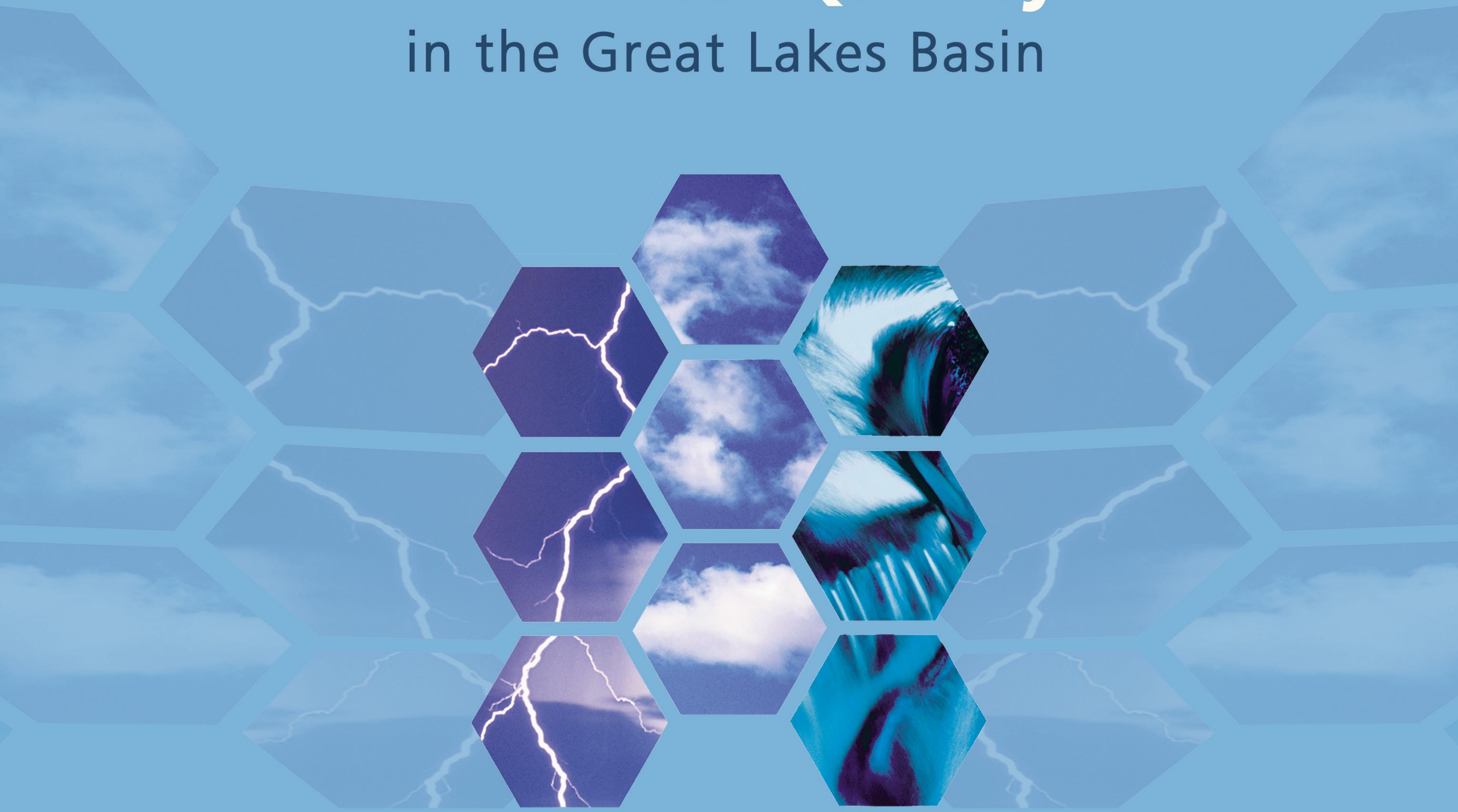
Climate Change and Water Quality
in the Great Lakes Basin



Report of the Great Lakes Water Quality Board to the International Joint Commission

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Office Addresses of the International Joint Commission

Great Lakes Regional Office

International Joint Commission
100 Ouellette Avenue, 8th Floor
Windsor, Ontario
N9A 6T3
Tel. (519) 257-6700
commission@windsor.ijc.org

or

International Joint Commission
P.O. Box 32869
Detroit, Michigan
48232
Tel. (313) 226-2170
commission@windsor.ijc.org

Canadian Section

International Joint Commission
234 Laurier Ave., W., 22nd Floor
Ottawa, Ontario
K1P 6K6
Tel. (613) 995-2984
commission@ottawa.ijc.org

U. S. Section

International Joint Commission
1250 23rd Street N.W.
Suite 100
Washington, D.C. 20440
Tel. (202) 736-9000
commission@washington.ijc.org

Visit the International Joint Commission website at http://www.ijc.org

Contents

PART 1
EXECUTIVE SUMMARY
BACKGROUND TO THE CLIMATE CHANGE ISSUE AND THE WHITE PAPER'S FINDINGS

"The Great Lakes basin, its people and its commerce, is a microcosm of society as a whole. The 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." — William Evans, 1989

INTRODUCTION AND BACKGROUND

Climate provides fundamental bounds on, and opportunities for human activities and ecosystem functioning. Climate has changed in the past, is changing today, and will continue to change. As early as 1985, the Great Lakes scientific community began to recognize the potential implications of climate change on the Great Lakes. In that year, Environment Canada's Canadian Climate Program and the University of Toronto's Institute for Environmental Studies convened a binational workshop to review the effects of climate change on the physical, bio-physical, and socio-economic systems of the Great Lakes basin and to develop a research strategy. Other workshops followed, and investigations on impacts of climate change were undertaken. In 1992 the binational Great Lakes-St. Lawrence Basin Project sought to identify the impacts of climate change on ecosystem health, human health, land use and management, and water use and management, and to develop adaptation strategies.

In its 1989 report, the Science Advisory Board alerted the International Joint Commission to the potential impact of global climate change. The Board noted that climate warming "... would affect the frequency, intensity, duration and location of extreme meteorological events. The assessment of such events in the recent past and their ecological and societal implications might provide a first approximation of how climate change might affect the Great Lakes basin, and how societies in the basin might be prepared to cope with such changes."

In its 1989, 1991, and 1993 reports, the Board presented projected changes in Great Lakes conditions and consequent impacts on the system (Table 1), including impacts on socio-economic interests, which would be both positive and negative and would surely involve tradeoffs. The Board also expressed concern about whether climate warming would counter restoration successes, make the lakes more eutrophic, and increase the probability of invasions of alien species. Further, the Science Advisory Board indicated the need for policy changes for water level regulation, water diversion, fisheries, and shoreline management.

Table 1. Projected Great Lakes Changes and Impacts - 1989

Higher over-land evapotranspiration and lower available soil moisture.
Reduced land runoff and earlier runoff peaks.
Shortened snow season.
Warmer lake surface water temperature and increased evaporation.
Reduced water level and ice cover.
Altered lake dynamics, *e.g.* storm events, turnover, and waves.
Altered fish distribution and production.
Impacts on winter tourism and recreational activities, agriculture.
Altered ecological relationships within and among biological communities.
Altered fish reproduction, growth, and harvests.
Altered nutrient inputs.

The Board concluded that predicting effects of climate change and then proactively adapting to, or planning for such changes were important issues to address under the Great Lakes Water Quality Agreement. The Board further concluded that "... variability and the uncertainty that variability provides are perhaps the most difficult environmental properties for managers, planners and policy-makers to deal with effectively." The Board detailed a course of action for the Great Lakes community.

Evidence developed over the past decade has strengthened and extended the confidence that climate change and associated impacts are valid concerns (see Figure 1). The magnitude of changes presently occurring and projected to occur in our climate raises questions about not only the extent of their impact but also our ability to adapt, not only globally but more specifically in the Great Lakes region.

Compounding the issue, numerous stresses already challenge the Great Lakes - land use changes, chemical contamination, nutrient over-enrichment, alien invasive species, and acid precipitation. Climate change is yet another agent, acting in concert with other stresses.

THE COMMISSION'S CHARGE TO THE WATER QUALITY BOARD

The Commission has expressed its concern about the impact of climate change and variability for the Great Lakes region and its residents, in particular, to restore and maintain the integrity of the waters of the Great Lakes basin ecosystem and to achieve the beneficial uses given in Annex 2 of the Agreement. In late 2001, the Commission asked its Water Quality Board to provide advice about implications and impacts of climate change on Great Lakes water quality and beneficial uses, and how we can address changes.

THE BOARD'S INVESTIGATION

A change in climate could lead to alterations and impacts on environmental quality (air, water, soil, sediment); surface and ground water quantity; ecosystem health and functioning; human health; the "built" environment (sewer and treatment plant capacity); and socio-economic systems, including agriculture, forestry, fisheries, recreation, tourism, energy, transportation, and manufacturing. The climate changes for a number of reasons - natural and anthropogenic - and studies have been and are being carried out to detect changes in climate and identify associated impacts. Natural climate variability is influenced by changes in solar radiation, wobbles in the earth's orbit, and volcanic activity. Humans influence the climate by urban development, changes in land-use patterns, and increased emissions of greenhouse gases.

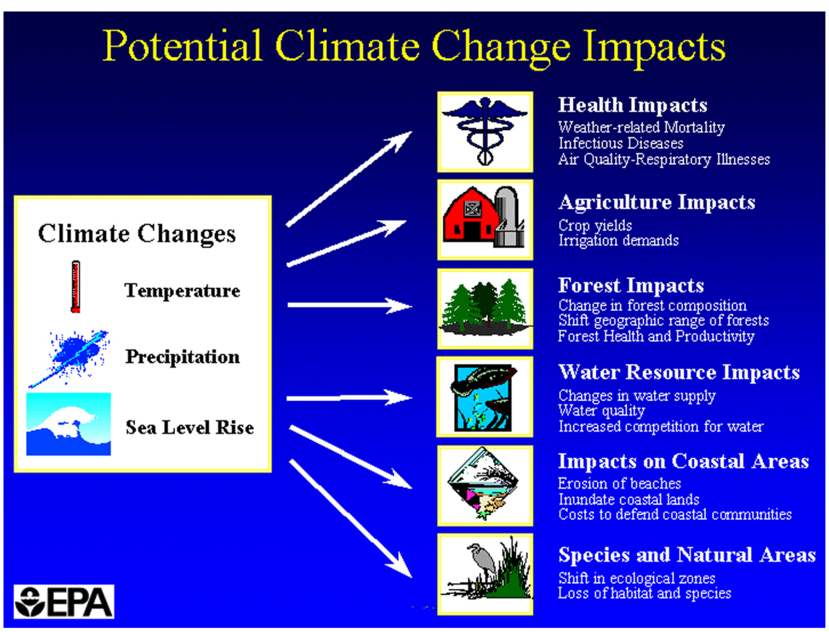

Figure 1. Potential Climate Change Impacts

Both mitigation and adaptation actions are required as a balanced response to climate change. Mitigation measures are geared to reduce emissions and increase sinks of greenhouse gases, while adaptation actions seek to increase resilience by reducing risks and taking advantage of opportunities due to a changing climate. Mitigation of climate change is being addressed by governments and stakeholders at global, national, and regional scales. Yet, even if mitigation measures aimed at reducing, for example, greenhouse gas emissions and slowing change are implemented, the earth's climate will continue to change due to natural forces and human-caused effects.

Impacts of climate change manifest themselves uniquely in regions such as the Great Lakes basin. As a result, adaptation measures need to be designed and implemented to accommodate each locality's specific context and capacity. Therefore, in its investigation, the Board chose to focus on adaptation. A focus on adaptation in no way minimizes the importance of concomitant mitigation actions, which the Board will continue to monitor.

To provide insight into the issues and impacts associated with climate change in the Great Lakes region, the options available to address those impacts, and the challenges associated with taking action, the Board commissioned a white paper, "Climate Change and Water Quality in the Great Lakes Region: Risks, Opportunities, and Responses." The white paper addressed four key questions:

- What are the Great Lakes water quality issues associated with climate change?
- What are potential impacts of climate change on beneficial uses?
- How might impacts vary across the Great Lakes region?
- What are the implications for decision making?

To confirm the scientific and technical basis that characterizes and underpins the conclusions and findings, the white paper was subjected to external review. In addition, to ensure that the Board had properly characterized the consequences of climate change, appreciated the challenges for taking action, and could provide sound advice to address impacts, the findings presented in the white paper were "ground-truthed" at a stakeholder workshop held May 28-29, 2003. The white paper, revised in light of the external review and the contributions from workshop participants, constitutes Part 3 of this report to the Commission. The white paper draws upon published materials with a nationwide or global perspective. Information specific to the Great Lakes is highlighted. The white paper's findings are summarized below, and further details are contained in the references cited therein.

The white paper is followed (Parts 4 and 5, respectively) by a synopsis of the workshop, which consists of the agenda, the list of participants, and the discussion summary; and the presentation by guest speaker Georges Beauchemin. The Board's advice to the Commission, which draws upon the white paper's findings as well as the workshop presentations and deliberations, is presented in Part 2.

THE WHITE PAPER'S FINDINGS

Climate Variability and Change during the 20th Century

Key trends are summarized in Table 2, with details in Chapter 2.

Table 2. Key Trends in Climate and Hydrology

Mean annual air temperature increases; most warming in winter and spring, least in the fall.
Minimum air temperature increases more than maximum air temperature.
Frost-free period lengthens and other temperature indices change.
Annual precipitation increases.
Ratio of snow to total precipitation decreases.
Extreme precipitation increases in the U.S.; no trend in Canada.
Snow cover (depth, areal coverage, and duration) is reduced.
Both wet and dry periods increase.
Onset of spring melt (freshet) is earlier.
Great Lakes water levels respond to climate variability.
Dates for freezing of lakes is later; dates for ice off are earlier.
Timing of phenological events (periodically recurring natural phenomena related to climate and seasonal change) is changing in North America and Europe.

Specific climate-related impacts already observed in the Great Lakes region include changes in ice cover, Canadian port gains with diminished ice, shifts in bird ranges and abundance, and a shift in the maple syrup industry. Based on changes observed during the 20th century, Chapter 2 presents analogues for the types of climatic conditions and events that might be experienced during the 21st century and, hence, insight into the vulnerability of key systems in the Great Lakes region, notably: changes in lake levels with consequent impacts on commercial shipping and recreational boating; the impact of climate change on lake-effect snow storms; and the impact of climate variability on agriculture, forests, water use, and human health.

Potential Impacts of Regional Climate Change

Attributes of the climate system in the Great Lakes region that are projected to change are summarized in Table 3. Details are in Chapter 3.

Table 3. Projected Changes in Great Lakes Climate

Air temperatures increase.
Daily air temperature range may decrease.
Total annual precipitation increases but precipitation during key seasons may decrease.
More precipitation may fall as rain and less as snow.
Intensity of precipitation events may increase.
Potential evapotranspiration increases with warmer air temperature.

Projected changes in Great Lakes water supply are summarized in Table 4.

Table 4. Projected Changes in Great Lakes Water Supply

Annual runoff decreases for most climate change scenarios.
More runoff may occur in winter.
Spring freshet may occur earlier and have less flow.
Summer and fall low flows may be lower and last longer.
High flows may increase due to extreme precipitation events.
Ground water recharge and levels may decrease.
Amount and timing of ground water base flow to streams, lakes, and wetlands may change.
Water levels in lakes decline.
Seasonal cycle of water levels is shifting.
Ice cover season is reduced or eliminated completely.

The implications of climate change for Great Lakes water quality are summarized in Table 5.

Table 5. Implications of Climate Change for Great Lakes Water Quality

Warmer water temperatures affect physical, chemical, and biological processes.
Taste and odor problems in drinking water may increase.
Periods of thermal stratification may be extended with associated declines in dissolved oxygen.
Changes in mixing depth affect productivity.
Non-point source pollution increases with higher intensity precipitation events.
Climate change may make it significantly more costly to meet water quality goals.
Water quality remediation targets may not be met.

A number of human health outcomes are associated with weather and / or climate. Because human health is intricately bound to weather and the many complex natural systems it affects, it is possible that projected climate change will have measurable impacts, both beneficial and adverse, on health. However, projections of the extent and direction of potential impacts are extremely difficult to make, so human health outcomes in response to climate change are highly uncertain. Chapter 3 examines climate-induced health effects on water-borne diseases, effects related to extreme weather events, air pollution-related effects, heat-related illnesses and deaths, and vector- and rodent-borne diseases.

Natural ecosystems will be affected by a changing climate. Implications are summarized in Table 6.

Table 6. Implications of Climate Change on Natural Ecosystems

Biological productivity is expected to increase with moderate temperature increases.
Zoogeographical boundaries move in a changing climate.
Introduction of invasive species could be exacerbated.
Existing community structures and interactions may change.
A changing climate is expected to lead to reduction in some habitats.
Wetland vegetation communities, functioning, and values may change.
Wildlife are susceptible to climate changes.
Rare and endangered species may be more vulnerable.

Climate change and variability will also impact agriculture in the Great Lakes region, as well as forests, recreation, and tourism.

Implications for Beneficial Uses

Annex 2 of the Agreement lists 14 beneficial uses, 12 of which are potentially vulnerable to climate change. Chapter 4 of the white paper reviews potential impacts, asking three questions:

- Will climate change impact areas already deemed environmentally sensitive?
- Will climate change create new Areas of Concern?
- Will climate change impair beneficial uses that have already been restored?

There is, however, a lack of specific research about the impacts of climate change on several beneficial uses. Therefore, impacts were assessed indirectly from associated literature.

The Uncertainty of Climate Change and Impacts

Most of the climate change impacts presented above are developed from impact assessments that are based on case studies of sensitivity to current and historical climate (*e.g.* extreme events) as analogues, or are based on studies where climate change scenarios are used as models to project future conditions such as for ecosystems and economic sectors. These assessments identify risks due to climate change. Uncertainties in the causes of climate change, the rate and the magnitude of the changes, and the associated impacts to the Great Lakes region lead to ambiguity and constrain adaptation or actions to deal with impacts.

This creates a challenge for society as a whole to believe that human activities contribute to climate change, that climate change is an issue to be concerned about, and whether they should act. Without a high degree of certainty, public understanding, and support, policy and decision-makers, although concerned, are not necessarily disposed to act.

However, uncertainty should not be used as an excuse not to act. Failure to adapt may leave the Great Lakes region poorly prepared to cope with adverse changes, and with increased probability of severe consequences. As the climate continues to change, society's ability to protect sensitive systems may be further challenged. In addition, analogous to the acid rain issue, there may be climatic surprises, *e.g.* unanticipated effects or a threshold change which may not necessarily be reversible after the stress is reduced or removed.

Many decisions to act do not, however, require projections of future impacts. There is a wealth of knowledge - including traditional ecological knowledge - in the community to document impacts and trends. As noted earlier, we have historic analogues. We can also use climate change scenarios to guide "what if" exercises. For example, if the climate is warmer and storm events more intense, water quality may be impaired by combined sewer overflows and negatively affect human health.

ADAPTATION TO CLIMATE CHANGE

What is Adaptation?

The Intergovernmental Panel on Climate Change defines adaptation as "adjustment in natural or human systems in response to actual or expected stimuli or their effects, which moderates harm or exploits beneficial opportunities." Other definitions can be found in the literature, and the definition continues to evolve. The Board views adaptation in broad terms, considering not only the ability of natural ecosystems to adjust on their own accord, but also adjustments to human systems, from urban infrastructure, to health alert protocols and economic incentives.

Adaptation actions fall into two broad categories - reaction to climate change as it occurs or anticipation of future change. Adaptation in natural systems is reactive, but adaptation in human systems can also be anticipatory, for example, development of new crop varieties.

The Challenge of Adaptation

A changing climate challenges managers. They must ask:

- How is the climate changing?
- How great or rapid are the changes?
- What and who might be affected?
- What existing issues are exacerbated and how?
- What new problems or opportunities emerge?
- What adaptations must be made to cope with the changes?
- When or how fast must adaptations be made?
- What are the costs?
- What are the impediments to adaptation?
- What is the capacity to adapt?

Many management practices in the Great Lakes region are predicated on the fact that the past is a reliable guide to the future. However, a changing climate adds a new component to consider in planning, management, and program implementation. Adaptation links needs of today with problems of tomorrow.

Adaptation Measures

The first step is to identify possible adaptation measures. Chapter 6 of the white paper contains an extensive but preliminary list for a range of economic activities, human health, water resources, ecosystems, communication, and management (Table 7). The list was drawn from the proceedings of symposia and workshops as well as climate change assessment reports.

Table 7. Implications of Climate Change

Economic Activities	- Hydro-electric power generation and transmission - Commercial navigation - Urban development and infrastructure - Agriculture - Recreation and tourism - Industry - Forestry
Human Health	- Water quality - Heat stress - Air quality - Disease and illness
Water Resources	- Drought - Flood - Water use - Water quality
Ecosystems	- Vegetation - Wetlands - Wildlife - Fish
Communication	- Environmental stewardship - Local stakeholders - High-risk populations (human health and weather extremes) - Sustainable use of water - Risk communication
Management	- Emergency planning, preparedness, forecasting, and disaster relief - Watershed planning and management - Data collection

The next steps are more difficult. Because managing to meet multiple demands in a changing environment requires an integrated approach, stakeholders and practitioners in the Great Lakes region must consult and collaborate to:

- Assess and evaluate potential adaptation measures.
- Choose preferred adaptation measures.
- Develop action plans that contain a portfolio of adaptation measures and incorporate means to address barriers to adaptation.
- Implement adaptations.
- Monitor impacts and adaptation measures for effectiveness.
- Reassess adaptation measures.

The basic considerations presented below provide a general framework for undertaking these steps.

> "The key element for adaptation strategies is knowledge."
> "The poorer you are, the more you need to know."
> — Luc Crépeault

Basic Considerations in the Development of Adaptation Strategies

After all is said and done, three considerations drive the decision to expend resources to avoid the effects of climate change - the perception of risk imposed by climate change, the perceived costs of the effort, and possible negative consequences of action taken. If stakeholders decide to commit resources, six issues must be considered to ensure that the responses are effective.

Distributional Effects

The design of adaptive responses should vary by locality, sector, and demographic group. The effects of climate change vary across localities within the Great Lakes basin, by sector (*e.g.* commercial fishery, shipping, transportation), and by demographic group (*e.g.* the elderly, the young). Since potential risks and human capacity to respond to risks varies, adaptive measures must be tailored to take account of geography, sectors, and demographics. However, any one particular effect of climate change (*e.g.* change in snowfall) may benefit one group or region but harm another. Therefore, any assessment of potential adaptation strategies must lay out the risks and opportunities associated with potential effects, as well as the options for reducing risks and exploiting opportunities.

Multiple Stresses

Climate change should be viewed as one of several stresses of concern. Many beneficial uses in the Great Lakes region that are sensitive to climate change are already under stress for other reasons. Climate change may either exacerbate or ameliorate existing stresses. Consider, for example, the impact of land use and land use changes on natural ecosystems and species diversity. Factor in climate change as an additional stress, and the resiliency of the ecosystem and its capacity to adapt may be further challenged. Consider also the present demand for water for human consumption, recreation, irrigation, and power generation. Climate change will increase demand for water, resulting in even less water being available for such natural ecosystems as wetlands and forests, further threatening their survival.

Any assessment of the vulnerability of Great Lakes systems to climate change, as well as assessment of potential adaptation strategies must consider multiple stressors on affected systems. Otherwise, adaptive responses may prove ineffective and fail. By the same token, placing climate change into the context of multiple stressors opens up opportunities to simultaneously reduce vulnerabilities to both climate change and other environmental stresses, for example, through the formulation of sustainable land-use practices.

Costs

The costs of adaptation must be considered. Adaptation comes with a cost. Resources to adapt to climate change likely have to be diverted from other productive activities, such as reduction of other stresses. The decision of when to incur adaptation costs hinges on the value of expected net benefits associated with acting now rather than later. Also, what will the resources buy? Decision makers must weigh the costs and tradeoffs among alternative adaptation strategies and living with residual impacts associated with the decisions taken.

In addition to funding costs, the potential effectiveness of adaptation also requires consideration of the availability of appropriate technology and trained personnel, cultural and social values, and political and legal institutions.

Lastly, the willingness of society to divert resources from other uses must be considered. Consider, for example, the costs associated with adapting to low lake levels. Lower levels impact commercial shippers and recreational boaters. The usual response is to dredge, but this response comes with operational costs for dredging, treatment, and disposal. Since much of the dredged material is contaminated, dredging also comes with environmental costs when material is disturbed and contaminants exposed.

Effectiveness of Adaptations

The reasons for varying effectiveness of adaptations need to be understood and incorporated into strategy designs. Different adaptive responses may vary in effectiveness. Historic evidence demonstrates that societies have not always adapted effectively to existing risk. Consider, for example, deaths from exposure to extreme heat, even in years without heat waves. The reasons for society's failure to adapt to existing risk must be understood in order to improve the design of future adaptation measures.

Maladaptation

There are dangers of maladaptation in poorly designed adaptation strategies. Adaptive responses may have unintended, adverse consequences that outweigh the benefits of undertaking the action. To avoid maladaptation, the strategy must consider interdependent systems that are sensitive to climate change as well as potential non-climate-related side effects. There may well be adverse consequences for human health and the environment, as well as for social well-being. The societal acceptability of a particular adaptive response may depend on who benefits and who loses. The key is to evaluate all potential adaptive responses in order to identify possible adverse consequences and conclude whether implementation of a particular adaptive response is therefore feasible and desirable.

Multiple Benefits

Sensible options have multiple benefits. Many opportunities for adaptation make human systems more resilient to climate variability today and are beneficial whether or not climate change results in future effects. Win-win strategies such as heat-wave planning and vector-borne disease surveillance systems are important to protect lives and health regardless of future climate change. Consideration of climate change and associated incremental effects may enhance or ameliorate the urgency of particular measures.

Although such strategies would lead to more efficient resource allocation, public policies often involve considerations other than efficiency - for example, equity, political feasibility - that must be accounted for. It is also worth noting that some existing institutional arrangements and public policies result in systems that are more rigid and unable to respond to change. For example, U.S. federal flood insurance provides an incentive for development in high-risk flood plains and coastal areas, a risk that would increase with more severe storm events and further sea-level rise.

Adaptation Strategy Implementation

Investments in adaptation are warranted to reduce vulnerability to climate change and to exploit opportunities that may increase social well-being. The agreed-upon adaptation strategy and its implementation depend upon societal values and selection criteria identified by decision makers - not researchers and assessors. Such policy decisions are often complex because of the need to consider multiple social objectives and the need to assess their importance and relevance in some consistent way. Thus, the strategy chosen may depend upon such considerations as equity (within and across generations), political feasibility, and specific environmental objectives chosen by society, such as the beneficial uses in Annex 2 of the Agreement.

RESEARCH NEEDS

As climate impact assessment moves toward a more participatory process, research must reflect practitioner/stakeholder as well as researcher views of what is needed to understand climate change, the impacts, and adaptive responses. Chapter 7 of the white paper contains an extensive list of research needs, compiled from numerous sources. The list requires further refinement through dialogue within the Great Lakes community about what needs to be done. Emphasis has been placed on understanding bio-physical systems. More attention must be placed on understanding human and institutional behaviour in the face of a changing climate. Research is also required to determine the sensitivity of the Agreement's 14 beneficial uses to climate change. Research needs are tabulated by seven themes:

- Monitoring, surveillance, and analysis.
- Climate change scenarios.
- Model development.
- Vulnerability, impact, and adaptation assessments.
- Economic assessment.
- Adaptation.
- Communication.

An associated requirement is to ensure that data are preserved for future reference and use.

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Great Lakes Science Advisory Board. *1991 Report to the International Joint Commission.* Windsor, Ontario, September 1991. 126 pp. ISBN 1-895085-28-4. See pp. 82-83.

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PART 2
THE WATER QUALITY BOARD'S ADVICE TO THE INTERNATIONAL JOINT COMMISSION

In late 2001, the International Joint Commission asked its Great Lakes Water Quality Board to provide advice about implications and impacts of climate change on Great Lakes water quality and on achievement of the 14 beneficial uses identified in Annex 2 of the Great Lakes Water Quality Agreement. The Commission also asked how we can address climate change. In response, the Board commissioned a white paper (Part 3 of this report) and held a workshop (Parts 4 and 5).

The Water Quality Board believes that climate change and variability is a serious issue that requires action. The white paper identifies changes in climate and hydrology within the Great Lakes region. People, communities, economic activities, wildlife, and ecosystems are sensitive to climate variability and change. However, through proactive planning, management adjustments, investments, legislation, institutional change, and education and training, modifications can be made to minimize impacts and take advantage of opportunities.

Both mitigation and adaptation actions are required as a balanced response to climate change. Mitigation of climate change is being addressed by governments and stakeholders at global, national, and regional scales. Yet, even if mitigation measures are implemented, the earth's climate will continue to change due to natural forces and human-caused effects.

Impacts of climate change manifest themselves uniquely in regions such as the Great Lakes basin. Adaptation measures need to be designed and implemented to accommodate each locality's specific context and capacity. Therefore, the board chose to focus on adaptation.

The Water Quality Board presents the following advice to the Commission. Based on the information presented in the white paper and from discussion at the climate change workshop, the Board concludes that there is a need for:

- Development and implementation of an adaptation strategy.
- Research on climate impacts and adaptation, with a focus on the Great Lakes region.
- Development of decision-making tools.
- Communication and outreach.

DEVELOPMENT AND IMPLEMENTATION OF AN ADAPTATION STRATEGY

The Board concludes that there is a need to embrace a risk assessment and management process to deal with climate change. The Board has identified elements of a general framework for development of adaptation strategies, with details in the white paper. The Board recognizes the magnitude of the climate change issue and the requirements and challenges associated with development of a strategy and implementation of adaptive measures, especially the consideration that must be given to spatial and temporal variability of climate change and impacts across the Great Lakes region.

A crucial element for any strategy is stakeholder involvement. This necessitates communication and outreach - especially with those vulnerable to climate change - to identify, define, and analyze issues and impacts, to develop responses, and to define goals and end points. The Board supports a staged approach of consultation by sector, to work in partnership to address issues, impacts, and consequences - both environmental and economic - then to explore sensible approaches to adapt. The strategy should identify and prioritize specific actions to be taken.

Another important component of a climate change adaptation strategy is to link with other stressors that challenge the Great Lakes, and to develop and implement programs and actions in concert, to mutual benefit.

The Board acknowledges that additional impacts and adaptation research is required and effective decision-making tools need to be developed. Nonetheless, there is sufficient risk-based information on climate change to take incremental, win-win actions now.

RESEARCH ON CLIMATE IMPACTS AND ADAPTATION

The Board recognizes the need to focus research on the Great Lakes, in order to better understand climate change and associated impacts on the region and to better understand the results of adaptive responses. The research must incorporate the interests of both researchers and Great Lakes stakeholders. In particular, research is required to better understand human and institutional behaviour in the face of a changing climate. Research is also required to better understand the implications of climate change on achievement of beneficial uses given in Annex 2 of the Agreement.

The Board recognizes the need to bring a broader range of Great Lakes stakeholders to the table for consultation within the community to develop a focussed research strategy for the Great Lakes region that will, in turn, inform the decision-making process and contribute to formulation of appropriate programs and policies in order to adapt to climate change.

DEVELOPMENT OF DECISION-MAKING TOOLS

Those affected by climate change want and need a quantified, integrated picture of the range of potential climate impacts and the consequences of taking action. The challenge is to construct scenarios and develop application methods that aid decision making. This requires models; the linkage of models, *e.g.* climate and lake level models, may be fruitful. This also requires dialogue between researchers and practitioners to identify research needs and priorities. To facilitate decision making, a practical approach is required to develop and apply tools, for instance, climate / economic scenarios scaled from the global to the regional and local perspective. For example, Ouranos, a consortium of public and private organizations and headquartered in Montréal, has undertaken such work for Québec.

Scenarios at the scale of watersheds will help decision-makers understand vulnerabilities better. The Canadian Institute for Climate Studies is providing global climate scenarios and statistical downscaling tools in order to develop the necessary local perspectives. Modelling and scenarios will also help establish priorities for action, develop a portfolio of adaptation tools, and convey the consequences of taking (or not taking) particular actions.

COMMUNICATION AND OUTREACH

Climate change is a difficult, complex, and controversial issue. The International Joint Commission can advance and inform the dialogue by providing clear, manageable information about climate change, the effects, and what can be done to adapt. There is a need to communicate in clear language that the climate changes and that there are consequences and impacts as a result of these changes. The message needs to be tailored to a wide audience, including the general public and those who influence public opinion; private and public corporations and municipalities; and the insurance industry, financial lenders and investors, and corporate and governance teams.

Informing stakeholders about climate change, climate impacts, the need for timely action, and available adaptation options poses challenges and opportunities. To be effective, communication and outreach should raise awareness, confer understanding, and motivate action. Communication and outreach should:

- Present success stories.
- Lay out proposed actions so that society is motivated to act and requisite resources are sought and provided.
- Quantify uncertainty and present implications for resource management decisions.
- Provide decision-makers with the tools to facilitate decision-making under uncertainty.
- Equip people to act, once a decision has been made.

Addressing climate change requires more than scientific facts and technical solutions; it requires dialogue about perceptions, social values, and expectations as well as consensus on what priorities and trade-offs society chooses and what risks and changes it is willing to accept. The communication process should present and reconcile different, often contradictory, information about climate change, its impacts and severity, and what should be done.

Communication becomes an important part in the science-policy link in adaptive planning and management. The dialogue it engenders ideally assists in developing a common perception or shared framing of the problem, from which cooperation and collective action can be developed. Communication simplifies the problem into a number of key concepts, builds upon existing knowledge with facts and proof, clears misconceptions, and generates imagery to personalize the issue.

Communication that provides factual information builds understanding. It is easier to accept new facts than new opinions. It summarizes what is known, based on the weight of scientific evidence, what the certainty is, what the available options and risks are, the costs and benefits, and how these are distributed within society.

THE NEXT STEP

Building upon its work to date, the Great Lakes Water Quality Board plans further investigation of climate change within the context of the Great Lakes Water Quality Agreement and the development of additional insight and advice for the International Joint Commission.

CLIMATE CHANGE AND WATER QUALITY IN THE GREAT LAKES REGION

Risks, Opportunities, and Responses

A Report
prepared for the
Great Lakes Water Quality Board
of the
International Joint Commission

Linda Mortsch and Marianne Alden
Environment Canada /
University of Waterloo

Joel. D. Scheraga
United States Environmental
Protection Agency

August 2003

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

Climate provides fundamental limits on and opportunities for human activities and ecosystem functioning within the Great Lakes region. A changing climate could lead to alterations in the frequency and severity of droughts and floods; water supply; air, soil, and water quality; ecosystem health; human health; and resource use and the economy. Climate change may act through multiple pathways; interactions in and impacts on the Great Lakes ecosystem can be dynamic and non-linear. Within the Great Lakes watershed, there are already numerous stressors that cause ecosystem change including land use change, pollution, eutrophication, invasion of exotic species, and acid precipitation. A changing climate should be considered as another agent of change acting in concert with other ecosystem stresses (Easterling and Karl, 2001; Magnuson *et al.,* 1996).

Recognizing that this emerging issue required a survey of the potential impacts and the ability to adapt, the Great Lakes Water Quality Board commissioned a white paper to explore the implications of a changing climate on the Great Lakes watershed (Figure 1-1). The white paper addresses four broad questions:

Figure 1-1. Great Lakes watershed

- **What are the Great Lakes water quality issues associated with climate change?**
- **What are the potential impacts of climate change on the "beneficial uses" in the Great Lakes Water Quality Agreement?**
- **How might these impacts vary across the Great Lakes?**
- **What are the implications for decision-making?**

Rather than simply focusing on the physical, chemical, and biological changes in water quality due to a changing climate, this paper has taken an ecosystem approach as outlined in the Great Lakes Water Quality Agreement. This approach recognizes that all components of the ecosystem are interdependent, including the water, biota, surrounding watershed, and atmosphere; humans are considered an integral part of this system (Lake Erie LAMP, 2000). Then, climate change can be considered from a broader, sustainability perspective. Identifying risks and opportunities of a changing climate on human activities and ecosystems of the Great Lakes watershed facilitates decision-making and planning on how to respond to the problem.

This paper is written for a cross-section of the Great Lakes science, business, resource management, and policy community experts. It is relevant to those who need to be aware of potential impacts of a changing climate as well as those who are in a position to develop policies and programmes in response to the changes. This white paper was used to facilitate discussion among experts at a workshop May 28-29, 2003. Discussion topics included: What are the key impacts of a changing climate? What are the options to adapt to impacts? How can climate change be successfully incorporated into long-term planning and decisions in the Great Lakes watershed? What are the scientific, programme, and information needs? The deliberations from the workshop are included in the Water Quality Board's advice to the International Joint Commission.

By necessity, the white paper often uses published reports and journal articles with a nationwide or global perspective to develop the background for a changing climate. However, information specific to the Great Lakes is highlighted where possible but, where there is no literature for the watershed, information from elsewhere is used to illustrate an impact or adaptation option.

A number of experts on the Great Lakes, climate change detection, and climate change impact and adaptation assessment have reviewed the document. Also, the comments from and expertise of the May 2003 workshop participants have been incorporated into this document.

The task of surveying the issue of a changing climate in the Great Lakes watershed was approached in a number of steps and is reflected in the organization of the paper. First, the 20th century changes in climate are described in Chapter 2. Chapter 3 provides a general overview of the potential changes in climate and associated effects on ecosystems and human activities within the Great Lakes watershed; while Chapter 4 specifically focuses on the sensitivity of beneficial uses to a changing climate. A primer on adaptation to climate change is developed in Chapter 5 and potential adaptation options are explored in Chapter 6. Lastly, Chapter 7 summarizes knowledge gaps and research needs.

References

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Lake Erie LAMP. 2000. *The Lake Erie Lakewide Management Plan*. Prepared by the Lake Erie LAMP Group under the direction of the Lake Erie LAMP Management Committee. Environment Canada, Ontario Region and U.S. Environmental Protection Agency, Region 5.

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2.0 CLIMATE VARIABILITY AND CHANGE IN THE GREAT LAKES WATERSHED

Has climate and hydrology in the Great Lakes watershed changed significantly during the 20th century? In what ways has it changed and by how much? This chapter explores recent trends in selected climatological and hydrological parameters. Primarily, it draws from published literature at the global and national scale and relates results to the Great Lakes region.

Key trends include:

- Mean annual air temperature increases; most warming occurs in winter and spring and the least in fall;
- Minimum air temperature increases more than maximum air temperature;
- Frost-free period lengthens and other temperature indices change;
- Annual precipitation increases;
- Ratio of snow to total precipitation decreases;
- Extreme precipitation increases in the United States and shows no trend in Canada;
- Snow cover (depth, areal coverage, and duration) is reduced;
- Both wet and dry periods increase;
- The onset of the spring melt (freshet) is earlier;
- Great Lakes water levels respond to climate variability but show no long-term changes;
- Dates for freezing of lakes are later and dates for ice off are earlier; and
- Timing of phenological events is changing in North America and Europe.

2.1 DETECTING CHANGES

Large-scale processes such as population growth, land use change (agricultural expansion and urbanization), and intensification of land uses confound the detection of changing climate and hydrology. Data quality is also an issue. Changes in station location, instrumentation, observing practices, urbanization, and exposure introduce inhomogeneities to the observations that need to be corrected. Canadian and American observing practices and methods of "correcting" data can be dissimilar and differences are noted at the border. Here we have reported results from trend analysis using the longest period of record available with the most homogeneous data.

2.1.1 Air Temperature

Mean annual air temperature increases.

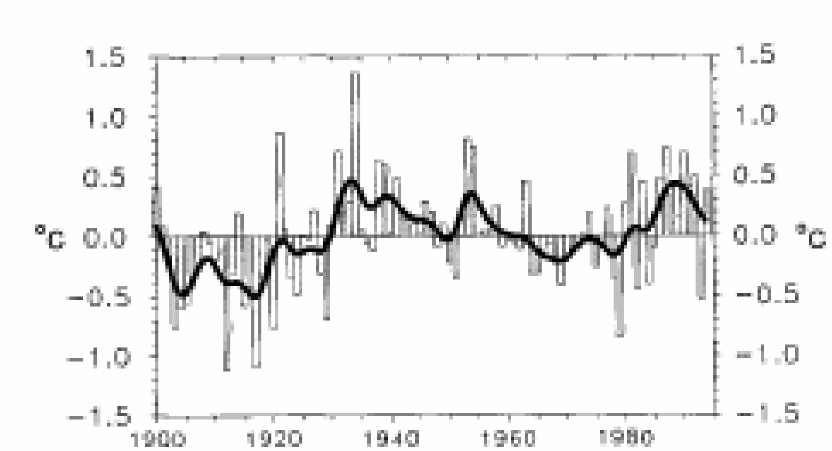
The global mean temperature has increased 0.6 ± 0.2 ^{o}C over the 20th century. Analysis of the instrumental record since 1861 suggests that the warmest decade globally may have been the 1990s and 1998 may have been the warmest year (IPCC, 2001: 26). Paleoclimate data for the Northern Hemisphere corroborates this; it also indicates that the temperature increase of the 20th century was the largest during the past 1000 years.

Mean annual temperatures for Canada and the United States have increased (see Figures 2-1 and 2-2). The increase from 1900 to 1998 was 0.9°C for southern Canada while in the contiguous United States it was 0.4°C from 1900 to 1994 (Zhang *et al.,* 2000, 405; Karl *et al.,* 1996: 282). Regional differences in the patterns of warming for Canada and United States are illustrated in Figures 2-3 and 2-4.

Winter and spring in Canada have exhibited the greatest warming, while summer has less warming; in autumn some areas actually experienced a small cooling (Zhang *et al.*, 2000). Most of the warming in the United States has also occurred in winter and spring (Karl *et al.,* 1996).

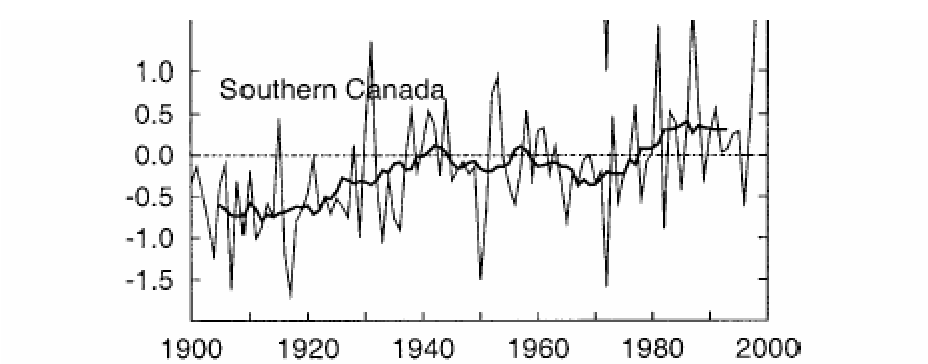
Within the Great Lakes region, annual mean temperatures have increased by 0.7°C from 1895 to 1999 for the southern portion of the Great Lakes and St. Lawrence lowlands in Canada, (Mortsch *et al.,* 2000: 159). Paleoclimate reconstructions over the last 12,000 years for the Great Lakes region indicate that temperatures have been up to 7°C cooler and 3°C warmer in the past (Magnuson *et al.,* 1997: 829).

