Draft Report.

conducted as part of the second National Water Assessment (WRC, 1978). They show a decline in water withdrawals that is substantial by subsequent analysis of the U.S. Geological Survey. Figure 2 demonstrates how the numerous studies and forecasts of future water use have gradually decreased as resource availability has diminished and both market and nonmarket measures have served to impose a greater degree of water conservation.

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GLERL Activities: Abstract

Frank H. Quinn*

The Great Lakes Environmental Research Laboratory (GLERL) is an interdisciplinary laboratory of the National Oceanic and Atmospheric Administration located in Ann Arbor, Michigan. Its mission is to conduct research directed toward understanding the environmental processes and toward solving problems in resource management and environmental services in coastal and estuarine waters, with a special emphasis on the Great Lakes. The ultimate goal of the GLERL program is to understand the lake-land-atmosphere-sediment system to the extent that environmental simulation and prediction models can be built that will provide sufficiently precise information on Great Lakes and coastal and estuarine processes and phenomena to support enlightened use of the regions' resources.

As part of its research program the GLERL has been investigating the potential impacts of climate change on the Great Lakes region. Research to date has focused upon the impacts on lake levels and water quantity management, the Great Lakes ice cover, and the thermal structure of the lakes. This presentation addresses the water quantity aspects of the research. Conceptual model-based techniques have been developed for simulating moisture storages and runoff from the 121 watersheds draining into the Laurentian Great Lakes, over-lake precipitation into each lake, and the heat storages and evaporation from each lake. Each of these components is modeled separately and used in conjunction with operational regulation plans and hydraulic routing models of outlet and connecting channel flows to estimate water levels on Lakes Superior, Michigan, Huron, St. Clair, Erie, and Ontario. Integration of the models allows the consideration of climate change scenarios developed from atmospheric circulation models through linkages on air temperature, precipitation, humidity, wind speed, and cloud cover. Alternate scenarios are considered by abstracting changes in linkages, making these changes in historical data, observing the impact of the changed data in the model outputs, and comparing the changed data to model results using unchanged data.

As part of a major EPA study on the impacts of climate change, three steady-state climate change scenarios corresponding to atmospheric modeling of a doubling of CO_2 in the atmosphere were considered with the hydrologic models. They are compared to a steady-state simulation obtained with historical data representing an unchanged atmosphere. The study results should be received with caution, as they are, of course, dependent on the atmospheric circulation model output with large uncertainties and are only possibilities for a future with increased atmospheric CO_2 content.

The higher air temperatures under the $2xCO_2$ scenarios lead to higher overland evapotranspiration and lower runoff to the lakes, with earlier runoff peaks since snowpack is reduced up to 100 percent and the snow season is shortened by two to four weeks. This also results in more than a 50 percent reduction in available soil moisture. Water surface temperatures peak earlier on Lake Superior; since the climate becomes similar to present-day climates on the southern lakes, the lake temperature behaves similarly to present-day southern deep lakes. There are larger amounts of heat resident in the deep lakes throughout the year. As a result, buoyancy-driven turnovers of the water column do not occur many times on four of the six lakes. Currently, they occur twice-a-year on all lakes.

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Ice formation also will be greatly reduced over winter on the deep Great Lakes, and lake evaporation increases will occur on all lakes. The average steady-state lake levels are seen to drop between 0.5 to 1.3 meters for the GISS $2xCO_2$ climate scenario, drop 2 to 2.5 meters for the GFDL, and drop 0.5 to 1 meter for the OSU scenario. The Lake Ontario regulation plan fails in all steady-state and transient climate change analyses, reflecting its design for regulation of current ranges of Lake Ontario water levels and St. Lawrence Seaway flows.

The climate change effects, if they occur, will require new paradigms in water management in the Great Lakes Basin. Allocation conflicts between users of the Great Lakes will likely result. Lowered lake levels could produce large reductions in wetland areas and lower hydropower production. While reduced lake ice formation could lengthen the shipping season, lower lake levels could also increase waterborne shipping costs via lower vessel load limits, traffic backups at the Welland Canal and Sault Ste. Marie, and dredging of sediments highly contaminated with toxics. Dredging and disposal of toxic-contaminated harbor sediments may pose critical problems for municipal and private marinas and create conflicts between the many governments having jurisdiction over the lakes. To manage potential allocation conflicts, the Boundary Waters Treaty of 1909 may have to be modified to consider commercial, industrial, riparian, recreational, and ecological interests in addition to presently considered domestic and sanitary water supply, navigation, hydropower, and irrigation interests. The Lake Superior and Ontario regulation plans would probably have to be revised to handle persistently low water supplies.

No historical analog comparable to conditions suggested by the climate change scenarios exists to provide insight as to what the management response will be to a prolonged period of extremely low lake levels. During the relatively mild and short-term low levels of the mid-1960's, there was an increased emphasis on bringing additional water into the system, improved regulation, and on further systemwide water level regulations to counteract lake level lowerings that resulted from historical dredging and mining operations. A major thrust of water management under a warmer climate will probably be to keep water in the system. This will require extensive revision of the existing Lake Superior and Ontario regulation plans, as well as the possible regulation of Lakes Michigan-Huron and Erie. The existing regulation plans were not designed for the low net supplies expected with climate change and failed in the assessment simulations. The debate over interbasin diversions of water will also likely intensify. There will probably be demands to increase the amount of water brought into the Great Lakes through existing diversions into Lake Superior, as well as the consideration of new incoming diversions. In addition, efforts will likely be made to curtail the water diversion out of Lake Michigan at Chicago. Presently, an informal agreement, "The Great Lakes Charter," between governors and premiers in the Great Lakes region exists to forestall new diversions out of the Great Lakes basin. With probably increased demands for water from outside the basin, that agreement will require greater authority to remain effective.

Effects on Lake Erie Water Quality

Alan F. Blumberg and Dominic M. DiToro*

Simulations of the water quality in the Central Basin of Lake Erie with a coupled hydrodynamic and water quality model have been used to quantify the response of the system to possible global climate warming trends. It appears that no matter what the detailed changes of the lake stratification dynamics may be, climate warming will lead to a degradation in water quality. Losses of 1 mgl^{-1} of dissolved oxygen in the upper layers and losses of 1 to 2 mgl^{-1} in the lower layers can be expected. There will also be a concomitant increase in the area of the lake that is anoxic. Even for the historically oxygen-rich periods which occur during windy years, the impact of climate warming will be to produce a depletion in the dissolved oxygen levels.

An area averaged thermocline model constructed from the more general hydrodynamic equations of motion has been used to estimate the lake temperatures and thermocline variability as forced by surface heating and winds. The highly variable vertical turbulence mixing processes are parameterized by the use of a second-moment, turbulence closure submodel with no adjustments from previous applications to its requisite coefficients. Applications of the thermocline model succeed reasonably well in reproducing the physical behavior of the lake during two very different periods, 1970 and 1975. An already calibrated Lake Erie eutrophication model using the vertical mixing information emanating from the thermocline model formed the basis of the water quality analysis.