Figure 2-1. Departures from the long-term mean for area-average mean temperature in °C, 1900 – 1994 for the United States.



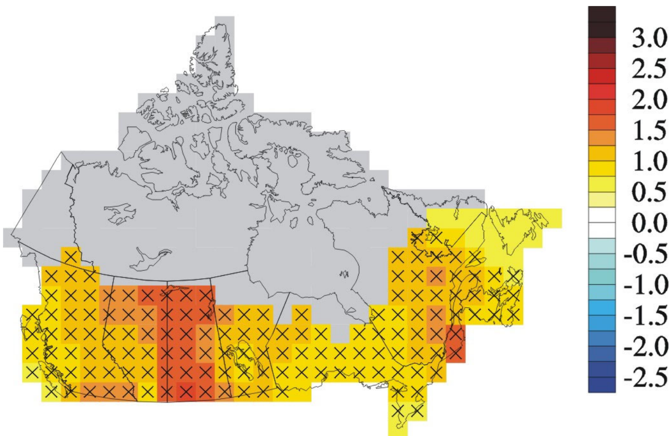
Source: Karl *et al.*, 1996: 282

Figure 2-2. Departures from the 1961-1990 mean of area-average mean temperature (°C), 1900-1999 for southern Canada (south of 60° N).



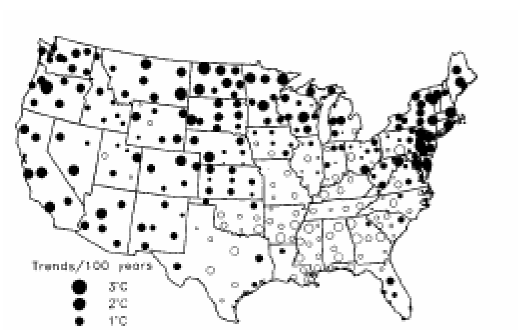
Source: Zhang *et al.,* 2000: 405

Figure 2-3. Mean annual temperature change for 1900–1998 (°C per 99-year period).



Note: In grid squares marked with crosses, trends are significant at five percent; grey areas indicate insufficient data.

Figure 2-4. Mean annual temperature trends from 1900-1994 (°C per 100-years).



Note: Solid circles represent warming; open circles represent cooling.
Source: Karl *et al.,* 1996: 282.

Minimum air temperature increases more than maximum air temperature.
Extremes – very high or low daily air temperatures – can negatively affect human comfort and health, exacerbate air pollution, or exceed an ecological threshold. Notable trends in maximum and minimum temperatures have been reported for the United States and Canada. They include:

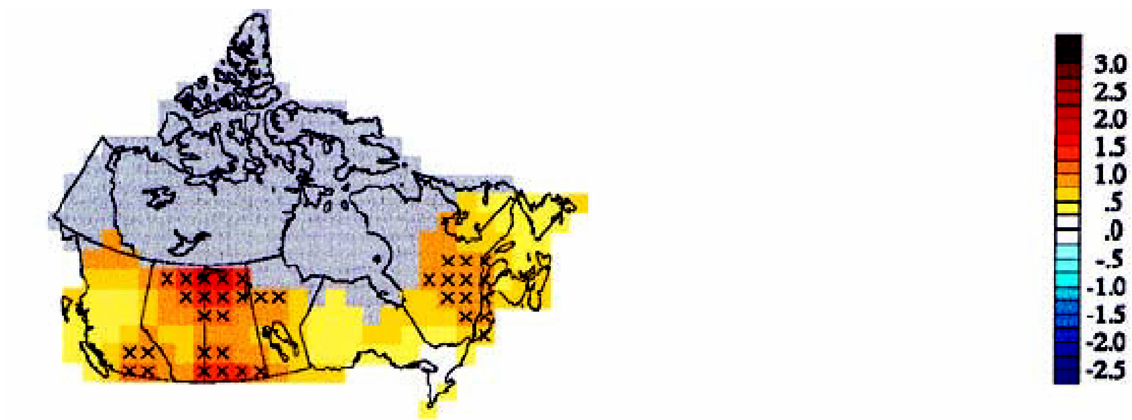
- Minimum (*i.e.* nighttime) temperatures are warming more rapidly than maximum (*i.e.* daytime) temperatures (Skinner and Gullet, 1993; Vincent *et al.*, 1999; Bonsal *et al.,* 2001; Easterling *et al.,* 1997; Zhang *et al.*, 2000);
- Fewer days with extreme low minimum temperatures particularly in winter, spring, and summer (DeGaetano, 1996; Karl *et al.,* 1996; Easterling *et al.*, 2000; Bonsal *et al.,* 2001);
- More days with extreme high temperature in winter and spring are occurring although the increase is not as pronounced as the minimum low temperature increase (Bonsal *et al.*, 2001);
- No consistent evidence of an increase in the number of extreme hot summer days (Skinner and Gullet, 1993; DeGaetano, 1996; Bonsal *et al.,* 2001);

- Autumn temperatures have remained the same or cooled. Maximum autumn temperatures have cooled in the United States (Easterling *et al.,* 1997). In southern Canada, most autumn cooling has occurred late in the season during the freezing period;
- The diurnal temperature range is compressed (Bonsal *et al.,* 2001).

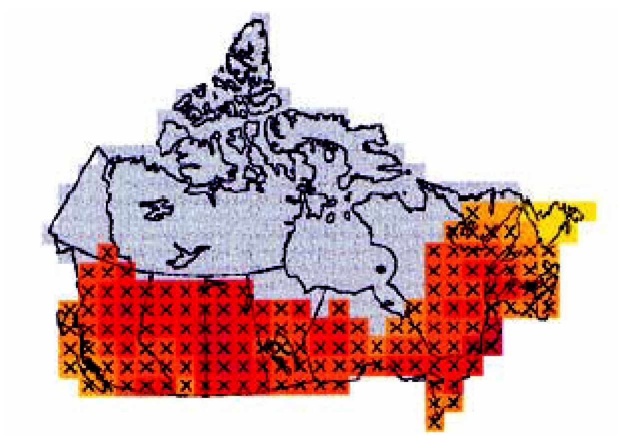
The regional changes in annual maximum and minimum temperatures for Canada are shown in Figure 2-5. Minimum temperature increase had a significant trend in the Great Lakes region, while daily maximum temperature increases were not significant (Zhang *et al.,* 2000).

Figure 2-5. Trends in daily maximum and minimum temperature from 1900-1998 (^{o}C per 99-year period).

a) Maximum Temperature.



b) Minimum Temperature.



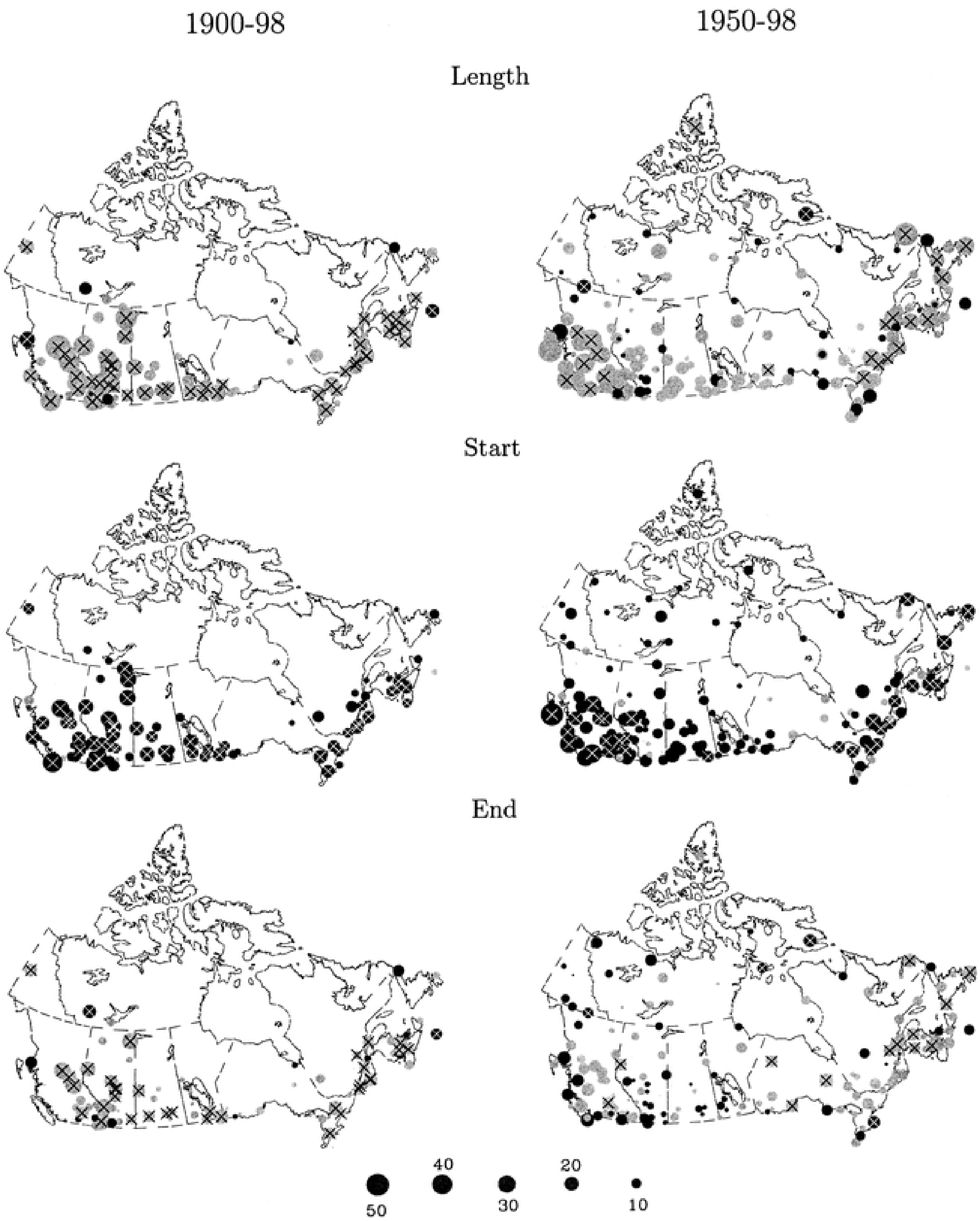
Note: In grid squares marked with crosses, trends are significant at five percent.
Grey areas indicate insufficient data (Source: Zhang *et al.*, 2000).

Frost-free period lengthens and other temperature indices change.

Warming of the minimum and maximum temperatures in winter and spring has influenced the frost-free period indicator that provides a measure of the period for growth of vegetation and agricultural crops. Similarly, warming in spring, summer, and fall influences growing degree-days, a measure of the energy available to plants for growth. It is an important reflection of plant distribution. In Canada, the length of the frost-free period has increased primarily due to spring warming (an earlier start day) and to a lesser degree due to later end dates because of frost (Bonsal *et al.,* 2001: 1973) (Figure 2-6). A similar lengthening of the frost-free period was noted in northeastern United States (Cooter and Leduc, 1995).

Socio-economic indices such as cooling degree-days and heating degree-days provide a measure of building heating and cooling requirements; they are affected by warming in winter and summer, respectively. Heating requirements have decreased considerably and cooling requirements have increased but not as much (Bonsal *et al.,* 2001: 1972). More cooling requirements may have implications for energy demand as air conditioning is primarily served by electricity. Demand for energy may be rising during a season when streamflow for hydroelectric generating may decrease; more electrical energy may have to be provided by fossil fuel burning or nuclear power.

Figure 2-6. Length, start, and end of the frost-free period (Number of days per 99-years or 49-years, respectively).



Note: Light grey dots signify an increase in the length and a later start/end and black dots signify a decrease in length and an earlier start/end to the frost-free period.
Source: Bonsal *et al.,* 2001: 1974.

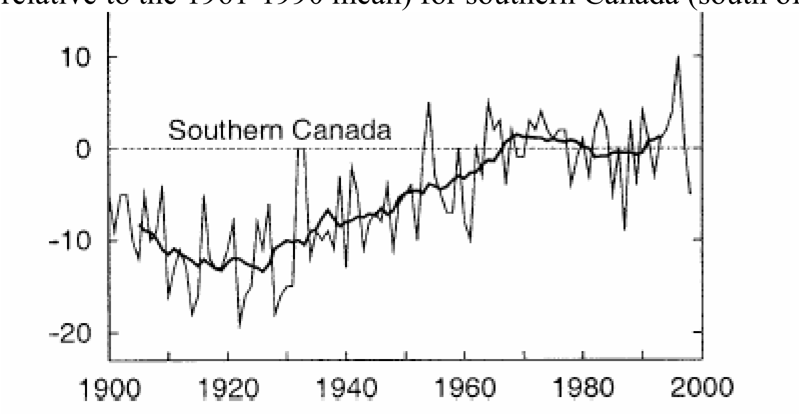
2.1.2 Precipitation

Total annual precipitation increases.

Globally, annual land precipitation has increased about 0.5 - 1 % per decade during the 20th century in the mid to high latitudes of the Northern Hemisphere; increases in northern regions are highest during the cold season (IPCC, 2001: 30; Zhang *et al.*, 2000: 396). On average, annual precipitation increased for Canada and the United States in the 20th century (see Figures 2-7 and 2-8).

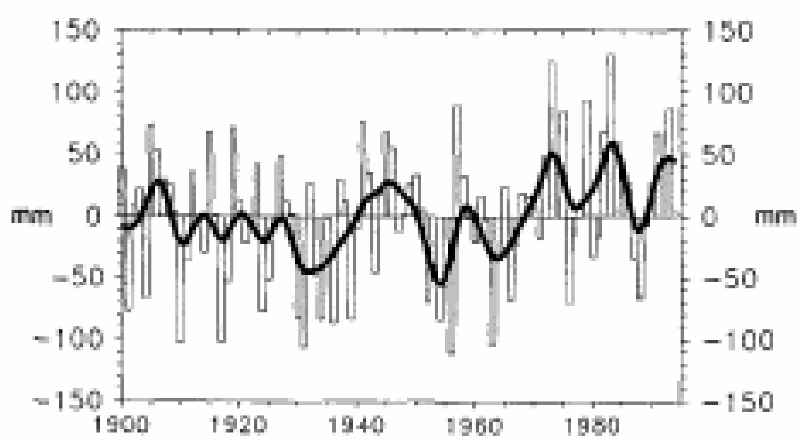
Analyses to determine precipitation trends in the Canadian Great Lakes - St. Lawrence basin indicate that total precipitation has increased over the period from 1895 to 1995; snow has decreased and rain has increased (Mortsch *et al.,* 2000). Paleoclimatological reconstructions of precipitation in the Great Lakes region indicate current precipitation is high relative to the past 12,000 years; around 9,000 BP it was wetter than present. Precipitation has at times been 180 millimetres (7.1 inches) less than and 40 millimetres (1.6 inches) greater than at present (Magnuson *et al.,* 1997).

Figure 2-7. Departures from the 1961-1990 mean of area-average annual precipitation (in % relative to the 1961-1990 mean) for southern Canada (south of 60°N).



Source: Zhang *et al.*, 2000: 411.

Figure 2-8. Departures from the long-term mean of area-average annual precipitation over the conterminous United States, 1900-1994.

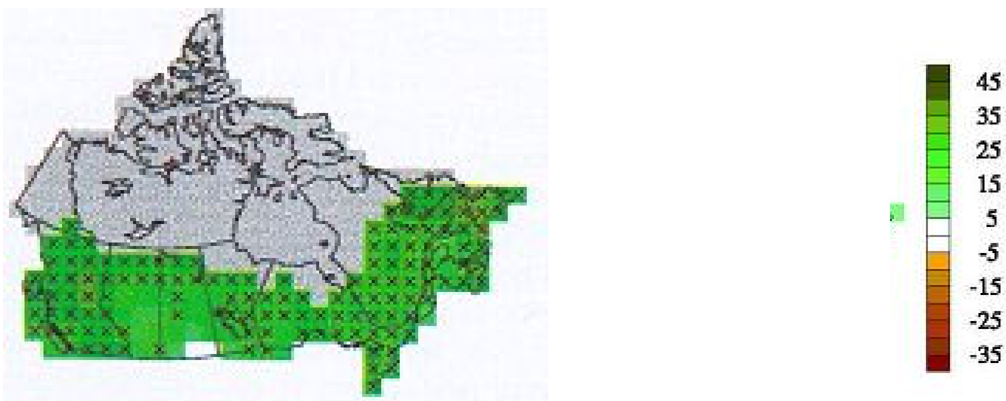


Source: Karl *et al.*, 1996: 281.

For most regions in southern Canada, annual total precipitation increased from 1900 to 1998 and likewise annual precipitation increased for much of the United States except the Central Plains (Groisman and Easterling, 1994: 203; Karl *et al.,* 1996: 282; Zhang *et al.,* 2000: 396) (see Figures 2-9 and 2-10).

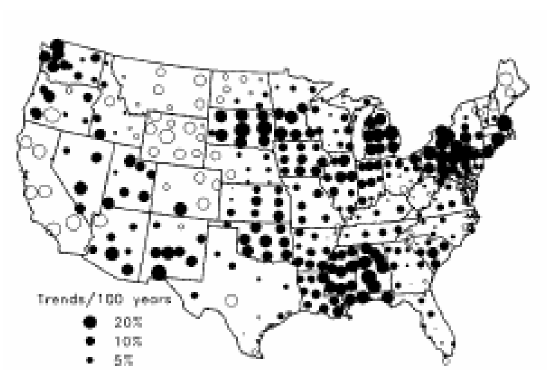
In a U.S. study of the correlation between temperature change and precipitation, Zhao and Khalil (1993) reported that, in a region to the south of the Great Lakes, when winter temperature increased precipitation also increased. Conversely, this region showed a decrease in precipitation with increasing temperature in May, June, July (not significant); a similar strong relationship (significant) occurred in the Central Great Plains agricultural area.

Figures 2-9. Trends in precipitation totals from 1900-1998 (% change over 99-year period).



Note: In grid squares marked with crosses, trends are significant at five percent; grey areas indicate insufficient data.
Source: Zhang *et al.,* 2000: 412.

Figures 2-10. Mean precipitation trends, 1900-1994 (% per 100 years).



Note: Solid circles represent an increase and open circles a decrease.
Source: Karl *et al.,* 1996: 282

Ratio of snow to total precipitation decreases.

In southerly regions such as the Great Lakes watershed, the ratio of annual snow to total precipitation is decreasing; the trend is particularly significant in spring (Karl *et al.,* 1993; Zhang *et al.*, 2000). Higher air temperatures are associated with this trend (Groisman and Easterling, 1994; Davis *et al.,* 1999). Late winter and spring warming, with temperatures periodically rising above freezing, may result in more precipitation falling as rain than snow although total precipitation remains the same (Brown and Goodison, 1996; Brown and Braaten, 1998; Zhang *et al.*, 2000). A reduction in the proportion of total precipitation that falls as snow has hydrologic implications; there is less storage of precipitation in snowcover and more runoff from rainfall occurs in winter. Less snow, and winter rainfall and ice formation can stress forage crops through frost heaving and ice encasement (Bélanger *et al.,* 2002).

Extreme precipitation increases in the United States and shows no trend in Canada.

Extreme precipitation events (high amount of precipitation within a short period of time) create risks for flooding and erosion, water quality deterioration (entrainment of pollutants and sewer overflow) and human health concerns (more frequent outbreaks of water-borne diseases especially in rural areas).

In the United States, extreme events have made up a disproportionate share of the observed increases in total annual precipitation. For example, the number of days with precipitation greater than 50.8 millimetres (two inches) has increased (Karl *et al.,* 1996). Easterling *et al.* (2000) reported an increase in the frequency of one-day to seven-day precipitation accumulations exceeding one-year and five-year return periods. These increases are largest in the Great Lakes, and southwest and midwest regions of the United States. In Canada, annual extremes in daily rainfall and snowfall are variable from decade to decade but there is no evidence of changes in intensity (Kunkel *et al.,* 1999; Zhang *et al.*, 2001b). Much of the observed increase in annual precipitation has been due to more small-to-moderate precipitation events. Stone *et al.* (2000) reported that, in the Great Lakes region, light events decreased in winter, intermediate events increased in autumn, and heavy events increased in summer from 1950 - 1995.

Both wet and dry periods increase.

Across the United States in the 20th century, there is no long-term trend in drought but there is much variability from decade to decade (Karl *et al.,* 1996). Since 1970, more area of the United States has tended to be excessively wet (*e.g.* Mississippi flood). However, during the past few decades a greater proportion of the United States was either in severe drought or severe moisture surplus (Karl *et al.,* 1996). Areas in southern Canada affected by both extreme dry and extreme wet conditions during summer increased when comparing the 1900-49 and 1950-98 periods (Zhang *et al.,* 2000a).

Snow cover (depth, areal coverage, and duration) is reduced.

The snow cover season may be ending earlier and, in some places, becoming more unreliable due to higher winter and spring temperatures. Winter and early-spring snow depths in Canada decreased during the period from 1946 to 1995 coincident with an increase in air temperature (Brown and Braaten, 1998). Canadian snow cover statistics reveal widespread trends toward earlier dates of maximum snow depth and earlier disappearance of snow over the 1955 to 1997 period (Brown, 2000). Frei *et al.* (1999) analysed snow cover from 1900 to 1994 and reported that, during the last three decades, decreases in spring snow extent in North America occurred with a possible shift in the snow season. Since the 1960s, November snow extent increased and March snow extent decreased.

2.1.3 Hydrology

Evapotranspiration

Evapotranspiration is the loss of water to the atmosphere through evaporation from the earth's surface (land and water) and the transpiration of plants. A significant proportion of the precipitation that falls in the Great Lakes watershed returns to the atmosphere; for example, in Ontario, almost two-thirds is lost to evapotranspiration. Evaporation plays a very important role in determining water availability; it affects soil moisture, streamflow, ground water recharge, and lake levels.

Evaporation has increased with warming in some regions.

Twenty years (1970-1990) of data for the Experimental Lakes Area in northwestern Ontario illustrate the relationship between temperature and evaporation in small boreal lakes and streams. During this period, air temperature increased by 1.6ºC, precipitation decreased (approximately 60 % of highest years), and average annual evaporation increased by approximately 50 %. Evaporation increased by an average of 35 mm/1ºC increase in annual air temperature or 68 mm/1ºC increase in summer air temperature (Schindler *et al.,* 1990; Schindler *et al.,* 1996). For the twenty-year record, evaporation increased by an average of nine mm/year. The net effect of these changes was decreased streamflow, with annual runoff declining significantly from about 400 mm/yr to less than 150 mm/yr in the late 1980s. The lakes had longer water renewal times. The changes in climate and hydrology influenced chemical exports from the watersheds to the lakes and affected in-lake processes, lake chemistry, and biology.

Streamflow

The onset of the spring melt (freshet) is earlier.

The timing of hydrologic events is important to ecosystems (wetland and perched lake renewal) and for water resource management (reservoir filling). Temperature can have an important effect by shifting the magnitude and timing of hydrologic events. In a changing climate, the first adjustments noted may not be changes in volume of flow but alterations to timing of events (*e.g.* freshet), particularly if they are tied to snow accumulation and melt (Westmacott and Burn, 1997; Whitfield and Canon, 2000). During spring warming, above freezing temperatures contribute to melting of the snowpack that has accumulated over the winter; this causes a period of high flow, the freshet, in numerous watersheds. To assess trends in the timing of peak spring runoff, Burn (1994) analyzed the long-term record of 84 unregulated river basins extending from northwestern Ontario to Alberta. The more northerly rivers displayed trends to earlier spring snowmelt runoff; the trend was more prevalent in the recent years of data. Whitfield and Canon (2000) also reported an earlier onset of runoff. Similarly, Zhang *et al.* (2001a) mapped a significant trend toward the earlier occurrence of the freshet season across Canada (see Figure 2-11).

Figure 2-11. Trends in the starting date of the spring high-flow season.

Note: Upward and downward pointing triangles represent delaying and advancing trends, respectively. Trends significant at the one percent and ten percent levels are marked by larger solid and open triangles, respectively. Smaller triangles indicate that trends are not significant at the ten percent level
Source: Zhang *et al.,* 2001a

Shifts in timing and amount of streamflow are detected.
Shifts in timing and amount of streamflow have important socio-economic and ecological impacts. For example, low flows, particularly in summer, affect assimilation of wastes, recreation opportunities, and habitat for fish. Changes in timing and flow have been reported but the changes are not consistent between the United States and Canada.

Whitfield and Cannon (2000) compared the streamflow in natural flow rivers for the period 1976-1985 with 1986-1995; hydrologic shifts detected for the Canadian Great Lakes region included higher winter flows, changes in spring peak and lower summer flows; these were in response to warmer winter temperatures and higher winter precipitation. In the U.S. portion of the Great Lakes region, annual low flows (drought) are decreasing and baseflow is increasing; average annual flows are increasing and maximum annual flow (including floods) are not increasing or decreasing (Lins and Slack, 1999). However, a pattern toward an increase in mean discharge in the autumn and winter months was reported. The increase in extreme precipitation (greater than 50.8 millimetres or 2 inches) reported by Karl *et al.* (1996) is not detected in more flooding events (Lins and Slack, 1999). The precipitation increase is considered too modest.

2.1.4 Great Lakes Water Levels
High water levels cause flooding and erosion that damage homes, recreational property, and coastal infrastructure. Low water levels also have wide-ranging impacts that include reducing hydroelectric generation, curtailing commercial navigation and recreational boating, and affecting wetland functioning.

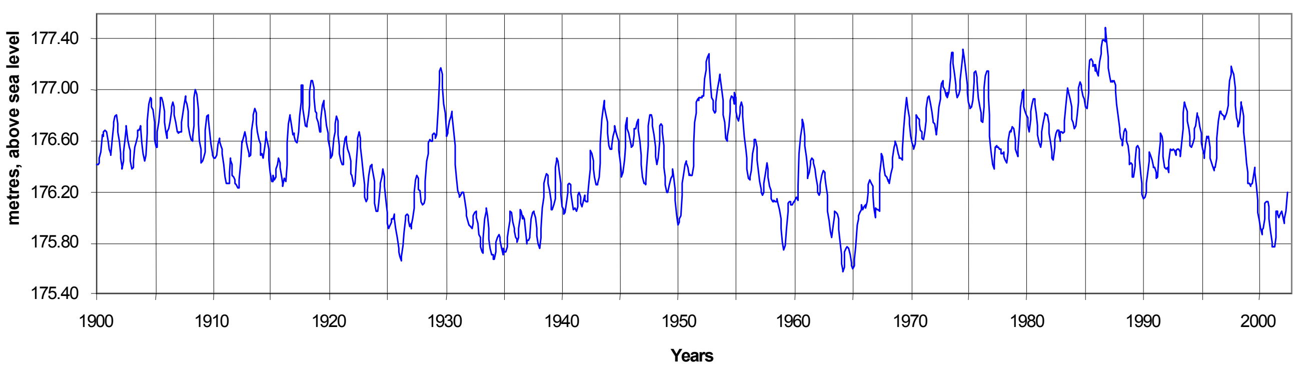
Great Lakes water levels respond to climate variability but show no long-term changes.
Lake levels fluctuate on different time scales ranging from: short-duration storm surge and wind set-up; seasonal progression of high and low levels (snow melt and evaporation), and inter-annual water level changes caused by long-term changes in climate (evaporation, precipitation)

(Kite, 1992). The Great Lakes are a naturally well-regulated system because of the large storage volume with respect to the small inflow and outlet channel capacities. Lakes Superior and Ontario have outflows regulated by control structures to minimize the high and low levels.

Annual water levels in the Great Lakes have only fluctuated about 1.8 metres (six feet) from measured maximum and minimum levels. Water levels were very high in 1973-75, 1985-86, and 1997. They were very low in 1934-35 and 1964-65. Since the late 1800s, dredging and navigation improvements in the St. Clair River have lowered Lake Michigan-Huron by 37 to 62 centimetres (15 to 24 inches) (Bishop, 1990; Quinn and Sellinger, 1990).

Since the early 1970s, there has been a run of relatively high water supplies (wet weather) with water levels generally above long-term average (Magnuson *et al.,* 1997). The trend for Lake Huron is shown in Figure 2-12. Levels dropped dramatically from their record highs in 1986 due to the drought of 1988 with low precipitation and high evaporation. They dropped again from highs in 1997 in part because 1998 was the hottest year (+2.3 °C) and fifth driest year (-11.5 %) in the region for 51 years. Water levels in 2000 also approached record lows.

Figure 2-12. Mean monthly water levels in Lake Michigan-Huron for the period 1900 – 2000.



Source: Environment Canada, 2001.

Kite (1992) analyzed monthly mean Lake Erie levels recorded at Cleveland and Buffalo for trend, periodic, and autoregressive components. No trends related to climate change were found. A periodic component included the 12-month seasonal cycle. The self-regulating effect of large lakes (autoregression) dominated, meaning that there is a tendency that high levels follow high levels and low lake levels follow low levels.

2.1.5 Ice Cover

Changes in ice can affect evaporation, lake levels, shoreline erosion and lake-effect snow as well as ecosystem processes such as winter fish kills and over-winter survival of fish eggs.

Dates for freezing of lakes are later and dates for ice off are earlier.
In the Northern Hemisphere, ice break up on small lakes has been occurring earlier in the season, and freeze dates are happening later. Magnuson *et al.* (2000) reported that between 1846-1995, break-up dates advanced 6.5 days and freeze dates were 5.8 days later. Air temperature during this time increased 1.2°C per 100 years. These trends are in agreement with Great Lakes regional freeze-up and break-up dates (Assel and Robertson, 1995). For example, Assel *et al.* (1995) examined six locations in the Great Lakes; between 1823-1994 freeze-up dates gradually became later and ice-off dates earlier. In the 1980s, there was a significant trend to earlier ice loss dates. Assel and Robertson (1995) examined lake ice records for Traverse Bay, Michigan from 1851-1993. Here, the 1980s also had the shortest duration of ice cover when compared to the previous 13 decades. Assel *et al.* (2003) examined the annual maximum ice concentration (AMIC) in the Great Lakes for trends. They reported that 60 % of lowest AMICs occurred in the winters between 1983-2001.

2.1.6 Phenology

Phenology studies the seasonal timing of different developmental stages or life cycles of plants and animals (Bradley *et al*, 1999). For plants, the stages are bud and leaf emergence, flowering, and leaf development. Ecological studies have demonstrated that the timing of bloom, bud, and leaf emergence of many plant species in different eco-regions is influenced by temperature and heat accumulation (Lieth, 1997; Beaubien and Freeland, 2000). Other phenological indicators include timing of breeding, migration, and stages of development for invertebrates, mammals, amphibians, and reptiles. No phenological studies focusing directly on the Great Lakes region were found. As a result, studies conducted in other regions of the United States and Canada, and globally are used to illustrate some changes.

Dates for breeding and migration are occurring earlier.
Globally, McCarty (2001) reported the earlier breeding and migration dates of birds. There has also been an earlier appearance of crop pests and breeding of amphibians and wildflowers. Hughs (2000) found the warmer climatic events of the past century have advanced phenological timings for insects, plants, birds, and amphibians. Walther (2002) discovered that since the 1960s, spring activities (such as bird migration) have begun much earlier. There has also been evidence of the later onset of fall activities, although not to the same extent as the spring. Examples include advance, delay, or no change in bird migration and the changing colour of leaves on trees.

In Europe, the effects of a warmer spring can include earlier insect and bird arrival and breeding times (Sparks *et al.,* 2002). Kuchlein *et al.* (1997) found many organisms respond to temperature change with acceleration in the rate of development. They may live for shorter periods but become more active. Insects may even produce extra generations throughout the year. Butterfly populations have shifted northward in response to increased temperatures. Other climate-sensitive organisms with similar population structures, such as beetles, grasshoppers, rodents, and frogs could also exhibit a change in geographic boundaries. Forchhammer *et al.* (1998) found that warmer winters led to an earlier breeding of amphibians. Spring plant phenology events are also occurring earlier (Chmielewski *et al.,* 2000). Sparks *et al.* (2002) reported the changes in plant phenology were most prominent earlier in the year (late winter and early spring). Chmielewski *et al.* (2001) reported that a warming in the early spring by 1 °C caused the growing season to begin seven days earlier. Ahas *et al.* (2002) noted plant ecosystems in snow climates were more sensitive to small temperature fluctuations (the melting point) during the early spring.

In North America, Schwartz *et al.* (2000) discovered first leaf data were increasing at a linear rate of 5.4 days over what period. First bloom dates and last frost dates also began earlier, 4.2 days and 4.5 days respectively. Lilac first-bloom dates began an average of five to six days earlier between 1959-1993. Studies in southern Wisconsin have found photosynthetic activity has begun earlier between the latitudes 45°N and 65°N (Bradley *et al.*, 1999). In the low altitudes of Colorado, there have been changes in the hibernation habits of yellow-bellied marmots (emerging 38 days earlier than 23 years ago) and the arrival of the American robin (arriving 14 days earlier than in 1981) (Inouye *et al.,* 2000).

Some studies have also related phenology to temperatures in parts of Canada. In Alberta, studies on Aspen Poplar, Chokecherry, and Saskatoon have found that the flowering of these species is mainly a reaction to temperature, where earlier blooming has occurred in years with higher spring temperatures (Beaubien *et al.,* 2000). The red squirrel, located in the southern Yukon, has exhibited earlier breeding habits due to warmer temperatures (Reale *et al.*, 2003).

Changes in phenology can influence human health (*i.e.* earlier pollen release and insect infestations) and production (horticulture, viticulture, forestry, and agriculture) (Sparks and Menzel, 2002). For example, earlier flowering, and subsequent earlier pollen release, may advance the start of the hay fever season (Van Vliet *et al.*, 2002).

2.2 LESSONS LEARNED ABOUT VULNERABILITIES FROM HISTORIC ANALOGUES

How will changes in climate affect sensitive human and natural systems in the Great Lakes region? Records from the past provide an informed perspective on this question. There have been a number of climate variations during the 20th century that provide analogues for the types of climatic conditions and events we might experience with increasing frequency and intensity in the Great Lakes region in the 21st century. These include substantial warming, increases in the quantity and intensity of precipitation, droughts and floods, significant reductions in lake levels, reductions in duration and extent of ice cover, and reductions in snow cover extent. Analyzing these variations, and their effects on human and natural systems, provides important insights into how resilient or vulnerable we may be in the future.

In this section we provide six illustrations of how insights can be gained from historic analogues about the vulnerability of key systems in the Great Lakes region to variations in climate. Examples include changes in Great Lakes levels and their impacts on commercial shipping and recreational boating, the impacts of changes in lake-effect snowstorms, and the impacts of climate variability on agriculture, forests, water use, and human health.

2.2.1 Changes in Lake Levels and the Shipping Industry and Recreational Boating

Current reductions in Great Lakes levels have had a significant effect on both the commercial shipping economy and recreational boating. Starting in the fall of 1998, lake levels dropped precipitously as a result of the extremely mild 1997-98 winter. With below-normal precipitation and above-normal temperatures in 1998-99, lake levels continued to drop and were below Chart Datum by as much as 15 centimetres (six inches).

Lower lake levels mean ships cannot carry as much cargo. Commercial carriers are very dependent on water depth in channel-ways and harbours. According to the Great Lakes Carrier's Association, a 1,000-foot (305 metre) long vessel (of the type that is used for intra-lake transportation) loses 270 tonnes of capacity for each inch of draft loss. Draft is the distance between the water line and the bottom of the vessel. Ocean-going vessels (sized for passageway through the St. Lawrence Seaway), which are approximately 740 feet (226 metres) long, lose 100 tonnes of capacity for each inch of draft lost. Clearly, in an environment where other modes of transportation (rail and truck) are extremely price-competitive with Great Lakes shipping, the loss of even one inch of draft can seriously disadvantage Great Lakes carriers and ports (Great Lakes Regional Assessment Group, 2000).

Low water also makes it more difficult for recreational boaters. There is a greater chance of damage when entering or leaving the water. There is greater risk of running aground in harbours, marinas, or while underway in lakes or rivers because of propeller, keel, or hull strikes on lake bottom, boulders, or shoals (Pearce, 1999). The most common approach for managing lowered lake level situations in marinas, harbours, and channel-ways is by dredging. Dredging imposes both operational and environmental costs. Material dredged from channels and harbours can be contaminated by industrial waste and spills. This must be buried in existing landfills, which are nearing capacity. In the 1970s, the U.S. federal government built 26 confined disposal facilities (CDFs) for dredged sediments of the Great Lakes. The CDFs are viewed as an alternative to the open lake disposal of these sometimes contaminated materials. Currently these 26 CDFs are either full or nearly full, and by 2006 only two facilities will have room. Furthermore, ongoing federal support for their continued construction and operation is questionable. In addition, if not done properly, the dredging process could release buried toxins into the lake water (though effective environmental dredging that does not release toxins can be conducted). Non-environmental dredging would threaten to reverse the trend towards less contaminated fish in the Great Lakes.

The last time that the Great Lakes experienced a significant decline in water levels was during 1962-1964. These declines resulted in dramatic increase in dredging activity and expenditure by the U.S. Army Corps of Engineers (the Corps is responsible for 145 harbours and 745 miles (1,200 kilometres) of channels in the Great Lakes/St. Lawrence area). Prior to 1963, dredging activity for all of the U.S. federal port facilities in the Great Lakes averaged 372,000 cubic yards (284,000 cubic metres) annually. In the five years after 1963, dredging activity averaged 4,119,000 cubic yards (3,149,000 cubic metres) annually. Activity was curtailed as lake levels rose in the subsequent 20 years.

This tenfold increase in dredging activity is likely to be exceeded in circumstances like those projected in some climate scenarios. During the last five years, average annual dredging activity has removed approximately 752,000 cubic yards (575,000 cubic metres). Additionally, costs for dredging have risen significantly since the 1960s. Current prices for dredging are averaging approximately \$8.00 (U.S.) per cubic yard (0.8 cubic metres) with local highs going above \$12.00 (U.S.) per cubic yard. This implies that in a situation with heightened demand for dredging services, it would not be unreasonable to assume prices would be at least \$10.00 to

$12.00 (U.S.) per cubic yard on average. Therefore, in a situation where 7,500,000 to 12,500,000 cubic yards (5,730,000 to 9,560,000 cubic metres) are being removed from federal harbours on an annual basis, it is reasonable to assume that annual expenditures of $75 to $125 million (U.S.) could be expected as a minimal investment in Great Lakes shipping infrastructure.

2.2.2 Impacts of Lake-Effect Snow

Lake-effect snow is a common cold season phenomenon in the Great Lakes region, occurring most frequently in late autumn and early winter. This type of snow results from the rapid warming and moistening of Arctic air masses that pass over lakes that are still relatively warm. The Arctic air becomes unstable and the resulting convection forms clouds and precipitation. The precipitation falls over and downwind of the lakes. For very cold air masses, temperatures remain below freezing even after passage over the warmer lakes, causing the precipitation to fall as snow. Lake-effect snow causes considerable enhancement of snowfall in narrow snowbelts along the downwind lakeshores. For example, Detroit, Michigan on the western (upwind) shore of Lake Erie receives an average of 1.1 metres (42 inches) of snow per year, while Buffalo, New York, on the eastern (downwind) shore of Lake Erie, receives an average of 2.3 metres (92 inches) per year. Toronto, Ontario, on the northwestern (upwind) shore of Lake Ontario, receives about 1.4 metres (54 inches) per year, while Syracuse, New York, located to the southeast (downwind) shore of Lake Ontario, receives 2.8 metres (109 inches) per year and is the snowiest metropolitan area in the United States.

Lake-effect snow creates transportation problems and results in additional costs to keep roads clear. A major transportation artery, Interstate 90, passes along the southern shore of Lake Erie and is vulnerable to lake-effect snow storms. Increased property damage, injuries, and deaths due to accidents and exertion accompany such events. Major airports, such as those in Buffalo and Cleveland, are also vulnerable to disruptions. The roofs of buildings in the snowbelts must be built to support heavier loads of snow than for locations away from the snowbelts (Schmidlin *et al.,* 1992). Retail sales may drop temporarily. A single lake-effect snowstorm near Cleveland, Ohio in November 1996 resulted in eight deaths, hundreds of human injuries, widespread power outages, damage to numerous buildings, and over $30 million (U.S.) in economic losses (Schmidlin and Kosarik, 1999). On the positive side, there is a large private snow removal business sector that benefits from the snowfall. Sales of winter-related products may increase. Lake-effect snowfall also supports an important winter recreational industry in some parts of the Great Lakes. Although there is not a large downhill ski industry in the Lake Erie snowbelt, many of the Midwest's premier downhill ski resorts are located in the snowbelts of the other lakes in the region.

Abnormally light snowfall amounts during the winter season have also created significant negative impacts, particularly when snowfall deficiencies have been widespread and the associated losses have affected many locations throughout the Great Lakes region. Such was the case over most of the Great Lakes region during the 1997-1998 El Nino year. The widespread nature of this event resulted in impacts over a large area. For example, business at Midwest U.S. ski resorts was down 50 % and losses were estimated at $120 million (U.S.) (Great Lakes Regional Assessment Group, 2000).

2.2.3 Great Lakes Water Diversion

In 1900, the city of Chicago built the Chicago Sanitary and Ship Canal to keep sewage from contaminating the Chicago water supply intakes in Lake Michigan. The flow of water down the Chicago River was reversed; sizeable amounts of water were diverted from Lake Michigan. This diversion launched a series of continuing legal controversies involving Illinois as a defendant against claims by the U.S. federal government, various lake states, and Canada (which wanted the diversion stopped or drastically reduced). During the past 96 years, extended dry periods lowered the lake levels. Using these dry periods as surrogates for future conditions, their effects on the past controversies provide analogues for what might occur as a result of climate change. The results suggest that changing socio-economic factors, including population growth, will likely cause increased water use, with Chicago seeking additional water from the Great Lakes. New priorities for water use will emerge as in the past. Future reductions in available water could lead to increased diversions from the Great Lakes to serve interests in and outside the basin. Lower lake levels in the future could lead to conflicts related to existing and proposed diversions, and these conflicts would be exacerbated by the consequences of global warming. Costs of coping with the new water levels could also be significant. Should Lake Michigan levels drop by as much as five feet (1.6 metres) by the end of the 21st century (as projected using one Canadian climate change scenario), it is possible that a lowering of the level of the canal would be needed. To lower the canal by four feet (1.2 metres), at least 30 miles (48 kilometres) of the canal would need to be dredged, and 15-17 miles (24-27 kilometres) would be rock excavation at huge financial costs (Injerd, 1998). A warmer climate, even with modest increases in precipitation, will likely lead to a drier climatic regime and will tax the economy and challenge existing laws and institutions for dealing with Great Lakes water issues.