Climate scenarios from three different atmospheric general circulation models are used to drive the coupled thermocline/water quality model. The general circulation models estimate the equilibrium climate induced by a doubling of the atmospheric CO_2 concentration. All the models show global warming trends of 2.8 to 4.2°C in surface air temperature. While there is a need to improve the state-of-the-art in simulating equilibrium climatic change, the range of conditions used in this study encompasses a large part of the expected atmospheric response.

An analysis of the results from the coupled model forced by the climate warming scenarios and specifically designed sensitivity experiments suggest that there will be a significant decline in the lake's water quality. The decline is due to the expected warmer lake temperatures which increase the rate of bacterial activity in the hypolimnion waters and sediment enough to drive the system to lower dissolved oxygen levels independent of the depth at which the thermocline becomes established; that is, the dynamics of the lake stratification. These conclusions, it must be mentioned, apply to the Central Basin only. The Eastern Basin, being much deeper, and the Western Basin, being much shallower, are certain to have different responses to the climate warming.

In future efforts it may be possible to estimate the reductions in the total phosphorus loading that would be required to return the lake to its present conditions. However, simulations with the water quality model of five years or longer need to be made so that the long-term response of the sediment can be properly incorporated. These simulations, once conducted, can be analyzed to establish target loadings for phosphorus that would eliminate the anoxia in the Central Basin.

*HydraQual, Inc.

Climate Change Effects On Ontario's Water Quality

Jim Bishop*

Good afternoon, ladies and gentlemen. We have all listened with great interest to the speakers this morning. Most of you are considerably more aware than I am of atmospheric and climatological events concerning global warming and the potential impacts on the Great Lakes Basin. Speaking as a manager of water resources in the Province of Ontario, I have a great interest in any event that has such potential for affecting the quantity and quality of the water in the Great Lakes Basin. I am also impressed with the overall lack of agreement within the atmospheric scientific fraternity regarding the reality, or lack thereof, of climate change in the Great Lakes Basin.

Background on Ontario

Ontario is a water-rich area. We share four of the five Great Lakes with the United States, we share the common airshed over these lakes and over our province and states, and we have 250,000 inland lakes and 40,000-50,000 connecting channels of rivers. In fact, the number of inland lakes is so large that their combined surface area is equal to four or five more Lake Ontarios or one more Lake Superior.

The Ontario Ministry of Environment is committed to protecting these resources. We have been actively involved in various programs aimed at fighting acid rain, industrial discharges, and municipal pollution. The Ministry also has programs that monitor and curtail nonpoint sources of pollution (urban and rural), as well as ground water, drinking water, and biota programs that provide information on quality, quantity, and trends.

The Impact of Changing Climate

This newest threat is in addition to the other threats to our water resources. While the specifics are unclear at present, there is little doubt that climate change will affect many aspects of our environment: the amount and quality of our ground water, drinking water quality, municipal and industrial discharges as well as the runoff from farmland, and the quality and amount of receiving water in both inland lakes and the Great Lakes.

MOE Program

One of the consistent themes emerging from this conference so far is the need to develop and maintain monitoring and research programs that allow us to assess the sensitivity of water systems and to identify and prioritize the lakes, embayments, and rivers where changes in hydrological processes and in water demand are likely to cause serious problems.

At the Ministry of the Environment, we have many programs in place that can be used to accomplish this. These programs have been running for some time (some for as long as 25 years), and while they suffer the same problems as most data bases, I believe that they

***Water Resources Branch, Ontario Ministry of the Environment**

are among the most reliable, long-standing, and data-rich information bases in existence. Within the Ministry, we are in the process of integrating these data bases; however, this is not likely to be accomplished for at least five more years.

I would like to very briefly list some specific MOE monitoring programs.

- *Industrial Monitoring*—There are 400 direct dischargers and 14,000 indirect discharges. These are to be monitored on a regular basis for a wide range of parameters, as part of the monitoring regulation within the MISA program.
- *Municipalities*—There are about 400 sewage treatment plants, 93 of which are over 1-million-gallon-per-day plants. These will also be monitored under the MISA program.
- *Drinking Water*—Ontario has research programs, drinking water monitoring programs, and an optimization program which is aimed at ensuring that the 500 water treatment plants in Ontario are operated at peak efficiency. The monitoring program so far has produced about 600,000 data covering 48 water treatment plants (serving eight million residents of Ontario). The program monitors raw and treated water for 154 parameters including most organic and inorganic chemicals of concern.
- *River Monitoring*—There are 800 stations; these are monitored for up to 20 parameters.
- *Acid Rain*—In the acid rain program, there are aquatic, biogeochemical, and atmospheric studies aimed at determining current quality of water in the lakes, the water in the tributaries leading to the lakes, atmospheric quality including that of rainfall and snowfall, and the chemical content of interstitial water, as well as the forest cover in the study area. About 6,000 lakes have been sampled so far.
- *Biological Programs*—There are young-of-the-year fish programs; local, small fish programs; and a major sport fish program. About 120,000 fish have been monitored so far over the past 20 years. In general, these data indicate that levels of both organics and metals are decreasing throughout the Great Lakes and many of the inland lakes; however, there are numerous areas that are still of concern because of the levels of contaminants found in fish. It is safe to say, however, that there are more species available for safe human consumption today than there were in past years. These studies are supported by clam, algae, and other biota studies. We also do numerous bioassays and mutagenicity studies.
- *Great Lakes Monitoring*—There are numerous nearshore surveys that have been carried out for the past two decades and which have led us to the conclusion that Ontario has some areas of concern. As a consequence, the Remedial Action Plan (RAP) program was developed, and Ontario has played a major role in the development of the 17 RAPs within Ontario's borders.

The direction we have taken in Ontario is to base most of our decisions on a technically sound data foundation. It is clear that if climate change has an effect on the water resources of Ontario, we are in a reasonably good position to determine the impact by maintaining these monitoring programs.

If we consider that one of the main predicted outcomes of an increased temperature within the Great Lakes Basin is the reduction in the amount of receiving water available, then it is clear that the underlying principle of the MISA program and of the RAPs program—that of virtual elimination as opposed to the use of dilution—is a step in the right direction. This is good luck, rather than good management, since as far as I know, this decision was not influenced by information on climate change. It was a decision that was based on the common sense notion that toxic and persistent chemicals should not be present in the water in the first place, particularly if there is a proven technological fix that would enable the would-be discharger to remove it from its wastes *before* it becomes a problem.

Predicted Effects of Climate Change On Ontario's Water Quality

Climate change and its effects have been the subject of great controversy over the past months. I believe that part of the controversy stems from the dramatic—and even melodramatic—rhetoric that often accompanies some of the statements made by the scientific and political community in dealing with this topic. For example, the *Toronto Star* on June 28, 1988, quotes Norway's PM, Gro Harlem Brundtland as claiming that "The effect of climatic changes may be greater than any other challenge the world has faced except the threat of nuclear war." In an article around that same time, Hans Martin of Environment Canada claimed that acid rain has just been a "kindergarten" practice run for handling the far bigger global perils of greenhouse-effect heating and thinning of the high altitude ozone layer. He referred to the threat to life on earth as "scary," and said that the threats could not be tackled effectively with the "Mickey Mouse research budgets" that politicians had allotted for acid rain.

On the other hand, Kenneth Hare said that while the temperature could be boosted globally by as much as 4.5°C, one of the outcomes would be that the farmers would have to relearn their trade. They will have to learn to plant different varieties, use different field calendars, and so on, and he concluded by saying, "Given what's happening now in agriculture, I think farmers can take the greenhouse effect in their stride." Finally, there is a reference from the Saskatoon, Saskatchewan Magazine dated July 7, 1988, where a U.N. Food and Agriculture expert predicted that, as a result of the hotter climate, there would be no substantial change in global grains produced, but the producers and the type of food would be different. A background paper summarizing a recent U.S. National Academy of Sciences meeting indicated that Canada and the U.S.S.R. are two countries that may stand to *gain* from a global warming trend.

These quotations indicated there are some widely differing views on the relative impact of the global warming trend. I am not an atmospheric or climatic scientist, and so I think it best to proceed with caution. It is my belief that we need to gather all of the information we can, monitor the real condition of the air, the water, and the land, integrate the data, model it, and continue with international efforts such as today's meeting as we look for a solution together.

Regarding Ontario's water quality, the scenario proffered by most models calls for increased evaporation losses from the lakes under higher air temperatures and lake water temperatures, increased evapotransformation from vegetation and land sources, and decreased runoff from the land drainage area. There will be significant reductions in lake levels and in the flows of interconnecting channels. A warmer, drier climate could translate into greater water shortages and lower mean-lake levels.

Snow cover will not last as long. Many of these Great Lakes are expected to be ice-free for much of the year or even all of the year, so that year-round transportation may be possible. Ports like Churchill on Hudson's Bay would be expected to enjoy the increased shipping season. On the other hand, with lake levels down, the ships used on the Great Lakes will likely either have to carry lower loads or there will be increased dredging so that the draft of the boats will not result in running aground. The former would probably mean much more travel to deliver the same load and therefore increased costs. Some specific impacts include:

- Tourism
- Skiing and other winter activities will be curtailed. This will be offset by increased golfing, camping, etc.

- Decreased river flows will reduce Ontario's potential for generation of hydroelectric power. A two times CO_2 increase is estimated to result in a 4,000-megawatt-hour deficit in power production. Demands for electricity for air conditioning will increase. However, demands for power consumption for winter heating also will decrease. With increased demands for electricity, and limits on hydroelectric generation, clearly either fossil fuel or nuclear power generation will increase. Consequences of either alternative will be very significant from an environmental viewpoint. Conservation and alternative means of power generation are likely to increase as public issues.
- The growing season in southern Ontario could increase by 61 days. The timber line could move 100-150 kilometers north. Drier soils in southern Ontario may require a switch to different crops; this would be offset by a more viable northern Ontario agricultural base, such as soybeans, corn, wheat, and other grains that currently are not viable in this area.
- In forestry, there would be increased litter breakdown and release of nutrients, as well as warmer temperatures that could stimulate tree growth (increased CO_2 would also assist). However, increased droughts and higher temperatures would also affect forest diversity, patterns, and frequency.
- With less runoff, there is likely to be less fertilizer and pesticide runoff in the spring. However, if the season is lengthened, and there are two applications per year and three tillings per year, the amount of runoff material may increase even with lower water runoff.
- Warmer water temperatures and lower lake levels could lead to deeper thermoclines and to greater metabolism of aquatic organisms. Higher rates of production of algae and bacteria could be anticipated, with subsequent mobilization of metals from sediments, recycling of nutrients, and increased decomposition and dissolved oxygen.
- Impact on fisheries—fisheries production would increase, but cold water species would decrease.
- With decreased river flows, the amount of sediment movement would decrease, and therefore cover-up of spilled materials such as mercury would be slower, and the systems would recover more slowly.

Specific Drinking Water Impacts

1. "Elevated" intakes would be more exposed to internal seiche influences—algae-rich epilimnial water fluctuating with nutrient-rich hypolimnial water with greater frequency.
2. Potential for more algae blooms and associated taste and odour occurrences, filter clogging with attendant operational problems in treatment.
3. Possibility, particularly in northern Ontario, of warmer temperatures leading to easier water treatment (less viscosity, chemical reaction faster, etc.) and thus to more economical designs.
4. On the other hand, a drier climate means less dilution effect for the coloured waters draining to the Great Lakes and therefore treatment in southern Ontario might be more difficult.
5. High algae blooms leading to higher pH's and greater difficulty of treating with alum (aluminum residuals higher with attendant postflocculation problems).
6. With more surface water problems, a potential switch to greater ground water use is possible; ground water can be affected by acid rain from pH and aluminum availability aspects.

7. Drier climate leads to less runoff, and
   - fewer pesticides in surface waters;
   - lower sediment/turbidity;
   - fewer storm sewer overflows—higher raw water qualities.

All in all, one can foresee a greater opportunity for confrontation between state and provincial water control agencies and between these agencies and the municipalities within their jurisdictions. In general, the municipalities appear to regard the lakes as an infinite resource, and, as has been the case with municipalities requesting larger and larger intakes to compensate for the potential lowering of lake levels due to climate change, there is likely to be more confrontation with state and provincial regulatory agencies.

Similarly, the issue of water diversions between Canada and the U.S. is likely to become a hotter topic as droughts become more frequent and more intense in the American south and southwest. This will increase the probability of confrontation, not just between Canada and the U.S., but between the U.S. Great Lakes states and their southwest U.S. counterparts, and likely between Ontario and the prairie provinces.

Comments on Report of Panel C Findings

AUDIENCE MEMBER: One of the things you refer to is regulation of Lake Ontario. What are the implications for the St. Lawrence River?

MR. CLAMEN: That's a very important topic. Our IJC reference study shows fluctuating water levels hopefully will extend the basin rate right down to the Gulf of St. Lawrence, in terms of its impa ct. There are impacts of the projects as far away as the Gulf of St. Lawrence. They need to be considered.

AUDIENCE MEMBER: You mentioned the data base needs, and I was wondering if besides the physical data, you also talked about other kinds of data such as consumptive use?

MR. CLAMEN: I forgot to mention that. It is most important because we felt that there is not presently a very good data base on water uses.