2.2.4 Agriculture and Drought

The agricultural impacts in the U.S. of the drought of 1988 illustrate potential impacts of one possible future climate scenario, one that is warmer and much drier (National Assessment Synthesis Team, 2001). The temperature and precipitation conditions in 1988 were similar to conditions in the 1930s. Overall grain production was down by 31 %, with corn production down by 45 %. The supply of grain was adequate to meet demand because of large surpluses from previous years; however, the drought reduced surpluses by 60 %. Interestingly, overall farm income was not reduced because grain prices increased substantially (35 % for corn, 45 % for soybeans); however, these overall figures mask large losses in the heart of the drought region where yield reductions were much larger than the U.S. national average. The reduced production caused slightly higher domestic food prices, estimated at a one percent increase in 1988 and a two percent rise in 1989. (In 1989, the drought persisted in some areas and surpluses were much reduced following 1988). In summary, the drought of 1988 demonstrated that the agribusiness sector remains vulnerable to severe climatic anomalies, despite decades of advances in agricultural technology.

2.2.5 Droughts, Insects, and the Decline of Forest Species

In the late 1930s, many hemlock trees showed signs of deterioration in the Menominee Indian Reservation in east-central Wisconsin. Hemlock is an important forest tree at Menominee, which is located about 30 miles (48 km) north of the southwestern range limit of the tree. By the late 1930s, the hemlock borer, ordinarily not a problem, reached epidemic proportions. Careful examination (Secrest *et al.,* 1941) revealed that extensive root damage had occurred during the drought years 1930-1937. Borer attacks in 1938 were successful only on trees that had 10 % or less of their root system still alive. In 1939, attacks were successful only on trees with less than half of the main lateral roots alive. Obviously, hemlock borer attacks were successful only on trees that were already heavily damaged by unfavourable climatic conditions. The 1930s droughts were ultimately responsible for the loss of trees near the range limit, but insect attack was the proximate cause of death of trees already weakened by drought. The insight to be gained from this example is that unfavourable climatic conditions may not kill trees outright, but by stressing the trees, climate can contribute to death by insect attack.

2.2.6 Heat Waves and Human Mortality

A variety of weather phenomena can cause injury and death to humans. People who lack protection from extremely hot or cold weather will eventually suffer from disturbances of normal physiological functions. Exposure to extreme, prolonged heat is associated with cramps, fainting (syncope), heat exhaustion, and ultimately heat stroke. Within limits, however, what is meant by "extreme" is somewhat relative, partly depending on previous exposure, physiological adaptation, age, and other health conditions. Furthermore, the impact of temperature extremes depends on the length of time that people have been exposed to local conditions, socio-economic status and ability to cope, genetic predispositions to various conditions, and various physiological factors (Martens, 1998). Some heat waves may last for a few days or for weeks, but the difference can influence how people with previous exposure or social conditions respond. Long or repeated heat waves may not allow people's bodies to recover from the heat. Also, since heat waves often occur with little or no rain, high humidity, elevated ozone, and other air pollutants, susceptibility to these conditions also will affect health outcomes.

Historic analogues have taught us that the impacts of climate change on human health in the Great Lakes region are likely to be greatest in urban areas, especially where extremely high temperatures historically have been rare. For example, July 1999 was the hottest on record in New York. As many as 70 people died in Chicago during a 1999 summer heat wave where temperatures reached 37 ^{o}C (99 ^{o}F) (Currie, 1999). But heat waves are not new to Chicago. In 1995, more than 700 people died from exposure to extreme heat. Most of these people were elderly. The impact from heat stress can be minimized through appropriate behavioural adaptation, such as using air conditioning, wearing light clothing, and maintaining hydration. But the repeated occurrence of avoidable deaths during heat waves in the Great Lakes region suggests that adaptation is still imperfect (Great Lakes Regional Assessment Group, 2000).

2.3 CLIMATE-RELATED IMPACTS ALREADY OBSERVED

The climate of the Great Lakes region has changed, is changing, and will continue to change in the future (Great Lakes Regional Assessment Group, 2000; IPCC, 1996a). Since there are a variety of systems in the region sensitive to climate, including human health, ecosystems, and socio-economic systems, it is reasonable to ask whether there have been noticeable changes in these systems as the climate has changed (IPCC, 1996b, 1997; Scheraga, 1998).

This is an important question for several reasons. First, identifying impacts that have already occurred can help us better understand potential vulnerabilities to climate change. Second, adaptation measures can, in many cases, reduce the magnitude of harmful impacts, or take advantage of beneficial impacts. While it is impossible to attribute any of the observed impacts to human-induced climate change, as opposed to natural climatic variation, examination of impacts that have been manifested in the past may help us better evaluate our ability, or inability, to cope with future changes. We may, for example, discover that as the climate continues to change, our ability to protect sensitive systems may be further challenged. Third, any inability to cope with future changes may provide justification for taking actions to slow the rate of anthropogenically induced climate change, *i.e.* to reduce emissions of greenhouse gases from human activities.[1] Fourth, identifying impacts that have already occurred conveys the important point that climate change poses an immediate challenge to communities in the Great Lakes region. It is not a long-term phenomenon that will first result in impacts 50 to 100 years from now.

The distinction between climate variability and climate change is important if one is trying to associate observed impacts with longer-term climate change. At any point in time, the climate in a region can be described by average conditions (where characterization of average conditions depends upon the length of the time period under consideration).[2] Climate *variability* refers to fluctuations around the average conditions, and can refer to daily, weekly, monthly, or even inter-annual deviations (as in the case of El Nino events). Climate *change* refers to longer-term changes in average conditions. Typically, changes in climate can be described as "short-term" (*e.g.* inter-annual), "medium-term" (*e.g.* inter-decadal), or "long-term" (*e.g.* across centuries or millennia). The magnitude of impacts to climate-sensitive systems depends on the time period and geographic scale under consideration. Short-term impacts (*e.g.* infrastructure damages resulting from one unexpected ice storm) differ from long-term impacts (*e.g.* expected infrastructure damages given a change in the frequency of expected ice storms as the climate changes).

In this section, we provide several illustrations of the types of impacts that have been manifested as a result of changes in climate that have already occurred in the Great Lakes region. They illustrate the types of effects (both positive and negative) that may occur at an increasing rate as the climate in the Great Lakes region continues to change during the 21st century – and at a faster rate than observed during the 20th century (National Assessment Synthesis Team, 2000). Some of the expected change in regional climate will occur as the result of natural climatic variation. Some will occur as the result of human activities that have already altered the atmosphere and committed us to future climate change. Regardless of the source of change,

[1] The capacity to adapt or "cope" with climate change varies considerably throughout the Great Lakes region and across demographic groups. It also will vary over time. Locations and communities with limited economic resources, low levels of technology, poor information and skills, poor infrastructure, unstable or weak institutions, and inequitable empowerment and access to resources have the least capacity to adapt. They will also be the most vulnerable (IPCC 2001).

[2] Climate is what you expect. Weather is what you get. If one lives in a particular location, you expect certain weather conditions on any particular day. For example, on a typical winter day in January, one might expect freezing conditions and blustery winds in Chicago, given the current climate. But it is still possible to be surprised and have a spring-like day with 60^{o}F (16°C) temperatures and clear skies in the middle of winter.

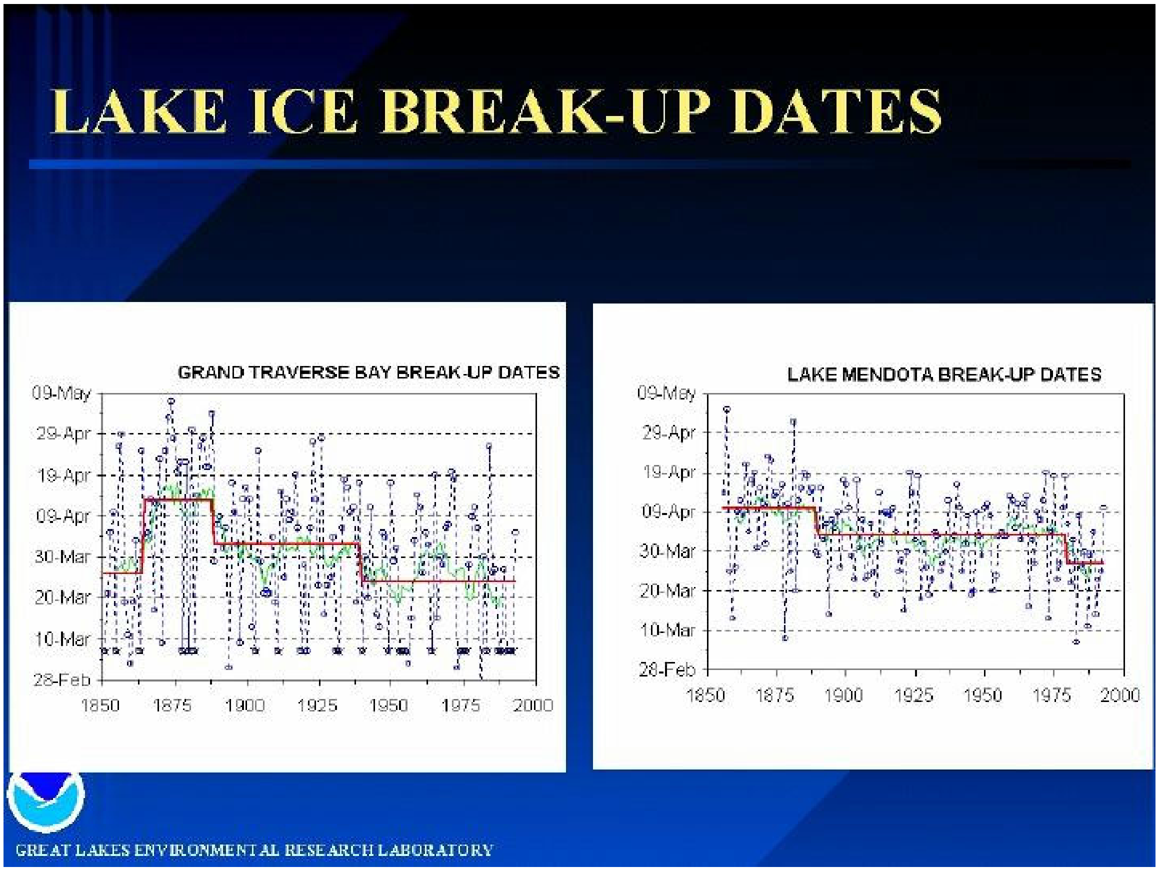
systems that are sensitive to changes in climatic conditions will be affected (Scheraga and Grambsch, 1998).

2.3.1 Changes in Ice Cover

Past studies have suggested that water temperature increases that would accompany climatechange in the Great Lakes region may lead to decreases in the duration and extent of ice cover over the 21st century (Lofgren *et al.,* 2002; National Assessment Synthesis Team, 2001; Quinn *et al.,* 1999; Fang and Stefan, 1998). Such changes would have economic and ecological impacts. Reduced ice cover duration would have feedbacks on lake evaporation, lake levels, and even lake-effect snowfall (by possibly affecting the seasonality of lake-effect snowstorms). A longer ice-free season could translate into hundreds of millions of dollars of additional business revenue, although the shipping cost per ton would likely increase due to lower water levels (Chao, 1999). Ecosystem services that could possibly be lost with a reduction of lake ice include storage of airborne atmospheric particulates until their rapid release in the spring, enhancement of overwinter survival of fish and fish eggs, and protection of the shore against erosion. For the thousands of smaller lakes in the region, changes in the duration and extent of ice cover could eliminate fish winterkill in most shallow lakes, but possibly endanger wildlife, as well as traditional recreational users of these lakes because of reduced ice thickness.

Figure 2-13 demonstrates that changes in the duration and extent of ice cover have already been observed in the Great Lakes region. A 142-year record (1856-1998) of lake ice duration at Lake Mendota in Madison, Wisconsin is presented (National Assessment Synthesis Team, 2000). It shows that lake ice duration has decreased by nearly one month over the past 150 years, with a record low in the winter of 1997-98. This is consistent with observed increases in temperature.

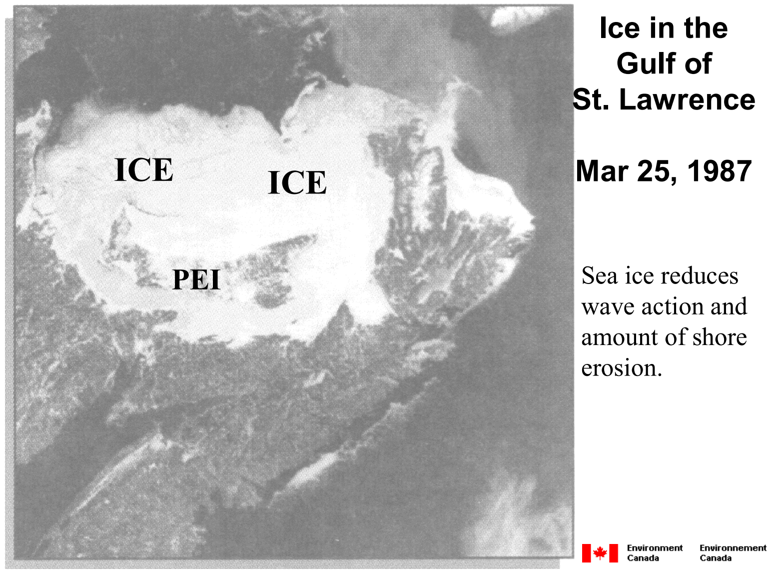
Figure 2-13. Changes in lake ice duration at Lake Mendota, Wisconsin.



Source: National Assessment Synthesis Team, 2000

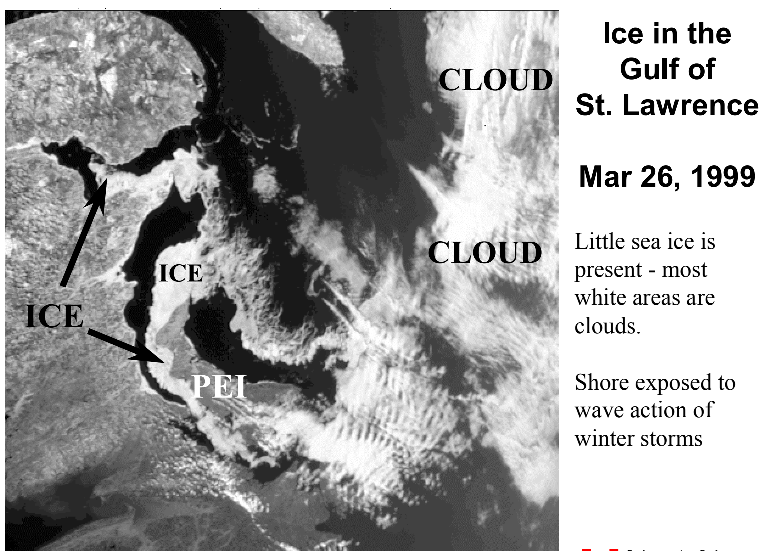
Figures 2-14 and 2-15 present satellite photographs of the Gulf of St. Lawrence, taken 12 years apart. Although one must be careful not to draw conclusions about long-term trends from two observations, the photographs depict dramatic differences in ice cover that were observed 12 years apart in the same location during the month of March. In March 1987, most of the gulf is covered by ice, reducing wave action and the amount of shore erosion, while on March 26, 1999, little sea ice is present, exposing the shore to wave action produced by winter storms and increasing the risk of damages to the shoreline.

Figure 2-14. Ice in the Gulf of St. Lawrence, March 25, 1987.



Source: Environment Canada

Figure 2-15. Ice in the Gulf of St. Lawrence, March 26, 1999.



Source: Environment Canada

2.3.2 Canadian Port Gains as Ice Diminishes

As the climate changes in the Great Lakes region, shippers are shifting marine routes to Churchill in Manitoba (Brooke, 2000). Churchill is the northernmost industrial harbour in Canada and the only major port on Hudson Bay. For decades, Churchill was not an attractive harbour because of ice hazards. But decreases in the duration and extent of ice cover are making Churchill a more attractive port. By docking at Churchill (population 1,100), ocean-going ships benefit from rail links to the prairie heartlands of Canada and the U.S.

The Canadian Ice Service has measured ice extent on July 15, the benchmark date for the annual start of shipping in Hudson Bay, since 1971. Although there is variability in the amounts, the trend is that over the last three decades the expanse of Hudson Bay ice on that date has decreased by about one third. The ice is gone from the port earlier and forms in the port later.

In 1997, the Denver-based company, Omnitrax Inc., bought the port. They hope to expand the standard insured shipping season from three months to five months, from July 1 to the end of November. Currently, the season is from July 21 to October 21.

In addition to climate change, increased shipping in Churchill is a result of better ice mapping by the Canadian government, better ice detection equipment on ships, and aggressive marketing.

Shipping wheat and other grains grown in the prairies through Churchill saves as much as $20 (U.S.) a tonne in shipping costs compared with the cost of sending grain through its competitor, Thunder Bay, Ontario, the starting point for the Great Lakes and St. Lawrence Seaway system. Since Churchill is the closest port for one-quarter of Canada's prairie farmers, they saved $10 million (U.S.) in international shipping costs in 2000.

Thunder Bay's season is still twice as long as Churchill's. However, shipping through Churchill is often cheaper because there are no seaway fees and grain does not have to be transferred from lake boats to ocean-going vessels. Also, recent dredging increased Churchill's navigation depth, allowing it to handle vessels loaded with 50,000 tonnes of grain, double the loads ocean-going boats at Thunder Bay can carry.

With shippers shifting to Hudson Bay from Thunder Bay, about one third of Thunder Bay's grain tonnage is now being shipped through Churchill – double the average share in the 1990s.

This real example of a manifestation of climate change with significant economic impacts also illustrates how there will be "winners" and "losers" as the climate in the Great Lakes region changes.

2.3.3 Shifts in Bird Ranges and Abundance

A changing climate throughout North America – including the Great Lakes region – is already having direct and indirect effects on birds. Higher temperatures are directly altering their life cycles. The loss of wetlands, beaches, and other habitat could also have an important indirect effect, by making some regions less hospitable to birds than those regions are today.

Many animals already may be responding to local climatic changes. The types of changes already observed include poleward and elevational movement of ranges, changes in animal abundance, changes in body size, and shifts in the timing of events, such as earlier breeding in spring. Possible climatically associated shifts in animal ranges and densities have been noted on many continents and within each major taxonomic group of animals (IPCC, 2001).

Climate and climate change are strong drivers of biotic systems. The distribution and survival of most species are moderated by climate (Root, 1988a,b,c; Martin, 1998; Duellman, 1999).

Although species have responded to climatic changes throughout evolutionary time (Harris, 1993), the primary concern today is the projected rapid rate of change. High species richness appears to be related to stable conditions; abrupt impoverishment of species has occurred during times of rapid change (Tambussi *et al.,* 1993).

As temperatures warm, birds will tend to inhabit more northerly areas (in the Northern Hemisphere). Data collected by the National Audubon Society's Christmas Bird Count show that during years with warmer temperatures, the majority of bird species do not fly as far south for the winter. Warmer temperatures also allow birds to spend their summers farther north. A 1997 study examined the impact of warmer summers on the bobolink (a North American songbird) (Schneider and Root, 1997). During summer, this bird is currently found throughout New England, the states that border the Great Lakes, and north of a line stretching from Missouri to Idaho. With the projected climate changes under a $2xCO_2$ scenario, the bobolink would not be found south of the Great Lakes.

2.3.4 Maple Syrup Industry in the U.S. and Canada

The maple sugar industry represents an important component of both New York's and New England's character and economy. The successful maple syrup season depends on the proper combination of freezing nights and warm daytime temperatures greater than 40 ^oF (4 ^oC). Once a string of days occurs where night-time temperatures no longer fall below freezing, sap flow stops. The first sap flow of the season generally has the highest sugar content and the lowest nitrogen content, resulting in the highest quality syrup of a given season. Therefore, the maple industry in New York and New England depends to a large extent on the timing of these critical climate events.

The maple syrup industry in the U.S. has exhibited a dramatic *decline* since early in the 20th century (New England Regional Assessment Group, 2001). This decline is due to many factors, including climate. Climate impacts, such as drought and ice storms, have resulted in significant local and regional-scale maple tree damage, which has influenced sap flow and syrup production. For example, the ice storms of 1998 appear to have had significant impacts on maple syrup production and tree health in the New York/New England region. In areas where maple stands were affected by the ice storms, moderate to severe damage occurred on 22 % of the trees. Northern New York was severely affected by the ice storms and an average of 26 % of the trees within damaged sugar bushes were severely damaged (80-100 % crown loss). In addition, changes in the freeze/thaw cycle in New York and New England have affected sap flows.

This is another example, however, of how there will be "winners," as well as "losers," as the climate changes (New England Regional Assessment Group, 2001). Over the past 30 years, the Canadian maple industry has shown a dramatic *increase*, also due to many factors, including climate change, aggressive marketing, and the advent of tubing-based methods of sap collection. In the past, the success of the maple syrup industry in Canada was limited by deep snow cover (limiting access to individual trees) and fewer freeze/thaw cycles due to prolonged periods of low night-time and day-time temperatures. The development of tubing-based sap collection methods that provide easier access to trees and early initial flows and warmer night-time temperatures (fewer freeze/thaw cycles and reduced cold recharge periods) across New York and New England over the past two decades, have resulted in a shift in syrup production to the Gaspé Peninsula of Quebec.

The increased Canadian production of maple syrup has increased market competition with the U.S. Canadian production of maple syrup has tripled since the 1970s.

Most disturbing are the results of ecological modeling efforts that show the changes in climate could potentially eradicate the sugar maple within New England. The maple syrup industry is an important part of the New England and New York character, way of life, and economy that, because it is highly dependent upon prevailing climatic conditions, may be irreparably altered under a changing climate.

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3.0 CONSEQUENCES OF REGIONAL CLIMATE CHANGE: OVERVIEW OF POTENTIAL IMPACTS

This section provides a general overview of the potential changes in climate and the associated effects on ecosystems and human activities within the Great Lakes watershed. Impacts to water quantity and water quality as well as impacts to quality of life (human health), resource use (*e.g.* forestry) and ecosystem health are key sustainability issues for the Great Lakes region.

3.1 APPROACHES FOR THINKING ABOUT FUTURE CHANGES IN CLIMATE

Confident predictions of the future state of the climate are not possible because of the complexity of the climate system and the social and economic drivers of global change as well as inherent uncertainties and indeterminacies. Recognizing this, a variety of techniques have been used to develop "climate scenarios" for climate change impact and adaptation assessments. Scenarios are developed from global climate models (GCMs), regional climate models (RCMs), downscaling, analogues (spatial and temporal), and systematic changes to observed climate data. Numerous resources provide guidance on climate scenario development (Rosenberg *et al.,* 1993; Wilby and Wigley, 1997; IPCC, 1999; Beersma *et al.,* 2000; CCIS, 2002).

Most climate change impact assessments in the Great Lakes region have used GCM scenarios (Croley, 1990; Chao, 1999; Mortsch *et al.,* 2000; Lofgren *et al.*, 2002). GCM scenarios are currently the best tools for understanding the human-caused influence on enhancing the greenhouse effect. RCMs, when they are available, will be even more useful because of their smaller scale. Spatial analogues have been used (Mortsch and Quinn, 1996; Croley *et al.,* 1998; Kunkel *et al.,* 1998). Historical/temporal analogues (usually of extremes) and systematic changes to climate variables have been used infrequently (Schwartz, 2001). The benefit of these techniques is that they can explore vulnerability or sensitivity to current climate extremes and thresholds of changes. These scenarios are described in more detail in Appendix A.

3.2 PROJECTED CHANGES IN CLIMATE

Many attributes of the climate system in the Great Lakes watershed are projected to change. Key changes discussed include:

- Air temperatures increase.
- Daily air temperature range may decrease.
- Total annual precipitation increases but precipitation during key seasons may decrease.
- More precipitation may fall as rain and less as snow.
- Intensity of precipitation events may increase.
- Potential evapotranspiration increases with warmer air temperatures.

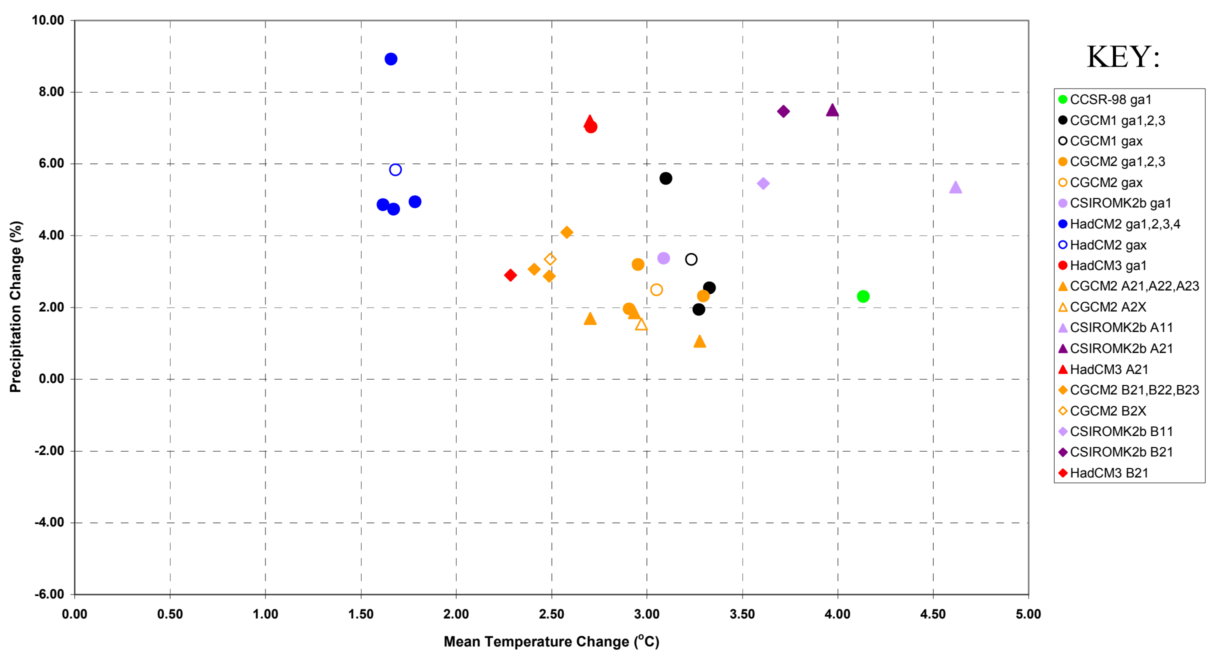
3.2.1 Air Temperature

Air temperatures increase.

All GCM scenarios showed an increase in annual and seasonal mean temperatures for the Great Lakes watershed (Figure 3-1 and Appendix B for the seasons). Spring (0.75 to 5.0 °C) had the greatest range in temperature increase while summer had the least (1.5 to 4.0 °C).

Air temperature has an important role in defining the range limits of species through length of the growing season, the frost-free season and other important temperature thresholds. It affects freeze and thaw cycles, the rate of chemical reactions, and biological productivity. Cold temperatures often limit pests and diseases. Increases in air temperature can drive other changes such as water surface temperatures.

Figure 3-1. Basin-wide annual temperature change (°C) versus annual precipitation change (%) for a number of GCMs using a range of emission scenarios (SRES and IS92a) for 2050, relative to 1961 – 1990.



Source: CICS, 2002

Daily air temperature range may decrease.

Numerous GCM experiments have determined that the daily temperature range, the difference between the daily high and daily low temperature, tends to decrease with increasing greenhouse gas forcing and aerosol cooling. For example, in the Canadian CGCM1 decreases are greatest during the winter while significant decreases also occur in spring and fall (Stone and Weaver, 2002).

3.2.2 Precipitation

Total annual precipitation increases but precipitation during key seasons may decrease.

Annual average precipitation increases in all scenarios (see Figure 3-1); however, precipitation change is not consistent throughout all seasons (see Appendix B – Figures B-1 to B-4). All winter and spring scenarios have consistent increases in precipitation. Summer has some modest increases but half the scenarios show a decrease in precipitation. In autumn, about one third of the scenarios have precipitation decreases.

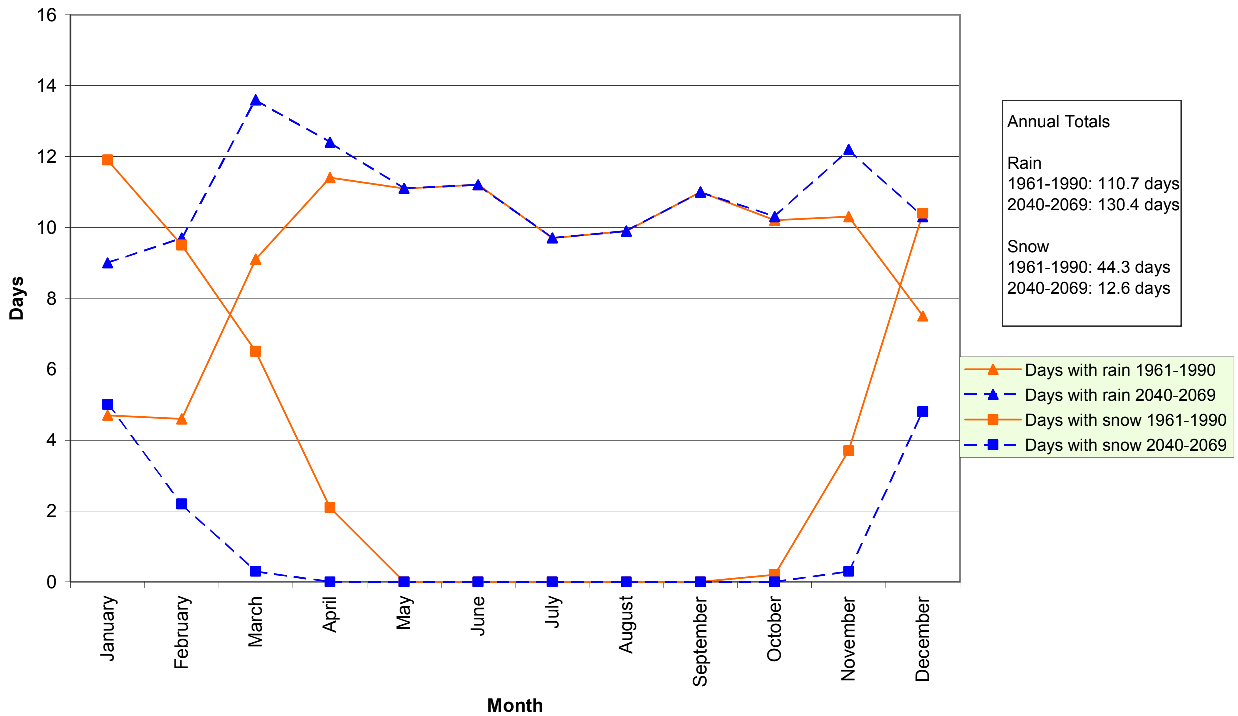
Changes in precipitation, combined with temperature increases, will influence soil moisture, ground water recharge, and runoff in the Great Lakes watershed. The critical factor for water availability is whether projected increases in precipitation will be offset by more water loss due to higher evaporation. From a hydrologic perspective, the potential for decreases in precipitation during the summer and autumn is significant. In the basin, these seasons are typically characterized by low stream flow. In some scenarios, low flow conditions could become more extreme and Great Lakes residents and activities could become more vulnerable to water supply and demand mismatches in summer and autumn.

More precipitation may fall as rain and less as snow.

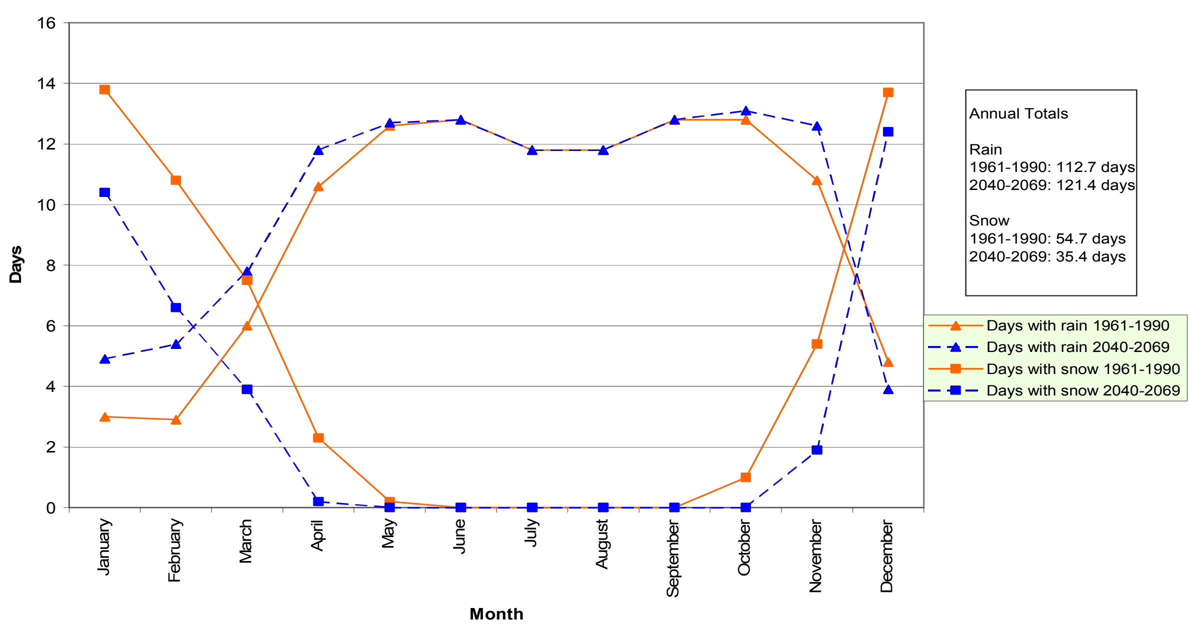
In the more southerly parts of Canada, such as the Great Lakes watershed, warmer air temperatures in winter and early spring affect the frequency of temperatures rising above the 0^{o}C threshold and precipitation that previously fell as snow may fall as rain. The sensitivity of the form of precipitation to a changing climate is illustrated in Figure 3-2. A 2050 scenario shows that the number of days with snow decreases and days with rain increases relative to 1961-90. As a result, more runoff may occur in winter; less snow may accumulate and it may become more intermittent.

Figure 3-2. Comparison of days with rain and days with snow for selected Canadian stations for current climate (1961-1990) and 2050 scenario climate from the CGCM1.

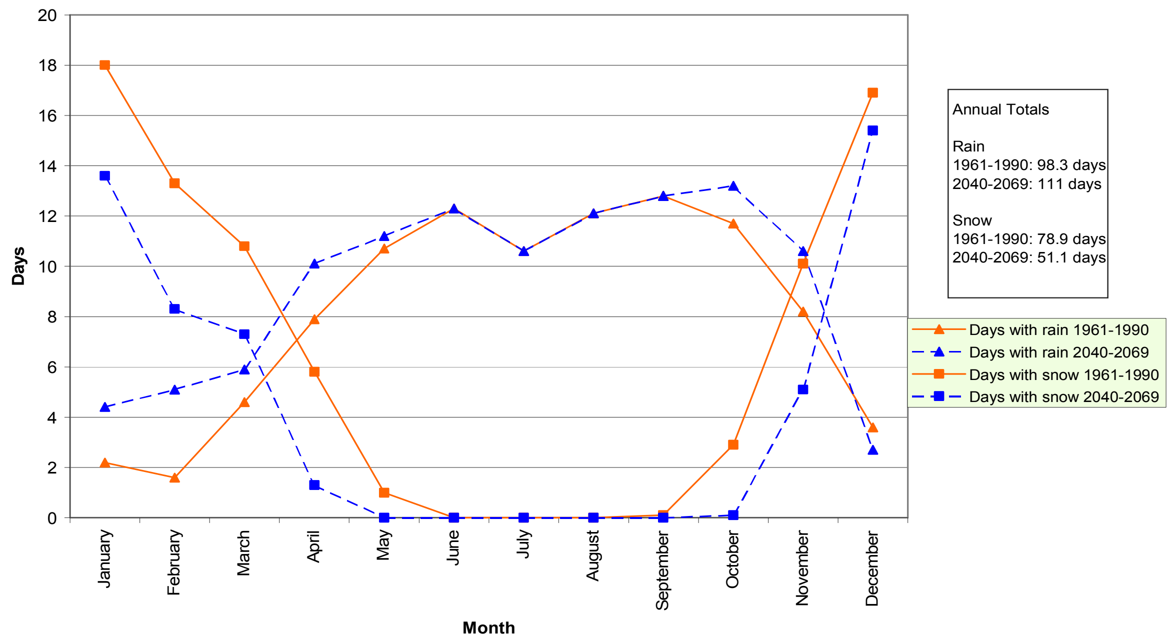
A. Windsor, Ontario (Station # 6139525)



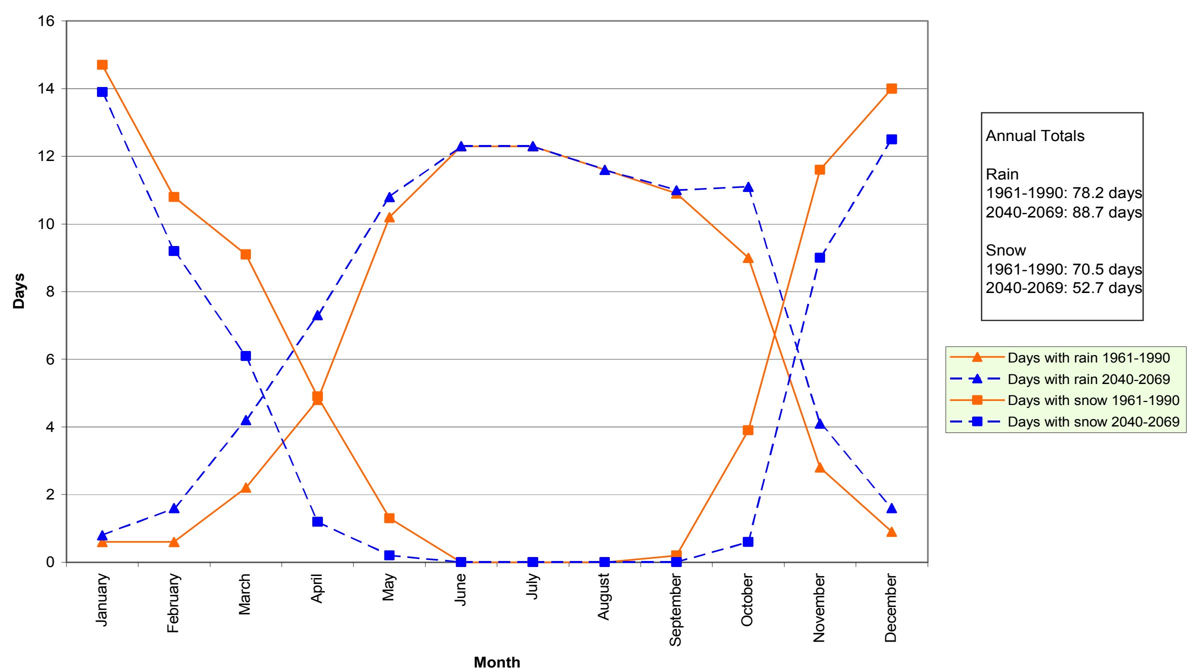
B. Ottawa, Ontario (Station #6105976)



C. Sudbury, Ontario (Station #6068150)



D. Kenora, Ontario (Station #6034075)



Intensity of precipitation events may increase.
Extreme precipitation is expected to increase in a warmer world; this is consistent with a warmer atmosphere having a greater moisture-holding capacity (Trenberth, 1999; Kharin and Zwiers, 2000). Moderate and heavy precipitation depends primarily upon the moisture already in the atmosphere with advection and re-supply of moisture by storm circulation also playing a role (Trenberth, 1999).

Analyses of precipitation extremes in GCMs and RCMs indicate more heavy precipitation events, fewer moderate events and more dry days or days with light precipitation (Cubasch *et al.,* 1995; Hennessy *et al.,* 1997; Jones *et al.,* 1997 in Trenberth, 1999; Trenberth, 1999). On a global scale, Kharin and Zwiers (2000: 3784) report that the 20-year return values of daily precipitation increased by 8 % and 14 % in 2040-2060 and 2080-2100, respectively, while the global precipitation rate increased by 1 % and 4 % during the same period.

Changes in precipitation intensity can increase the risk of soil erosion, land and water quality degradation, flooding, and infrastructure failure. In urban areas, longer periods of dry weather between rainfall events allow more pollutants to accumulate on road and land surfaces. This creates high loadings during the early onset of a precipitation event.

3.2.3 Evaporation/Evapotranspiration

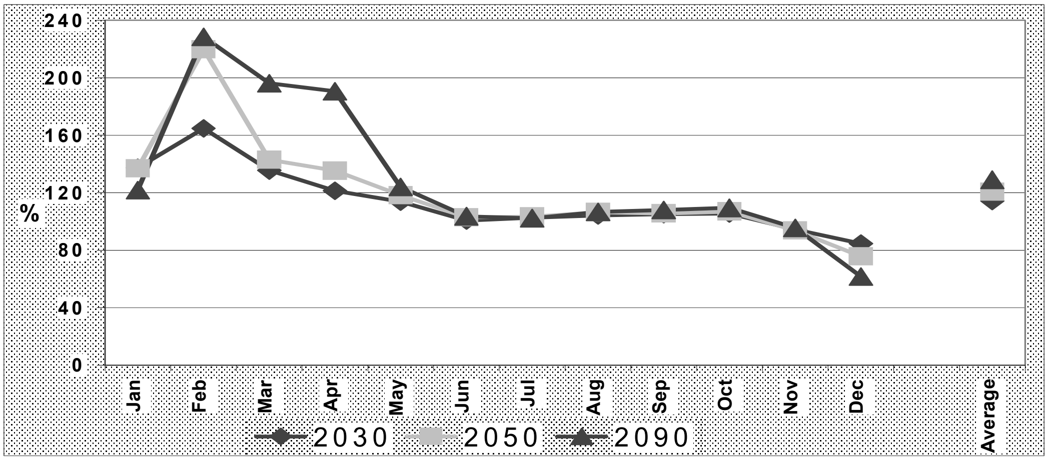
Potential evapotranspiration increases with warmer air temperatures.
As air temperature increases, the moisture-holding capacity of the atmosphere is enhanced. The potential for loss of water to the atmosphere through evaporation/evapotranspiration demand should also increase. Other factors such as wind speed, cloud cover, vapour pressure, and vegetation changes also influence the potential for water loss to the atmosphere, but in a humid region such as the Great Lakes, atmospheric moisture content is the most important factor. Figure 3-3 illustrates the change in potential evapotranspiration for climate change scenarios. Actual evapotranspiration loss, however, is constrained by water availability as soil moisture and ground water.

In a recent impact assessment for the Great Lakes, mean annual lake surface evaporation increased by +6 to +39 % (CGCM1 and HadCM2 scenarios) due to an increase in lake surface temperatures (Lofgren *et al.,* 2002).

3.2.4 Summary

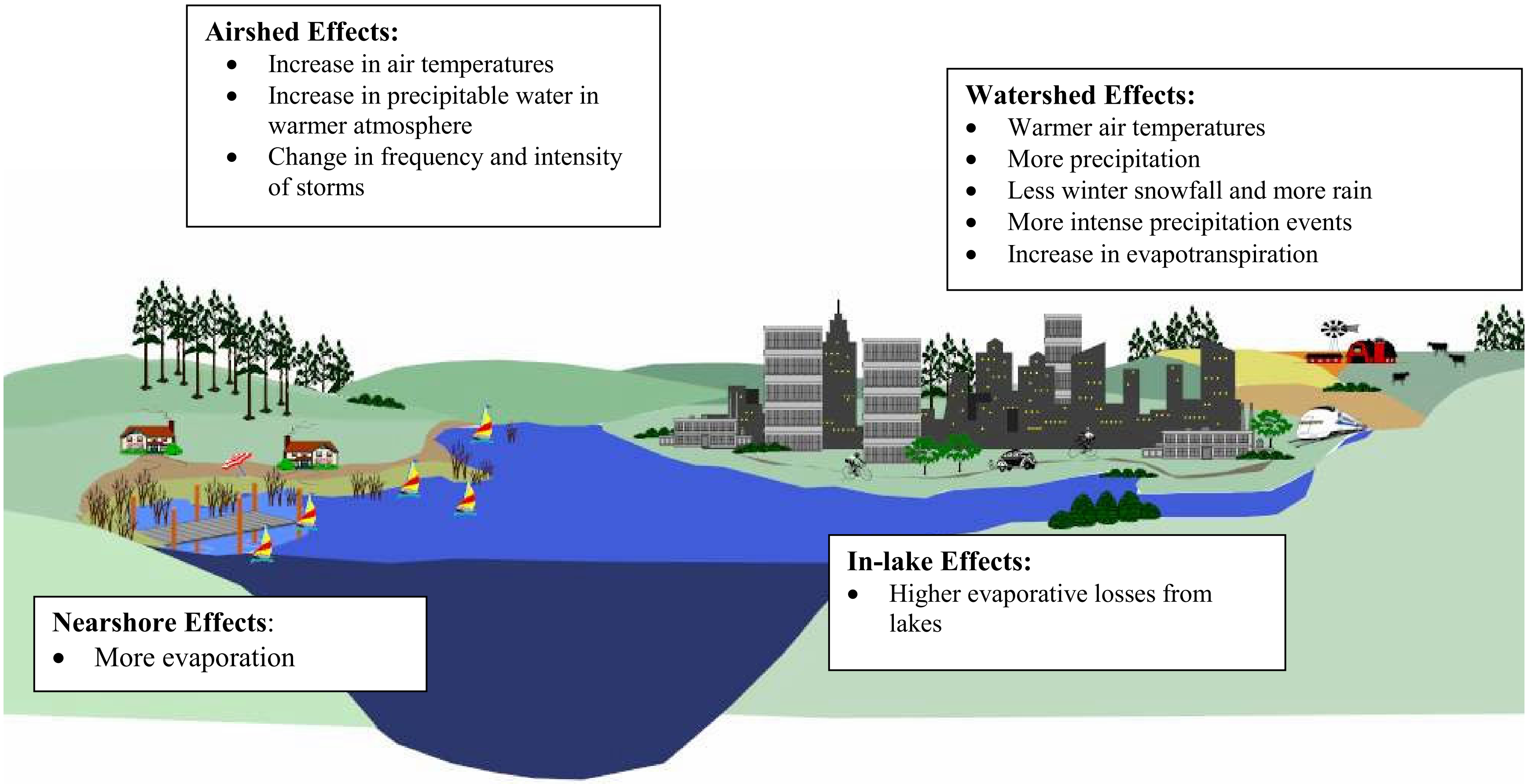
The climate changes discussed in this section are summarized in Figure 3-4 and are categorized into whether their effects influence the airshed, nearshore, watershed, or in-lake regions.

Figure 3-3. Relative change in monthly potential evapotranspiration for the climate change scenarios (CGCM1) for the Bay of Quinte watershed



Source: Walker, 2001

Figure 3-4. Summary of potential changes in climate in the Great Lakes watershed



3.3 IMPACTS OF PROJECTED CHANGES IN CLIMATE

3.3.1 Water Supply

Increasing air temperatures with associated evaporation and evapotranspiration changes as well as alterations to precipitation amount, timing, and duration could lead to more variability of water supply in the Great Lakes region. The frequency of both droughts and flooding are expected to increase. Stream flow, lake levels, and ground water are affected.

Key changes include:

- Annual runoff decreases for most climate change scenarios.
- More runoff may occur in winter.
- Spring freshet may occur earlier and have less flow.
- Summer and fall low flows may be lower and last longer.
- High flows may increase due to extreme precipitation events.
- Ground water recharge and levels may decrease.
- The amount and timing of ground water base flow to streams, lakes, and wetlands may change.
- Water levels in lakes decline.
- Seasonal cycle of water levels is shifting.
- The ice cover season is reduced or eliminated completely.

Stream flow/runoff

A changing climate could have an effect on the magnitude of the mean, minimum, and extreme stream flows as well as their seasonal distribution and duration.

Annual runoff decreases for most climate change scenarios.

The impact of climate change scenarios on runoff reflects the complex interaction between gains due to precipitation increases and losses through more evaporation and transpiration. Timing of these interactions is also important. Most projections are for reductions in runoff for the Great Lakes watershed (Croley 1990; Lofgren *et al.,* 2002). Annual runoff changes for rivers in the Great Lakes basin are summarized in Table 3-1. Decreases in mean annual flow suggest a decrease in stream flow persistence due to a decrease in base flow and higher evapotranspiration.

The implications of mean flow changes range from influences on Great Lakes water levels, in-stream assimilative capacity changes affecting water quality, habitat deterioration, curtailment of water-based recreation, and access to water for irrigation, drinking water, and hydropower.

Table 3-1. Annual runoff changes for selected rivers in the Great Lakes-St. Lawrence watershed

Watershed	River Basin	Impact on Runoff	Annual Runoff Change (percent)			
			Recent transient results (with aerosols) IS92a "business as usual"			Older 2xCO_2 equilibrium results (no aerosols)
			2030	2050	2090	
Lake Ontario	Bay of Quinte, Ontario	Decrease	-6.5 to -11.6	-12.3 to -1.7	- 8.6 to -20.6	-12.0
Lake Erie	Grand River, Ontario	Decrease				-11.0 to –22.0
St. Lawrence River	Moisie River, Québec	Decrease and increase		+0.6 to +5.7		-5.0

Sources: Slivitzky and Morin, 1996; Walker 2001

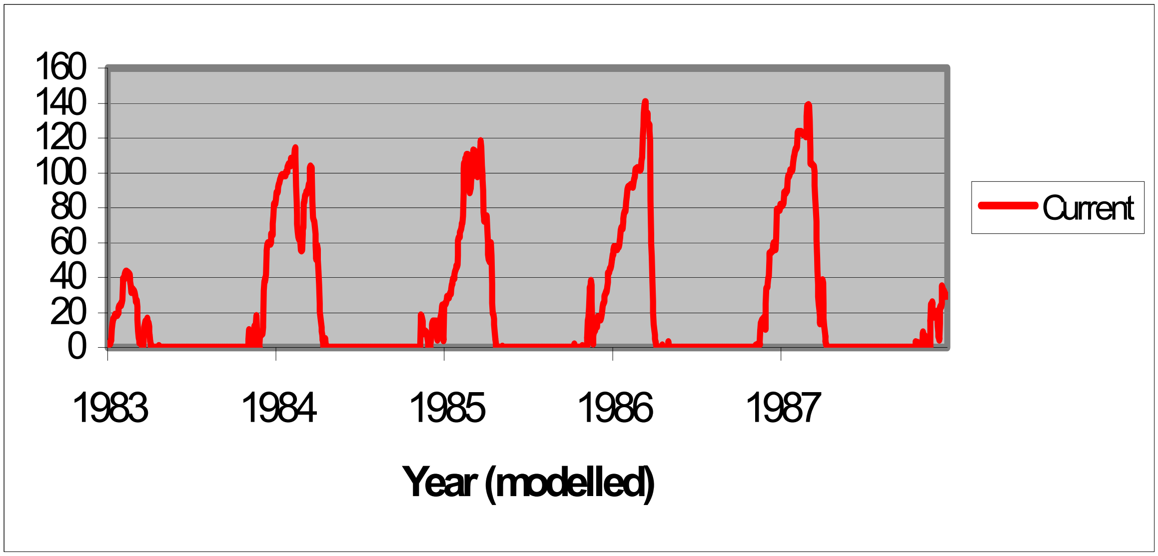
More runoff may occur in winter.

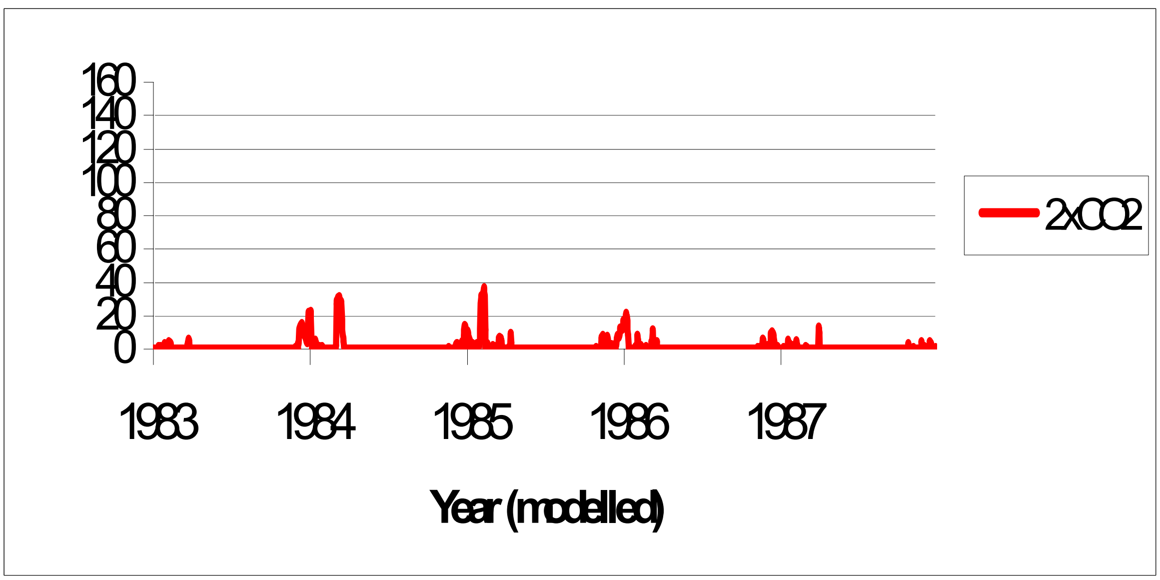
Winter in the Great Lakes region is typically a period with reduced runoff due to frozen conditions; most precipitation falls as snow and is stored in snow pack. Warmer winter temperatures may lead to more winter rainfall events, which create runoff. Often infiltration is reduced at this time due to frozen ground conditions and more overland runoff may occur rather than infiltration. Also, more frequent thaw and freezing episodes could melt the snow pack and contribute to runoff in winter. In response, flow in rivers and streams increase. Winter flooding could be more of a risk.

Spring freshet may occur earlier and have less flow.

A key feature of the hydrology of the Great Lakes region is that winter precipitation is stored in snow pack for a number of months and contributes very little to infiltration and runoff. However, in the spring as temperatures rise above freezing, melt of the snow pack occurs and stream flow increases. Peak flows can be high as the snow cover often melts during a short period. Warmer temperatures throughout the winter may reduce precipitation falling as snow and over-winter storage of precipitation as snow cover. Figure 3-5 illustrates that snow packs may become more intermittent and shallower because of warmer winter temperatures. Earlier spring warming may bring on an earlier melt. Since there may be less snow stored in the snow pack, the amount of water available to runoff and contribute to the peak flow will be less. As a result, an earlier and less pronounced volume of runoff in spring - the freshet - occurs.

Figure 3-5. Changes in snow cover depth (cm) between current climate and $2xCO_2$ climate.





Summer and fall low flows may be lower and last longer.
Flows in the Great Lakes watershed are typically low in late summer and early fall because of the effects of lower soil moisture, increased evapotranspiration and minimal ground water input. However, summer and fall low flows may become even lower due to higher air temperatures, greater evapotranspiration losses, a longer evapotranspiration/evaporation season and reductions in groundwater base flow (Leavesley, 1994).

Table 3-2 summarizes annual and summertime flow reduction at three locations in the Bay of Quinte watershed: the mouth of the Trent River as it enters the Bay, the Gull River (a headwater location), and the outlet of Stony Lake midway in the watershed. Despite small increases in precipitation, flow rates decrease relative to the 1996 baseline due to higher air temperatures and greater potential evapotranspiration. The precipitation for the 2090 scenario is 10 % higher than the 1996 base line and this accounts for a rebound in annual average flow rates from 2050 to 2090. The reductions in annual flow rate are the greatest at the Stony Lake site. It is at the downstream portion of the Kawartha Lakes chain and is sensitive to water management activities and lake evaporation upstream. Summertime flow reductions are very pronounced at all locations. Summer reductions exceed the annual average changes because the GCM climate scenarios have lower summertime rainfall, slightly higher potential evapotranspiration, and warmer air temperatures. The outflow from Stony Lake constitutes most of the flow in the Otonabee River that flows past and assimilates wastewater from the City of Peterborough.

Table 3-2. Changes in annual and summer flow for rivers in the Bay of Quinte watershed under climate change scenarios

Location	Watershed Area (km^2)	Average Flow Rate (m^3/s)	Relative Flow Change (percent)					
			2030		2050		2090	
			Annual	Summer	Annual	Summer	Annual	Summer
Gull River	1,800	21.9	6.5	16.1	12.3	24.2	8.6	28.0
Stony River	7,640	89.5	11.6	30.0	21.7	50.8	20.6	62.5
Trent River	12,500	154	9.1	21.9	18.2	36.9	15.6	55.2

Source: Walker, 2001

High flows may increase due to extreme precipitation events.

More extreme rainfall events, rain on snow, or rapid snowmelt, may cause more extreme runoff events and flooding (Whetton *et al.,* 1993; IPCC, 1996).

3.3.2 Ground Water

Ground water is the source of drinking water for about 30 % of Canadian and U.S. residents in the Great Lakes region. In Ontario, over 90 % of the rural population is supplied by ground water for drinking water as well as irrigation (Grannemann *et al.,* 2000; Piggott *et al.,* 2001). The slow release of water from this underground reservoir provides a reliable, minimum flow of high quality water throughout the year to streams, lakes, and wetlands. This is critical to aquatic habitat. Ground water indirectly contributes more than 50 % of the flow in streams discharging to the Great Lakes (Grannemann *et al.,* 2000).

Ground water recharge and levels may decrease.

Spatial and temporal changes in temperature (and associated evapotranspiration) and the magnitude and timing of precipitation and snowmelt modify infiltration of water to aquifers. Both the increased frequency of droughts and heavy precipitation due to a changing climate can reduce recharge and water levels in aquifers. Shallow aquifers consisting of unconsolidated sediments, weathered or fractured bedrock are more vulnerable to these changes in the short term whereas deeper aquifers will only exhibit changes in the long term.

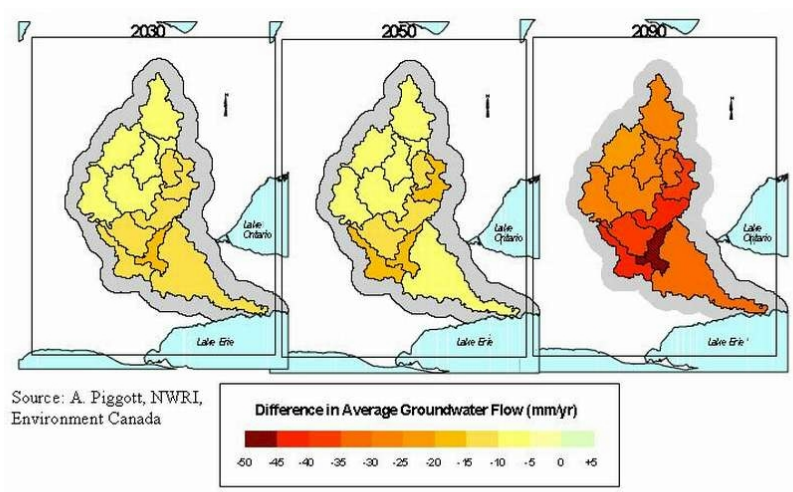
Less rainfall, higher evapotranspiration losses, and lower soil moisture during droughts reduce recharge and lower water levels in aquifers. Development of dry, crusty tops on soils can impede infiltration once rain occurs. Drought-like conditions in Ontario from 1997 to 2000 revealed the vulnerability of southern Ontario rural areas to reduced ground water levels; some areas had reductions while others suffered a complete loss of water supply (Piggott *et al.*, 2001).

In extreme precipitation events, much of the precipitation is lost as overland flow or runoff rather than infiltrating to recharge groundwater (Soil and Water Conservation Society, 2003). Although a changing climate may result in higher total annual precipitation, this may not correspond to an increase in actual aquifer recharge (Nastev *et al.,* 2002).

The amount and timing of ground water base flow to streams, lakes, and wetlands may change.

Two climate change scenarios were applied to a network of 174 southwestern Ontario watersheds to determine potential impacts on groundwater conditions. For the total annual base flow, the Canadian CGCM1 scenario projected an average decrease of 19 %, while the UK HadCM2 projected a modest 3 % increase (Piggott *et al.,* 2001). Both scenarios projected similar changes in the annual distribution of base flow; flow increased during the winter (less snow accumulation and more winter rain and runoff) and flow decreased during the spring and early summer. On a smaller scale, a study on the Grand River watershed in Canada also projected decreases in ground water flow (see Figure 3-6.) A U.S.-based assessment of the sensitivity of Lansing's regional ground water supply to climate change reported similar base flow changes (Lofgren *et al.,* 2002). Base flow decreased by 19.7 % with the CGCM1 (2030 scenario) while it increased by 4.1 % with the HadCM2 scenario. Ground water contribution to local stream flow was also influenced (-32 % CGCM1 2030 scenario and +6 % HadCM2 2030 scenario).

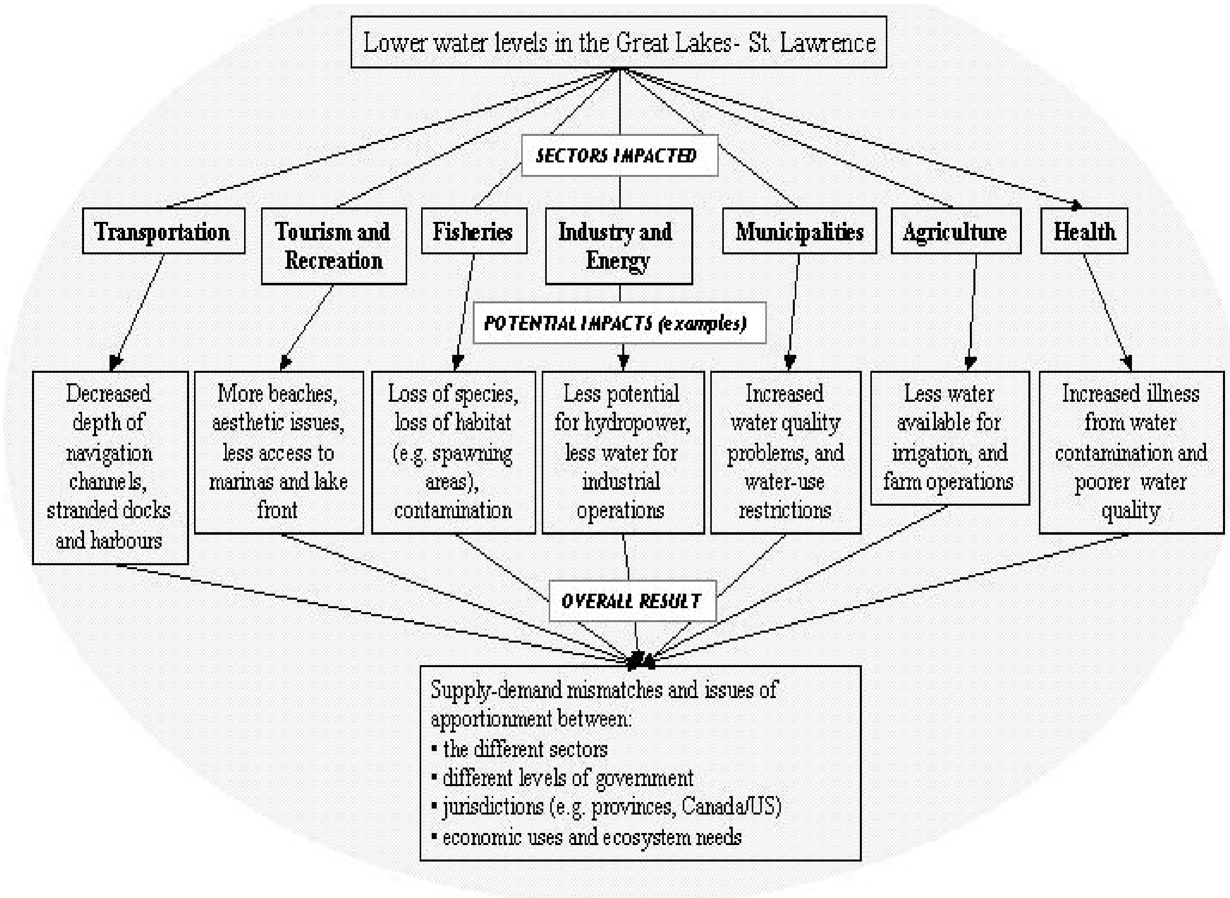
Figure 3-6. Projected CCCma differences in average ground water flow (mm/yr) for 2030, 2050, and 2090



3.3.3 Great Lakes Water Levels

A changing climate has a high likelihood of lowering water levels in the Great Lakes. Figure 3-7 illustrates the crosscutting implications of a reduction in levels for ecosystems, economic activity, and policy development in the region.

Figure 3-7. Inter-connected impacts of lower water levels in the Great Lakes due to a changing climate



Source: Natural Resources Canada, 2003

Water levels in lakes decline.
Most climate change impact assessments project lower net basin supplies and reductions in water levels (see Table 3-3). As a result, the frequency and duration of low water levels could increase; average water levels could be below historic low extremes more frequently. Only the UK HadCM2 scenario, wetter with less warming (see Appendix B), projects future increases in water levels. These water level results reflect the critical balance between the timing and amount of precipitation and higher air temperatures and evapotranspiration.

The low water levels experienced in the Great Lakes during 1999 to 2001 (and the associated issues) could occur more frequently in the future due to a changing climate. Low water level conditions experienced in the summer of 2000 along portions of the Lake Huron shoreline are illustrated in Figure 3-8. The degree of shoreline exposure is a function of water level change and the slope of the shoreline (Wall, 1998). Exposed shoreline and mudflats diminish aesthetics and enjoyment of recreational property. Access for recreational boaters and at marinas is curtailed; safety issues arise. Infrastructure needs to be modified and expenditures made to extend docks and dredge for access. Lower lake levels reduce the risk of flooding, however, interest in developing on the exposed shoreline may increase (Moulton and Cuthbert, 2000).

Low water levels restrict access of commercial navigation vessels in shipping channels, locks, and ports. The Great Lakes shipping industry adapts by decreasing cargo to maintain draft for access to ports and shipping lanes and making more trips to carry cargo. However, costs to the shipping industry as well as their customers increase.

Dredging is a common response to low water levels but it is expensive. A climate impact assessment of water level change on Goderich, Ontario found that dredging costs for the harbour could be as high as $6.84 million (CAD) (Schwartz, 2001). The estimated cost of compensating for a 1.25 to 2.5 metre drop in the 101-kilometre stretch of the Illinois shoreline, including Chicago, entailed expenditures of $251 to $515 million (U.S.) over 50 years (Changnon *et al.,* 1989). This included harbour dredging as well as costs for refitting bulkheads, slips, and docks. Sometimes it is not feasible to dredge. The Welland Canal is underlain by rock and deepening would entail a multi-year project with drilling and blasting (Lindeberg and Albercook, 2000). Ironically, in the long term, dredging in connecting channels has the effect of further reducing water levels as more water flows through the dredged channel.

Dredging raises environmental and human health concerns particularly where there may be contaminated sediment (Rhodes and Wiley, 1993). Improperly conducted dredging can resuspend material that has been “stored” in the sediments. Disposal of the dredged material raises issues of designating sites, ensuring the safe and secure containment of materials, and costs.

Hydroelectric power production is reduced by lower water levels and reductions in connecting channel flows.

Seasonal cycle of water levels is shifting.
Lake levels in the Great Lakes typically progress through an annual cycle of high and low that ranges from 30 to 50 centimetres. Minimum levels occur in late autumn and early winter; they rise in spring with snowmelt and reach a maximum in July to September (depending on the

lake). Then, they decline in autumn due to evaporation and reduction in runoff. A changing climate could increase winter rainfall events creating more runoff in winter. The spring water level rise may occur sooner due to warmer springs, but the maximum level attained may be reduced because of less snow to melt and more evaporation. The fall decline may occur earlier and the minimum may be lower due to reduced runoff to the lakes during summer and fall.

Distinct shifts are being detected in the seasonal cycle of water levels for the Great Lakes. In Lakes Erie and Ontario, during the period from 1860 to 1990, the annual rise and fall of levels occurred approximately one month earlier; spring levels are becoming higher and fall levels are becoming lower sooner (Lenters, 2001). Michigan-Huron exhibited a change in the timing and range of the seasonal water level cycle since 1860 (Argyilan and Forman, in press). The largest changes were detecting in the transition from winter to spring. Levels were higher in winter and reflected a shift, since 1965, to more runoff in winter and less spring runoff. In Lake Superior, summer and fall levels are decreasing (typically the high period) while spring and winter levels remain roughly the same. The amplitude of the seasonal cycle has decreased.

A change in the seasonal cycle has ecological implications (Mortsch, 1998). For example, wetland vegetation relies on patterns of water level change to encourage particular vegetation growth. Fish spawning could be affected through curtailed access to spawning beds and exposure of eggs once they are laid.

Table 3-3. GCM climate change scenario impacts on mean annual water level - changes from reference level.

	Lake level changes (difference from base – in centimetres)									
	Recent transient results (with aerosols) IS92a "business as usual"						Older 2xCO_2 equilibrium results (no aerosols)			
	Canadian (CGCM1)			UK (HadCM2)			Canadian CCC	U.S. GFDL	U.S. GISS	U.S. OSU
Lake / River	**2030**	**2050**	**2090**	**2030**	**2050**	**2090**				
Superior	-22	-31	-42	+4	-1	+11	-23	-	-46	-47
Michigan-Huron	-72	-101	-138	+14	+3	+35	-162	-248	-131	-99
Erie	-60	-83	-113	+11	+4	+27	-136	-191	-116	-87
Ontario	-35	-53	-99	+25	+4	+1	-130	-	-	-
St. Lawrence at Montreal	-	-	-	-	-	-	-130	-	-	-

Sources: Mortsch *et al.,* 2000; Lofgren *et al.*, 2002

Figure 3-8. Honey Harbour shoreline during low water levels of 2000 illustrates vulnerability.

3.3.4 Ice Cover

The ice cover season is reduced or eliminated completely.

Climate warming could shorten the duration of the ice season on the lakes and reduce the extent of ice cover or even result in ice-free winters. Lofgren *et al.* (2002) reported significant reductions in ice duration and extent on Lakes Erie and Superior. For the CGCM1 scenario, reductions ranged from 12 to 47 days (2030 scenario), 16 to 52 days (2050 scenario) and 37 to 81 days (2090 scenario). Earlier assessments of these lakes with three 2xCO_2 scenarios projected that the average ice duration could decrease by five to 13 weeks (Assel, 1991). The maximum ice cover extent demonstrates the influence of a lake's thermal capacity and is less sensitive to warming on Lake Erie than on Lake Superior (Lofgren *et al.*, 2002).

Changes in duration of ice can have impacts on evaporation, lake levels, and lake effect snow. Ice cover acts as a barrier, cutting off interaction between the atmosphere and the lakes. The greatest evaporative losses from the Great Lakes occur in late fall and winter when cold, dry air passes over the warmer moist lakes. A longer open water season enhances lake-effect snowfall if air temperatures do not rise above the threshold that prevents the formation of snow (Kunkel *et al.*, 2003). Ice is also important in protecting the shoreline from winter storms, as it is an effective barrier against wave erosion. Ice also has important ecosystem functions such as over winter survival of fish eggs and winter fish kills due to low dissolved oxygen conditions.

3.3.5 Water Quality

Interactions between atmospheric, terrestrial, and aquatic processes in a watershed as well as the human use of resources affect water quality. Climate change will influence these components leading to direct and indirect changes in water quality.

Murdoch *et al.* (2000) produced an extensive review of the impact of climate change on water quality in North America. The implications of an increase in temperature and a decrease in moisture (temperature increases and evapotranspiration exceed increases in precipitation) were reviewed. Effects relevant to the Great Lakes watershed are summarized in Tables 3-4 and 3-5.

Table 3-4. Effects of increased air temperature on factors that control water quality.

Hydrologic Factors	Terrestrial Factors
INCREASED WATER TEMPERATURE **- Decreased oxygen-carrying capacity** • *Increased anoxia in eutrophic waters* • *Earlier, more intense lake stratification, warmer epilimnion* • *Temperate dimictic lakes become monomictic (more productive)* • *Cold monomictic lakes become stratified (less productive)* **- Decreased volume of water for dilution of chemical inputs** **- Increased concentration of nutrients and pollutants** **- Decreased ice cover, ice jam flooding, and depth of lake freezing** • *Increased nutrient and chemical cycling*	**VEGETATION CHANGE** **- Species distribution changes** • *Changes in nutrient leaching rates* **- Invasion by temperature-sensitive exotic species, pests** • *Shifts in nutrient cycling, carbon storage* **- Soil change: increased microbial processing rates in soils** • *Increased leaching of nitrate to surface waters*
INCREASED RATES OF PRODUCTIVITY, DECOMPOSITION AND CHEMICAL REACTIONS **- Longer growing season and faster metabolic rates** • *Decreased bioavailable carbon* • *Increased nutrient and mineral cycling* **- Larger epilimnion volume (lake thermoclines are deeper)** • *Increased biologically active zone: increased nutrient cycling* **- Warmer hypolimnion water and sediment** • *Increased chemical reactions between water and sediment* **- Increased biological processing of toxins and other contaminants** • *Decreased concentration of toxins and contaminants* • *Increased nutrient uptake and bioaccumulation in sediment*	
DECREASED WATER VOLUME FOR DILUTION OF CHEMICAL INPUTS - Increased concentration of nutrients and pollutants	
INVASION BY TEMPERATURE-SENSITIVE EXOTIC SPECIES **- Increased algal blooms, macrophyte recycling**	

Source: modified from Murdoch *et al.,* 2000.

Table 3-5. Effects of increased air temperature and decreased moisture on factors that control water quality.

Hydrologic Factors	Terrestrial Factors
INCREASES IN TEMPERATURE CAUSED BY DECREASED FLOW **- Low dissolved oxygen** **- Enhanced in-stream, in-lake chemical processes**	**CHANGES IN EROSION** **- Decreased infiltration rates, increased runoff flashiness** • *More concentrated episodes of non-point source pollutants and sediments*
LOWER GROUND WATER LEVELS AND DECREASED STREAM DISCHARGE (DECREASED DILUTION CAPACITY) **- Decreased export from streams** **- Increased chemical concentrations in streams** **- Increased concentration of point source pollution** **- Increased flushing time for contaminants**	**CHANGES IN CHEMICAL EXPORT FROM WATERSHEDS** **- Decreased weathering and weathering-product exports** • *Decreased base-cation and silica concentrations in streams* **- Decreased soil flushing** • *Delayed sulphate decrease and recovery from acid rain* • *Enhanced nitrate and sulphate export following drought periods* **- Earlier, smaller snowmelt flux** • *Decreased nitrate runoff and surface water acidification*
INCREASED LAKE STRATIFICATION **- Hypolimnetic anoxia in lakes more common** **- Greater sediment biomass accumulation and nutrient release**	**INCREASED FIRE FREQUENCY** **- Short-term increase in nitrate concentrations** **- Removal of vegetation by fire increases sedimentation**

Source: Modified from Murdoch *et al.,* 2000

51

Key implications for water quality discussed in this paper include:

- Warmer water temperatures affect physical, chemical, and biological processes.
- Taste and odour problems in drinking water may increase.
- Periods of thermal stratification may be extended with associated declines in dissolved oxygen.
- Changes in mixing depth affect productivity.
- Non-point source pollution increases with higher intensity precipitation events.
- Climate change may make it significantly more costly to meet water quality goals.
- Water quality remediation targets may not be met.

Warmer water temperatures affect physical, chemical, and biological processes.
As air temperature increases, water temperatures in rivers, streams, lakes, reservoirs, and ground water are also expected to mirror that rise. Warmer water temperatures reduce dissolved oxygen concentrations, which are a critical aquatic ecosystem requirement. Changes in rate of chemical reactions in the water column, sediment-water interface, and water-atmosphere interface are also expected.

In Lake Superior, the deepest coldest lake, average annual surface water temperatures could increase 5 ^oC by 2100 (CGCM1 and HadCM2 scenarios). Summer maximum surface water temperatures could be greater than 20 ^oC (68 ^oF) (Lehman, 2003). Bottom water temperatures also increase but not as dramatically. Higher bottom water temperatures increase the metabolic rates of invertebrates and microbes and accelerate dissolved oxygen use (Lehman, 2003).

Warming may result in water temperature thresholds being reached for certain species. Breeding windows may be compressed or shifted. Optimum temperatures for lake trout spawning in the autumn is 8 ^oC to 11 ^oC (46 ^oF to 52 ^oF) and spring spawning for northern pike is 4 ^oC to 12 ^oC (39 ^oF to 54 ^oF); warming could affect timing. Similarly, other developmental responses that are cued by temperature could be affected. Although metabolism changes and growth rates of species are important implications, the more serious biological concern is invasion by southerly species (Lehman, 2003).

Ground water discharge plays an important role in maintaining cooler water temperatures in streams; this cooling effect could be reduced as ground water temperatures are expected to warm with increases in air temperature (Meisner *et al.,* 1988). Cold-water fish could lose important habitat as temperatures rise above their thermal thresholds (Meisner, 1990). Shading by riparian vegetation could offset this effect.

A water quality sensitivity analysis for the Grand River in Ontario showed that, in conjunction with nutrient loading, the dissolved oxygen levels in this eutrophic system were more sensitive to changes in water temperature, particularly over-night water temperature, than to changes in flow. Similar relationships were observed during the 1998 and 1999 droughts. Reduction/ control of water temperature pollution may require a higher degree of consideration in the future (Minshall, 2000).

The temperature of the water released from dams is dependent on whether the water is removed from warmer top of the reservoir (epilimnion) or the cooler bottom waters of the hypolimnion. Release of cold reservoir water can influence water temperatures 48 kilometres downstream in small, shaded Minnesota streams but the distance is shortened by 25 to 50 % in a $2xCO_2$ scenario (Sinokrot *et al.,* 1995).

Taste and odour problems in drinking water may increase.
Phytoplankton community composition in lakes is influenced by water temperature; blue-green algae dominate at the highest temperatures, followed by green algae, then flagellates and finally diatoms at lowest temperatures (Magnuson *et al.,* 1997). Blue-green algae have been associated with taste and odour problems in drinking water during the summer (Anderson and Quartermaine, 1998). Fishy, grassy, or earthy-musty odours occur. Warmer water temperatures may increase algal blooms and may require changes to the water supply system as well as water treatment processes. Various methods, granular-activated carbon and powder-activated carbon, can be used but water treatment costs increase (Johnson, 2001).

Periods of thermal stratification may be extended with associated declines in dissolved oxygen.
As air temperatures increase, water temperatures also warm leading to changes in thermal-density driven mixing dynamics. These effects were modelled by Blumberg and DiToro (1990) for Lake Erie and McCormick (1990) for Lake Michigan, while Lehman (2003) assessed the impact on all Great Lakes; $2xCO_2$ scenarios were used in the first two studies and transient scenarios (CGCM1 and HadCM2) in the other. Warming led to longer summer stratification (by up to two months). Other implications reported include: surface waters warm more than bottom waters, a sharper temperature gradient occurs in the thermocline, physical exchange with the deep bottom waters decreases (McCormick 1990), bottom water temperatures increase (above 4 ^{o}C in 2090 for most lakes), sediment temperatures are warmer (Lehman, 2003), and dissolved oxygen in hypolimnetic water is depleted (Blumberg and DiToro, 1990; Lehman, 2003). Lake Superior exhibits the greatest relative changes while Lake Erie exhibits the least. Vulnerability to oxygen depletion in the lake bottom waters can be estimated using lake geometry ratios (relating surface area to maximum depth); Lake Ontario may be the most sensitive to hypolimnetic oxygen depletion, then Lake Superior, and then Lake Michigan (Lehman, 2003).

Changes in mixing depth affect productivity.
With increased stability of the thermocline, there may be less mixing and cycling of nutrients from the bottom waters. Offshore areas are more dependent upon annual density-temperature driven mixing to bring up nutrients from the sediment; longer periods of nutrient limitation could occur (Lehman, 2003). Mixing depth interacts with algal biomass and rates of primary productivity. Most algal biomass is produced in a primary bloom in spring with a secondary bloom in autumn. The spring bloom was projected to diminish if early stratification capped the nutrient supply and increased cloud cover reduced light input for photosynthesis (Brooks and Zastrow, 2003). Fall production could also decrease due to an extension of the stratified period. Nearshore areas may not be as nutrient limited because they receive nutrients from catchment runoff and are exposed to wave and wind mixing (Bootsma, 2001).

Non-point source pollution increases with higher intensity precipitation events.
Climate change is projected to increase the intensity of precipitation events. As precipitation intensity increases, delivery of sediment, sediment-attached pollutants (*e.g.* phosphorus, ammonium, and pesticides), and soluble pollutants (*e.g.* nitrates, phosphorus, and pesticides) to water bodies increases. Precipitation intensity has a greater effect on soil erosion than an increase in the frequency of precipitation events (see Table 3-6). With more intense precipitation events, more pollutants reach watercourses directly and rapidly through surface transport than subsurface (ground water) flow. Soil type, slope, and vegetation cover influence how changes in precipitation intensity and frequency affect soil erosion and runoff. In agricultural areas, timing of planting, harvesting, tillage practices, and nutrient and pesticide applications interact and lead to different vulnerabilities for soil erosion during the seasons. Spring can be a high runoff and pollution-loading period because fertilizer and pesticide application combine with little vegetative cover to increase vulnerability. Episodic water quality problems increase in a changing climate (Soil and Water Conservation Society, 2003).

Table 3-6. Potential effects on soil erosion and runoff from cropland of observed changes in precipitation.

	Increase in Mean Annual Precipitation			
	5%	**10%**	**20%**	**40%**
Change in Erosion				
Increase only frequency of precipitation	4%	9%	17%	34%
Increase only intensity of precipitation	12%	24%	48%	95%
Increase frequency and intensity of precipitation	8%	17%	33%	66%
Change in Runoff				
Increase only frequency of precipitation	6%	13%	26%	51%
Increase only intensity of precipitation	13%	25%	50%	100%
Increase frequency and intensity of precipitation	10%	20%	39%	79%

Source: Pruski and Nearing, 2002 in Soil and Water Conservation Society, 2003.

Climate change may make it significantly more costly to meet water quality goals.
Aside from its direct effects on the hydrology of the Great Lakes, climate change may also affect water quality and the cost of environmental protection. In the United States, current discharge limits for large point sources of pollution are generally based on the U.S. Environmental Protection Agency's (EPA's) evaluation of water treatment technology – in the parlance of the Clean Water Act, the best available technology economically achievable. Hundreds of streams, rivers, and lakes in the Great Lakes region do not meet water quality standards even though most large point sources are already complying with these discharge limits. In such cases, more stringent limits – total maximum daily loads (TMDLs) – must be developed for all the pollutant sources within an impaired water body's watershed. For the point sources, increasing their treatment efficiency to meet TMDLs can be an expensive proposition, and climate change may have the effect of increasing the costs of treatment to meet water quality goals.

Flow in the water body is one of the key determinants in setting TMDLs. In the same way that floods (high flow conditions) can be characterized in terms of recurrence interval (*e.g.* the 100-year flood), so can low flow conditions. Water quality planners use the 10-year recurrence interval low flow (averaged over a seven-day period) as the "design flow," *i.e.* the basis for determining how much pollutant a water body can receive without exceeding a water quality standard – the lower the flow, the more stringent the TMDL. Some simulations of climate change indicate that precipitation patterns are likely to shift and evapotranspiration increases such that drier periods will become more common. This would lead to a shift in flow patterns; for a given stream, the 10-year recurrence interval low flow would become lower than it is now, and TMDLs would need to be more stringent.

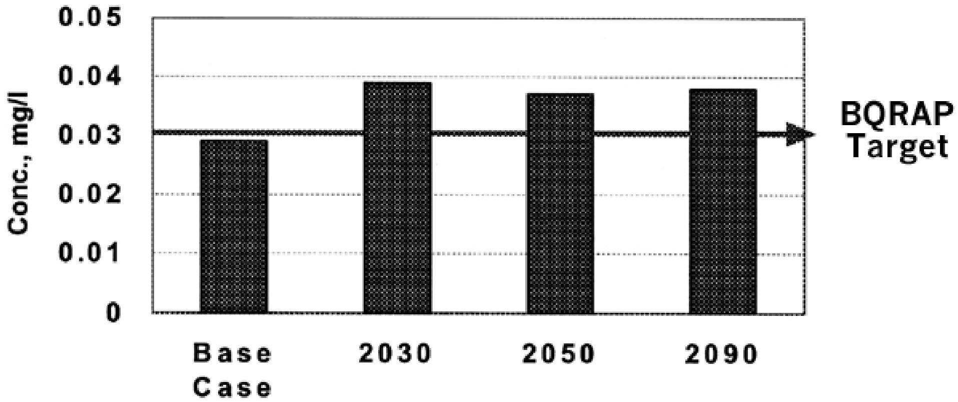
The potential impact of climate change on low flow standards could be substantial. A recent study by Eheart *et al.* (1999) examined a range of climate change scenarios and scenarios of stream-supplied irrigation. Their results suggest that a 25 % decrease in mean precipitation could lead to a 63 % reduction in design flow, even in the absence of irrigation. With irrigation, the reduction could be as much as 100 %. These changes would affect the frequency of single violations and multiple violations of low flow criteria. Single violations could increase several-fold with irrigation, and multiple violations in a three-year period could increase from around 20 % to nearly 100 % as climate change becomes more severe.