Report of the Panel on Agriculture, Forestry, and Urban Land Use*

Introduction

This panel began with a set of four scientific presentations. One addressed forestry management issues related to climate change; another concerned the sensitivities of certain agroclimatically fragile Great Lakes production systems such as fruit growing; and two others addressed the response of major Midwestern crops to different kinds of projected future climate scenarios. These were followed by a discussion, and from these the panel identified pressing climate change issues that need to be addressed in agriculture, forestry, and urban land use. The issues and their recommendations are treated together.

Issues and Recommendations

Competition for Resources. Climate change will heighten the competition for scarce resources; for example, for land, water, and most other environmental resources. Agriculture in the Midwest will likely require more water, including the possibility that the Great Lakes could become a source of water for irrigation. In this connection, water allocation was identified as one of the major issues that may arise.

Continued urbanization around the Great Lakes, which will likely occur whether climate change occurs or not, will tighten the competition for land. Urban land use may compete with agricultural land use, and cropped agriculture may compete with forestry.

The panel identified recommendations for how to address these issues and thereby increase understanding of these issues. A bilateral integrated assessment of resources that are critical to forestry, agriculture, and urban land use is recommended. Many existing inventories of natural resources have been done with an assumption of a stable climate. It is now time to take stock of soils, water, terrain, and other components of the natural resource base in light of effects of rapid climate changes. We should also assess changing economic resources such as infrastructure and location with respect to markets.

The panel also recommended a bilateral assessment of the agricultural potential in the Great Lakes Basin. As climate change occurs, some lands might become more productive and some might become less productive. We need to assess the physical, biological, and economic limits of agricultural production under different scenarios of climate change. We need to do the same assessment for forestry.

Coping Strategies are Essential. Studies of how society might cope with or adapt to climatic change need to begin. As climate change becomes more apparent to economic agents such as farmers, and resource managers such as foresters and hydrologists, there will be attempts to adjust production technologies to try to offset the negative effects of the changes.

We recommend studies of types of adjustments to existing operations and to existing technologies. An example would be crop varieties that might be used in place of the ones that are being affected or impacted. Studies are needed which show the potential for research to develop new coping strategies such as more efficient irrigation and genetically

***Presented by William Easterling, Panel Rapporteur**

altered crop strains. The panel further recommended studies of how weather information is being used in management and decision making today and what might be done to improve its use in the future.

High Uncertainty and Changing Risks. A major issue is the uncertainty over changing risks associated with climatic change. Uncertainty is high about what the climate will do, and what the impacts of that climate change might be. The panel is very concerned that the current impact studies not be identified as forecasts, but rather as a means of reducing the number of surprises that may be in store for society by considering as many alternatives as possible.

The recommendations include the study of possible changes in short-term risks due to climate change. There is little understanding of the minimum level of risk in current agriculture and forestry with respect to shorter-term variations in climate. Better understanding of how farmers and foresters currently incorporate climatic risk into their decision making is an important first step to gain better understanding of the ways that the risks posed by climatic changes will be dealt with.

We need research to know how these risks are changing as the climate changes. We presumably know the first step—that it is important to look at short-term variations, but how might those short-term variations change with changing climate? We need to have more precise information from the climate models about the variability in climate.

Communicating Climate Information. The fourth cross-cutting issue identified concerned communication about knowledge of climate change to the general population and the impacted sectors. Critical to addressing the issue is to share research among scientists; research sharing across the border has not been good. We recommend that there be formal exchanges, joint research, joint access to common data bases, and centers developed for interdisciplinary research.

The Past as a Guide to the Future. There is no guarantee that the past will be a good guide to the future in assessing the possible effects of climate change on the Great Lakes agriculture, urban land use, or forestry. The rate of future climatic change could be greater than any of human experience. Moreover, our social and economic systems are undergoing enormous and rapid changes, many of which are unprecedented. In short, our climate, economy, and society 50 to 75 years hence are likely to have no known historical analog. All of this makes it impossible to use the past to simulate the future.

We recommend that studies be undertaken to create base line scenarios of future Great Lakes agriculture, forestry, and urban land use to be templates against which to measure the possible effects of future climatic change. We should not be caught in the dilemma of trying to estimate future climate changes and then impose those changes on today's society and economy.

Sensitivities to Climate Change. Scientific consensus is emerging that future climate changes create problems for agriculture, forestry, and urban land use. Hence it is important to understand the basic underlying present climate sensitivities of these sectors. Our present understanding of the climate sensitivities of those sectors is quite limited. What are the critical thresholds of climate sensitivity that if exceeded by climate change will leave little doubt as to the effects on these sectors? What are the characteristics of climate change that will be most difficult to deal with? We do not know.

We recommend that research attempt to identify aspects of Great Lakes climate variability which are relevant to agriculture, forestry, and urban land use. The climate models do not always yield information needed to assess impacts. We need to know and be able to tell the climate modelers exactly what the thresholds of sensitivity are to climate variation to guide their work. For example, in agriculture it may be more important to have some idea of expected changes in the probable occurrence of extreme events, such as heat waves and droughts, than of expected changes in mean temperature or precipitation.

Impact on Forestry in Central Canada

S. C. Zoltai*

It is widely accepted that the accumulation of carbon dioxide and other 'greenhouse' gases in the atmosphere will result in a progressive change in climate. At northern latitude this would result in a climate that is warmer and somewhat moister than at present, causing a generally northward displacement of vegetation zones. Conditions would allow the establishment of boreal forests several hundreds of kilometres north of their present occurrence. Conversely, conditions will not be favourable for trees now present in the southern portion of the boreal forest.

We do not know with absolute certainty that the predicted changes will indeed occur, or what form they will take. Nevertheless, we should be prepared to evaluate the expected conditions to adapt to the changes. Forestry, by its very nature, involves long range planning. A tree planted today will not be harvested for many decades. The tree will experience a progressively changing climate that will affect its growth and create hazards for its success. This will pose a unique, unprecedented challenge for the scientist, manager, and policy maker.

Projections

The anticipated climatic change is projected to result in a gradual rise in the mean annual temperature, reaching temperatures 2-3° higher than at present by the middle of the next century. Precipitation predictions are uncertain; however, if the precipitation regime remains the same, higher summer temperatures will result in higher evapotranspiration and less available moisture for plant growth.

The consequence of such change will be gradual northward movement of ecologically effective climate. Conditions now prevalent at any location will shift northward by some 300-400 km by 2050. The response of the natural vegetation will be much slower, especially in occupying new ecological niches, due to limitations imposed by seed dispersal. Already established plants growing in increasingly less favourable conditions will cease to reproduce successfully, will have reduced vigour, and may fall prey to insects or diseases. Wildfire is seen as a major vehicle of destruction of vegetation no longer suited to the climatic regime.

The Challenge

Forest Science

The progressive climate change will affect all aspects of the science of growing trees. Given a reasonable climatic scenario, we can predict the shift in climatic conditions. However, we need to know how different species and plant communities react to the changes. Reproduction success, growth, vigour, and competition will change during the life of a stand. We do not know how well different species or combinations of species react to such changes.