The effects of climate change on stream flow could have significant implications for the cost of meeting water quality standards in the United States. Preliminary results from a screening study being conducted by U.S. EPA's Global Change Research Program suggest that even a small reduction in the design flow would have significant cost implications, *i.e.* holding all other factors constant, climate change may make it significantly more costly to meet water quality goals in the Great Lakes region. The study is focusing on 235 publicly owned treatment works (POTWs, or sewage treatment plants) discharging to streams and rivers that are impaired due to organic enrichment and low dissolved oxygen. These POTWs will probably be required to meet TMDLs more stringent than current discharge levels, and the effect of climate change on streamflow could result in even more stringent discharge limitations.

Water quality remediation targets may not be met.

Lower streamflow and higher non-point source runoff results in a phosphorus increase of 25 to 35 % to the Bay of Quinte. Average annual phosphorus projections at the mouth of the Trent River are presented in Figure 3-9 for CGCM1 scenarios. Although runoff is projected to decrease, non-point source loadings of phosphorus increase by about 25 %, 10 %, and 15 % in 2030, 2050, and 2090, respectively. All point source loadings as well as agricultural/livestock and septic system inputs were not modified for future changes. Winter precipitation increases and erosion also increases because precipitation falls as rain on exposed soils. Under 1996 base case conditions, the Bay of Quinte Remedial Action Plan target for phosphorus is achieved on average. However, under the climate change scenarios, the target becomes very difficult to achieve, especially as the more easily managed components of the watershed phosphorus load become a smaller percentage of the total (Walker, 2001).

Figure 3-9. Annual average phosphorus concentration of Bay of Quinte inflow (at the Trent River) for CCCma CGCM1 transient scenarios.



3.3.6 Human Health

Certain health outcomes are known to be associated with weather and/or climate, including: illnesses and deaths associated with temperature; extreme precipitation events; air pollution; water contamination; and diseases carried by mosquitoes, ticks, and rodents. Because human health is intricately bound to weather and the many complex natural systems it affects, it is possible that projected climate change will have measurable impacts, both beneficial and adverse, on health. Projections of the extent and direction of potential impacts of climate variability and change on health are extremely difficult to make because of many confounding and poorly understood factors associated with potential health outcomes, population vulnerability, and adaptation.

Health outcomes in response to climate change are highly uncertain. Currently available information suggests that a range of negative health impacts is possible, although some positive health outcomes (*e.g.* reductions in cold-weather mortality) could occur. In this section, the categories of climate-induced health effects that have received the most attention in the literature are examined: water-borne and food-borne diseases; health effects related to extreme weather events; air pollution-related health effects; heat-related illnesses and death; and vector-borne and rodent-borne diseases.

Key implications for human health discussed in this paper include:

- Water-borne diseases may increase.
- Health effects related to extreme weather events may increase.
- Air pollution-related health effects could intensify.
- The number of heat-related illnesses and deaths may rise.
- Vector-borne and rodent-borne diseases may become more common.

At present, much of the U.S. and Canadian populations are protected against adverse health outcomes associated with weather and/or climate, although certain demographic and geographic populations are at greater risk. Adaptation, primarily through the maintenance and improvement of public health systems and their responsiveness to changing climate conditions and to identify vulnerable subpopulations, should help to protect the U.S. population from adverse health outcomes of projected climate change. The costs, benefits, and availability of resources for such adaptation must be considered, and further research into key knowledge gaps on the relationships between climate/weather and health is needed. (National Assessment Synthesis Team, 2000).

Populations Most Vulnerable to Climate Change Health Threats in the Great Lakes Region

Within the Great Lakes region, the elderly, children, low-income, and immune-compromised individuals already are at higher risk from a variety of environmental hazards, including air pollution, water pollution, heat stroke, and infectious diseases. These same individuals may be more vulnerable to health risks that can be intensified by climate change.

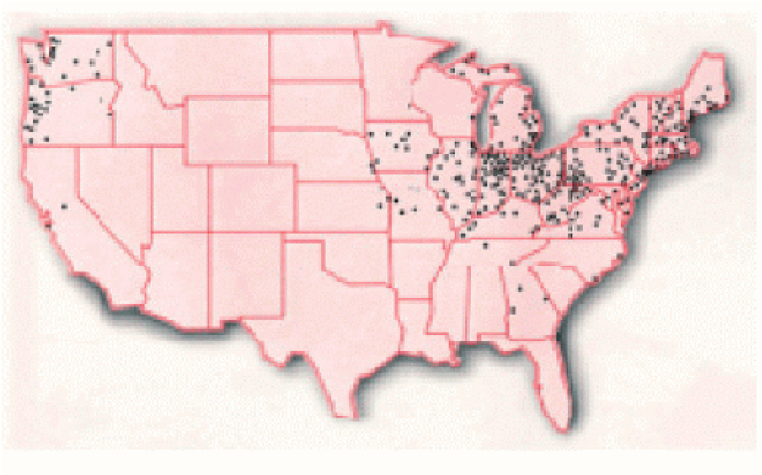
Despite the capacity to adapt in the United States and Canada, one cannot be cavalier about the effectiveness of adaptive strategies when making projections of future vulnerabilities to climate change. As noted in section 5.1.4 of this paper, historic evidence suggests that society has not always successfully adapted to existing risks. For example, public health and emergency infrastructure have experienced difficulties in coping with multiple emergencies and health threats such as floods, ice storms, and disease-causing organisms such as E. coli, coronavirus (SARS), and West Nile virus. The reasons for such shortcomings need to be explored to help improve the design of future adaptation measures.

Water-borne diseases may increase.

Climate change and weather variability in the Great Lakes region pose threats for water-borne diseases, some food-borne diseases, and marine and coastal issues, including harmful algal blooms and ecological disruption. Changes in precipitation, temperature, humidity, salinity, and wind have a measurable effect on the quality of water used for drinking, recreation, and commerce. Heavy rainfall has been associated with water-borne disease outbreaks throughout the United States and Canada.

Although environmental regulations protect much of the U.S. and Canadian populations, current deficiencies in watershed protection and storm drainage systems can increase the risk of contamination events if rainfall increases as projected with climate change. For example, wastewater systems that combine storm water drainage and sewage are still in use in about 950 communities in the United States (Figure 3-10). These systems service both public wastewater and drinking water. Increased storm events could lead to more combined sewage overflow events. During periods of heavy rainfall, these systems discharge excess wastewater directly into surface water bodies that may be used to provide public drinking water.

Figure 3-10. Location of combined wastewater systems in the United States (National Assessment Synthesis Team, 2000).



Also, many experts agree that the Canadian population is not as well protected from water-borne illness as it could be. Coast-to-coast enforceability of drinking water standards in all jurisdictions and the evolution of a preventive quality management approach would better protect public health, and would foster greater adaptability to changing conditions.

Strategies that could reduce the risks of water-borne diseases include:

- Improved surveillance for infectious diseases.
- Enhanced water systems and improved water systems engineering.
- Watershed protection policies.
- Enforceability of drinking water regulations.
- Water quality management approaches that foster continuous improvement and prevention.

Health effects related to extreme weather events may increase.

Changes in the frequency, timing, intensity, and duration of extreme weather events, such as floods and storms, could have negative health impacts in the Great Lakes region. Potential effects from weather disasters range from acute trauma and drowning to conditions of unsafe water and post-traumatic stress disorder.

The health impacts of floods, storms, and other extreme weather events hinge on a number of factors, the most important being the vulnerabilities of the natural environment and the local population, as well as on their capacity to recover. The location of development in high-risk areas, such as coasts and floodplains, increases a community's vulnerability to extreme weather effects.

Strategies that could reduce the risks from extreme weather events include:

- Emergency response plans with transportation and power back up plans.
- Continued refinements to public early warning systems.
- Improved engineering for flood control.
- Enhanced zoning and building codes.

Air pollution-related health effects could intensify.

Climate change and variability may affect exposure to air pollutants in the Great Lakes region by influencing local weather, changing the distribution and types of airborne allergens, and increasing both human-driven and natural emissions.

The mechanisms by which climate change affects exposures to air pollutants include (1) affecting weather and thereby local and regional pollution concentrations; (2) affecting human-caused emissions; (3) affecting natural sources of air pollutant emissions; and (4) changing the distribution and types of allergens (National Assessment Synthesis Team, 2000).

Warmer and more variable weather may cause increases in ground-level ozone (Figure 3-11). These increases could intensify respiratory diseases by damaging lung tissue, reducing lung function, and sensitizing the respiratory tract to other irritants. More air conditioning use due to warmer temperatures could cause an increase in potentially harmful power plant emissions. Exposure to particulate matter from these and other combustion-related sources can aggravate chronic respiratory and cardiovascular diseases, alter host defences, damage lung tissue, lead to premature death, and possibly contribute to cancer.

Figure 3-11. Ozone concentrations versus maximum temperature (National Assessment Synthesis Team, 2000).

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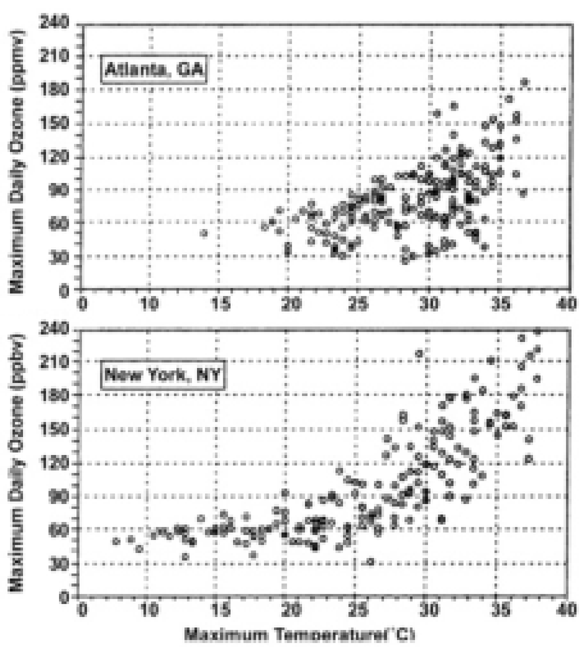


Without knowledge of future emissions in specific places, the success of air pollution policies, and local and regional meteorological scenarios, more specific predictions of exposure to air pollutants and health effects cannot be made with confidence.

Strategies that could reduce the risks from air pollution include:

- Improved early warning systems for air quality.
- Increased use of mass transit.
- Better urban planning.
- Improved pollution control policies.
- Changes to building codes to design cooler buildings.
- More non-emitting energy sources.

The number of heat-related illnesses and deaths may rise.
More frequent heat waves are projected to accompany climate change in the Great Lakes region. In addition, it is expected that average nighttime temperatures will continue to rise faster than average daytime temperatures, removing the possibility of nighttime heat relief for exposed populations.

Studies in urban areas, mostly in temperate regions, show an association between increases in heat and increases in mortality (McGeehin and Mirabelli, 2001). The risk of heat stress may rise as a result of climate change (Kalkstein and Greene, 1997). The most vulnerable populations within heat-sensitive regions are urban populations. They are likely to experience the greatest number of heat-related deaths and illnesses, which include heat cramps, fainting, heat exhaustion, and stroke. Within these vulnerable populations, the elderly, young children, the poor, and people who are bedridden or are on certain medications are at particular risk.

Cities in the Great Lakes region are particularly vulnerable to heat-related illnesses and deaths. High temperatures currently occur infrequently or irregularly in these cities, so people living in these urban areas have not acclimatized to heat to the same degree as populations in more southern cities.

Milder winters could potentially reduce the current level of winter deaths. In general, however, more research is needed to understand the relationship between temperature and winter deaths. Strategies that could reduce the risks of heat-related illnesses and death include:

- Individual behaviour changes, including increased fluid intake and increased use of air conditioning.
- Development of community-wide heat emergency plans.

To be effective, adaptive responses must target these vulnerable regions and demographic groups, some of which may be difficult to reach (Chestnut *et al.*, 1998). For example, the elderly are less likely to perceive excess heat (Blum *et al.*, 1998). They may be socially isolated and physically frail (Semenza *et al.*, 1996; Kilbourne *et al.*, 1982). This may make it difficult to convince them to use air conditioning (*i.e.* because they do not feel the heat) or to travel to air-conditioned environments (*e.g.* they may have no one to take them and may be unable to travel on their own). The poor may not be able to afford air conditioning, and if they live in high crime areas, then they may be afraid to visit cooling shelters. Finally, for infants and young children, decisions about how warmly to dress and how much time to spend in hot environments are often made by adults, with the children and infants unable to effectively communicate their discomfort (Blum *et al.*, 1998).

Vector-borne and rodent-borne diseases may become more common.

Vector-borne diseases result from infections transmitted to humans and other animals by blood-feeding insects, such as mosquitoes, ticks, and fleas. Most vector-borne diseases exhibit a distinct seasonal pattern, which clearly suggests that they are weather sensitive. Specifically, some vector-borne diseases are sensitive to changes in temperature and humidity because the reproductive success and feeding habits of vectors (*e.g.* mosquitoes), as well as pathogen replication within vectors, may be sensitive to temperature and humidity. For example, past St. Louis encephalitis outbreaks have been associated with a pattern of warm, wet winters, cool springs, and hot, dry summers.

Rodent-borne diseases are less directly affected by temperature. However, the impact of weather on disease-carrying rodent populations (for example, increased food supply or exposure during flooding) can affect transmission of diseases such as hantavirus and flea-borne plague.

Case Study: Hantavirus Pulmonary Syndrome in the Southwestern United States

In 1993, a disease characterized by acute respiratory distress with a high death rate (>50 %) among previously healthy persons was identified in the southwestern United States. This disease, hantavirus pulmonary syndrome (HPS), was traced to a virus maintained and transmitted primarily within populations of a common native rodent, the deer mouse.

After the outbreak occurred, researchers hypothesized that it was due to environmental conditions and increased rodent populations caused by unusual weather associated with the El Niño Southern Oscillation (ENSO) in 1991-92. It was suggested that a cascading series of events from weather (unseasonable rains in 1991 and 1992, and the mild winter of 1992), through changes in vegetation, to virus maintenance and transmission within rodent populations, culminated in changes in human disease risk from HPS. Public health officials wanted to understand the cause of the outbreak so they could develop effective techniques for intervening and preventing the disease.

An EPA-sponsored study at The Johns Hopkins School of Hygiene and Public Health explored this hypothesis by comparing the environmental characteristics of sites where people were infected with those sites where people were not infected (Glass *et al.*, 2000). This research found that high-risk areas for HPS can be predicted over 6 months in advance based on satellite-generated risk maps of climate-dependent land cover. Predicted risk paralleled vegetative growth, supporting the hypothesis that heavy rainfall from El Niño in 1992 was associated with higher rodent populations that triggered the Hantavirus outbreak in 1993. Landsat satellite remote sensing images from 1995, a non El Niño “control” year, showed low risk in the region, whereas the images from the 1998 strong El Niño again showed high risk areas as in 1992-93. Trapping mice in the field (collectors blinded to risk category) validated these satellite-generated risk maps with mouse populations directly related to risk level, with a correlation factor of over 0.90. Risk classification also was consistent with the numbers of HPS cases in 1994, 1996, 1998, and 1999.

In general, disease transmission by insects and rodents is a complex process and unique for each disease. Population characteristics, human behaviour, and ecological factors play a critical role in determining when and where disease occurs, which makes it unlikely that increasing temperatures alone will have a major impact on tropical diseases spreading into the United States and Canada. There is even greater uncertainty regarding diseases that cycle through animals and can also infect humans, such as Lyme disease and mosquito-carried encephalitis viruses.

Strategies that could reduce the risks of vector-borne diseases include:
- Improved disease surveillance in humans and animals, vectors.
- Enhanced insect-control programs.
- Reduced human exposure by identifying risk areas or risk behaviours.
- Vaccine development and improved protections for U.S. and Canadian travelers to disease-endemic areas.
- Changed building codes (screens for example).
- Removal of standing water in areas such as parks and fountains.

3.3.7 Natural Ecosystems and Biodiversity

In a changing climate, natural ecosystems will be affected by CO_2 enrichment, changes in timing and amount of precipitation, warmer temperatures, higher evaporation, less water availability, and extreme events. However, it is expected that natural ecosystem responses to a changing climate are likely to be non-linear; change may not occur until a threshold has been reached and then rapid, dramatic transitions may occur (Moll and Hudon, 1998). Ecological surprises are expected. Some species will benefit while others will not. Detailed assessments of impacts on particular species and ecosystem functioning are limited by the complexity and interconnectedness of ecosystems (Fisher *et al.,* 2000).

Nevertheless, some key implications of climate change on natural ecosystems have emerged; they include:

- Biological productivity is expected to increase with moderate temperature increases.
- Zoogeographical boundaries move in a changing climate.
- Introduction of invasive species could be exacerbated.
- Existing community structures and interactions may change.
- A changing climate is expected to lead to reduction in some habitats.
- Wetland vegetation communities, functioning, and values may change.
- Wildlife is susceptible to climate changes.
- Rare and endangered species may be more vulnerable.

Biological productivity is expected to increase with moderate temperature increases.
Earlier warming of spring temperatures and later cooling of temperatures in autumn contribute to an earlier start for plant growth and a longer growing season. If other factors such as

nutrients, water availability, and sunlight are not limited, plant productivity is expected to increase. Terrestrial photosynthetic activity monitored from satellite from 1981-1991 has shown an increase that may be rated to warming. The greatest increases were from 45 ^{o}N to 70 ^{o}N (Myneni *et al.,* 1997).

Zoogeographical boundaries move in a changing climate.
Climate change is projected to alter the fundamental climatic basis for contemporary diversity gradients (based on factors such as energy requirements or temperature thresholds). For example, species currently at the limits of their physiological tolerance to temperature may not persist if climate warming takes local climate beyond their temperature threshold. They will need to migrate in order to remain within a climatically suitable region (Kerr and Packer, 1998). Or, a species may be opportunistic and expand to suitable conditions. Adaptation by migrating assumes that species are able to move rapidly enough to remain within their preferred climate zones even with natural and human-caused barriers. For example, birds, mammals, and annual plants may be able to migrate more easily than fish that are constrained by interconnectedness of water systems and trees that have slow growth rates influencing dispersion.

Range extensions have been observed; the average latitude of occurrence of 43 % of warblers in the U.S. has shifted north an average 70 kilometres in 20 years (Price and Root, 2000). Climate change impact assessments have projected that fish ranges could move more than 500-600 kilometres northward leading to invasions of warmer water fish and extirpations of colder water fish (Magnuson *et al.,* 1997). Similarly, a study by Kerr and Packer (1998) demonstrated the potential for an influx of southern species; mammal diversity was projected to increase by 10 % in southern Canada.

Introduction of invasive species could be exacerbated.
An invasive species is a species that is beyond its natural range or natural zone of potential dispersion. Invasive species, a current stress in the Great Lakes region, could be exacerbated with a changing climate. Species currently limited to southern states may be able to extend their range northward into the Great Lakes region. Accidental introductions (*e.g.* bilge water) may be more successful because of altered environmental conditions and stress to existing native species. Through this process, indigenous species are threatened and ecosystems can be radically changed through transformations and extinctions (Rendell, 2002). Species such as carp, zebra mussel, purple loosestrife, curly-leaf pondweed, and Eurasian milfoil are examples of species whose introductions have affected the Great Lakes ecosystem. Warmer water temperatures due to a changing climate may allow the zebra mussel to become more widespread on Lake Superior. At present, it is primarily found in the lower Great Lakes while the cold water of Lake Superior limits its expansion (Easterling and Karl, 2001).

Existing community structures and interactions may change.
Existing community structures may be vulnerable because species will have different adaptation potential to a changing climate (Gitay *et al.,* 2001). For example, some plants may not be able to migrate quickly due to their dispersion rates and growth rates while others may be more adept at filling emerging niches or overcoming human and natural barriers (Fisher *et al.,* 2000). As a result, ecosystems may not be able to respond with a cohesive turnover from one group of species to another. Instead, certain ecosystem components (*e.g.* some species or age classes) may react more quickly than others and will move individually thereby producing new

combinations in colonized areas (Fleming and Candau, 1998). Resident ecosystems may lose their more sensitive components. Biodiversity measured by richness (number of species) and evenness (lack of dominance) could change dramatically as ecosystems respond. For example, blue-green algae dominate at warm water temperatures. This has ecological and socio-economic implications; blue-green algae cause taste and odour problems in drinking water and are not preferred food.

Fleming and Candau (1998) provide an excellent case study of the spruce budworm-forest ecosystem that illustrates how a changing climate affects population level processes, interactions, and timings that influence the ecosystem's characteristics. For example, alteration in rates of phenological development shifted the synchrony between life stages of the spruce budworm as a prey and its vulnerability to parasites; natural mortality processes were affected. Weather extremes and forest fires altered the health and distribution of the host trees affecting the severity and opportunity for spruce budworm infestation.

A changing climate is expected to lead to reduction in some habitats.
Climate change is another factor that contributes to habitat change and destruction; it also causes habitat fragmentation. Terrestrial and aquatic ecosystems in the Great Lakes region will not necessarily respond to a changing climate similarly due to different edaphic characteristics, hydrology, surrounding land uses, and human stresses. This is expected to lead to reduction in some habitats and an increase in others. Loss of habitat can reduce genetic diversity through the loss of locally adapted genotypes, particularly those species with limited migration capability (Anderson *et al.,* 1998).

In climate warming scenarios, habitat for warm-, cool-, and cold-water fish increases in deep stratified lakes if dissolved oxygen concentrations do not become limiting. But, habitat for cold-water fish decreases in shallow, unstratified lakes (Magnuson *et al.,* 1997). The cold-water stream habitat of some fish species decreases with warmer air temperatures and warming of surface waters and ground water inputs. For example, cold-water habitat for brook trout in two southern Ontario streams decreased significantly with climate change scenarios (Meisner, 1990). Small, shallow lakes (*e.g.* Wisconsin) could disappear where evaporative losses exceed input by precipitation. Reductions in volume and increases in residence time may cause these lakes to undergo marked shifts to more eutrophic, saline, and contaminated states (Magnuson *et al.,* 1997). Small semi-permanent, pothole wetlands are also vulnerable to water balance changes. Area of wetland decreases, vegetation composition changes to drier species, and the interspersion of water and wetland plants decreases (Poiani and Johnson, 1993). Waterfowl populations decrease as habitat declines.

Wetland vegetation communities, functioning, and values may change.
Air temperature and water balance changes may have significant implications for wetland functioning and values as well as vegetation community composition. Other impacts on wetlands from a changing climate include warmer water; reduction in water levels; changes in timing and amount of water flowing through a wetland affecting flushing, sedimentation, nutrient input; and length of ice cover.

Wetlands that are directly dependent on precipitation input (with evapotranspiration losses) such as bogs are likely to be more vulnerable to climate change than those that are reliant on ground water drainage. Great Lakes shoreline wetlands such as marshes linked to the lakes may be the least vulnerable (depending on geomorphology) (Jacobs *et al.*, 2001). The annual and perennial vegetation of marsh wetlands may be able to migrate in response to water level declines; however, trees in swamps are slow to respond to environmental changes. Great Lakes shoreline fens may be vulnerable because they are more strongly influenced by regional ground water input than Great Lakes water levels.

A changing climate will have two important effects on water levels: an increased frequency and duration of low water levels and a change in the seasonal cycle of high and low. Generally, wetland vegetative zones shift lakeward in response to a decrease in water levels, as the landward margins of the wetland dry up. Wetland vegetation communities requiring little water such as sedges, grasses, wet meadows, and trees replace emergents and submergents. Indirect effects of lower lake levels include an increase in the occurrence of fires and oxidation of wetland bottoms, which can cause the germination of seeds buried in the substrate. The geomorphology of the wetland, shoreline slope, soils, and man-made structures affect a wetland's ability to adapt to water level changes (Mortsch, 1998).

Wildlife is susceptible to climate changes.
Wildlife is susceptible to extreme climate events. Droughts and periods of excessive wetness can affect habitat and food supply. Reproduction can decrease leading to poor recruitment and declines in population (Easterling and Karl, 2001). Temperature changes can influence the timing of events such as breeding and bird migration (earlier arrival dates of spring migrants and later autumn departure dates) (Kerr and Packer, 1998).

Rare and endangered species may be more vulnerable.
Species are identified as rare or endangered because they have a small range size, a limited distribution of suitable habitat within their range, and/or a small population size. These populations have very restricted habitat requirements or habitat availability; they are the most vulnerable to changes and have the least adaptation options.

3.3.8 Agriculture

Agriculture is of vital importance to the entire Great Lakes region, the United States and Canada, and the world. It is an economically important sector and a major source of food supplies. At the same time, agriculture is a weather- and climate-sensitive sector. The types of crops that can be grown is partly a function of the regional climate. The yields of these crops are sensitive to the amount of water and the frequency of its availability.

<u>Key impacts</u> of climate change include:

- Yields are expected to increase but not in all regions.
- Demand for water by the agricultural sector will likely increase.
- The impact of climate change on agriculture may be enhanced by current stresses.
- Adaptation strategies will likely be necessary.

Yields are expected to increase but not in all regions.

Agriculture has exhibited a capacity to adapt to moderate differences in growing season climate, and it is likely that agriculture would be able to continue to adapt. With an increase in the length of the growing season, double cropping, the practice of planting a second crop after the first is harvested, is likely to become more prevalent. The CO_2 fertilization effect is likely to enhance plant growth and contribute to generally higher yields. The largest increases are projected to occur in the northern areas of the region, where crop yields are currently temperature limited. However, yields are not likely to increase in all parts of the region. For example, in the southern portions of Indiana in the United States, corn yields are likely to decline, with 10-20 % decreases projected in some locations. Consumers are likely to pay lower prices due to generally increased yields, while most producers are likely to suffer reduced profits due to declining prices. Increased use of pesticides and herbicides is very likely to be required and to present new challenges.

Demand for water by the agricultural sector will likely increase.
Water is used for agricultural irrigation on a small percentage of harvested cropland in the Great Lakes region. Irrigation water is applied as a supplemental production input to natural rainfall, especially during short periods of drought. Irrigation is applied because the rainfall is not adequate or reliable during the critical growth stage, the soil may offer a low soil moisture holding capacity that may increase the need to irrigate during critical stages, or the crops are water insensitive and are subject to soil moisture stress.

The estimation of the quantities of water required for irrigation, however, must be an integral component of any framework to determine the total water withdrawal or the consumptive use with the Great Lakes region, especially within basins that may experience water shortages due to climate changes and have more intensive agricultural development. There is the potential for changes in irrigation demand in certain localized, but limited areas, that already have a higher percentage of farms utilizing irrigation due to the increase in temperature. A small percentage decrease in the amount of water used in agriculture could greatly reduce the possibilities for water conflicts and enhance the possibilities for economic growth within the region. The comparative stability of surface water use for irrigated agriculture in the face of increasing water scarcity reflects the insulation of water costs to surface irrigators from market considerations and energy costs.

Agriculture use generally exhibits a relatively low marginal value for water use. The incentives for farmers to utilize water more efficiently without incurring financial losses and their ability to substitute other production inputs (labour, energy, fertilizer, and pesticides) are the keys to the future viability of irrigated agriculture, especially in basins or sub-basins that exhibit water scarcity. The efficient and productive use of factors of production on the farm, the policies that affect the technology or preferences underlying the demand for supplemental water, the associated costs, and the resulting profit in relation to climate change variables are major issues to be investigated in the Great Lakes.

The impact of climate change on agriculture may be enhanced by current stresses.
The major stresses on agriculture in the upper Great Lakes region can generally be categorized as economic, social, environmental, and regulatory. The amount of water and the frequency of its availability are the primary climatological constraints for the production of most annual

crops. Growing season precipitation provides the bulk of the moisture used by crops during the season, with the remainder provided by soil moisture storage accumulated during the off-season.

Several factors will affect water management and water withdrawal for agricultural use in the future: the availability of ground water and surface water; supplemental irrigation requirements; the real cost of energy for pumping; uncertainty regarding water application and crop yield; technical developments for management of irrigation delivery systems; and adverse environmental impacts from irrigation. The issue of adverse environmental impacts, in the form of non-point source pollution, may become more widespread with more intensive irrigated crop production on light soils and the predicted changes in water levels in the Great Lakes.

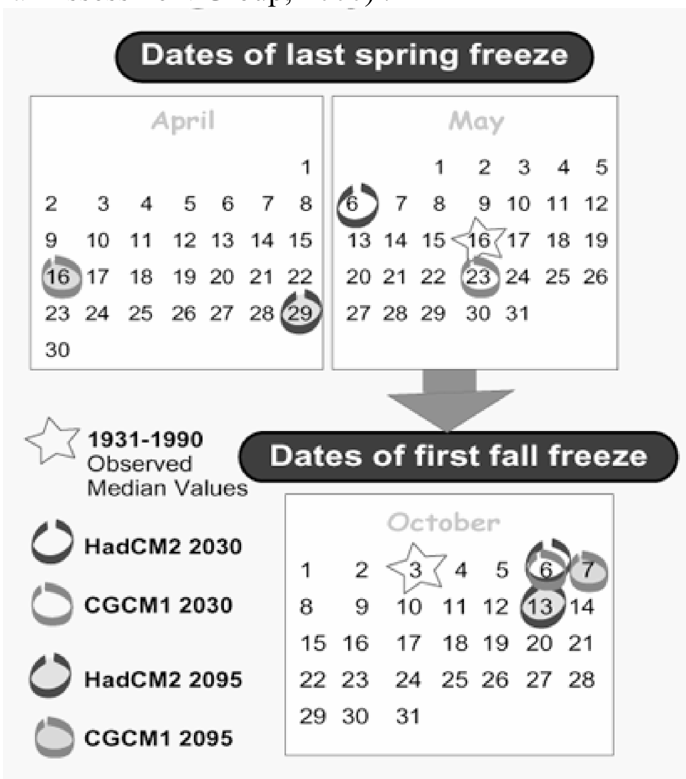
Given significant land use changes occurring across the region, farmers are facing increasing pressure from urban encroachment and the loss of prime or productive agricultural land to urbanization. The future rate of change of this loss is dependent on growth of population, especially around urban areas, and the vitality of regional economies.

Environmental factors like climate and its inherent variability, long-term degradation of soil resources, geographical concentration of livestock production and the associated management of large amounts of livestock waste, and the contamination of surface waters and ground water by agricultural chemicals may also create direct stress on regional agriculture.

Finally, one category of stresses that integrates many of the above factors is governmental regulation, which may drastically change standards or alter the economics of the production system. One current example in the United States is the gradual implementation of the Food Quality Protection Act, which may ultimately result in the loss of many pesticides used commercially in agriculture (especially in fruit and vegetable production) and for which few, if any, substitutes now exist.

The potential impacts of climate change on agriculture in the Great Lakes region will depend greatly on the magnitude, timing, and the variability associated with the change. Variability is generally considered to be the most difficult aspect with which to cope and adapt. Most of the recent research on climate change in the Great Lakes region has suggested a warmer and wetter climate in the future, with relatively more warming occurring in the winter and spring than in other seasons. Agriculturally, this would most likely lead to a longer growing season and greater potential productivity, but also to greater potential rates of evapotranspiration (Figure 3-12). An additional critical factor in determining potential productivity is CO_2 enrichment, which has been associated with increases in total plant dry matter accumulation and improved crop water use efficiency through decreases in transpiration rates. While some research studies have shown that yield-increases from higher atmospheric CO_2 levels may actually decrease when other resources are limiting and that the enrichment effect may decrease over time for some plant species, most scientific literature suggests that there will be significant long-term benefits to agriculture as atmospheric CO_2 levels increase in the future.

Figure 3-12. Impacts of climate change on growing seasons, Sturgeon Bay, Wisconsin (Great Lakes Regional Assessment Group, 2000) .



There may be potential changes in the productivity of arable land for specific crops in sub-regions, especially where specialty crops will be sensitive to increases in CO_2 enrichment, temperature, or rainfall during critical growth periods. Potential productivity may also be affected by changes in the rate of vegetative development in a season prior to the last spring frost and in the frequency of sub-freezing temperatures after critical growth stages for specialty crops such as cherries.

Other economic changes may occur in the commodity prices for field crops driven by worldwide changes in production and demand. This may affect the profitability of farm operations. There is likely to be an increasing dependence upon agriculture's use of rail and truck for moving agricultural commodities to market due to decreased capacity of shipping on the Great Lakes. Finally, the impact of regulations may dictate changes in farming practices, including the types and amounts of fuel and fertilizers used to produce crops that can affect the cost structure of farm operations.

Adaptation strategies will likely be necessary.

Adaptations such as changing planting dates and choosing longer season varieties are likely to offset losses or further increase yields. Breeding for response to CO_2 will likely be necessary to achieve the strong fertilization effect assumed in the crop studies. This is an unexploited opportunity and the prospects for selecting CO_2 response are good. However, attempts to breed for a single characteristic are often not successful, unless other traits and interactions are considered. Breeding for tolerance to climatic stress has already been heavily exploited and varieties that do best under ideal conditions usually also outperform other varieties under stress conditions. Breeding specific varieties for specific conditions of climate stress is therefore less likely to encounter stress.

Some adaptations to climate change and its impacts can have negative secondary effects. For example, an increase in the use of pesticides and herbicides is one adaptation to increased insects, weeds, and diseases associated with warming. Runoff of these chemicals into prairie wetlands, groundwater, and rivers and lakes could threaten drinking water supplies, coastal waters, recreation areas, and waterfowl habitat.

Some of the possible ways in which agriculture in the Great Lakes region can adapt to climate change include:

- Change sowing dates.
- Introduce new crop varieties.
- Increase use of water supplies, irrigation, and drainage systems.
- Change tillage practices.
- Use near-term climate predictions to reduce losses due to weather variability.
- Make other management adjustments in virtually all components of the farming system from planting to harvesting to selling to adjust to climate change.

3.3.9 Forests

Forests cover a significant portion of the Great Lakes region, providing wildlife habitat, clean air and water, cultural and aesthetic values, carbon storage, recreational opportunities such as hiking, camping, fishing, and autumn leaf tours, and products that can be harvested such as timber, pulpwood, fuelwood, wild game, ferns, mushrooms, and berries. This wealth depends on forest biodiversity (the variety of plant and animal species) and forest functioning (water flows, nutrient cycling, and productivity). These aspects of forests are strongly influenced by climate. Native forests are adapted to their local climates.

The forest resources of the Great Lakes region are already under stress, even without the potential for increases in temperatures caused by climate change. Dutch elm disease contributed to an almost complete dieoff of this species throughout the region in the 1970s. Forests, particularly in the urban areas, used this as a lesson to promote diversity among the species that are planted in cities.

Currently, gypsy moth-related defoliation exists and is clearly worsening in all parts of the region. State authorities are aggressively seeking to combat this infestation with ground and satellite-based surveys, biological controls, and trapping methods. With these efforts, the spread of this infestation would be even greater. Oak wilt is another disease that exists in many parts of the region, although it mostly affects the northern portion. Other forest-related diseases and pests that are found in the region in non-epidemic numbers include spruce budworm, cankerworms, forest tent caterpillar, white pine blister rust, white pine weevil, basswood thrips, butternut canker, and Asian long-horned beetle.

Extreme weather certainly plays a role in regional forest destruction. Severe storms with lightning, high winds, hail, or tornadoes can quickly destroy whole stands of trees. Recently thinned or logged areas and older forests, from which fire has been excluded, are particularly susceptible to destruction in these circumstances. Exceptionally cold or hot (and dry) weather can also retard growth or kill trees depending on the duration and location of such weather. Also, the potential for increased risk of fires could pose human health hazards such as direct loss of life and injury, and health effects resulting from changes in air quality.

Land use is also a serious stress. Increasing development, coupled with declining rates of agricultural abandonment, is likely to lead to declines in forest area in the long term. Furthermore, large-scale management of forests on private lands is becoming increasingly difficult as ownership is becoming increasingly fragmented into more and smaller parcels.

Shifts in potential tree species range limits in the Great Lakes region.
Current climate patterns correlate with geographic ranges of plants, leading to the expectation that future climate change will cause shifts in the distribution of vegetation (Peters and Lovejoy, 1992; Prentic *et al.*, 1992). Rapid global warming might cause species to die off along their southern range margin long before replacement species can immigrate from the south, leaving behind a reduced array of species (Solomon and Kirilenko, 1997).

Will tree species that are now important in Great Lakes forests continue to grow here? Which trees will die out and which will remain, and what forest species that are presently absent disperse into the region? To arrive at a realistic prediction of future forest composition in the Great Lakes region, the impact of climate change must be considered separately for each species. Each has a different current geographic range and an individualistic response to climate.

Researchers have used various types of models to predict the future ranges of different forest species. For example, equilibrium models predict species ranges using bioclimatic variables that physiologically limit species to particular geographic regions. Species-specific parameters (minimum and/or maximum tolerance values for each bioclimatic variable) define the climate-space suitable for the species. Using tolerance values for each species and a set of climate values predicted by global climate models, it is possible to map the potential geographic range for each species under future equilibrium conditions.

Modelling efforts that have addressed the impacts of climate change on forests in the Great Lakes region have consistently projected a northward shift in species ranges. Most of these efforts have shown that species at the southern boundaries of their ranges, like boreal species within the region or northern hardwood species in the southern part of the region, will experience increased mortality and will be eventually replaced by species from communities to the south. Although there is no general agreement on the time that it will take for this replacement to occur, the models are in general agreement about the northward shift in ranges. Mortality, disturbance, migration rates, pests, disease, land use, and management will play a critical role in forest health and composition in the coming decades. To date, only a few of the more advanced dynamic or transient analyses of climate change and tree species (migration) have been conducted. Many more steady-state analyses, although easier to design and run, simulate current and future climates separated by a sudden and unrealistic jump in CO_2.

The timing of replacement is critical because dieback of northern species could occur from heat or drought stress, increased winter damage due to diminished dormancy, or increased pest activity, before the southern species are available for replacement. This possibility raises questions about just how susceptible the forests are to increased mortality, how disturbance regimes will be affected by climate change, and how quickly the southern species can migrate. Other questions relate to the possibility that established trees may persist longer than shown in early studies. Confounded with these questions is the possibility that CO_2 enrichment, by improving water use efficiency by trees and increasing productivity, could speed the succession process.

Several tree species will retreat from their southern and southwestern range limits in the Great Lakes region during the 21st century. This may mean that in the area close to their southern range limits, these trees will experience reduced growth rates, reproductive failure, and increased disease and mortality. Increased fuel loading will increase the likelihood of fire in the forests where the trees are moribund. Unfortunately, some of the most economically valuable trees in the Great Lakes region are included in this category. White pine, aspen, jack pine, red pine, and yellow birch are all predicted to show signs of stress along their southern range limits in the early decades of the 21st century.

The dieback and retreat of these species depends on the steep rise in summer temperature predicted by the climate models. However, the projected summer temperature increases differ among models. In cases where the temperature increases are less severe, dieback from southern range limits would be delayed, and the magnitude of species loss would not be as severe, but the direction of change would be similar. In all cases, further dieback could occur if climate continues to change after the end of the 21st century.

The four categories of tree responses are summarized here. The first category is composed of trees that are presently confined to the southern part of the Great Lakes region, and are predicted to expand northward (*e.g.* cherry and black walnut). The potential range of black walnut will also expand toward the eastern part of the region along the southern shores of Lakes Erie and Ontario.

The second category includes trees whose range limits within the Great Lakes region are not greatly affected, but which may show signs of stress in some areas (*e.g.* red oak and sugar maples). It is predicted that red oak will persist within its present range, expanding a few tens of kilometres westward into the present-day prairie. Toward the end of the 21st century, warm conditions in summer will begin to stress this species in the southern part of the region. Soil moisture deficits near the limit for this species will stress populations in the lower peninsula of Michigan throughout the century.

The third category is composed of species that are predicted to retreat gradually from the southern part of their ranges in the Great Lakes region due to the predicted rise in summer temperatures. Some of the most important timber trees are included in this category: quaking aspen, yellow birch, jack pine, red pine, and white pine (Figures 3-13 and 3-14).

The fourth category includes only beech. Study results widely differ, however. Some show beech retreating from its western limit and moving northward. Others suggest that this tree may expand westward. And still others predict complete elimination of beech from the Great Lakes region. All of the studies have had difficulty specifying the climate parameters that correspond to the present range of beech. This may explain why results differ so widely, and adds considerable uncertainty to future predictions.

Figure 3-13. Retreat of aspen, birch, and pine trees: 1994-2003 (Great Lakes Regional Assessment Group, 2000).

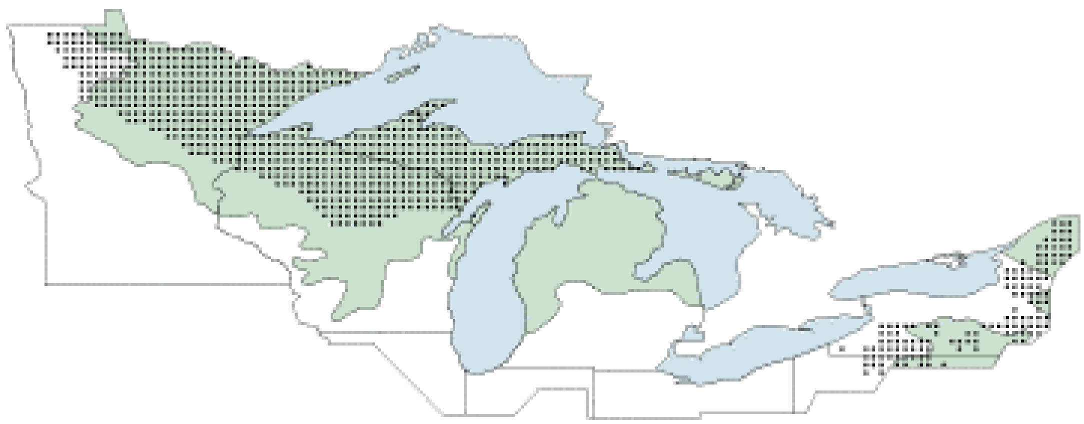
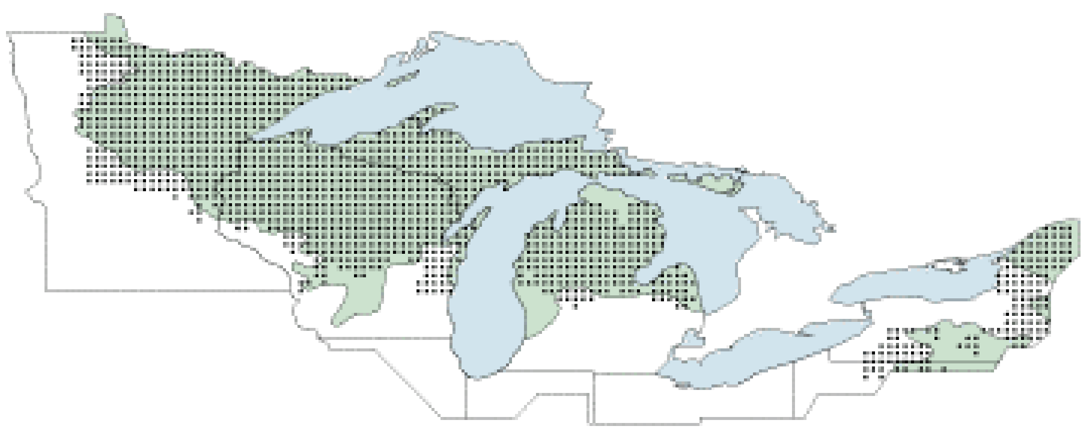


Figure 3-14. Retreat of aspen, birch, and pine trees: 2025-2034 (Great Lakes Regional Assessment Group, 2000).



By the end of this century, forests of the Great Lakes region may have changed greatly as a result of climate warming. Studies that use different methods differ in the extent of predicted changes, but the direction of changes are similar. Many of the forest dominants, including some of the most commercially valuable trees (aspen and white pine) may no longer be able to grow in much of the region. Hardwood trees that are predicted to remain in the region, such as sugar maple and red oak, may come to dominate additional forest stands once their competitors retreat. Because dispersal of southern species such as black walnut and black cherry is unlikely to occur as rapidly as dieback of northern species, forests may be much less diverse than at present. Haphazard dispersal by humans may bring some southern trees to limited areas of the north, but widespread distribution and establishment of these species will likely take longer than a century. New, unknown dynamics in these changing, low-diversity forests will present a challenge to forest managers.

Human activities modify forests. Native forests have been converted to agricultural and urban uses. In some cases, forests have re-grown on abandoned agricultural lands. Expansion of urban areas has fragmented forests into smaller, less contiguous patches. Fire suppression has changed the species found in Great Lakes forests. Harvesting methods, where all trees or a few trees are cut, have also changed species composition. Trees have been planted for aesthetics and landscaping purposes in urban and rural areas that are often far outside of the species' natural range. Intensive management along with favourable climates in parts of the U.S. and Canada have resulted in highly productive forests. Human activities will continue to modify forests while forests are also experiencing the effects of climate change.

3.3.10 Recreation and Tourism

Key impacts of climate change include:

- Season length for recreation activities changes – lengthens for warm-weather activities and shortens for cold weather activities.
- The resource base for recreation activities may be altered.

Season length for recreation activities changes – lengthens for warm-weather activities and shortens for cold weather activities.

Cold weather activities, such as ice fishing, skiing, and snowmobiling, are sensitive to warmer air temperatures in winter that affect the duration and depth of snow on the ground and ice in waterways. The length of the reliable season decreases (Scott *et al.,* 2002). However, warm-weather activities such as camping, trail use, swimming, fishing, boating, and golfing may have an extended season with the amenable conditions including more of the shoulder seasons of spring and fall. However, an increase in the frequency of extremely high air temperatures in summer may reduce some recreation opportunities because it is too warm. While there may be economic benefits from an extended season, the increase in number of users as well as a longer period of use may lead to environmental deterioration. Parks and natural areas will need to assess vulnerability. Management practices such as limiting access or the number of visitors may have to be instituted (Cohen *et al.,* 2001).

The resource base for recreation activities may be altered.

Climate change may alter the availability and quality of the resource base upon which recreational activities depend (Cohen *et al.,* 2001). Projected water level reductions in the Great Lakes could significantly limit the access, navigability, and safety of marinas and recreational boating waters. Recreational boating is a very important economic activity in the region; there are over 4.2 million recreational boats in the Great Lakes states while Ontario has over 1.2 million recreational boats registered (Institute for Agriculture and Trade Policy, 2002). Nearshore areas with shallow sloping shorelines, narrow bays, shifting sand bars, or variable bathymetry would be most vulnerable. Recent low water levels in 2000 and 2001 illustrate the sensitivity. Beach width, however, may expand with lower water levels but aesthetics may suffer in the short term. Water-contact activities, particularly swimming, could be affected by water quality changes. Combined sewer overflows and contaminant entrainment may increase with more intense precipitation events; more beaches may be closed due to bacterial contamination. Warmer water temperatures may also increase potential for summer algae blooms and bacterial pollution. Changes in the range and habitat of fish, waterfowl and other birds, and mammals alter opportunities for angling (particularly cold-water fishery), hunting, and birdwatching. For example, 20 to 40 % of warblers are currently found further north than 25 years ago. In 2001, more than 1.9 million Minnesotans spent $532 (U.S.) million watching wildlife (Great Lakes Regional Climate Change Assessment, 2002). An important recreational feature of the autumn is the display of fall foliage. Warmer temperatures in autumn are associated with muting of fall foliage colours. Drought also decreases leaf colour in addition to changing the timing of leaf drop (Barron, 2001).

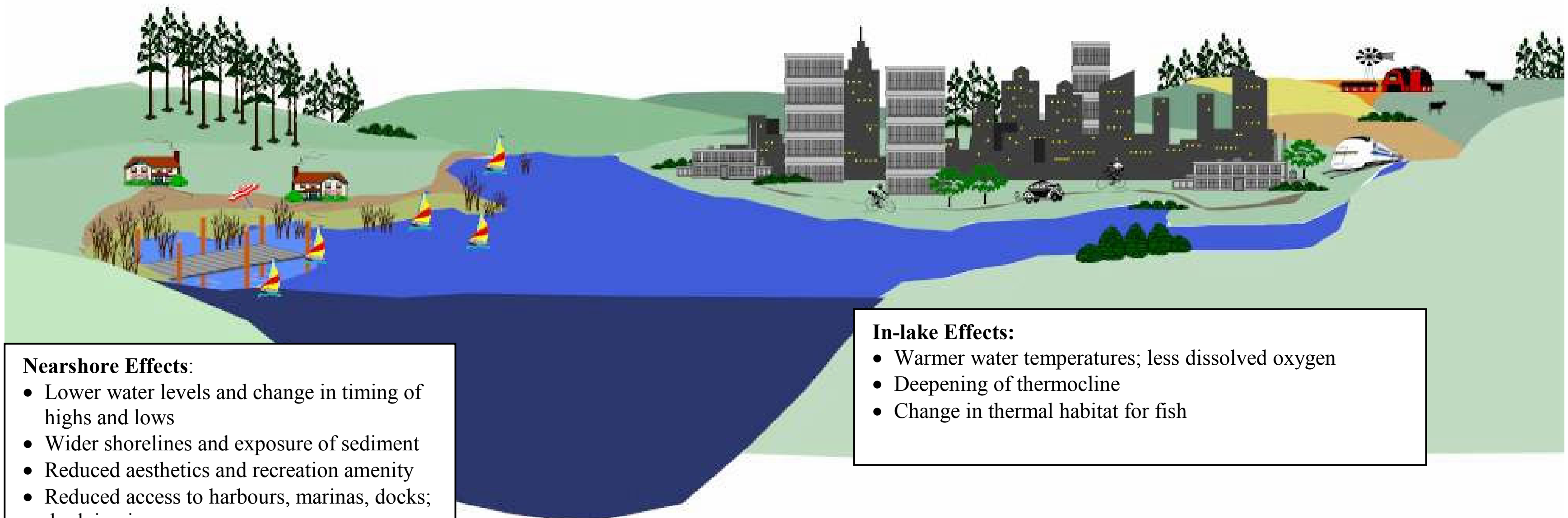
3.3.11 Summary

The key impacts of climate change affecting the Great Lakes watershed are summarized in Figure 3-15.

Figure 3- 15. Summary of key climate change impacts on the Great Lakes ecosystem.

Watershed Effects:

- Overflowing of combined sewers
- Less ground water recharge and baseflow
- More winter rain on bare soil; more erosion
- Lower stream flow especially in summer; poorer water quality
- Changing agricultural practices (crops, pest management, and irrigation);
- Changing forest cover (more fires, pests, tree die-off, and changing species)



Nearshore Effects:

- Lower water levels and change in timing of highs and lows
- Wider shorelines and exposure of sediment
- Reduced aesthetics and recreation amenity
- Reduced access to harbours, marinas, docks; dredging increases
- Less shoreline ice – winter wave erosion
- Wetland vegetation and area change
- Fish and waterfowl habitat change

In-lake Effects:

- Warmer water temperatures; less dissolved oxygen
- Deepening of thermocline
- Change in thermal habitat for fish

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4.0 SPECIFIC IMPLICATIONS FOR BENEFICIAL USES IDENTIFIED IN THE GREAT LAKES WATER QUALITY AGREEMENT

Environmentally sensitive areas became an issue for policy makers in the Canadian and United States governments in the early 1970s (IJC, 2002). As outlined by the International Joint Commission (IJC) (2002), water pollution problems led to the development of the Great Lakes Water Quality Agreement. This document was an accord between Canada and the United States to study and restore the health of the Great Lakes freshwater resource shared by both countries. Over time, this agreement has been modified. In 1978, there was a call to end the discharge of toxic substances (such as PCBs) into the lakes. In 1987, another revision was added for the cleanup and restoration of areas impacted by one or more of the 14 beneficial uses impairments identified in the Great Lakes. An impaired beneficial use occurs when there is a change in the chemical, physical, or biological integrity of the Great Lakes system, causing use impairments or other related issues, such as the microbial objective for waters used for body contact recreational activities (IJC, 1991).

Environmental restoration of environmentally sensitive areas is long-term activity that could be impeded by a changing climate and an altered hydrological regime (Rhodes *et al.*, 1993). For the white paper, 12 of the 14 beneficial uses were identified as having a potential vulnerability to climate change. They are listed in Table 4-1 in *italics*.

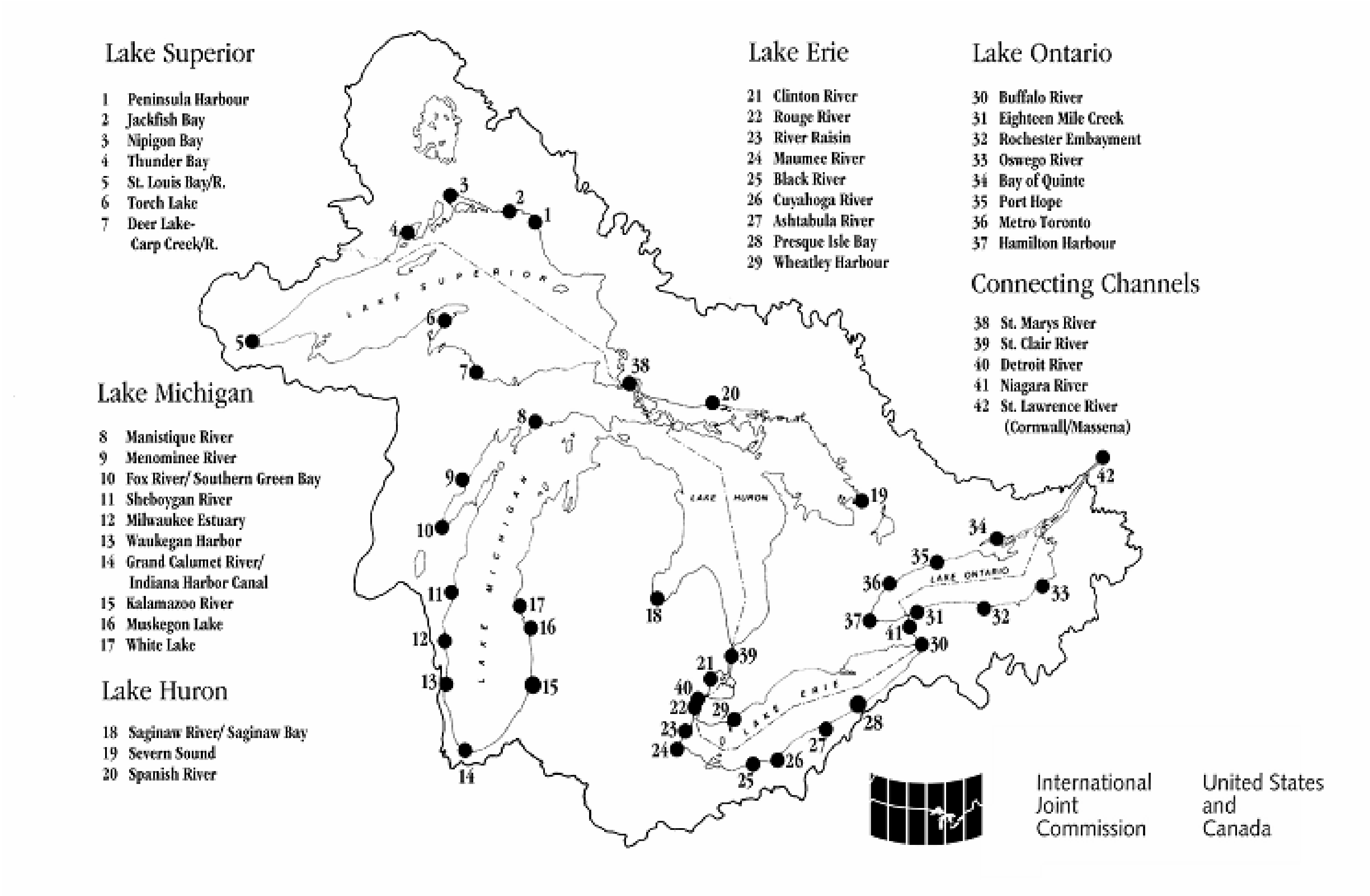
Table 4 -1. Beneficial use impairments.

Loss of fish and wildlife habitat	*Degradation of aesthetics*
Degradation of phytoplankton and zooplankton populations	*Degradation of fish and wildlife populations*
Added costs to agriculture or industry	*Restrictions on drinking water consumption, or taste and odour problems*
Eutrophication or undesirable algae	*Restrictions on dredging activities*
Degradation of benthos	*Tainting of fish and wildlife flavour*
Restrictions on fish and wildlife consumption	*Beach closings*
Fish tumors or other deformities	Bird or animal deformities or reproductive problems

Source: IJC, 1991

An area where one or more beneficial uses are impaired has been termed an Area of Concern (AOC). Annex 2 of the 1987 Protocol to the Agreement defines an AOC as "… a geographic area that fails to meet the General or Specific Objectives of the Agreement where such failure has caused or is likely to cause impairment of beneficial use or of the area's ability to support aquatic life". For each AOC, a Remedial Action Plan (RAP) is to be developed and implemented to restore and protect the beneficial uses. For open lake waters, Lakewide Management Plans (LaMPs) were developed to distinguish pollutants that could affect humans or aquatic life and to restore beneficial uses that were impaired. There are currently 41 AOCs (there were 43) (Figure 4-1). Collingwood Harbour (IJC, 1991) and Severn Sound (Kirschner, 2003) have been delisted.

Figure 4-1. Areas of concern in the Great Lakes.



Source: Bratzel, 2003

There are 26 AOCs identified in U.S. waters, 10 in Canadian waters and five are bi-national efforts on connecting river systems (GLIN, 2003). The impairments to beneficial uses by AOC are listed in Table 4-2. For each AOC, a beneficial use is either impaired, unimpaired, under assessment, or restored. A use is deemed impaired if it meets the listing guidelines approved by the IJC and unimpaired if it does not. A use is under assessment when environmental conditions are unknown or under review and restored when the delisting guidelines have been achieved.

Each of the 12 beneficial uses potentially vulnerable to climate change are reviewed in the following section. The listing guideline for each use is described, and then the potential impacts from climate change are identified using published literature (if available).

Table 4-2. Areas of concern and their impaired beneficial uses in the Great Lakes basin.

Location	Area of Concern	Loss of fish and wildlife habitat	Degradation of phytoplankton and zooplankton communities	Added cost to agriculture and industry	Degradation of aesthetics	Beach closures	Restrictions on drinking water, taste and odour problems	Eutrophication or undesirable algae	Restriction on dredging activities	Degradation of benthos	Degradation of fish and wildlife populations	Restriction on fish and wildlife consumption	Tainting of fish and wildlife flavour
Lake Superior	Deer Lake	U	U	U	U	U	U	U	U	U	U	I	U
	Jackfish Bay	I	U	U	I	U	U	U	I	I	I	A	U
	Nipigon Bay	I	U	U	I	U	U	I	R	I	I	R	R
	Peninsula Harbour	I	U	U	U	U	U	U	I	I	I	I	U
	St. Louis River	I	U	U	I	I	U	I	I	I	I	I	U
	Thunder Bay	I	I	I	I	I	U	U	I	I	I	I	U
	Torch Lake	I	U	U	I	U	U	U	I	I	U	I	U
Lake Huron	Collingwood Harbour	R	U	U	U	U	U	R	R	U	U	R	U
	Saginaw River/Bay	I	I	U	I	I	I	I	I	I	I	I	U
	Severn Sound	R	R	U	R	I	U	R	R	R	I	I	U
	Spanish Harbour	R	U	R	U	R	U	U	I	I	R	I	U
	St. Clair	I	U	I	I	I	I	U	I	I	A	I	A
	St. Mary	I	U	U	I	I	U	I	I	I	I	I	A
Lake Michigan	Grand Calumet	I	I	I	I	I	I	I	I	I	I	I	I
	Kalamazoo River	I	U	U	I	I	U	U	I	I	I	I	U
	Lower Green Bay and Fox River	U	I	U	I	I	I	I	I	I	I	I	U
	Manistique River	I	U	U	U	I	U	U	I	I	U	I	U
	Menominee River	I	U	U	U	I	U	U	I	I	I	I	U
	Milwaukee Estuary	I	I	U	I	I	U	I	I	I	I	I	U
	Muskegon Lake	I	U	U	U	U	U	U	I	I	I	I	U
	Sheboygan River	U	I	U	U	U	U	I	I	I	I	I	U
	Waukegan Harbour	I	I	U	U	I	U	U	I	I	U	U	U
	White Lake	U	U	U	I	U	I	U	I	I	I	I	U

I – Impaired Beneficial Use R – Restored Beneficial Use U – Unimpaired Beneficial Use A – Under Assessment

Areas of concern and their impaired beneficial uses in the Great Lakes basin continued

Location	Area of Concern	Loss of fish and wildlife habitat	Degradation of phytoplankton and zooplankton communities	Added cost to agriculture and industry	Degradation of aesthetics	Beach closures	Restrictions on drinking water, taste and odour problems	Eutrophication or undesirable algae	Restriction on dredging activities	Degradation of benthos	Degradation of fish and wildlife populations	Restriction on fish and wildlife consumption	Tainting of fish and wildlife flavour
Lake Ontario	Bay of Quinte	I	I	U	I	I	I	I	I	I	I	I	I
	Hamilton Harbour	I	I	I	I	I	I	I	I	I	I	I	I
	Metro Toronto and Region	I	A	U	I	I	U	I	I	I	I	I	U
	Oswego River	I	U	U	U	U	U	I	U	U	I	I	U
	Port Hope	U	U	U	U	U	U	U	I	U	U	U	U
	Rochester Embayment	I	I	I	I	I	I	I	I	I	I	I	U
Lake Erie	Ashtabula River	I	U	U	U	U	U	U	I	I	I	I	U
	Black River	I	U	U	I	I	I	I	I	I	I	I	U
	Cuyahoga River	I	I	U	I	I	U	I	I	I	I	I	U
	Maumee River	I	U	U	I	I	I	I	I	I	I	I	U
	Presque Isle Bay	U	U	U	U	U	U	U	I	U	U	U	U
	Rouge River	I	U	U	I	I	U	I	I	I	I	I	U
	Wheatley Harbour	I	U	U	U	A	U	A	I	U	U	U	U
Connecting Channels	Clinton River	I	U	U	I	I	U	I	I	I	I	I	U
	Detroit River	I	U	U	I	I	I	U	I	I	U	I	U
	Eighteenmile Creek	U	U	U	U	U	U	U	I	I	U	I	U
	Niagara River (New York)	I	U	U	U	U	U	U	I	I	U	I	U
	Niagara River (Ontario)	I	A	U	U	I	I	I	I	I	I	I	U
	St. Lawrence River (New York)	I	U	U	U	U	U	U	U	U	U	I	U
	St. Lawrence River (Ontario)	I	A	U	U	I	I	I	I	I	I	I	A

Source: Hamilton Harbour AOC - Remedial Action Plan for Hamilton Harbour, 2002
Severn Sound AOC – Kirschner, 2003
All other AOCs – Great Lakes Information Network, 2003

4.1 IMPAIRED BENEFICIAL USES IN THE GREAT LAKES BASIN

A changing climate may put added stress on beneficial uses that are already impaired, possibly create new stresses within ecologically healthy areas, and influence remediation plans. Projected changes in climate outlined in Section 3.2 are used as a guide to discuss potential implications for beneficial uses. Many papers were reviewed for this section and are summarized in the tables below. Preference was given to research findings directly related to the impacts of climate change on the beneficial uses in the Great Lakes basin. They are presented in the following research findings tables in *italics*. Research findings drawn from areas outside of the Great Lakes basin are used to illustrate a further range of climate change impacts where relevant; they are presented in the research findings tables in normal font.

4.1.1 Loss of Fish and Wildlife Habitat

> **Listing Guideline:** When fish and wildlife management goals have not been met as a result of loss of fish and wildlife habitat due to a perturbation in the physical, chemical, or biological integrity of the Boundary Waters, including wetlands (IJC, 1991).

Increases in temperature, changes in precipitation, and water levels can have an impact on vegetation biodiversity (Thompson *et al.*, 1998). For example, shoreline wetlands surrounding the Great Lakes are negatively impacted by lower water levels, resulting in loss of diversity and areal extent (Mortsch, 1998) which could impact important spawning and nursery sites for fish (Edsall *et al.*, 1997). Changes in the population and species of herbivores (*e.g.* through climate change) can also impact and accelerate changes in vegetation (Hobbs, 1996). Climate changes, such as increased atmospheric CO_2, warmer air temperatures, and increased drought severity and frequency can alter the physiology of plants and influence physiological processes such as photosynthesis, phenology, and respiration (Table 4-3).

Table 4-3. Three aspects of climate change (increased atmospheric CO_2, warmer air temperature, and drought) and their effects on plant physiological processes.

Physiological Process	Elevated CO_2	Warmer Temperature/Longer Frost-Free Season	Increased Drought Severity and Frequency
Photosynthesis	Increased with possible feedback reductions due to resource limitations (*i.e.* nutrient supply)	Increased but with possible feedback reductions or resource limitations	Reduced during drought and for a period following drought relief
Photorespiration	Decreased (usually)	Increased	Increased
Dark respiration	Slightly increased	Increased	Increased
Stomatal conductance	Reduced	Increased at temperatures up to 30-35°C	Reduced
Light use efficiency	Increased	No change	Decreased
Water use efficiency	Increased	Reduced at warmer temperatures (if vapour deficit unchanged)	Increased
Nutrient use efficiency	Increased	No effect	May be increased
Phenology	Shortened growing season due to delayed bud burst in the spring and earlier bud in the fall	• Earlier bud break • Later development of winter frost hardiness • Potential lack of chilling for dormancy in southwestern Ontario	Earlier cessation of shoot elongation
Carbon partitioning/plant structure	• Increased growth rates • Reduced stomatal density in many species • Increased root growth (species dependent) and greater allocation to stemwood volume	• Increased growth rates • Earlier bud burst and flowering	• Increased flowering and seed production • Increased root growth/ reduced shoot growth • Reduced leaf area
Susceptibility to stress	Increased drought tolerance due to stomatal closure	Potentially increased damage from spring and winter freezing	Increased susceptibility to other stresses (*i.e.* acid precipitation, ozone) and insects and disease

Source: Colombo, 1998

Table 4-4. Loss of fish and wildlife habitat research findings.

Climate Sensitivities	**Research Findings**
Changes in timing, duration, height/elevation of annual and seasonal water levels.	• *Perturbations can alter the natural succession of plants in wetlands* (Wilcox *et al.*, 1995, Mortsch, 1998, Bedford, 1992: 571)*, which influences the species, diversity, and number of wildlife a wetland can support* (Mortsch, 1998). • *Receding shorelines* (Gabriel *et al.*, 1993: 124; Koonce *et al.*, 1996) *and wetlands* (Atkinson *et al.*, 1999: 7-16) *decrease spawning and nursery areas for Great Lakes fish.*
Intensity of precipitation events may increase, but duration between events may increase.	• For many tree species, precipitation is a more determinate factor in survival than temperature (Peters, 1990).
Changes in disturbance hazards (*e.g.* forest fires and insect outbreaks).	• *There could be an increase in insect and disease occurrences* (Cherry, 1998). • Under climate change, intense spruce budworm outbreaks could reduce the renewal capacity of host tree populations and cause local extinctions in the Canadian boreal forest (Fleming *et al*., 1997: 245-246). • Changes to disturbance regimes (for example forest fires) may alter forest ecosystem distribution and type (Thompson *et al*., 1998: 221).
Air temperatures increase.	• Changes in the distribution of tree species and species richness in the United States (Bachelet *et al*., 2001; Iverson *et al*., 2001). • *Valuable timber trees, including white, red, and jack pine, with southern limits in the Great Lakes basin, are expected to move north due to an increase in summer air temperatures. One scenario showed the complete disappearance of these species by the end of the century; another scenario showed movement of 100-200 km from the southern limits* (Walker *et al.,* 2002: 566).
Changes in timing and duration of ice break up.	• Changes in ice break-up intensity can alter channel morphology, affecting riparian vegetation, since its succession is linked to the scouring effects of the ice (Prowse *et al*., 2002: 818). • Loss of winter ice cover and associated warming may be beneficial to fish populations where productivity and growth are currently limited by the duration of open water periods (Hostetler *et al*., 1999: 1635).

4.1.2 Degradation of Phytoplankton and Zooplankton Populations

> **Listing Guideline:** When phytoplankton or zooplankton community structure significantly diverges from unimpacted control sites of comparable physical and chemical characteristics. In addition, this use will be considered impaired when relevant, field-validated, phytoplankton or zooplankton bioassays (*e.g.* Ceriodaphnia, algal fractionation bioassays) with appropriate quality assurance/quality controls confirm toxicity in ambient waters (IJC, 1991).

Phytoplankton are tiny plants and zooplankton are tiny animals that reside in the waters of the Great Lakes. Both play important roles in the food chain, as they are essential sources of food for fish, benthos, and larger zooplankton. They can be good indicators of the health of an aquatic environment. Changes in climate may stress plankton, inhibiting their ability to function normally.

Table 4-5. Degradation of phytoplankton and zooplankton populations research findings.

Climate Sensitivities	**Research Findings**
Air temperature increase.	• Cooler conditions in northeast United States are correlated with a higher species diversity (Stemberger *et al.* 1996, Chen *et al.*, 2002: 586). • Off the coast of California, an increase in surface water temperature has been coupled with a decrease in zooplankton (Roemmich *et al.*, 1995). • Studies in the Mediterranean have shown a drastic reduction in phytoplankton between 1979 and 1998, in relation to an increase in surface water temperature (Goffart *et al.*, 2002). • *In the Experimental Lakes Area of northwest Ontario, phytoplankton biomass and the number of species was observed to increase during periods of drought, even though there was a decrease in nutrient input* (Findlay *et al.*, 2001). • *Annual phytoplankton and zooplankton production may increase, but there would be many complex reactions in the community due to altered temperatures, thermocline depths, light penetration, and nutrient inputs* (Magnuson, 1998: 103). • Warmer temperatures may lead to smaller sizes for zooplankton (Chen *et al.*, 2002). • Fall warming may activate zooplankton sexual and asexual reproduction and the resting stages (Chen *et al.* 1996).
Changes in runoff.	• *Warmer temperatures and drier hydrological conditions have been shown to reduce the dissolved organic carbon concentration in the lakes, exposing the biota to increased UV-B radiation* (Schindler *et al.*, 1996).
Changes in timing and duration of ice break up.	• A climate-induced decrease in the duration of the river-ice season, or an increase in the size and frequency of open water sections where re-aeration can occur, should decrease the potential for biologically damaging oxygen depletion (Prowse *et al.*, 2002: 818).

4.1.3 Added Costs to Agriculture or Industry

> **Listing Guideline:** When there are additional costs required to treat the water prior to use for agricultural purposes … or industrial purposes (IJC, 1991).

There is no published literature found concerning the impact of climate change on the costs of water treatment for agricultural and industrial use.

4.1.4 Degradation of Aesthetics

> **Listing Guideline:** When any substance in water produces a persistent objectionable deposit, unnatural color or turbidity, or unnatural odor (*e.g.* oil slick, surface scum). (IJC, 1991).

There were no publications found pertaining directly to the impacts of climate change on degradation of aesthetics, but one was found pertaining to low water levels.

Table 4-6. Degradation of aesthetics research findings.

Climate Sensitivities	Research Findings
Changes in the timing, duration and height of annual and seasonal water levels.	• *Extreme precipitation in July 1988 washed waste from the streets and caused sewage plant overflows. This resulted in the closure of almost every beach in Toronto, Hamilton, St. Catharines, Peterborough, Kingston and Ottawa* (Gabriel *et al.*, 1993: 124).

4.1.5 Beach Closings

> **Listing Guideline:** When waters, which are commonly used for total-body contact or partial-body contact recreation, exceed standards, objectives, or guidelines for such use (IJC, 1991).

There was no literature discovered that dealt directly with the impacts of climate change on beach closings. There was minimal information found concerning the impacts of two key climatic changes, increased intensity of precipitation and lower water levels, and their impacts on beach closures.

Table 4-7. Beach closings research findings.

Climate Sensitivities	**Research Findings**
Intensity of precipitation events may increase	• *Extreme precipitation in July 1988 washed waste from the streets and caused sewage plant overflows. This resulted in the closure of almost every beach in Toronto, Hamilton, St. Catharines, Peterborough, Kingston and Ottawa* (Gabriel *et al.*, 1993: 124).
Changes in the timing, duration and height/elevation of annual and seasonal water levels.	• *Pollution problems can be exacerbated on some beaches due to low water levels, often resulting in beach closures* (Gabriel *et al.*, 1993: 124).

4.1.6 Restrictions on Drinking Water Consumption or Taste and Odour Problems

> **Listing Guideline:** When treated drinking water supplies are impacted to the extent that: (1) densities of disease-causing organisms or concentrations of hazardous toxic chemicals or radioactive substances exceed human health standards, objectives or guidelines; (2) taste and odor problems are present; or (3) treatment needed to make raw water suitable for drinking is beyond the standard treatment used in comparable portions of the Great Lakes which are not degraded (*i.e.* settling, coagulation, disinfection). (IJC, 1991).

Seasonal taste and odour problems in drinking water are experienced by communities drawing water from the Great Lakes (Anderson *et al.*, 1998). These unpleasant odours can raise questions concerning the quality of drinking water, though in many cases substances can be detected by taste and odour at concentrations far below levels that could affect the health of people (Young *et al.*, 1996). In the Great Lakes, the majority of taste and odour problems occur during the late summer and early fall when algae are at their optimal growing conditions (Anderson *et al.,* 1998).

Table 4-8. Restrictions on drinking water consumption or taste and odour problems research findings.

Climate Sensitivities	**Research Findings**
Air temperature increase	• *Warmer temperatures can increase the amount of algae* (Anderson *et al.*, 1998). • There could be social costs as a result of reductions in stream flow. An example is the decrease of water quality as a result of an increase in algae blooms, which pose health risks (Poff *et al.,* 2002).
Changes in the timing, duration and height of annual and seasonal water levels.	• *A decrease in discharge from the St. Lawrence and Ottawa Rivers between the summers of 1994 and 1995 corresponded with an increase in aquatic taxa that create noxious odours* (Hudon *et al.*, 1996).

4.1.7 Eutrophication or Undesirable Algae

> **Listing Guideline:** When there are persistent water quality problems (*e.g.* dissolved oxygen depletion of bottom waters, nuisance algal blooms or accumulation, decreased water clarity, etc.) attributed to cultural eutrophication (IJC, 1991).

Warmer waters may lead to growth of undesirable species of algae. This problem could be exaggerated in areas where predatory fish have been eliminated due to a loss of suitable habitat.

Table 4-9. Eutrophication or undesirable algae research findings.

Climate Sensitivities	**Research Findings**
Air temperature increase; water temperature increase	• Water quality could decline with warmer temperatures. Warmer water enhances productivity, but could lead to an increase in the growth of undesirable species (*e.g.* algae blooms) (Poff *et al.*, 2000). • *Increased water clarity due to an increase in zebra mussels accelerates algae growth. This has led to the suggestion that the average summer temperature has increased over the past 10 years, allowing for improved growing conditions* (Anderson *et al.*, 1998: 861). • *2xCO_2 scenarios show an early temperature increase of Lake Erie could lead to an increase in nutrient uptake by algae in the early spring and lengthened algae production* (Atkinson *et al.*, 1999). • *Warmer lake temperatures could lead to anoxia or hypoxia by increasing the metabolic rate of sediment bacteria and biological productivity and respiration in the water column, and by decreasing dissolved oxygen saturation values* (Blumberg *et al.*, 1990: 210). • *A decrease in dissolved oxygen due to warmer water temperatures would increase the rate of bacterial activity in hypolimnon water and sediment* (Blumberg *et al.,* 1990: 210). • Insufficient oxygen in the deep, cooler water during the late summer, to support large game fish could lead to an increase in smaller fish and a decrease in the zooplankton population, allowing algae to grow (Kitchell, 1993). • A climate-induced decrease in the duration of river ice or an increase in the size and frequency of open water sections where re-aeration can occur could decrease the potential for biologically damaging oxygen depletion (Prowse, 2000).
Low flow in rivers	• *Summer peaks in total phosphorus in the inner Bay of Quinte have evidently corresponded with periods of warmest water temperature and the lowest flow rates from major rivers draining to the Bay of Quinte* (Nicholls, 1999: 253).
Increase in the intensity of precipitation events	• When warmer lake water is combined with excess nutrients from agricultural fertilizers (which are washed in to the lake by heavy rains), algae blooms occur on the lake decreasing the water of oxygen and damaging other organisms (National Assessment Synthesis Team, 2001: 99).
Loss of native species	• Fish predators that need cool water may be lost from smaller lakes, which could indirectly cause an increase in nuisance algae blooms (Poff *et al.,* 2002:13).

4.1.8 Restrictions on Dredging Activities

> **Listing Guideline:** When contaminants in sediments exceed standards, criteria, or guidelines such that there are restrictions on dredging or disposal activities (IJC, 1991).

According to the IJC's Sediment Priority Action Committee (1999), there are a number of AOCs with impairment of beneficial uses as a result of contaminated sediment. These impairments are listed in Table 4-10.

Table 4-10. AOCs impaired by contaminated sediment.

Beneficial Use Impairment	**Number of AOCs Impaired (% of 42 AOCs)**
Restrictions on fish and wildlife consumption	36 (86%)
Degradation of fish and wildlife populations	30 (71%)
Degradation of benthos	35 (83%)
Loss of fish and wildlife habitat	34 (81%)
Eutrophication or undesirable algae	21 (50%)
Degradation of phytoplankton or zooplankton populations	10 (24%)

Source: SedPAC, 1999

There was no literature found directly focusing on the impacts of climate change on dredging activities and the possible impacts on the ecosystem. There were a few studies found pertaining to contaminated sediment and changes in water levels, suspended sediment and disposal sites.

Table 4-11. Restrictions on dredging activities research findings.

Climate Sensitivities	**Research Findings**
Lower water levels	• *Dredging can lead to the resuspension of containments in the water column, causing ecosystem health problems* (Colborn *et al.*, 1990). • *Leaving toxic contaminants undisturbed on the on the lake bed could be a viable alternative remediation option for some of the contaminated areas to avoid resuspension* (Rhodes *et al.*, 1993: 293). • *Shallow contaminated sediment are most vulnerable to changes in water levels, and are also the most difficult for remediation. The AOCs not consistently dredged for navigational purposes may take the longest to be cleaned up* (Rhodes *et al.*, 1993: 302). • There have been problems finding disposal sites for contaminated sediment. The added cost of dredging and disposal increases the costs for all levels of government (Colborn *et al.*, 1990).

4.1.9 Degradation of Benthos

> **Listing Guideline:** When the benthic macroinvertebrate community structure significantly diverges from unimpacted control sites of comparable physical and chemical characteristics. In addition, this use will be considered impaired when toxicity (as defined by relevant, field-validated, bioassays with appropriate quality assurance/quality controls) of sediment associated contaminants at a site is significantly higher than controls (IJC, 1991).

Benthos are animals that live in or on the lake bottom. A variety of benthic species can indicate a healthy lake ecosystem. No literature focusing specifically with the impacts of climate change on benthos in the Great Lakes was found (Table 4-12).

Table 4-12. Degradation of benthos research findings.

Climate Sensitivities	Research Findings
Water quality changes	• *Shallow water fauna can be more sensitive to changes in overall water quality in a large lake than those in deep water* (Kilgour *et al.*, 2000).
Air temperatures increase	• *Climate change effects on benthos sources can occur as a result of the effects on water column mixing and resuspension of bottom sediment* (Atkinson *et al.*, 1999: 7-18).

4.1.10. Degradation of Fish and Wildlife Populations

> **Listing Guideline:** When fish and wildlife management programs have identified degraded fish or wildlife populations due to a cause within the watershed. In addition, this use will be considered impaired when relevant, field-validated, fish or wildlife bioassays with appropriate quality assurance/quality controls confirm significant toxicity from water column or sediment contaminants (IJC, 1991).

Climate change effects on fish and wildlife populations are not expected to be gradual and transitional (Cherry, 1998). The reaction of these populations to climatic change can significantly depend on species and genetic diversity (Peters, 1990; Cherry, 1998; Hogg *et al.*, 1998). Cherry (1998) found species that are, at present, widespread will experience extreme shifts in range boundaries and undergo certain losses of genetic variation and some population extirpation. Some smaller and more localized species may undergo severe reductions in size or even extinction. Those with greater levels of genetic variability may be able to inhabit a wider range of environmental conditions and would be better able to adapt to environmental change relative to species with lower genetic variability (Hogg *et al.*, 1998). Climate responses are dependent on the both the timing and magnitude of warming, and the vulnerability of a species in response to seasonal changes (Chen *et al.*, 1996).

Table 4-13. Degradation of fish and wildlife populations research findings.

Climate Sensitivities	**Research Findings**
Lower water levels and increased temperatures can impact the physical health of a species.	• Cold water fish species (*e.g.* trout and salmon) are expected to disappear from fresh water lakes in the United States, as water temperatures increase, exceeding their tolerance limits. Other species that can tolerate warmer temperatures (*e.g.* large mouth bass and carp) may expand (Poff *et al.*, 2002). • Most species may experience a time lag before extensive colonization is possible into the new habitat and in the short term may show a range diminishment (Peters, 1990). • Increases in water temperature by 2 and 4 °C decreased growth and reproductive success in female rainbow trout in California (Van Winkle *et al.*, 1997). • *Higher lake levels maintain larger wildlife diversity, while lower levels lead to poorer conditions* (Mortsch, 1998). • *Positive results from changes (increased temperature and precipitation include "faster growth and maturation rates, less winter mortality due to cold or anoxia, and expanded habitats with ice retreat". This should offset negative factors such as increased summer anoxia, demands for food (due to higher metabolism), negative changes in lake thermal structure, and decreased thermal habitat for cold-water species* (Regier *et al.*, 1996: 11). • *There could be an overall increase in fish production due to an increase in growth rates and food supply. There would be a change in some species as a result of thermal tolerances. There would be a shift away from traditional cold-water fisheries to warm-water fisheries as a result of a shrinking habitat for cold-water species* (Atkinson *et al.*, 1999: 7-16). • *Warmer water temperatures could lead to an increase in the growth potential of lake trout, striped bass, and Chinook salmon in Lake Michigan* (Brandt *et al.*, 2002). • *Water temperature increases in epilimnetic habitats would alter yearling growth and prey consumption. The degree of alteration would depend on how close the species were to their optimal temperature and their ability to thermoregulate* (Hill *et al.*, 1990: 271-272). • *Historically important fish species in Lake Erie may be lost due to water level change as it limits the availability of spawning and nursery habitat* (Koonce *et al.*, 1996). • *An increase in mean global temperature could lead to an increase in the year class strength of small mouth bass, a warmwater species, in Lake Ontario (*Casselman *et al.,* 2002). • *Global warming will significantly decrease the recruitment of cold and cool-water fish species and increase the recruitment of warm-water fish species in the Great Lakes* (Casselman, 2002).
Warmer water temperatures can lead to the invasion of non-native species.	• The zoogeographical boundary for fish in the northern U.S. could move north by 500-600 kilometres (Magnuson, 1998). • Invasion of exotic species and/or warm water fish should increase (Coutant, 1990; Magnuson, 1998: 104, Manadrak, 1989). • *Invasion of warm water species and a local extirpation of cool water and cold water species* (Mandrak, 1989). • *Warming can establish the potential for fish species invasions by expanding (or contracting) their geographic range. It would be very difficult to prevent*

	movement of southern species into the Great Lakes (International Association for Great Lakes Research, 2002: 14). • *Climate warming could lead to earlier spawning, decrease incubation period, lengthen the growing season, and increase survival rates of sea lamprey* (Holmes, 1990: 298).
Water chemistry	• *Less dissolved oxygen below the thermocline of the lakes would degrade stratified lakes for cold-water fish* (Magnuson, 1998: 103). • *Changes in water chemistry, including decreased oxygen in the bottom waters due to decay of dead algae and macrophytes, can make the bottom waters unusable for species like lake trout* (Crowder *et al.,* 1996: 131). • *Warming will lead to an increase in thermal stress and less productive conditions. Rivers with low oxygen at low flows will severely limit the fish population* (Regier *et al.,* 1996: 10).
Air temperature increase	• Reptile richness increases monotonically with temperature. Climate warming could be positive, resulting in large increases for the northern half of the United States (Currie, 2001: 220). • Increases in mean summer monthly minimum temperatures could lower elk population growth rates or juvenile recruitment in Rocky Mountain National Park, Colorado (Wang *et al.*, 2002: 218). • A study of painted turtles in Mississippi found that sex determination was based on air temperature. Years with warmer mean July temperatures produced more female offspring, cooler temperatures produced more male offspring (Janzen, 1994). • In Canada, the evolutionary process of mammals may be inhibited or reversed if climate change leads to an increased mixing of sub-species, where each species possesses distinct characteristics (Kerr *et al.*, 1997: 268). • In Canada, populations of plants and animals may experience the effect of climate change directly through shifts in their growth rates, and indirectly through feedback and interaction with other species and abiotic components of the environment (Fleming *et al.,* 1997: 237). • Salmon eggs in the freshwater Catamaran Brook of New Brunswick had the lowest survival rate during an atypical winter where ice break-up was initiated by rain on snow events that resulted in the scouring of the streambed (Cunjak *et al*., 1998: 174). • *Can result in the loss of sensitive animal species from lakeshores and national parks in the western Great Lakes. Because of the location of parks on the southern Lake Superior shore, migration to another potential range in the north will be problematic for many species* (Davis *et al.*, 1999: 981).
Impact on food sources	• Climate could indirectly affect elk populations in Rocky Mountain National Park, Colorado, by altering vegetation in their habitats (Wang *et al*., 2002: 218).