To a certain extent, we can get guidance from past climatic changes, although the expected change will be at an unprecedented scale. Through dendrochronological

***Canadian Forestry Service, Northern Forestry Centre**

studies we can get some idea of growth change in response to climatic fluctuations. Pollen studies can give an idea on the composition of the natural forest in response to past climatic changes. Study of peat and lacustrine sediments can shed light on soil hydrology during changing climatic regimes.

Computer modelling of risks posed by climatic change is another promising field of study. Increased risks of forest losses by fire, insects, and diseases under various climatic scenarios may be predicted, with estimates of possible losses.

Identification of species or special strains that are tolerant of the expected changed climate within the life of the trees is seen as a possible adaptation to the changes. Another option is the identification of commercially desirable tree species that can be grown on a short rotation basis to minimize the effect of the changing climate during the life of the stand.

Forest Management

The changing conditions will necessitate a flexibility in forest management to adapt to and take advantage of the changing conditions. In a given area, some traditionally successful species may have to be replaced by another species. Forestry may be practiced in the north, in areas that previously were unproductive forests. Initiative should be taken to plant or seed a tree crop that will be successful not only under the prevailing climate, but will continue to thrive under the changed conditions. In some areas fire frequency may be expected to be so high that the trees will have virtually no chance of growing to a mature age.

There will be practical problems to overcome. The use of winter roads to remove the timber may no longer be possible. Traditional winter logging operations may be in jeopardy, and new technology would have to be developed to harvest trees under unfrozen, soft ground conditions.

The forest manager will have to ensure that the proper species mix is produced to meet the needs of the mill. This may entail longer distances to the mill, unless the processing facility can be moved closer to the resource. Forest nurseries will have to be prepared to grow new species or new phenotypes. In some cases nurseries may have to be established closer to the areas of expected demand.

Forest Policy

Forest policy makers will face changing socio-economic conditions imposed by the changing climate. In the Great Lakes area some of the southern areas may no longer be suited to boreal species, and more emphasis may have to be placed on hardwoods. Other areas, especially in the west, will face increased fire hazard. A decision would have to be made as to whether to protect forests that are no longer suited to the climate.

Some northern areas that were only marginally suitable for agriculture may become prime farmland. This will introduce land use conflict between competing uses of land. Expansion of forestry into the hitherto unutilized, peat-covered Hudson Bay Lowlands will become an attractive alternative.

The relationship of forests, wildlife, and recreation will need to be examined, as regional emphasis may shift in response to the changing climate.

Canadian Forestry Service

The Canadian Forestry Service is meeting the challenge of a changing climate on several fronts. At the September 1988 meeting of the Canada Council of Forestry Ministers the problems posed by climate changes was discussed at length and its seriousness was recognized.

The CFS is in the process of developing a strategy for dealing with the effects of climatic change. The major areas of impacts have been identified, and a plan of action is being formulated. There is much already available knowledge that could be evaluated to make prognostications and suggest management actions. At the same time, studies are needed to sharpen the initial evaluations by filling knowledge gaps.

Some projects related to climatic change are already under way. The forest decline prevalent in eastern Canada has been shown to be related to climate. The rate of growth in trees, reflecting past and current climatic trends, is being examined. The present ecoclimatic regions of Canada have been described. This map could be used as a framework for the evaluation of climate change on a geographic basis. A model has been developed to assess the implications of climate change in the boreal forest in the Prairie Provinces.

Summary

The changing climate, if and when it comes, presents a challenge for the forestry community. Traditional practices must change to adapt to and take advantage of the changed conditions. Flexibility, based on informed projections, appears to hold a promise of success.

Implications of Climate Change for Agriculture and Land Use

Barry Smit*

Introduction

This paper is based upon a review of rapidly growing but still sparse literature on the impacts of climate change for human activities. It focuses on the impacts upon agriculture in the Great Lakes Basin of changes associated with the expected climatic warming resulting from the so-called "greenhouse effect." Agri-food has been identified as a sector likely to be especially sensitive to the expected long-term climatic change (Maunder and Ausubel, 1985; Postel, 1986; Schneider, 1977; Warrick and Riebsame, 1981). The paper also makes some brief observations about implications for forestry and urban land use. Given the limited amount of research relating specifically to this region, considerable generalization and interpolation has been undertaken to draw conclusions about the potential impacts of climate change in the Great Lakes Basin.

The Greenhouse Effect and Agroclimate

Much of the research on the impacts of climate change has taken as a starting point climatic scenarios associated with a doubling of atmospheric carbon dioxide, or the equivalent in carbon dioxide combined with other infrared absorbing gases. Many of the scenarios are generated by global-scale general circulation models, from which changes in climatic characteristics for subcontinental regions such as the Great Lakes Basin are rather difficult to derive (Cohen, 1986; Gates, 1985). Furthermore, we must acknowledge the considerable uncertainty surrounding the atmospheric response at any scale. While some agreement exists amongst climate modellers regarding the broad nature and direction of climate change under the greenhouse effect, there is very little confidence as to the speed of such changes, the regional configuration of shifts in climate, and the variability about changes in the norms.

Research suggests that under the greenhouse effect the Great Lakes Basin, like many other parts of North America, would experience increases in temperature, increases in the length of the growing season or the frost-free period, and increases in precipitation (Hengeveld and Street, 1985; Land Evaluation Group, 1985; Smit *et al.*, 1988). Evapotranspiration would also be increased likely resulting in many areas experiencing reductions in plant available moisture. Thus, overall the altered climate would be characterized by longer, warmer, and drier growing conditions. In crude terms, we might say that the climate for a specific location may come to resemble that which currently exists in a region several hundred miles to the south of it. Or looking at it another way, and recognizing that climate varies from year to year, we might speculate that the recent experience with hot dry years is indicative of what could be expected under a greenhouse effect. Undoubtedly, years with longer hot dry spells are likely to become more frequent.

In addition to the effect on agroclimatic properties, other impacts could result directly from changes in the chemical composition of the atmosphere. For example, increases in

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atmospheric carbon dioxide are likely to have direct bearing on plant growth (Ausubel, 1983; Kimball, 1983; Lemon, 1983; Rogers *et al.*, 1983; Rosenberg, 1981). Similarly, changes in low level ozone are known to have impacts on certain crops (Bennet *et al.*, 1974; Heck *et al.*, 1983; Weaver and Jackson, 1968), and the consequences from acid rain are also becoming increasingly understood (Irving, 1983; Ludlow and Smit, 1987).

Implications for Agricultural Production

Much of the research relating to impacts on agriculture has considered the prospect for crop growth under changed agroclimatic conditions. In the northern areas of the Great Lakes Basin (Northern Ontario, Northern Michigan, Wisconsin, and Minnesota) the climate is expected to become more favourable for agriculture due largely to the increased temperatures and length of the growing season. Increased yields can be expected for many of the forages and cereal grains already grown in these areas and other crops which presently are not viable, such as grain corn and soybeans, may be grown successfully. In the more southern parts of the region (Southwestern Ontario, Southern Michigan, Wisconsin, and New York State) the yields of many of the crops currently grown are likely to be reduced due to the expected deficits in available moisture coupled with temperature increases that exceed the optimum levels for plant growth. Without appropriate adjustments the losses to the agricultural system could be massive (Land Evaluation Group, 1985). Of course, soil conditions and local topography will influence the sensitivity of crop growth to changes in climate in all areas. The soil-related limitations to agriculture in the northern areas are likely to remain.

While many studies note the risks to agriculture of change in climate, opportunities may also accrue from the greenhouse effect. In the Great Lakes Basin higher yielding cultivars may become viable under the longer growing season. Expanded opportunities for horticultural crops are likely to arise. The expansion of the frost-free period and a reduction in the extreme winter temperatures are likely to extend the range of apples and tender fruits (Land Evaluation Group, 1986). Even the negative impacts of moisture stress may be offset by growth enhancement associated with an enriched carbon dioxide atmosphere. Research has shown that certain plants (e.g., oats, barley, rye, wheat, soybeans, potatoes) are likely to increase their photosynthetic rate and decrease the amount of water they lose under a CO_2-enriched atmosphere (Ausubel, 1983; Harrison, 1984; Kimball, 1983).

Uncertainty and Risk

Before concluding that climate change might be as beneficial for agriculture in the Great Lakes Basin as it is detrimental, we should consider the issue of uncertainty which is often stressed in the literature. Uncertainty relates to the nature of the climate change itself, to the response of biological systems, and to the human and management adjustments. Although studies often assume a $2XCO_2$ scenario, the climatic response to changes in the chemical composition of the atmosphere up to $2XCO_2$ and beyond can never be known with confidence. Whether or not there are certain thresholds at which sudden and dramatic changes in climate may occur is unknown. Unfortunately we cannot conduct a true experiment on this process: there is only one globe—we are the experiments.

A second major area of uncertainty involves the biological response to changes in climate. For example, elevated CO_2 could affect the timing of phenological events such as flowering in certain species, or affect root development which might increase the vulnerability to hazards such as prolonged drought (Rosenberg, 1981), occurrences which can be expected under climate change. Other results have shown that the food quality in some plant tissues declines as atmospheric CO_2 increases (Strain and Cure, 1985). The effects of climate change on insect populations and weeds are also largely unknown (Harrison, 1984; Strain and Cure, 1985).

Notwithstanding these uncertainties in atmospheric and biological systems, agriculture must operate within a climate which will vary from year to year regardless of the norms. The vulnerability of agriculture to extreme variation in temperature and precipitation is well illustrated whenever we experience a so-called 'abnormally dry' or 'abnormally wet' year. Such years are 'abnormal' only in that they are not likely to be as frequent as the 'normal' conditions, but it is certain that we will experience some kind of deviation from the 'average' climate almost every year. Variability from year to year is a fact of climate.

Deviations in climatic conditions from average conditions can have significant implications for crop growers, farm viability, regional and national food production, and international trade. Under a greenhouse effect it is possible for changes in both average climate and variation about the average to occur. There may well be greater opportunities for production, but there is also likely to be greater risk of failure. The risk of failure is enhanced if decisions in agriculture are made on the assumption that favourable atmospheric conditions of the recent past will continue into the future. The belief (hope?) that drought years are an extremely rare event, and therefore should be ignored in planning for agriculture, is dangerous enough under current conditions; it has potential for disaster under conditions where hot, dry years are likely to become even more frequent.

Farm Management Options

In many respects agriculture is in a particularly advantageous position to adapt to changes in climate, because agricultural production systems largely operate on annual cycles. Of course livestock, tree fruit production, and other systems do operate on a longer cycle, and fixed capital and infrastructure in agriculture also reduce adaptability. There are, however, numerous ways in which farm managers may reduce their risk to climate change and enhance their prospects of benefiting from some of the opportunities which may arise. For example, irrigation might be considered to combat problems associated with moisture deficiency, especially if this is combined with the introduction of more valuable crops. Farmers could check to see which crops may become viable for their location and soils under a changed climatic regime. In the crop development area there may well be a market for hybrids which utilize the warmer growing conditions and longer season, and yet are resistant to dry spells. Farmers might also be encouraged to diversify their production system in order to reduce their vulnerability to changing and variable climatic conditions.

Implications for Regions and Governments

Under a greenhouse effect we can expect some gradual changes in the regional patterns of agricultural production, either by conscious decision or by repeated losses forcing bankruptcy and turnover in operators. In general terms we might envisage a shift northward in the traditional patterns of agricultural land use. Such changes are likely to have repercussions for regional economies as processing operations, supply services, and even trading patterns may change in response to these shifts in production. The implications for governments have not been fully explored. One possible government response involves actions to encourage adaption to climate change or the mitigation of its effects. Examples of adaptive strategies include the development of hybrids better suited to new conditions, public agency demonstrations of production opportunities, and public agency encouragement either to adjust to more appropriate food production practices or to diversify production to reduce vulnerability. Simply informing public and private agencies of the existing knowledge regardidng climate change and its implications is a type of mitigative action.

Of course, it can be strongly argued that the most important government option should be working towards preventing further change in the atmosphere because the consequences of such actions are so uncertain.

Other Land Uses

Although this paper concentrates on the impacts of climate change upon agriculture, it is worthwhile to briefly touch upon the impacts on forestry and urban land use. In some ways the forest sector is likely to be even more sensitive to climate change than agriculture because the longer growth cycle of trees means there is less opportunity to adapt to changes. Yet there has probably been less research into the impacts of climate change upon forestry than there has been for agriculture. The longer plant harvest cycle and the greater sensitivity implies an urgent need to plan ahead in the case of forestry. The unprecedented speed of climate change predicted under the greenhouse effect becomes an important factor since species which do not have time to adapt or relocate could be threatened (Peters, 1988; Solomon, 1986; Woodwell, 1988).

Generally it is expected that the forest viability zones will move northward. Specific concerns which have been noted relate to possible increases in tree pests and disease (Solomon, 1986; Winget, 1988), in fire (Hoffman, 1984; Pollard, 1985), and in difficulty in harvesting in mild winters (Pollard, 1985; Stocks, 1985).

For urban land-use activities impacts of climate change relate to water supply and quality, to air quality, and to energy demands (Cohen, 1988; DPA Group, Inc., 1985). Implications for water are particularly important in the Great Lakes Basin. Increased demand for water for urban and industrial uses could well be competing with demands for irrigated agriculture, all at a time when the net water supplies in the basin might well be down. Thus, it is quite likely that a greenhouse effect will increase demands on a decreased water supply.