4.1.11 Restrictions on Fish and Wildlife Consumption

Listing Guideline: When contaminant levels in fish or wildlife populations exceed current standards, objectives or guidelines, or public health advisories are in effect for human consumption of fish or wildlife. Contaminant levels in fish and wildlife must be due to contaminant input from the watershed (IJC, 1991).

The IJC has identified 362 contaminants in the Great Lakes, and a third of these chemicals have been assessed for their potential toxic effects on wildlife, aquatic life, and human health (GLIN, 2003). In 1985, 11 of the most extensive and persistent chemicals were identified and termed "Critical Great Lakes Pollutants", and are listed in Table 4-14 (GLIN, 2003).

Table 4-14. Critical Great Lakes pollutants.

Alkylated lead	Hexachloronbenzene
Benzo[a]pyrene	Mercury
DDT and metabolites	Mirex
Dieldrin	Total PCBs
2,3,7,8-tetrachlorodibenzo-p-dioxin	Toxaphene
2,3,7,8-tetrachlorodibenzofuran	

Human exposure to contaminants is dependent, in part, on the amount of wildlife or fish eaten and the species consumed. There is currently minimal information concerning maximum exposure levels, body burden, and heath impacts (GLIN, 2003). There were no studies found regarding climate change impacts on fish and wildlife consumption restrictions and bioaccumulation of these chemicals in wildlife.

4.1.12 Tainting of Fish and Wildlife Flavour

> **Listing Guideline:** When ambient water quality standards, objectives, or guidelines for the anthropogenic substance(s) known to cause tainting, are being exceeded, or survey results have identified tainting of fish or wildlife flavour (IJC, 1991).

There have been no studies found concerning impacts of climate change on the tainting of fish and wildlife flavour. There have, however, been studies that have focused on water pollutants and the tainting of fish flavour. Shumway and Palensky (1973) performed fish bioassays and assessed the impacts of different chemical concentrations and exposure times on the taste of fish. They discovered that many organic compounds are capable of impairing the flavour at levels not considered detrimental to the fish.

4.2 SUMMARY

Potential impacts from climate change, using published literature, have been surveyed. There were numerous publications available relating to the impacts of climate change on loss of fish and wildlife habitat, degradation of fish and wildlife populations, and eutrophication or undesirable algae. Few publications were found for most of the other impaired beneficial uses. For three of the beneficial uses (added costs to agriculture or industry, restrictions on fish and wildlife consumption, and tainting of fish and wildlife flavour) no publications were found.

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5.0 PRIMER ON ADAPTATION TO CLIMATE CHANGE

As our understanding of the potential consequences of climate change in the Great Lakes region has grown, the importance placed on developing response options to reduce the risks, or take advantage of the opportunities, posed by climate change has also increased. Adaptation measures intended to increase the resilience of the Great Lakes region to change is a necessary complement to mitigation actions. Even if mitigation measures aimed at reducing greenhouse gases and slowing climate change are implemented, the earth's climate is expected to change, resulting in impacts throughout the Great Lakes region.

Many of the physical, biological, and ecological systems in the Great Lakes region are sensitive to weather and climate; *i.e.* many systems are affected to varying degrees by climate-related stimuli (encompassing all the elements of climate change, including mean climate characteristics, climate variability, and the frequency and magnitude of extremes). Many of these systems yield "beneficial uses" protected by the Great Lakes Water Quality Agreement of 1978 (as amended by the protocol signed November 18, 1987). Changes in climate will affect these systems. The effects may be direct (*e.g.* reductions in Great Lakes water levels due to changes in precipitation, temperature, and evaporation) or indirect (*e.g.* changes in water quality in rivers and streams as more intense precipitation leads to runoff of pesticides from farmland).

> **Adaptation** refers to adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2001).

Yet, many of the sensitive systems in the Great Lakes region also have the ability to adjust to climate change. The extent to which a system is vulnerable to a changing climate depends upon its adaptive capacity, *i.e.* on the ability of the system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2001). Vulnerability plays an essential role in determining whether climate change actually harms human populations, so that understanding the dynamics of vulnerability is as important as understanding climate itself (Liverman, 1990; Handmer *et al.*, 1999).

Adaptive actions are those responses or actions taken to enhance the resilience of vulnerable systems, thereby reducing damages to human and natural systems from climate change and variability.[1] These actions may be taken in reaction to climate change as it occurs or in anticipation of future climate change (Smith, 1997; WHO, 2000). In natural systems, adaptation is reactive, whereas in human systems it also can be anticipatory. For example, aquatic life must react to changes in the mix of surface nutrients and oxygen throughout the depth of the Great Lakes as air and lake temperature, sunshine, and winds change. In contrast, humans have

[1] Several definitions of climate-related adaptation can be found in the literature and they continue to evolve. Many definitions focus on human actions (*e.g.* Burton, 1992; Smith *et al.*, 1996), some include current climate variability and extreme events (*e.g.* Smit, 1993), and others are limited to adverse consequences of climate change (*e.g.* Stakhiv, 1993; Smith *et al.*, 1996). The IPCC (2001) definition is used through this chapter.

the opportunity and ability to anticipate the effects of climate change on agriculture and develop new varieties of crops that are more adaptable to inter-annual variations of weather (Sousounis and Bisanz, 2000).

While there is uncertainty about future climatic changes and their effects in the Great Lakes region, failure to invest in adaptation may leave the region poorly prepared to cope with adverse changes and increases the probability of severe consequences (Smith and Lenhart, 1996). As the climate continues to change, our ability to protect sensitive systems may be further challenged. In addition, the possibility of abrupt climatic "surprises" cannot be discounted. In these cases, waiting to react to climate change may be unsatisfactory because the adverse effects of climate change may be significant (OTA, 1993). It is therefore prudent to begin considering investments in adaptive responses to reduce the vulnerability of human health, ecosystems, and socio-economic systems to current climate variability and future climate change.

5.1 BASIC CONSIDERATIONS IN THE DEVELOPMENT OF ADAPTATION STRATEGIES

The extent to which interested stakeholders are willing to expend resources to avoid the effects of climate change will depend in part on their perceptions of the risks posed by climate change, the perceived costs of the effort, and how much they are willing to risk possible negative consequences (NAS, 1992; OTA, 1993). If stakeholders decide to implement adaptive measures in anticipation of climate change, six important issues must be considered to ensure that the adaptive responses are effective (Scheraga and Grambsch, 1998):

- **Distributional effects:** Stakeholders should focus on specific locations because the effects of climate change will vary across the region. Also, stakeholders should consider the distributional effects climate change will have on different sectors (*e.g.* commercial fishing, shipping, and transportation) and demographic groups (*e.g.* the elderly and very young children).

- **Multiple stresses:** The effects of climate change must be considered in the context of other stressors and factors, which may be as important to the design of adaptive responses as the sensitivity to change. Also, opportunities exist to adapt to multiple factors, including climate change.

- **Cost:** Adaptation comes at a cost.

- **Effectiveness of actions:** Stakeholders should investigate the varying degrees of effectiveness of alternative adaptive responses, as demonstrated by current efforts to cope with climate variability.

- **Maladaptation:** Maladaptation can result in negative effects that are as serious as the climate-induced effects being avoided.

- **Multiple benefits:** Many opportunities for adaptation make sense whether or not the effects of climate change are realized.

5.1.1 Distributional Effects

The design of adaptive responses should vary by locality, sector, and demographic group.

There is a regional texture to changes in climate and, therefore, to the effects of climate change (Shriner and Street, 1997; Scheraga, 1998). The unique location of the entire Great Lakes region – halfway between the equator and North Pole within a large continental land mass and co-located with the largest lakes in the world – gives it a unique climate. Warm summers, cold winters, and significant precipitation year-round characterize this climate. But within the region, there are significant variations in local climates. The Great Lakes are large enough and close enough to each other to exert significant impacts on local and regional weather. Areas in the north and west have lower temperatures, a larger seasonal temperature range, and less annual and less seasonally distributed precipitation than areas in the south and east. Areas close to the lakes have a smaller annual temperature range than areas farther away (Sousounis and Bisanz, 2000).

In the same way that there is a regional texture to ongoing climate change, there is a regional texture to the risks and opportunities presented by climate change. The human and ecological systems that are sensitive to climate change, and the degree to which they are vulnerable, will vary geographically. Even within specific geographic locations, the effects of climate change will vary across systems, sectors, and demographic groups.

> Adaptive strategies must be tailored to specific effects in specific locations.

CASE STUDY
Regional and Distributional Effects of Changes in Heavy Lake-effect Snowstorms

Consider, for example, the effects of an expected decrease in the frequency of heavy lake-effect snowstorms near Lake Erie and the other Great Lakes (Kunkel *et al.,* 2000). Such a change would yield benefits in some locations as the cost of snow removal declines and the frequency of transportation disruptions decreases. But in the southern portions of the Great Lakes, the winter recreational industry will be adversely affected. As illustrated by the experience of the 1997-1998 El Niño year, the financial losses could be significant. During the 1997-1998 period, business at midwestern ski resorts declined 50 % and losses were estimated at $120 million.

Particular demographic groups may also be differentially affected by climate change. Consider, for example, that climate change will likely increase the frequency and severity of very hot days and heat waves during the summer. Studies in urban areas show an association between increases in mortality and increases in heat (McGeehin and Mirabelli, 2001). The risk of heat stress may rise as a result of climate change (Kalkstein and Greene, 1997). The most vulnerable populations within heat-sensitive regions are urban populations. Within these vulnerable populations, the elderly, young children, the poor, and people who are bedridden or are on certain medications are at particular risk.

To be effective, adaptive responses must target these vulnerable regions and demographic groups, some of which may be difficult to reach (Chestnut *et al.*, 1998). For example, the elderly are less likely to perceive excess heat (Blum *et al.*, 1998). They may be socially isolated and physically frail (Semenza *et al.*, 1996; Kilbourne *et al.*, 1982). This may make it difficult to get them to use air conditioning (*i.e.* because they do not feel the heat) or to travel to air-conditioned environments (*e.g.* they have no one to take them and may be unable to travel on their own). The poor may not be able to afford air conditioning, and if they live in high crime areas then they may be afraid to visit cooling shelters. Finally, for young children and infants, adults often make decisions about how warmly to dress and time spent in hot environments, and the children and infants may be unable to communicate their discomfort (Blum *et al.*, 1998).

The variation of impacts across localities, sectors, and demographic groups must be considered if effective adaptive strategies are to be developed. Appropriate adaptive responses should vary across different geographic regions, sectors, and demographic groups since the potential risks, and human capacity to respond to those risks, vary regionally in scope and severity. At the same time, it should be recognized that as stakeholders strive to protect beneficial uses and increase society's well being through the implementation of adaptation policies, tradeoffs likely will have to be made. Any one particular effect of climate change may benefit one region or demographic group within a region, while harming another region or demographic group. "One person's opportunity may be another person's loss."[2] It is therefore important that any assessment of potential adaptation strategies to protect "beneficial uses" in the Great Lakes region articulate the range of potential effects, including both risks and opportunities, and the options for reducing the risks and exploiting the opportunities.

5.1.2 Multiple Stresses

Climate change should be viewed as one of several stressors of concern.

Many of the beneficial uses in the Great Lakes region that are sensitive to climate change and climate variability are already under stress for other reasons. Climate change may exacerbate or ameliorate existing stresses.

> Beneficial uses such as fish and wildlife consumption, access to beaches, agricultural productivity, and industrial productivity are sensitive to climate change. But these beneficial uses are already under stress for other reasons – such as population growth, land-use changes, and pollution.

To illustrate the importance of assessing the potential consequences of climate change within a larger context, consider the potential effect that climate change may have on natural ecosystems in the Great Lakes region. The rate of climate change, the size of species ranges, and the dispersal rates of individual species all are important determinants of the ability of natural ecosystems to adapt to changing climatic conditions. However, existing threats to natural ecosystems and species diversity will also affect ecosystem resiliency and capacity to adapt to climate change. Conversion of land for human activities (*e.g.* urban settlements, farming, harvesting of forests) can interfere directly with seed dispersal and cause changes in the composition of forested ecosystems. Natural and manmade barriers, such as roads, cities, bodies of water, and agricultural land may block migration of species. Manmade pollution and habitat degradation may impair the health of particular species, making them less able to withstand stresses from climate change. Fragmentation of ecosystems and competition from

[2] The comments were made at the 1998 A&WMA Annual Meeting, in the session on "Climate Change II - Impacts on North America: What Do We Know?", San Diego, CA.

introduced exotic species may make it impossible for species to migrate to suitable areas in response to climatic shifts. Failure to include these stressors in any evaluation of potential adaptation strategies will result in an incorrect picture of future ecosystem distributions.

CASE STUDY
Multiple Stresses on Great Lakes Rivers

Over the years, Great Lakes rivers have been subjected to numerous stresses. For example, the logging era resulted in cleared land, which led to warmer streams and increased sedimentation, which was further exacerbated by floating the logs to river mouths. Today, Grayling, Michigan, is a popular recreational destination, but its namesake, a salmonid fish much sought after by fly-fishers in Alaska and Canada, was extirpated in the 1990s. Other types of fish habitat destruction, invasions of non-native species, and chemical pollution are amongst the most important current stresses. Agriculture and sprawl are common examples of how changing land use and population can influence the delivery of sediment, nutrients, and contaminants into surface waters. Climate change will add yet another stress. Unless strategies focused on adapting to climate change also consider other significant stresses, the adaptive responses may prove ineffective and fail.

Humans may also indirectly affect ecosystem migration through other activities, such as through the consumption of water that is needed by the ecosystem to survive. Competition for water in the Great Lakes region is already a real concern, and is likely to increase with climate change. Consider that as the climate changes, water supplies will be directly affected by precipitation changes and increased evapotranspiration. The availability of water also will be indirectly affected by changes in the competition for water among multiple uses (*e.g.* urban water demand, recreational activities, irrigation in agriculture, hydropower). In such cases, the water required by natural ecosystems such as wetlands and forests to survive may become scarcer.

A complete assessment of the vulnerability of Great Lakes systems to climate change and potential adaptation strategies must consider the multiple stressors on the affected systems. Assessments that do not include these stressors will provide incorrect information to those who are developing adaptive responses in anticipation of future change, increasing the possibility that less effective adaptation, and in some cases maladaptive strategies, will be chosen.

By placing climate change in the context of multiple stressors, one opens up opportunities to reduce vulnerabilities to other environmental stresses as climate change is addressed, and vice versa (IPCC, 2002: 132). For example, removing societal stresses and managing resources in a sustainable manner may help unique and threatened systems also to cope with the additional stress posed by climate change. Addressing or avoiding land degradation also decreases vulnerability to climate change, especially when response strategies consider the social and economic factors defining the land-use practices together with the additional risks imposed by climate change. Problems with the availability, abundance, and pollution of freshwater, which are often caused by demographic and development pressures, can be exacerbated by climate change. Reducing vulnerability to water stress (*e.g.* by water conservation, water-demand management, and more efficient water use) also reduces vulnerability to additional stress by climate change.

5.1.3 Cost

The costs of adaptation must be considered.

Adaptation is not without cost. The scarce resources that are used to adapt to a changing climate in the Great Lakes region must be diverted from other productive activities.[3] Resources that are used to adapt to climate change could be used to reduce other stresses on human health, ecosystems, and economic systems. In the vernacular of economics, there are opportunity costs to using scarce resources for adaptation.

Society also has the option of incurring the costs of adaptation at different points in time. It can invest in adaptation immediately, or it can delay the investment for a future time (assuming that the effectiveness of the adaptation isn't compromised). In either case, there is a cost associated with adaptation. It is a question of when the costs are incurred and what they buy. The decision of whether to adapt now or later should be based on a comparison of the present value of expected net benefits associated with acting sooner versus later.

The costs of adaptation – whether they are incurred in the present or future – must be carefully weighed by decision makers when considering the tradeoffs among alternative adaptation strategies, reducing the cause of the change, and living with the residual impacts (Shriner and Street, 1997). It is therefore important that in assessing the potential effectiveness of adaptation, the availability of the resources required to implement alternative strategies be evaluated. The lack of appropriate technology and trained personnel, financial limitations, cultural and social values, and political and legal institutions may all restrict a nation's ability to implement adaptation measures, which will likely vary across regions and demographic groups. Also, one must evaluate the willingness of society to divert required resources away from other desired uses.

CASE STUDY
The Costs of Adapting to Low Lake Levels

There is a significant chance that Great Lake water levels will decline as the climate changes. Current reductions in Great Lakes levels have had a significant effect on both the commercial shipping economy and recreational boating. Lower lake levels mean ships cannot carry as much. Low water also makes it more difficult for recreational boaters. The most common approach for managing lowered lake level situations in marinas, harbours, and channel-ways is by dredging. Dredging imposes both operational and environmental costs. Much of the material dredged from channels and harbours is contaminated from industrial waste and spills, and must be buried in existing landfills. In the 1970s, the U.S. federal government built 26 confined disposal facilities (CDFs) for dredged sediments of the Great Lakes. The CDFs are viewed as an alternative to the open lake disposal of these sometimes contaminated materials. Currently, these 26 CDFs are either full or nearly full, and by 2006 only two facilities will have room.

[3] A resource is said to be scarce if it is desired but limited.

5.1.4 Effectiveness of Adaptations

The reasons for varying effectiveness of adaptations need to be understood and incorporated into strategy designs.

In assessing the capacity of society to adapt to climate change in order to project future vulnerabilities, it is instructive to look at the effectiveness of adaptation policy under current climatic conditions. Historic evidence demonstrates that society has not always adapted to existing risks effectively.

The difficulties involved in ensuring the effectiveness of future adaptive responses is illustrated by shortcomings in existing efforts to cope with the effects of climate variability under current climatic conditions. For example, exposure to extreme heat causes deaths in urban areas throughout the world, even during years with no heat waves. During heat waves, these numbers can increase dramatically. These deaths are preventable, yet they persist.

There is a wide array of possible explanations for society's failure to adapt effectively to existing risks. This may be due to a failure to identify and understand stressors and factors that affect the risk and the ability of society and individuals to respond. It may be due to limited resources available to society for adaptation. Or it may be due to a conscious decision by society not to invest scarce resources in adaptive responses. Regardless of the reasons for the limited effectiveness of existing adaptive responses, the historic evidence suggests that one cannot be cavalier about the effectiveness of adaptive strategies when making projections of future vulnerabilities to climate change. In cases where past adaptations have not been perfectly effective, the reasons for the shortcomings should be explored to help improve the design of future adaptation measures.

5.1.5 Maladaptation

There are dangers of maladaptation in poorly designed adaptation strategies.

Adaptive responses may have unintended, adverse, secondary consequences that outweigh the benefits of undertaking the strategy. An adaptive response that is made without consideration for interdependent systems may, inadvertently, increase risks to other systems that are sensitive to climate change. However, even when a comprehensive approach is taken to the development of strategies for adapting to climate-induced effects, one must account for potential non-climate related side effects of the adaptive strategies to avoid maladaptation. The possibility has to be considered that adaptive responses might have adverse consequences for human health or the environment (Shriner and Street, 1997; Parry and Carter, 1998). Adaptive responses also might have adverse consequences for social well-being. Consideration should be given in the design of adaptive strategies to issues of equity. The social acceptability of a particular adaptive response may depend upon who in society will benefit from the adaptation policy and who will lose (Smith *et al.*, 1995).

The concept of maladaptation can be illustrated by one possible response to risks posed by climate change to fisheries. Climate change is likely to exacerbate existing stresses on fish stocks. Hatcheries can be used to enhance natural recruitment of fish stocks when climate causes stocks to fall below the carrying capacity of an ecosystem for a given species. This adaptive response might increase stock productivity, reduce recruitment variability, and enable the colonization or re-colonization of new areas. But injudicious use may alter or impoverish the biodiversity of an ecosystem and the genetic pool of resources. It might also lead to the transmission of parasites and diseases (Everett, 1996).

A well-informed decision maker may decide that the adverse effects of the adaptive measures are of greater concern than the risks posed by climate change itself. It is important that all adaptive responses be evaluated in an assessment to identify possible adverse consequences and how they might affect the range of feasible and desirable adaptive responses that are available.

CASE STUDY
Low Lake Levels and Dredging

The dredging process that has become the most common approach for managing lowered lake level situations has adverse, secondary consequences. The dredging process may release buried toxins into the lake water. That is, there is a risk of re-suspending human-made inert toxins and heavy metals lying within the lake bottom sediment, significantly impacting water quality. This would reverse the trend towards less contaminated fish in the Great Lakes. The risks posed by future dredging operations need to be assessed and incorporated into any decisions about options for adapting to future low lake levels.

5.1.6 Multiple Benefits

Sensible options have multiple benefits.

Many strategies that would reduce risks posed by climate change or exploit opportunities make sense whether or not the effects of climate change are realized. These "win-win" adaptation measures result in human systems that are more resilient to climate variability today, and hence to future climate change. Win-win strategies such as heat-wave planning and vector-borne disease surveillance systems, are recognized by the public health community as important to the protection of lives and health regardless of future climate change (Bernard and Ebi, 2001). The urgency of implementing particular measures may be enhanced or ameliorated by considerations of climate change, and an understanding of the incremental effects of climate change is important. Nevertheless, the current importance of many measures suggests that an assessment of strategies for responding to climate change should reflect the fact that the measures will prove beneficial even if the projected effects of climate change never materialize.

In some cases, existing institutions and public policies result in systems that are more rigid and unable to respond to changing conditions. For example, the existence of federal flood insurance in the United States provides an incentive for development in high-risk coastal areas. Such development increases the risk of injury and death to coastal populations. Elimination of the federal flood insurance today would reduce the size of coastal communities that are at risk today, as well as in the future when sea level rises further.

Care must be taken, however, in evaluating such win-win strategies. These strategies would lead to a more efficient allocation of scarce resources under current and future climatic conditions. However, as noted earlier, the formulation of public policies – including public health policies – often involve considerations other than efficiency (*e.g.* equity considerations, political feasibility). These additional considerations must be accounted for in the assessment of win-win strategies for adapting to climate change in order to protect the physical, biological, and human resources of the Great Lakes region.

5.2 TOOLS TO FACILITATE DECISION MAKING

Once a decision has been made to implement adaptation strategies, the choice of a "best" policy for coping with climate change is a decision that inherently depends upon social values and selection criteria that must be identified by decision makers (not by researchers or assessors). Policy decisions are often complex because of the need to consider multiple social objectives, and the need to assess the importance and relevance of these objectives in some consistent way – which requires their own set of tools (Herrod-Julius and Scheraga, 2000). The choice of a specific best coping strategy may depend upon considerations other than climate change, such as equity considerations (both within and across generations) and political feasibility. Also, the choice of a best coping strategy may depend upon specific environmental objectives chosen by society, such as the protection of unique ecosystems or sustainable development goals.

5.3 CONCLUSIONS

Anticipatory adaptation is a risk management policy. Although many uncertainties exist about the potential consequences of future climate change, existing evidence suggests that climate in the Great Lakes region is changing and will continue to change. This will result in both beneficial and adverse effects on human health, ecosystems, and socio-economic systems that are sensitive to changes in climate. Investments in adaptation are warranted to reduce the vulnerability of systems to climate change and to exploit the opportunities that may increase social well-being.

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6.0 ADAPTATION MEASURES FOR CONSIDERATION

Many of the management practices in the Great Lakes region are predicated on the fact that the past is a reliable guide to the future. However, a changing climate challenges managers. They must examine: How is the climate changing? How great or rapid are the changes? What and who might be affected? What adaptations must be made to cope with the changes? When or how fast must these adaptations be made? What are the costs? What are the impediments to adaptation? What is the capacity to adapt? Climate change may exacerbate existing issues within the region and adds a new component to consider in planning, management, and program implementation. Adaptation links needs of today with problems of tomorrow.

A preliminary list of potential adaptation measures was drawn from the proceedings of symposia and workshops and well as climate change assessment reports (see Table 6-1). Identifying possible adaptations is the first step and numerous lists have been developed. The next steps are more difficult and require consultation and collaboration amongst stakeholders and practitioners in the Great Lakes region because managing to meet multiple demands in a changing environment requires an integrated approach. The process includes:

1. Assessing and evaluating potential adaptation measures;
2. Choosing preferred adaptation measures;
3. Developing action plans that contain a portfolio of adaptation measures and incorporate means to address barriers to adaptation;
4. Implementing adaptations;
5. Monitoring impacts and adaptation measures for effectiveness; and
6. Reassessing adaptation measures.

Table 6-1. List of potential adaptation measures.

SECTOR	ADAPTATION MEASURES
Economic Activity	
Hydro-electric power generation and transmission	• Expand water storage capacity • Implement drought surcharges • Assess standards for transmission equipment • Promote voluntary water conservation • Diversify power supply
Commercial Navigation	• Opportunity for year-round shipping with less or no ice cover • Lower water levels require lighter loads and more frequent trips • Dredge shipping channels (incorporate risk assessment for resuspension of pollutants and disposal of sediment) • Build locks and weirs to manage water levels for navigation • Assess implications (economic and environmental) of modal shifts

SECTOR	ADAPTATION MEASURES

Urban development and infrastructure	• Consider climate change in planning and design of new projects
	• Review building and engineering standards and best practices to incorporate information on climate change
	  - reassess intensity, duration, and frequency rainfall curves; probable maximum precipitation; probable maximum flood; freeze-thaw regimes
	  - assess engineering design for grading, draining, ditches, storm water detention ponds
	  - assess ventilation, cooling requirements
	• Limit development in flood-prone areas
	• Improve energy efficiency of buildings; design with climate considerations to minimize summer cooling requirements
	• Reduce the urban heat island effect through building design, green space (shade trees and parks), vertical and roof-top gardens
	• Modify existing infrastructure and design new infrastructure to accommodate extreme events:
	  - increase the size of storm drains, culverts, and bridge openings to accommodate intense precipitation runoff
	  - increase water infiltration capacity of the urban landscape
	• Consider sustainable asset management (full-cost accounting and full-cost recovery) for water supply infrastructure (includes planning for the maintenance and eventual replacement of the water supply infrastructure)
	• Integration of watershed source protection planning into broader urban planning realm

SECTOR	ADAPTATION MEASURES
Agriculture	• Change crop selection or variety (crops that are currently used in more southerly regions; new varieties) • Change time of planting to accommodate longer growing season and applying nutrients and pesticides; • Double cropping • Change tillage practices • Change farming practices to increase soil moisture • Improve water-efficient irrigation and incorporate monitoring • Irrigate only during peak growth period • Limit kinds of crops irrigated • Plant more drought- and pest-tolerant varieties • Meter water use • Encourage best management practices and watershed stewardship in rural areas that reduce sources of pollution and re-vegetate riparian corridors • Use near-term climate predictions to reduce losses due to weather variability
Recreation and Tourism	• Diversify recreational activities to more than one season (*e.g.* combine golf and skiing activities) or initiate other activities (*e.g.* festivals) to draw people • Marinas, cottagers install floating docks instead of fixed docks • Anglers self-regulate to limit catch-and-release activities when fish are thermally stressed • Monitor and evaluate response of natural areas, camping areas, canoe and hiking routes to longer season of use; institute visitor management programs if ecosystems are under stress • Ski areas may need to expand snow-making

SECTOR	ADAPTATION MEASURES
Industry	• Enhance water use efficiencies; metering; user pays • Maintain high standards of effluent discharged to receiving waters • Maintain high standards of air emissions • Incentive system for innovation for new or improved technologies for waste management (liquid, solid, or gaseous emissions) • Compliance incentives: financial; regulations and enforcement capability
Forestry	• Plant tree species more tolerant to changing climate - breed drought/disease resistant varieties - diversify species to promote flexibility • Improve fire weather forecasting and fire monitoring • Improve pest monitoring • Increase tree thinning to aid in adaptation to stress • Develop alternative products

Human Health	
Water Quality	• Source water protection a component of urban planning • Enforceable drinking water standards
Heat Stress	• Design buildings for better, natural cooling • Heat stress warning systems; heat contingency plans • Education on actions to take during a heat wave – focus on most vulnerable populations
Air Quality	• Improve reduction of sulphur dioxide, nitrogen oxides, and precursors for ground-level ozone • Regulate and monitor emissions from automobiles, buses, and trucks • Develop smog plans • Improve early warning systems for air quality • Increase use of mass transit • Modify building codes to design cooler buildings • Develop more "non-polluting" energy sources
Disease and Illness	• Improve measures to identify and address vector-borne and rodent-borne disease through monitoring and surveillance • Develop and institute insect and pest controls • Create an index (similar to the UV index) for climate-related health conditions • Develop heath care system emergency plans (extreme events and disease outbreaks) • Reduce human exposure by identifying risk areas or risk behaviours • Develop vaccines and improve protection for U.S. and Canadian travelers to disease-endemic areas • Remove standing water (*e.g.* in parks and fountains)

SECTOR	ADAPTATION MEASURES
Water Resources	
Drought	• Improve drought forecasting, warning, and monitoring systems • Develop drought management plans (determine priorities for water use and roles of agencies) • Improve contingency plans for water allocation during a shortage • Enhance water efficiency and conservation programs • Increase water storage in reservoirs • Optimize reservoir operation • Improve storage and conveyance procedures to reduce evaporation and seepage • Relocate intake structures to accommodate river channel and lake level changes • Conjunctive use of ground water and surface water; recharge ground water during high flow periods • Fines issued during water shortage periods
Flood	• Modify dam operating procedures • Create and improve existing flood storage facilities • Improve flood forecasting and public early warning systems • Improve emergency preparedness with transportation and power back up plans • Flood-proof buildings; elevate buildings • Restrict development in flood plains • Enhance zoning and building codes

SECTOR	ADAPTATION MEASURES

Water Use	• Meter water use
	• Enhance water efficiency and conservation programs (residential, industrial, commercial)
	• Promote research into water-efficient technology in commercial, agricultural, industrial, and residential sectors; incorporate new technologies
	• Educate public on need to reduce water use
	• Institute water pricing initiatives.
	  - price water at its replacement cost
	  - marginal cost pricing to replace average cost pricing
	  - rates increase with volume used
	• Regulate and monitor surface and ground water withdrawal

Water Quality	• Assess changes in assimilative capacity due to flow changes and examine effluent discharge standards • Manage reservoirs to attain water quality targets rather than flow targets • Change drinking water treatment technologies for taste and odour problems (*e.g.* activated carbon filtration or other processes) • Separate combined sewer and storm sewer systems; develop storage facilities to contain combined sewer overflow during high-flow episodes for subsequent treatment instead of discharging • Update waste water treatment facilities • Encourage land stewardship practices that reduce erosion of soil and time nutrient and herbicide/pesticide applications with less risk to water quality • Develop manure management plans • Protect existing wetlands and create new wetlands to retain and filter water • Maintain vegetated buffer zones around significant water bodies, streams and rivers, channels, and wetlands • Protect ground water recharge areas to maintain quantity as well as quality

SECTOR	ADAPTATION MEASURES
Ecosystems	
Vegetation, Wetlands, Wildlife, Fish	• Identify minimum standards of water required for in-stream needs • Implement incentives to promote the preservation and creation of wetlands • Manage for maintaining species habitat rather than preserving species • Protect species at the bottom of the food chain • Expand areas for wildlife refuges to decrease vulnerability • Maintain corridors between nature reserves to promote migration of species • Maintain flexible zoning around nature reserves to allow movement as the climate changes • Minimize fragmentation of habitat in rural areas • Encourage public programs for purchase of greenspace and wildlife corridors • Monitor to detect and assess impact of exotic, invasive species, changing biodiversity, and habitat disturbance • Continue to rebuild stocks of native species • Minimize degradation of habitat by human activities (*e.g.* spawning and nursery habitat) • Adjust stocking for sport fisheries • Education programs to explain changes to general public and fisheries people
Communication	
• Encourage community-based environmental stewardship • Involvement of local stakeholders in developing public policy priorities • Improve forecasting, information distribution, and special assistance to high-risk populations for human health effects, strengthen health-related weather advisory system • Promote areas of excellence by showcasing programs and projects that illustrate sustainable use of water • Improve risk communication (*e.g.* emerging pathogens, risks with public drinking water systems)	

Management
• Emergency planning and emergency preparedness for extreme events (*e.g.* flooding, wind, ice storms), health concerns • Extreme events – forecasting and advance warning – develop preparedness and disaster relief • Identify incentives/practices that place people, investments, wildlife, and ecosystems at a greater risk to climate variability and change • Improve watershed management to reduce flood and drought damages and protect water quality • Need reliable data in order to make decisions, calibrate models, make projections, evaluate adaptation measures
SOURCES: Anderson *et al.*, 1998; Arnell *et al.*, 2001; Bruce *et al.*, 2000a,b; Hoffman *et al.,* 1998; Mortsch *et al.*, 1998; Natural Resources Canada, 2002; O'Connor, 2002; Pollution Probe, 2002, Sousounis and Bisanz, 2000; Smit, 1993; Smith *et al.,* 1998; Toronto Region Conservation Authority, 1999

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7.0 RESEARCH NEEDS

As climate impact assessment moves to a more participatory process, the research undertaken needs to reflect practitioner/stakeholder as well as researcher views of what is needed to understand climate change, the impacts, and adaptive responses. To reflect this dialogue, a list of research needs has been compiled from numerous climate change workshop and symposia reports, and climate impact assessment documents (Mortsch *et al.,* 1998; Hofmann *et al.*, 1998; Mills and Craig, 1999; Fisher *et al.,* 2000; Scott *et al.,* 2000; Sousounis and Bisanz, 2000; Arnell *et al.,* 2001; Gitay *et al.,* 2001; Grondin and Gosselin, 2002). This is an extensive list that needs further refinement through dialogue within the Great Lakes community on what needs to be done to address climate change. Much emphasis has been placed on understanding biophysical systems and clearly more attention needs to be placed on understanding human and institutional behaviour in the face of a changing climate.

Also, assessing the sensitivity of beneficial uses to climate change uncovered numerous topics where there has been little or no research in the Great Lakes region. The tables in Chapter 4 highlight the gaps specifically; however, the general needs are incorporated below.

The research needs are organized into themes including: monitoring/surveillance/analysis, climate change scenarios, model development, vulnerability, impact and adaptation assessments, economic assessment, adaptation, and communication.

7.1 MONITORING/SURVEILLANCE/ANALYSIS

Long-term monitoring of systematically gathered environmental and socio-economic data is critical. Reliable data are required from which to make decisions, calibrate models, and make projections. Similarly, these data are important to understanding patterns of variability, for even without climate change the recent past may not be a reliable guide for management due to other agents of change.

<u>Needs</u> include:

- Critical assessments of current monitoring programs with adjustments identified to meet future needs;
- Collaboration and protocols for common methods of monitoring that allow intercomparison of data collected in different cities, states, or provinces (*e.g*. disease surveillance information; climate data);
- Gathering baseline data for the evaluation of climate, hydrological, water quality, and ecosystem variability and trends over time to provide context for changing climate;
- Monitoring and analysis for detecting changing climatic, hydrologic, water quality, and ecosystem conditions (using indices that are relevant to stakeholders and practitioners as well as researchers);
- Monitoring and analysis to corroborate climate change impacts (*e.g.* duration of effects, spatial extent of effects, changes in species or processes) identified in impact assessments;
- Monitoring, surveillance, and analysis for detecting human health issues (*e.g.* distribution and abundance of insect vectors and the pathogens that they carry; heat-

related illnesses, injuries, and fatalities; water quality and water-borne diseases; air quality and respiratory effects);
- Monitoring and assessment of water use, consumption, and withdrawal rates (lakes, streams, and ground water);
- Evaluate existing indicators of ecosystem health for applicability to climate change issue (*e.g.* SOLEC indicators); identify and monitor additional indicators assessing sensitivity of ecosystem health to climate change;
- Phenological studies for monitoring changes in amphibian, insect, plant, and wildlife behaviour;
- Monitoring of effectiveness of adaptation strategies that have been implemented (*e.g.* Toronto heat warning system).

7.2 CLIMATE CHANGE SCENARIOS

The development of credible climate change scenarios is a common research need. However, there are different scenario requirements for the research community and resource management practitioners. The challenge is to construct scenarios and develop methods of applying scenarios that aid decision-making. This requires frequent discussion between the researchers and practitioners on the evolving science and front-line needs. One critical requirement is to provide guidance on using a range of climate scenarios in impact assessments.

<u>Needs</u> include:
- Regional climate scenarios (with the Great Lakes incorporated in the landcover scheme);
- Downscaling techniques;
- Changes in variability at all time scales;
- Improved projections for frequency, timing, and intensity of extreme weather (especially precipitation).

7.3 MODEL DEVELOPMENT

Models are important tools to explore the sensitivity of systems to a changing climate. The sophistication of the climate impact assessment is, in part, affected by the complexity of the biophysical and socio-economic models that are used. Biophysical models (hydrology, forestry, and agriculture) are more common and advanced than socio-economic models (decision-making, adaptation process).

<u>Needs</u> include:
- More robust regulation models for Lakes Superior and Ontario as current regulation models have significant limitations under climate change scenarios including failure; need to expand interests that are considered (*e.g.* recreational boating and the environment);
- Second generation runoff models for the Great Lakes watershed that incorporate land surface processes as well as changes in land use and cover in a changing climate;
- Improved Great Lakes evaporation model;
- Models that include realistic representation of processes that generate streamflow and recharge as well as determine water quality;
- Advances in mixed layer modelling that include lake morphometry, heat advection by river discharge, and ice dynamics;

- Models that could assess changes to wetland form, functioning, vegetation, chemistry and, habitat due to hydrologic and temperature changes;
- Coupled models of ecosystem productivity with models of land use change to understand change under altered climate;
- Dynamic (transient) models of ecosystems (*e.g.* Gap model) combined with spatially distributed models of landscape function;
- Response of disturbance regimes (fires, pests, diseases) to climate change;
- The effect of seed dispersal on the rate of species establishment.

7.4 VULNERABILITY, IMPACT, AND ADAPTATION (VIA) ASSESSMENTS

7.4.1 Climate Link

This review uncovered a large range of topics that are climate sensitive but where there has been very little linkage made to climate variability, let alone climate change. Research needs include:

- Understanding the linkages between climate variables and ecosystem components such as species composition, diversity, production, respiration, recruitment, and mortality;
- Identifying aspects of climate variability that are most ecologically relevant and the segment of ecosystems most sensitive to climate change;
- Improving knowledge of how average and extreme weather affect fresh water quantity and quality, fisheries, ecosystems and wildlife, human health, and forests;
- Understanding the impact of greater warming at night.

7.4.2 Rate of Change

There is uncertainty regarding the rate of climate change. Our vulnerability to climate change will depend on both the nature of the impacts and our ability to adapt to them. The rate of climate change is a critical factor affecting the ability to adapt; rapid climate change could mean increased costs and disruption. No VIA assessments have addressed the implications of different rates of climate change.

7.4.3 Baseline

VIA assessments need a baseline or starting conditions from which to project a changing climate and to assess the changes to biophysical and socio-economic conditions. Many baselines exist due to the constantly evolving nature of institutions and economies as well as the natural resource base. Methods need to be developed to address this issue.

7.4.4 Infrastructure

- Assess vulnerability of “essential” services (electricity distribution system, communication networks, dams, reservoirs, storm water conveyance systems) to extreme events (ice storms, freeze/thaw changes, precipitation intensity);
- Assess impacts of extreme precipitation events on design and safety of storm sewers, combined sewers, culverts, storm runoff ponds, dams, and reservoirs;
- Evaluate (and update) engineering design specification for intensity, duration, frequency curves, probable maximum precipitation, and probable maximum flood;
- Estimate costs of replacing/upgrading infrastructure to deal with future extreme events.

7.4.5 Surface Water Supply

- Assess water balance (runoff, lake levels) of the Great Lakes watershed as well as tributary sub-watersheds and small lakes of the basin under various climate change scenarios;
- Assess effects of changes in streamflow, lake levels, and base flow on ecosystems (wetlands, fisheries) as well as economic activities (hydroelectricity generation, tourism, and recreation);
- Assess effects of changes in ice cover on lake levels and flows, water quality (dissolved oxygen and nutrient cycling);
- Identify in-stream ecological needs;
- Assess resilience of water supply systems to climate changes and population increase;
- Explore impacts of climate change on future demands for inter-basin transfers of water;
- Explore institutional arrangements for water allocation among different interests and regions in the watershed as well as mechanisms for dispute resolution over competing water demands.

7.4.6 Ground Water

- Assess implications of changes in precipitation and evaporation on ground water recharge, water levels, and base flow in shallow and deep aquifer systems;
- Assess how activities at the land surface may affect ground water recharge rates and water quality;
- Assess hydrologic interactions between ground water and surface water systems and the influence on the quantity and quality the water in these systems;
- Assess the impact of increased demand for ground water on sustainability of supply and quality.

7.4.7 Water Quality

- Assess interactions between the change in surface water amount and timing and the effect on water quality;
- Assess the impact on ground water chemistry and watershed runoff and nutrient and sediment loads due to climate-induced changes in agricultural land uses, farming practices, and climate (precipitation intensity, frequency of droughts);
- Assess magnitude and seasonality of changes to dissolved oxygen due to water temperature increases and associated circulation dynamics;
- Effects of surface water temperature change on drinking water quality (taste and odour);
- Assess implications of water temperature increase on chemical reactions, processes, and interactions (*e.g.* nutrient cycling, toxic chemicals);
- Assess effects on water quality of changes in low flow and the assimilation of point source inputs from municipalities and industry and high flows with runoff from agriculture and urban areas.

7.4.8 Ecosystems

- Studies on primary productivity changes in the Great Lakes;
- Rates of respiration in lakes and variation of the rates with temperature increase;

- Determine how productivity, decomposition, and disturbance in ecosystems are affected by climate change;
- Pest and disease interaction with climate change and the impact of these interactions on ecosystems;
- Impact of added stress of climate change on many ecosystems that are currently under pressure from human activities;
- Effects of climate change (and other effects such as land use change) on biodiversity and ecosystems functions;
- Wetland, riparian vegetation influence on downstream hydrology and effect on water quality;
- Assess vulnerability of inland wetland ecosystems to changes in precipitation, evaporation, and water supply;
- Assess vulnerability of rare and endangered species to climate change (individual species tolerances and availability of habitat);
- Assess links in food web between primary producers and top economically important fish, wildlife in systems;
- Management options for human-guided adaptation to climate change to allow ecosystem functioning;
- Management of exotics to achieve "desired" community structures (terrestrial and aquatic systems).

7.4.9 Vulnerability

- Methods for evaluating how proposed shifts in policy (land use, transportation, environmental, water, health) might affect the vulnerability of sectors to climate variability and change.

7.4.10 Economic Assessment

There is an overwhelming lack of economic analysis of the impact of climate change. More detailed regional analysis is needed on costs, benefits, interface between sectors, and distributional aspects of climate change impacts. Also, human adaptation needs to be costed.