Conclusions

Despite a recent flurry of research on impacts of climate change, our knowledge of its implications for agriculture and other uses in the Great Lakes Basin is limited. Climate change would likely impose constraints on certain types of agriculture, but it will also offer opportunities for expanding and diversifying production where adaptation is feasible. The overrididng concern is the great uncertainty associated with climate change and its impacts and the significant risks associated with this uncertainty. I would argue that two types of action are required. The first is that serious attempts should be made to reduce chemical damage to the atmosphere. The second is that we should plan for climate change so that we won't be surprised by an increased frequency of dry years if an increased likelihood of droughty conditions over the next decades is suspected. We would be foolish indeed to conduct our agriculture and forestry activities under the assumption that such years are very rare aberrations and are unlikely to occur again soon.

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Climate and Agriculture: Case of the Fruit Belt in Lower Michigan

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One unique climatic and agricultural aspect about the Great Lakes area is why do we have a fruit belt, a highly productive, very cost effective program, this far north? It is located in this area only because of the Great Lakes and their sizable influence on the climate of the basin. Climates in Michigan, Wisconsin, Ohio, New York, and parts of Canada are affected, but I am going to focus on Michigan conditions as a good example of the ameliorated climate of the Great Lakes Basin (Strommen, 1971; Phillips and McCullock, 1972).

An important aspect to focus on is the effect of the Great Lakes on temperature. This effect is realized in many ways including the length of growing season, a critical factor for all agricultural crops. In the past and through trial and error, different types of agriculture have developed across Michigan as a result of adaptation to the climate and its reliability. An area in one part of the state may have an average growing season of 70 days, but an area just a few miles away has 140 days as average. This relates to great differences in the temperatures due to lake influences.

Expansion of the growing season is reflected in both the spring and fall in terms of temperatures that occur for the first and last freeze. The lake temperature and the air differences are very important in determining the length of the growing season in all parts of Michigan. In the winter the temperatures are warmer on the lee side of the lake. This allows the maturity of some late crops. It is also colder in the spring, which retards the bud development until after the occurrence of the last freeze. This helps determine the type of agriculture.

The lake affects temperature extremes—when it's 15° below zero in Milwaukee, it's only 10° above in Michigan. This type of moderation of temperature extremes makes it possible to grow temperature-sensitive fruit trees in lower Michigan.

Analysis of all the snow events in western lower Michigan from 1965-1971 revealed lake effects under certain conditions (Strommen, 1975). If the lake and land temperature differences are about 15°, lake-effect snow development does not occur. Most of the snow events occur with differentials between the surface of the lake temperature and the 850 mb air temperature above 15°C. The frequency of occurrence of 4-inch lake-related snowstorms also increases as the temperature difference increases. However, in terms of 8-inch snows, these do not increase with the differential in temperatures.

The spatial distribution of lake-effect snows varies seasonally. Early in the spring and the fall the axis of maximum snow moves inland from the lakeshore. In midwinter, the axis shifts closer to the lakeshore (Strommen, 1969). There are two things driving the shift in the axis: 1) the speed of the winds in the upper levels, and 2) the magnitude of the differential in the temperature between the lake water surface and the air moving over it. If you have the same wind speed and increase temperature difference, you find the axis moves toward the lakeshore. If it is lower, it moves back inland.

A third area of lake influence on climate, and in turn on agriculture, relates to the effect on winter precipitation. This in turn determines the spatial differential in the

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frequency and intensity of droughts (Strommen *et al.*, 1969). The western part of lower Michigan has a lower frequency of droughts and a lower intensity (i.e., it does not reach the drought extremes found further away from the lake in the interior parts of the state). The distribution of lake-effect snows affects the distribution of soil moisture, and this in part contributes to the lower frequency of the drought along the west side (lee of Lake Michigan).

The lakes also affect the frequency of convective storms. In the spring, thunderstorm systems in the Midwest die out as they cross the Great Lakes' cold surfaces. Hail does not occur in the western part of the state in the spring when the fruit is vulnerable. In the fall, and after the fruit has been picked, hail peaks due to lake moisture in Michigan.

What happens if the basin experiences climate change? Slight changes in the lake water and air temperatures could greatly alter the frequency of lake-effect snows, or it could change the distribution pattern. The regional agriculture is very sensitive to the current climate. Hence, future changes could vastly alter the fruit-based agriculture of the Great Lakes.

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Summary: Effects on Corn and Soybean Production

Joe T. Ritchie*

Using weather scenarios created from two climate models (GISS and GFDL) and baseline observed weather data sets, corn and soybean production was simulated for normal and changed climates using the CERES-Maize model and the SOYGRO soybean model. The primary analysis was completed without including the direct effects of CO_2 on photosynthesis and transpiration. Thus, changes in temperature and rainfall were the principal causes of yield changes. Further analysis included the direct effects of CO_2.

For the humid Great Lakes region, changes in temperature had the greatest effect on model predicted crop yields. In most cases, an increase in temperature caused a decrease in the duration of crop life cycle. The more extreme GFDL weather change caused a decrease in yield ranging from 3 to 50 percent for irrigated corn with the decreases being greater for the more southerly stations. The soybean model predicted less yield decreases than the corn model under the irrigated GFDL conditions, the decrease ranging from zero to a maximum of 30 percent. The maximum decreases occurred in the southernmost locations. In the most northern latitudes where the warmer conditions provided a longer frost-free growing season, the increased temperatures had a beneficial effect on simulated yields. Because the GISS model generated smaller temperature increases, the effects on yield were less extreme, but followed the same general pattern as the GFDL model.

The rainfed crop yield under GFDL weather was reduced quite substantially when compared to irrigated crops at most sites. With a few exceptions, when using GISS weather with a slight increase of rain during the growing period, yield decreases were relatively small. The amount of irrigation water required for optimum yields was closely related to the amount of rainfall in the growing season. Water requirements increased an average of about 90 percent under GFDL conditions when compared to the baseline weather, and decreased an average of about 30 percent under GISS conditions.

At Fort Wayne a longer season corn cultivar adapted to a more southern climate could compensate for some of the lost yield due to climate change. Full compensation could not be obtained, however, because the grain-filling duration is not substantially different between corn cultivars.

The direct effects of CO_2 were studied by running versions of maize and soybean models with modified photosynthesis and transpiration calculations. The direct effect of CO_2, as approximated in the modified crop models, increased yields when compared to weather effects alone for both crops at all locations. In some situations the direct effects overcame the predicted weather related yield losses.

***Professor, Homer Nowlin Chair, Michigan State University**

Comments on Report of Panel D Findings

AUDIENCE MEMBER: We all know that revisions in our waterfronts will be needed and we need to develop a linkage between the water and land. Many cities are looking to invest, if they have not already invested, millions of dollars on revitalizing waterfronts. Such cities are in their formative stages in setting 25- and 50-year plans to do this.

I think we would be remiss if not somehow noting in this report the idea of flexibility in coping, as you indicated, as a long-term strategy incorporated into these plans to recognize the potential climate changes. Thus, I think that we need to stress the importance of designing flexibility into our long-term plans.

MR. HECHT: Perhaps most important, and the one that should have been at the top of our tasks, is to begin the process of strategic thinking about the long-term management of the basin. What will the policy officials have to do within 20 years, what tools will they need, what do they want the basin to do? So, there are several things that can be suggested. We need to consider the legal framework for the basin. We need to expand the education on climate change in the basin. We have to make this an open process, and we have to keep the general public informed.

MS. CUTLER: The Great Lakes Basin, as relates to global issues, is a microcosm of many issues and problems that can be anticipated worldwide. This includes transboundary migration of crop types, or for example, conflict over water demand in population centers. Our panel conceived a plan, or concept, about the multifaceted study needs in the Great Lakes Basin. A two-nation study can help us in how we are going to manage for the future. It could also attract interest and maybe support from other groups that are looking at this area on a national or international basis. We may be able to get the climate modelers to develop special model runs for us or to start developing some regional models, and to look at data considerations. We can draw on expertise, not only around the lakes but maybe around the world, to get a focus here. That's why we consider a basin program as having a global aspect and we think a major basin study is a key program to consider.

MR. HECHT: I think it is a very good idea.

AUDIENCE MEMBER: Remedial Action Plans (RAPS) for the current areas of concern are profoundly important. They are certainly going to take the time schedule that we are talking about for climatic change. We are talking about three or four decades to implement the RAPS if we do it. Therefore, in that sense climatic change should be a partner of RAPS. Other strategic thinking is going on and we should take that into account.

APPENDIX

AGENDA

FIRST UNITED STATES—CANADA SYMPOSIUM ON THE IMPACTS OF CLIMATE CHANGE ON THE GREAT LAKES BASIN

27-29 September 1988
Hyatt Regency Oak Brook Hotel, Chicago

Tuesday—September 27

Morning plenary session, Oak Brook Ballroom

8:30-9:00	Symposium convened Dr. Alan Hecht, Director, National Climate Program Office, plenary session chairperson Mr. Al Malinauskas, Head, Canadian Climate Program Office, Canadian Climate Centre (AES)
9:00-10:00	Mr. David Phillips, Canadian Climate Centre (AES) Climate Change in the Great Lakes Region
10:00-10:15	Mid-morning break
10:15-11:15	Dr. Michael MacCracken, Lawrence Livermore Laboratory Scenarios for Future Climate Change: Results of GCM Simulations
11:15-12:15	Prof. F.K. Hare, Chairman, Canadian Climate Program Planning Board Climate Sensitivity of the Great Lakes System
12:15-12:30	Dr. Alan Hecht—Instructions/Charge to Working Groups
12:30-2:00	Lunch (Regency Ballroom) Luncheon speaker: Dr. William Evans, Undersecretary for the Department of Commerce and Administrator for NOAA
2:00-5:00	Concurrent Panel Sessions (see last page) Hyatt Oak Brook Conference Rooms

Wednesday—September 28

Morning plenary session, Oak Brook Ballroom

8:30-8:45	Symposium reconvened—Mr. Al Malinauskas
8:45-9:45	Mr. Peter Timmerman, International Federation of Institutes for Advanced Study, University of Toronto Everything Else Will Not Remain Equal: The Challenge of Social Research in the Face of a Global Climate Warming
9:45-10:45	Prof. Stanley Changnon, Illinois State Water Survey Climate Change and Hydrologic and Atmospheric Issues: Lessons of the Past
10:45-11:00	Mid-morning break
11:00-12:20	Mr. Donald Totten, International Joint Commission, United States Dr. Elizabeth Dowdeswell, Conservation and Protection, Environment Canada Mrs. Lee Botts, Deputy Commissioner for Environmental Protection Potential Economic and Political Problems of Climate Change in the Great Lakes Basin
12:20-12:30	Mr. Al Malinauskas—Instructions/charge to working groups
12:30-2:00	Lunch (Regency Ballroom) Luncheon speaker: Dr. H.L. Ferguson, Ass't. Deputy Minister, Atmospheric Environment Service, Environment Canada
2:00-5:00	Concurrent Panel Sessions (see last page) Hyatt Oak Brook Conference Rooms
5:00-6:00	Organizational meeting—Organizers, Chairpersons, Rapporteurs (conference room to be designated)
6:30-8:00	Reception—Kent Room

Thursday—September 29

9:00-12:00	Oak Brook Ballroom Alan Hecht and Al Malinauskas, co-chairpersons Report of Rapporteurs of each working group Discussion and Questions Recommendations
12:00-12:30	Prof. Stanley Changnon—Final Remarks/Announcements
1:00	News Conference (Oak Brook Ballroom)

Concurrent Panel Sessions

Session A

CLIMATE IMPACTS ON ENERGY AND TRANSPORTATION

Dr. F.K. Hare, Chairperson, Chancellor Trent Univ., and Chairman Canadian Climate Program Planning Board
Dr. Andre Saulesleja, Rapporteur, Canadian Climate Centre (AES)
Dr. Stewart Cohen, Canadian Climate Centre (AES)
Mr. Randy Crissman, New York Power Authority
Mr. Angus Laidlaw, Dominion Marine Association
Mr. George Ryan, Lake Carriers Association
Mr. Mark Inglis, ICF Incorporated
Dr. O.T. Melo, Ontario Hydro

Session B

CLIMATE IMPACTS ON RECREATION, CONSERVATION, AND WETLANDS

Dr. Dennis Tirpak, Chairperson, Environmental Protection Agency
Ms. Linda Mortsch, Rapporteur, Canadian Climate Centre (AES)
Prof. John Magnuson, University of Wisconsin
Dr. Geoff Wall, University of Waterloo

Session C

CLIMATE CHANGE AND ITS EFFECTS ON MUNICIPAL WATER SUPPLY, LAKE POLLUTION, AND LAKE LEVELS

Dr. Alan Hecht, Chairperson, NCPO/NOAA
Dr. Murray Clamen, Rapporteur, IJC, Canada
Mr. Doug Cuthbert, Inland Waters Directorate, Environment Canada
Dr. Eugene Stakhiv, U.S. Army Corps of Engineers
Dr. Frank Quinn, Great Lakes Environmental Research Laboratories, NOAA
Dr. Alan Blumberg, HydroQual
Mr. Jim Bishop, Water Resources Branch, Ontario Environment

Session D

CLIMATE CHANGE ON AGRICULTURE, URBAN LAND USE, AND FOREST MANAGEMENT

Mrs. Nancy Cutler, Chairperson, Canadian Climate Centre (AES)
Dr. William Easterling, Rapporteur, Resources for the Future
Dr. Steven Zoltai, Canadian Forestry Service
Dr. Barry Smit, University of Guelph
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