<u>Needs</u> include:

- Determine base line economic values of sectors, commodities, and ecosystem functions;
- Assess the economic impacts of extreme events;
- Evaluate economic implications (costs of impacts and adaptation) of changes in the resource base to economic sectors/activities in the Great Lakes (*e.g.* hydroelectric generating, commercial navigation, recreational boating and marinas, tourism and recreation);
- Evaluate the economic implications of meeting environmental standards (*e.g.* estimate the treatment costs to maintain a given water quality standard such as dissolved oxygen)
- Cost the avoided impacts due to adaptation strategies;
- Cost adaptation strategies;
- Develop models and methods to evaluate the benefits and costs of alternative adaptation options.

7.4.11 Adaptation

- Need studies of climate change impacts on real-world water management systems to identify impacts, identify adaptation responses, and assess adaptive capacity of system;
- Need methods to evaluate merits of adaptation strategies from various perspectives including social, environmental, economic, legislative, institutional, equity, and distributive; need methods to integrate assessment of these perspectives to choose "appropriate" adaptation strategies instead of maladaptation;
- Identify obstacles to implementing adaptation options; determine how obstacles can be overcome;
- Study how managers make adaptation decisions with incomplete information; identify information and develop tools that assist in decision making;
- Determine the effects/costs of inefficient adaptation;
- Identify strategies to enhance the range of adaptation techniques considered by managers;
- Assess adaptive capacity of ecosystems, sectors, activities, institutions, and regions within the Great Lakes region;
- Methods to explore integration of adaptation strategies among sectors, jurisdictions, and regions; determine means to minimize maladaptation.

7.4.12 Communication

Most climate change assessment summaries and workshop proceedings call for more communication of climate change information among researchers, decision makers, practitioners, stakeholders, and the general public. However, there are few assessments of information needs, effective communication methods for different groups and various outcomes, and guidelines for "effective" communication.

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8.0 SUMMARY

Within the Great Lakes region, some notable changes in climate and hydrology have been identified. For example, air temperatures are rising, the minimums more than the maximums. Associated indices such as growing season length, frost-free season, cooling season, and heating season are also affected. Snow cover duration and areal extent are decreasing. The important spring runoff is occurring earlier.

The people, communities, economic activities, wildlife, and ecosystems of the Great Lakes region are sensitive to climate variability and change. However, their vulnerability depends on the capacity to adapt. Human systems have the greatest capacity to deal with a changing climate because they can be deliberate about adaptation. Through proactive planning, management adjustments, investment, legislation, institutional change, and education and training, modifications can be made to minimize impacts and take advantage of opportunities. It is not an easy task but it can be done. Yet, thresholds may be reached that significantly strain adaptive capacity. Natural ecosystems, their processes and wildlife are most vulnerable to a changing climate because adaptation is autonomous. The ecosystems respond through natural processes but the outcomes are uncertain. Significant human intervention may be required to "manage" change but managers do not have the knowledge or the capacity to address all the potential changes.

There is much to be done to address the issue of a changing climate in the Great Lakes watershed. Monitoring is required to detect changes in climate as well as identify impacts in ecosystems, to communities, and on economic activity. Climate change impact assessments are needed particularly on the effects on ecosystems and water quality. There is a crucial lack of understanding of the implications of a changing climate for the beneficial uses in the Great Lakes Water Quality Agreement. Adaptation measures need to be identified, assessed, costed, and incorporated into an adaptation strategy. This requires an integrated approach where a wide range of adaptations are considered; many practitioners and stakeholders are involved in dialogue and included in the decision process.

Appendix A

Climate Change Scenario Development

A scenario is a plausible, coherent, internally consistent description of a possible future state of the world (Carter *et al.,* 1994); it is not a prediction or forecast since no probability of occurrence is associated with the scenario. This appendix describes the three most common scenario-generating techniques that have been used for climate change impact assessments in the Great Lakes.

A.1 Global Climate Model (GCM) Scenarios

The most commonly used scenario-generating technique is GCM-based. Coupled general circulation models of the atmosphere and ocean (AOGCMs) provide the most credible quantitative estimate of the climate response to changing concentrations of greenhouse gases, sulphate aerosols, and other elements that affect climate forcing (IPCC, 1999).

Historically, GCM-based scenarios were developed from equilibrium-response climate change experiments where the atmospheric component was linked to highly simplified oceanic and sea-ice components. In these experiments, the global climate system was perturbed by an instantaneous increase in the atmospheric concentration of CO_2 (usually a doubling) and allowed to stabilize to a "new" climate. This is known as a $2xCO_2$ run. In addition, a $1xCO_2$ control run of the GCM was produced with pre-industrial or current atmospheric greenhouse gas concentrations. The $2xCO_2$ climate change scenario was derived from the difference (temperature) or the ratio (precipitation) between the $2xCO_2$ and $1xCO_2$ results. The $2xCO_2$ scenarios reported here include CCC92, GISS (87) and the GFDL (87).

Current climate change impact assessments use transient experiments in which AOGCMs simulate the response of the climate system to a gradual increase in CO_2 and sulphate aerosols. The AOGCM incorporates the ocean's important role in sequestering and distributing heat. In most cases, data are available depicting the evolution of the climate system to 2100 in response to historical and projected greenhouse gas and aerosol forcing described by the IS92 and Special Report on Emission Scenarios (SRES) emission scenarios (IPCC, 2000). In the scenario-generating process, the 30-year simulation period from 1961-90 is used as the reference climate from which "change fields" for future periods are calculated. Now, most scenarios are calculated for the 2020s (2010-2039), the 2050s (2040-2069), and the 2080s (2070-2099) although shorter 20-year periods were used in the U.S. National Assessment and recent International Joint Commission Studies (Lofgren *et al.,* 2002; Mortsch *et al.,* 2000).

IS92

Through the Intergovernmental Panel on Climate Change (IPCC), six (a to f) greenhouse gas and sulphate emission scenarios were developed using scenarios of economic development, population growth, and energy mix (Leggett *et al.,* 1992). The IS92a scenario is known as the "business as usual scenario" where emission scenarios are based on historical increases to 1990 and thereafter a 1 % annum growth, compounded. The IS92a emission scenario was used by all GCM modelling centres for their climate sensitivity experiments. The IS92a is the only scenario used in all climate impact assessments in the Great Lakes watershed.

SRES

The SRES emission futures consist of a series of four scenario families, A1, A2, B1, and B2, which represent different demographic, social, economic, and technological futures called "storylines" (Carter *et al.,* 1999). They differ from the IS92 by having lower population projections as well as other features. The A1 and A2 families have an economic development focus while B1 and B2 focus are more environmental (CCIS, 2002). The A1 and B1 scenarios have a global perspective while the A2 and B2 are more regional. To date no SRES scenarios have been used in climate change impact assessments in the Great Lakes; however, the International Joint Commission Lake Ontario Reference will be using these scenarios for an assessment of water level changes (Barrow, 2002).

SRES Storylines

- The **A1 storyline** is a world of very rapid economic growth, low population increase, and rapid introduction of new, more efficient technologies. The economy grows to approximately $550 (U.S.) trillion by 2100. Global populations reach 9 billion by 2050, and decrease to 7 billion by 2100. There are abundant energy and mineral resources available due to rapid technical progress.

- The **A2 storyline** is a diverse world. There is a reliance and preservation of local identities and a high population growth, 15 billion by 2100. Economic development is regionally orientated. Economic growth and technological change are more uneven and slower than the other storylines. Global per capita income is low compared to the other scenarios. The GDP is $250 (U.S.) trillion by 2100.

- The **B1 storyline** is a convergent world. There is low population growth, 9 billion by 2050 and a decrease to 7 billion by 2100. There are rapid changes in the economic organization through service, information economy, and resource-efficient technology. The GDP is $350 (U.S.) trillion by 2100.

- The **B2 storyline** concentrates on local solutions to economic, social, and environmental sustainability. There is a moderate population growth of 10 billion and the GDP is $250 (U.S.) trillion by 2100. This storyline focuses on local and regional levels of environmental protection and social equity IPCC (2000).

A.2 Climate Change Analogues

Analogue scenarios are constructed from real-world climatological observations and are defined as temporal or spatial analogues. Temporal analogues focus on an historical extreme event (drought, flood, wind storm, or ice storm) that has occurred in the past in the study area that may occur more frequently or severely in the future. The current vulnerability (or impacts) to climate can be demonstrated and as well adaptations implemented in response to the condition can be studied. For spatial analogues, measured observations (evaporation, precipitation, and temperature) from another region are used to test the potential vulnerability of the region to different mean climatic conditions and climate variability. Different boundary conditions (topographic, land use) and forcing factors (hurricanes) affect the validity of the application of these scenarios (Kunkel *et al.,* 1998; Mortsch and Quinn, 1996).

These scenarios may be more palatable to policy and decision-makers as they appear to have a greater "grounding" in reality; they have been experienced in the past. However, the magnitude and types of changes that may be expected as a result of climate change have not been experienced during recorded history, making it difficult to find appropriate analogues.

A.3 Systematic Changes to Climate Parameters

In this technique, scenarios are developed by making systematic changes to observed climate data, for example, 1 or 2 or 3 ^{o}C temperature increase or ±10 % or ±20 % precipitation change or other factors such as lake levels. These scenarios are developed with guidance from GCMs (*e.g.* limits of temperature changes) or stakeholder-specified vulnerabilities. These scenarios are often considered very simplistic representations of the complex response of the climate system. However, they can provide a preliminary exploration of critical thresholds or changes in a "sensitivity analysis". If warranted, more detailed scenario development and impact analysis can follow.

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Appendix B

Basin-average Seasonal Temperature and Precipitation Scatter Plots

The seasonal temperature and precipitation change fields displayed in the scatter plots are an average of all the GCM grid points that fall within the latitude and longitude box defined for the Great Lakes watershed. The change field is for 2050 (the period 2040-2069) relative to the base climate of the model during 1961-1990.

Figure B-1. Winter (December, January, February (DJF)) mean temperature and precipitation change

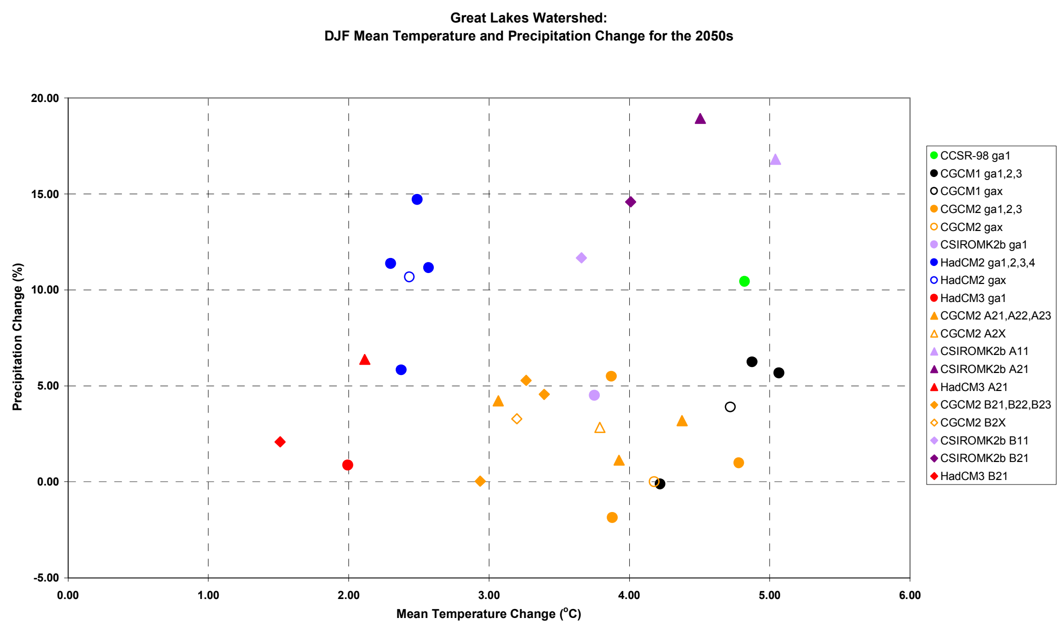


Figure B-2. Spring (March, April, May (MAM)) mean temperature and precipitation change

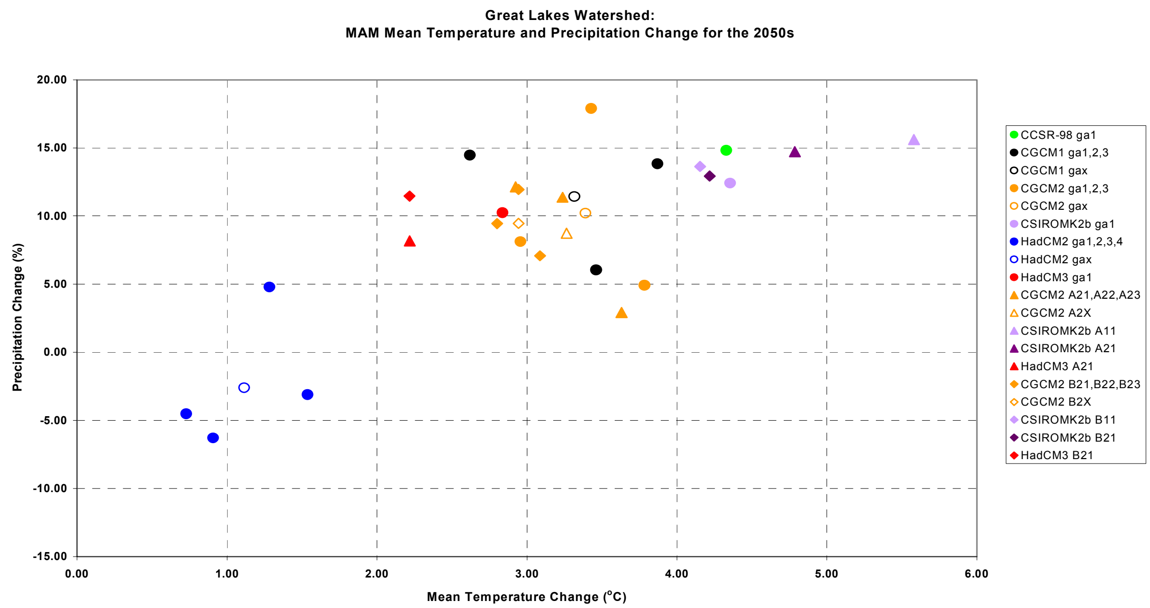


Figure B-3. Summer (June, July, August (JJA)) mean temperature and precipitation change

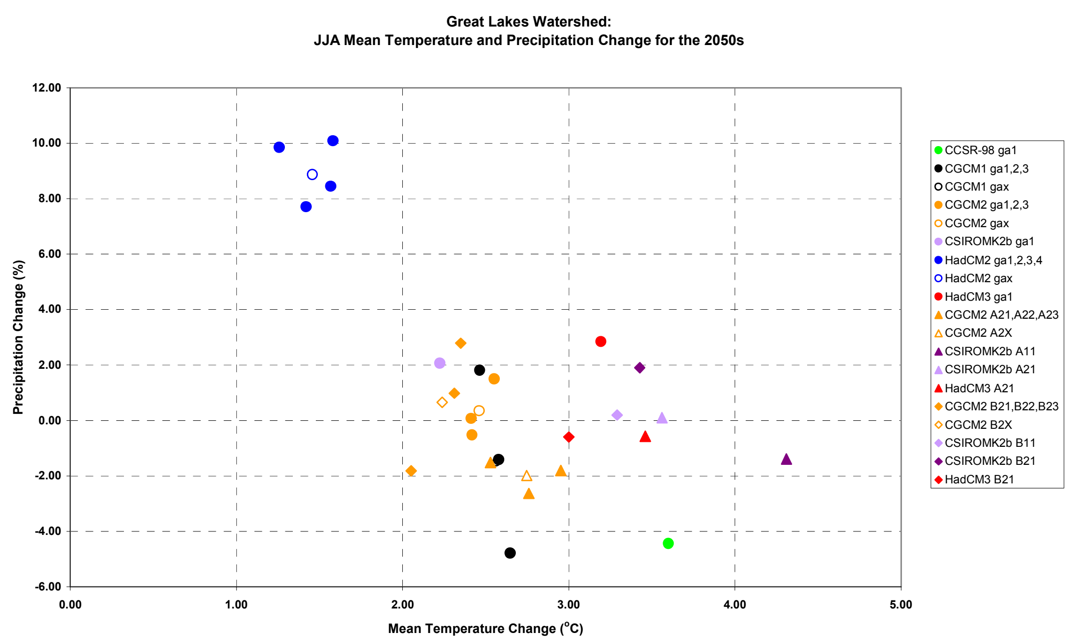
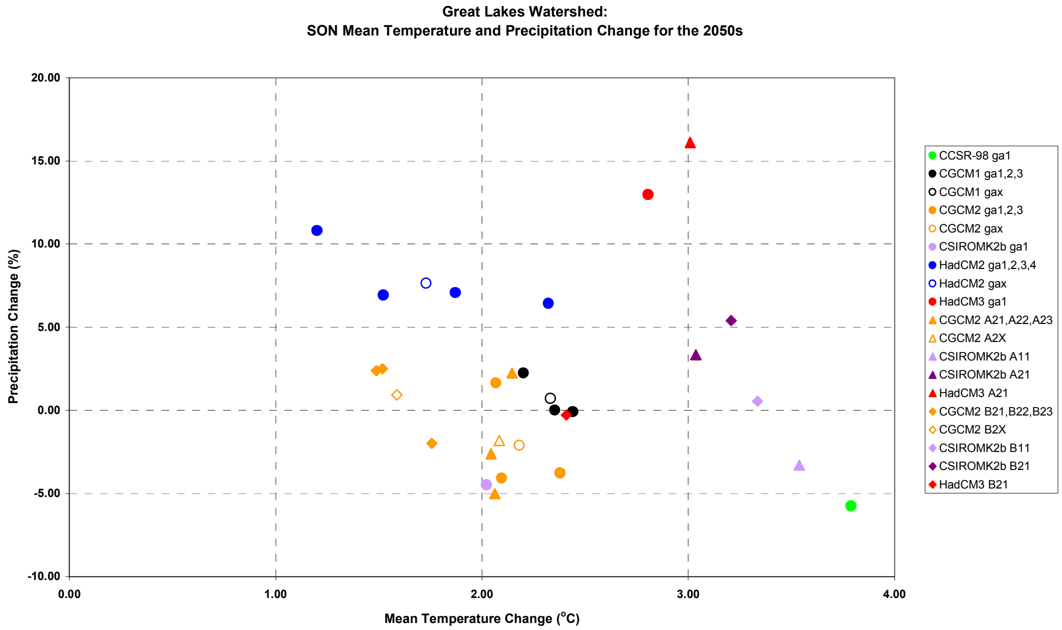


Figure B-4. Autumn (September, October, November (SON)) mean temperature and precipitation change



PART 4
SUMMARY OF THE CLIMATE CHANGE WORKSHOP
MAY 28-29, 2003

TABLE OF CONTENTS

Disclaimer

The views and opinions expressed in this summary are those of the workshop participants and not necessarily those of the Great Lakes Water Quality Board or the International Joint Commission. The views and opinions expressed by the white paper authors are theirs and do not represent official policy of the U.S. Environmental Protection Agency or Environment Canada.

Acknowledgements

The Water Quality Board is indebted to the U.S. Environmental Protection Agency and to Environment Canada for their collaboration, assistance, and support in the organization and conduct of the workshop. The Board is also indebted to Chris Hartnett, ERG, Inc., whose detailed notes and written report contributed significantly to this summary.

WORKSHOP PURPOSE

The draft white paper provided insight into the issues and impacts associated with climate change in the Great Lakes region, the options available to address those impacts, and the challenges associated with taking action. To ensure that the Water Quality Board had properly characterized the consequences of climate change, appreciated the challenges for taking action, and would provide sound advice to address impacts, the Board convened a two-day workshop, using the draft white paper as the basis for discussion.

The workshop was intended to appeal to members of the Great Lakes community familiar with impacts or impacted by climate change, as well as those positioned to implement adaptive measures and influence programs and policy. Workshop participants were asked to ground-truth the information in the draft white paper and to provide advice about how to address climate change, specifically to:

- Confirm that key impacts had been correctly identified.
- Identify how impacts on ecosystem quality, ecosystem health, human health, and beneficial uses of the Great Lakes interact and interrelate.
- Identify and assess adaptation options available to address impacts.
- Identify knowledge gaps and research needs to inform policy and decision making.
- Facilitate cross-border communication and cooperation.

Participants were encouraged to draw upon and share their personal real-world experiences: impacts encountered, specific response measures taken, the extent to which adaptation was possible, and limitations and barriers to taking action or further action.

WORKSHOP STRUCTURE

The workshop was designed to provide ample opportunity for dialogue among participants. The agenda is presented in Table 1. Formal presentations were limited to an overview of the white paper by the authors, plus a presentation by Georges Beauchemin who provided insight into real-world considerations of risks, opportunities, and responses. The revised white paper and M. Beauchemin's presentation respectively constitute Parts 3 and 5 of this report to the Commission.

Workshop participants were divided into breakout groups. To provide structure and focus to the breakout discussions, seven questions were posed (Table 2). The questions were not, however, intended to be exclusive nor answered sequentially. Rather, they were intended as a guide to draw out people's insight and experiences. The breakout groups met twice, once on each day.

To provide additional opportunity for discussion, the breakout session facilitators constituted a plenary panel during which they presented the key points arising from the breakout discussions. The panelists were also encouraged to share additional insights, to stimulate people to "think outside the box."

The workshop concluded with a group discussion to identify key points that would contribute to the Board's "bottom line" advice to the Commission.

Table 1. **Agenda for Workshop on Climate Change and Water Quality in the Great Lakes Region — Risks, Opportunities, and Responses**

Wednesday, May 28, 2003

9:00 AM	Registration Desk Opens
10:00 AM	**Welcome and Introductions** David Ullrich, U.S. Co-Chair, Great Lakes Water Quality Board Dennis Schornack, Chair, U.S. Section, International Joint Commission
10:05 AM	**Workshop Purpose** John Mills, Canadian Co-Chair, Great Lakes Water Quality Board
10:15 AM	**Impacts of Climate Change on Great Lakes Water Quality** Presentation of white paper findings. Linda Mortsch & Marianne Alden Open discussion
11:45 AM	**Instructions for Breakout Groups**
Noon	Luncheon Speaker – Georges Beauchemin – **Climate Change from a User's Perspective**
1:00 PM	**Breakout Groups – Implications of Climate Change Across the Great Lakes Region** Questions 1 & 2
3:00 PM	Break
3:15 PM	**Impacts Panel** David Ullrich, Moderator Breakout group highlights and panelist insights, followed by moderated discussion
5:00 PM	Adjourn

Thursday, May 29, 2003

8:30 AM	**Adaptation to Climate Change** A primer and presentation of white paper options. Dr. Joel Scheraga Open discussion
10:00 AM	Break
10:15 AM	**Breakout Groups – Adaptation to Climate Change** Questions 3 - 7
Noon	Lunch (on your own)
1:00 PM	**Adaptation Panel** David Ullrich, Moderator Breakout group highlights and panelist insights, followed by moderated discussion
2:00 PM	**Formulation of Advice for the Board** Dr. John Carey & David Ullrich, Moderators
2:45 PM	**The Board's Next Steps** Dr. John Carey & David Ullrich
3:00 PM	Adjourn

Table 2. Breakout Group Discussion Questions

Background. In addressing climate change, we want to take advantage of positive impacts, minimize negative impacts, and ensure compatibility among various interests. Each change, impact, intervention mode, and adaptation option poses opportunities, challenges, and barriers. In answering the questions, please consider the following:

- Responsibility. Who does what, when, where, how, and why?
- Cost.
- Time frame -- short-term action? long-term investment?
- Adequacy of existing institutional framework -- legal, management structure, programs, and policies.
- Availability and adequacy of engineering and technical infrastructure.
- Impact on Great Lakes governance.
- The extent to which adaptation options and mechanisms exist (including those for other stressors) and can be utilized.
- Socio-economic considerations, including consequences and incentives.
- Consequences of implementing adaptation options on competing interests.

Changes. The white paper identifies projected climate changes.

1. Based on your experiences, what changes do you foresee in the short, medium and long term?

Impacts. The white paper identifies impacts, both positive and negative, on the Great Lakes. Considering impacts in the broadest possible terms, including but not limited to food web alteration, human health, social, and economic ...

2. What impacts have you experienced?

Planning and Intervention. Addressing climate change can be either reactive -- in response to -- or planned -- in anticipation of an impact. Also, there are a number of ways to intervene, for example, technology, education, economic incentives, official development plans, emergency planning, health advisories, stream rehabilitation.

3. Based on your experiences, how can we anticipate and plan in advance, and to what end point?
4. Based on your experiences, how can we intervene in order to adapt?

Adaptation. The white paper identifies specific adaptation options.

5. How have you adapted? Were your choices correct? What constraints did you encounter? What consequences did maladaptation pose?

Overcoming Barriers. A number of factors conspire to limit our ability to act, for instance, surveillance and monitoring, technology, infrastructure, lack of perceived relevance to our health and well being. Based on your experiences:

6. What are the knowledge and information gaps, infrastructure and institutional limitations, program and research needs? How can these be filled? What are the priorities?
7. In an ideal world, what specifically would you like the Board to do to help you address climate change? A “top 10” list. Please be specific in your advice and recommendations.

The plenary discussions and breakout group deliberations are summarized below. The Water Quality Board subsequently incorporated many of the insightful comments provided by the workshop participants into the revised white paper. Written comments received subsequent to the workshop were also taken into consideration. The Board limited changes to those that corrected errors of fact and to those that extended, amplified, or clarified the information presented.

The Board also incorporated a number of key points into its advice to the Commission.

Some of the comments received were beyond the intended scope of the white paper, and other suggestions would have entailed additional time and investigation by the authors. Although the white paper would be more focussed by addressing these additional comments and suggestions, the Board concluded that there is no "end point." The information base - hence, our understanding of issues, impacts, and responses - will continue to evolve. The Board further concluded that the white paper is a snapshot in time and - although there are gaps - provides a good overview of the issue.

TERMINOLOGY — THE CONNOTATION OF ADAPTATION

Milt Clark advocated against using the word "adaptation." The term implies that climate change will be easy to adjust to and that people will just have to live with it. The draft white paper did not make the point that adaptations will not result in complete success nor "solve" problems posed by climate change. Clark preferred the term "strategies / responses" or "coping." Alain Bourque said that the idea of adaptation is captured in the phrase "limiting the adverse effects of climate change." Jim Bruce defended the use of "adaptation," noting that some of the effects will not be negative. "Adaptation" allows flexibility to discuss changes that should be made to address beneficial, as well as negative, effects. John Carey also defended the term and said that "strategies / responses" is too limiting, noting that impacts cannot always be addressed with strategies. At times it is necessary to adapt expectations.

Clark did not object to the term "adaptation" if the phrase were, for example, "adaptive action" rather than a more passive "adaptive measures" and if the white paper recognized the importance of mitigation efforts and that both adaptation and mitigation are required to address the climate change issue. The white paper, at a minimum, should recognize current mitigation measures.

THE WHITE PAPER

The authors provided an overview of the contents of the white paper. Their presentations are summarized below. Details are in the white paper (Part 3 of this report). The authors' visuals are available on the web at http://www.ijc.org .

Presentation - Climate Change and Water Quality in the Great Lakes Region. Linda Mortsch

The white paper embraces an ecosystem perspective: rather than focusing solely on water quality, the paper examines the impact that climate change could have at the ecosystem scale, and how the impacts could affect a variety of systems, including water resources, human health, agriculture, recreation, and the economy. Ms. Mortsch focussed on the impacts that a changing climate could have on the Great Lakes basin. She asked the audience to consider three questions: What impacts are of concern to me and my stakeholders? What adaptation measures need to be implemented? How can we facilitate adaptation?

Modeling exercises and various studies indicate that climate change could lead to significant airshed, nearshore, in-lake, and watershed effects. As air temperature rises, the following are projected: (1) the frequency and intensity of storms will change; (2) more precipitation will fall on an annual basis but less during key growing seasons; (3) high-intensity precipitation events will be more frequent; (4) evaporation and evapotranspiration rates will increase; (5) there will be less ice cover on lakes; and (6) there will be less snowfall (and therefore less snow pack) and more rain during the winter season. These effects could have significant implications on ecosystems and biodiversity, recreation and tourism, agriculture, streamflow, lake levels, ground water, and human health.

Ecosystems and Biodiversity

Thermal conditions and precipitation patterns - both of which are projected to change - set the boundaries which determine where different types of wildlife and vegetation are able to live. As the boundaries change, some types of habitat will be lost, some will expand, and existing community structures and interactions will likely be altered. While some animals and plants may find that climate change brings them new opportunities, others will be driven out of their homes. For example, studies suggest that southerly species of warm-water fish may be able to supplant northerly species of cold-water fish. Mortsch presented maps which show how the distribution of bobolink (a bird species) could change in the future. She also presented maps that showed how vegetation zones might change as more carbon dioxide (CO_2) enters the atmosphere in a 2 X CO_2 climate change scenario. The scenario suggests that existing forests may become severely stressed and that their boundaries may be altered due to changed climate conditions. Expanding on the topic of forestry, climate change might induce a major shift in the range of tree species, and it has the potential to degrade forest health, promote harmful plant diseases and pests, cause increases in forest fires, and induce changes in water availability and water quality.

Rare and endangered species which, by definition, may be few in number and have a small range and / or limited habitat, may be particularly vulnerable to the stress of a changing habitat. In addition, non-native species might be able to gain strong footholds as the climate changes. For example, although zebra mussels have already been introduced to Lake Superior through bilge water, they do not currently flourish in the lake because the water is too cold. What will happen if Lake Superior's water temperature rises?

Recreation and Tourism

Climate change could cause dramatic shifts in the recreation and tourism industry. For example, because climate change is expected to result in longer summers and shorter winters, the season for summer time activities (*e.g.* camping, boating, and hiking) will lengthen, but the season for winter sports will be curtailed. A shorter winter season would harm the skiing industry. Ski resorts would have a shorter reliable season and would have to rely on costly snow-making activities. Even those who manage summertime activities might have to face some tough management issues. For example, if the hiking season is longer, will resource managers have to limit access to trails to protect them from overuse and damage? Also, if climate change causes adverse effects, such as poor water quality, low water levels, species loss, or aesthetic problems, will hunting, bird watching, fishing, swimming, or canoeing still be desirable activities?

Agriculture

While climate change could result in a longer growing season, a warmer climate might induce some negative effects on the agricultural industry. For example, irrigation demand might increase, since precipitation during key seasons, such as summer and fall, may decrease as the climate changes. Also, some projections suggest that warmer temperatures will support the growth of more pests and weeds. If so, additional pesticides and herbicides will be needed to address the problem, but these products come at a cost for farmers and also cause environmental concerns. The agricultural industry might also be adversely impacted. An increase in soilerosion is projected to occur, because high-intensity rainfalls are expected to increase, and snow cover, which acts as a barrier to erosion, is expected to lessen, further exacerbated by an increase in winter rainfall. Water quality will be affected. In addition, climate change might require a change in the type of crops grown and the types of tillage practices used.

Streamflow

Studies suggest that climate change will cause changes in the timing and the amount of streamflow. While more water is expected to run off and flow through streams during the winter months, summer and fall low-flow events are expected to be exacerbated. Not only will these changes affect water quality, they could also increase the likelihood of conflicts about the apportionment of water among different users, such as in-stream ecological needs and economic uses. The results of a modeling exercise performed on the Trent River suggest that summer flow might be reduced by as much as 22% in 2030, 37% in 2050, and 55% in 2090.

Lake Levels

Most climate change scenarios project that water levels in the Great Lakes will decrease. While some models predict decreases of about 22 centimetres, others anticipate a drop of 2.5 metres. Low lake levels could have negative impacts on transportation, tourism, recreation, fisheries, industry, municipalities, agriculture, and human health. If water levels decreased by 1.6 metres, the shoreline of Lake St. Clair could shift by 0.5 to 6 kilometers. Such a drop in water level could impact the shipping channel and cause more boats to run aground. At least one boat salvage company has experienced a boost in business as more boats have started running aground because of present low levels. Changing water levels will also have dramatic impacts on wetlands and the types of plants and animals that live in such environments.

Ground Water

Some studies suggest that climate change could decrease ground-water recharge, levels, and base flow. If so, this would change the amount and timing of base flow to streams, lakes, and wetlands. The studies also suggest a seasonality effect. Less flow is expected during critical times, such as spring and early summer, and more flow during the wintertime. The proportion of ground water in stream flow is also altered.

Water Quality

Climate change could have dramatic impacts on water quality. Increases in water temperature could affect physical, chemical, and biological processes. Some work suggests that there will be extended thermal stratification and less mixing, increasing the potential for anoxia, and an increase in the metabolic rates of invertebrates and microbes. All of these factors could affect water quality. Also, non-point source pollution is expected to become a more significant problem as the climate changes. The Soil and Water Conservation Society recently released a report stating that increases in precipitation intensity could lead to greater erosion and entrainment of sediments, nutrients, and pesticides. Point source pollution might also pose a more serious problem as the climate changes; reductions in flow and increases in low-flow episodes could reduce assimilative capacity and make it more difficult for point sources to meet existing water quality discharge standards. A climate impact assessment for the Bay of Quinte watershed illustrated that phosphorus remediation targets may not be met.

Human Health

Climate change will affect human health. For example, humans could be affected by: (1) increases in extreme weather events, such as flooding and ice storms; (2) increases in heat stress episodes and decreases in cold stress episodes; (3) increases in vector-borne and rodent-borne diseases; and (4) poor air quality. To expand, ground-level ozone, which causes adverse health effects, becomes a bigger problem as temperatures rise. Those who might be the most vulnerable to health risks are children and the elderly, as well as low-income and immuno-compromised individuals. Climate change could cause more water quality impairment from combined sewer systems. These systems, which service many cities in the United States and Canada, contribute pollutants, including bacteria, into water bodies during intense precipitation events that cause high runoff. As the climate changes and the frequency of high-intensity rain events increases, more pollution incidents are anticipated.

Presentation - Implications for Beneficial Uses Identified in the Great Lakes Water Quality Agreement. Marianne Alden

The Great Lakes Water Quality Agreement calls for the restoration of 14 impaired beneficial uses. Also, there are currently 42 Areas of Concern (AOCs) in the Great Lakes. An AOC is defined as “a geographic area that fails to meet the General or Specific Objectives of the Agreement where such failure has caused or is likely to cause impairment of beneficial use or of the area’s ability to support aquatic life.” It is important to analyze the impact that climate change could have on achievement of beneficial uses and on AOCs. Three key questions require attention: Will climate change impact areas that have already been deemed environmentally sensitive? Will climate change create new AOCs? Will climate change impair beneficial uses that have already been restored?

The white paper summarizes research that examines the impact that climate change could have on 12 beneficial uses.

Loss of fish and wildlife habitat. Fish and wildlife habitat have been studied to examine the impacts of changing water levels, precipitation patterns, air temperatures, ice break up patterns, and disturbance hazards (*e.g.* forest fires and insect outbreaks). Some studies suggest that: (1) the areal extent of wetlands will be altered as water levels change; (2) tree lines will shift and certain tree species will disappear as air temperatures change; and (3) channel morphology could be altered due to changes in ice break-up intensity, affecting vegetation succession and fish-spawning habitat along the shoreline.

Degradation of phytoplankton and zooplankton populations. According to existing research, plankton populations appear to be sensitive to: (1) warmer air and water temperatures; (2) drier hydrological conditions; and (3) changes in ice break up. For example, some studies show that colder waters support larger and more diverse plankton populations.

Added costs to agriculture or industry. No research has been performed to determine exactly how climate change will impact costs incurred by these sectors.

Degradation of aesthetics. No specific research has been performed regarding the effect of climate change on aesthetics. Some studies do suggest, however, that decreases in water level result in shoreline changes that are not aesthetically pleasing, such as exposed and rotting vegetation and muddy shorelines and mudflats.

Beach closings. No specific research has been performed regarding the expected effect of climate change on beach closings. Some studies do suggest, however, that beaches are negatively impacted by increased precipitation events and lower water levels. For example, in July 1998, an intense rainstorm washed waste from the street and caused sewage plant overflows. This resulted in the closure of almost every beach in Kingston, Toronto, Hamilton, and St. Catharines, Ontario.

Restrictions on drinking water consumption or taste and odor problems. According to existing research, such impairments have been linked to air temperature increases and low water levels.

Eutrophication or undesirable algae. The following play a role in increasing eutrophication rates and promoting algal blooms: (1) increases in air and water temperatures; (2) decreases in water levels; and (3) increases in high-intensity precipitation events.

Restrictions on dredging activities. While no specific research has been performed regarding the effect of climate change on dredging activities, some studies do suggest that problems, such as resuspension of sediment, are exacerbated as water levels decrease.

Degradation of benthos. While no specific research has been performed regarding the effect of climate change on benthos populations, some studies do suggest that these populations are impacted by changes in water quality.

Degradation of fish and wildlife populations. A significant amount of research has been performed. The results suggest that fish and wildlife populations are affected by increases in water and air temperature, invasions of non-native species, changes in water chemistry, and changes in food sources. For example, the sex ratio of painted turtle populations is affected by air temperature; more females are born when conditions are warmer. Also, warmer water might allow sea lampreys to thrive and cold-water fish to be driven out of their habitats by warm-water fish. In addition, warmer temperatures have been known to prompt some species to mate or migrate early. In the case of the latter, an animal could arrive at its destination before its food source is available.

Restrictions on fish and wildlife consumption. No specific research has been performed regarding the effect of climate change.

Tainting of fish and wildlife flavor. No specific research has been performed regarding the effect of climate change.

Clearly, there are knowledge gaps that need to be filled.

Summary of Discussion following Presentations

The white paper should include information about **the link between climate change and greenhouse (GHG) emissions.** Omission would undermine the importance of GHG mitigation efforts and deprive readers of a full understanding of climate change issues. The linkage between GHGs and temperature change should be mentioned, but it would be unwise to engage in a lengthy debate on the topic. The conclusions of the Intergovernmental Panel on Climate Change (IPCC) and the National Academy of Science on this topic should be cited. Be clear that Canada and the United States are actively involved in GHG reduction efforts.

The white paper should incorporate recently published information on observed changes in **summer wind field patterns** across Green Bay. The changes will impact resuspension, sediment transport, and sediment burial rates. This could impact how long it takes for contaminants to be buried and could have ecological, human health, and water quality effects.

Although the white paper acknowledges that there will be winners and losers, it should provide **more examples of the positive benefits of climate change.**

Species may be able to better adapt to a changing climate if the changes occur gradually rather than abruptly. The white paper should include information on **the significance of the speed and magnitude of change on a species' ability to adapt.** More research needs to be performed on how adaptable humans and ecological systems are to the rate of change.

The white paper should discuss the potential **cumulative effects of climate change.** Some effects may be additive; others will cancel out. The combined effect of lower water levels, increased periods of stratification, and changes in precipitation regimes could cause serious anoxia problems.

The white paper should provide **more information about how an "ecosystem approach" to management will translate to action.**

The white paper should examine the potential **impact of rising temperatures on contaminant volatilization.** Volatile organic chemicals (VOCs) that currently contaminate the Great Lakes could volatilize at an increased rate, leading to negative impacts on northern communities, since VOCs may simply be redeposited in colder waters.

The white paper should acknowledge that surprises are to be expected. **Climate change will lead to effects that no one has anticipated yet.**

There is a need to **differentiate between physical habitat (the substrate) and overlying water.** Much more research needs to be performed on the nearshore zone.

Uncertainty is a fact of life and should not be an excuse for paralysis of action. The IPCC reports might have some useful discussions to draw upon regarding the issue of uncertainty. It is time to take action on climate change issues - "the perfect is the enemy of the good, so let's get on with it."

Presentation - Adapting To Climate Change. Joel Scheraga

Dr. Scheraga explained why decision makers in the Great Lakes basin must start implementing adaptation strategies to address climate change. According to a report by the Intergovernmental Panel on Climate Change, "Adaptation refers to adjustment in natural or human systems in response to actual or expected stimuli or their effects, which moderates harm or exploits beneficial opportunities." In his presentation, Scheraga explained the importance of adaptation, discussed basic considerations that should be taken into account when developing adaptation strategies, and offered recommendations to the Great Lakes Water Quality Board.

The Importance of Adaptation

Climate change poses a range of potential risks and opportunities. It is unclear how severe the impacts will be. Society is moving into unchartered territory: CO_2 levels are higher today than they have ever been during the course of human history and are only expected to increase. Humans are playing a grand experiment with the earth's systems. Greenhouse gas concentrations are building at a rate more rapid than anything humankind has experienced before.

The projected effects of climate change (*e.g.* higher temperatures, changes in precipitation patterns, and rising sea level) will exert impacts on a variety of systems that humans care about: human health, agriculture, forests, water resources, coastal areas, and species and natural areas. In order to protect these systems, humans should strive to develop a balanced portfolio of mitigation and adaptation strategies. While mitigation is important, the focus of the white paper is adaptation. Some people are reluctant to talk about adaptation because of the fear that efforts to implement adaptation strategies will detract from efforts to implement mitigation strategies. However, the opposite may be true: by implementing adaptation strategies, the public will become more aware of climate change issues and press more forcefully for mitigation strategies. Focussing on adaptation is also justified because climate change is happening now, and changes will continue to occur even if mitigation strategies are implemented today. Thus, because change is unavoidable, it makes sense for people to do what they can to build resilience and decrease vulnerabilities to impending changes. Compared to natural systems, humans are fortunate. While nature can only react to changes, humans can anticipate and act to reduce the negative effects that might result. Humans can also take advantage of the positive opportunities that could arise. To expand, some climate change effects could be beneficial and it is foolish not to take advantage.

While some policymakers agree that adaptation makes sense, they find it difficult to act since there is so much uncertainty about the rate and magnitude of climate change. This is a difficult problem, but policymakers must realize that failing to invest in adaptation today can leave regions vulnerable to severe consequences. As time goes on and the climate changes, it may become more difficult to protect sensitive systems. In addition, if policymakers fail to take climate change into account when designing new infrastructure, they may find themselves stuck with obsolete infrastructure that is incapable of addressing future stressors. When designing a new combined sewer, for example, planners should take projected changes in precipitation patterns into account.

Policymakers have asked the scientific community to make concrete predictions about climate change effects. Some have asked scientists to attach probabilities to anticipated outcomes. This type of information would help policymakers make smart decisions about adaptation strategies. While concrete predictions are difficult with the tools currently available, useful information can be obtained by running scenarios, performing "what if" analyses, and looking at historic analogs. Information provided from these sources should give planners sufficient information to at least start thinking about what needs to be done. Efforts should be made to improve methods for quantifying and displaying uncertainties and characterizing the implications for resource management decisions.

Basic Considerations in the Development of Adaptation Strategies

Following is a primer on basic considerations that need to be taken into account when developing adaptation strategies.

Distributional effects. The effects of climate change will vary by location, sector, and demographic group. Care needs to be taken to ensure that adaptation strategies are targeted to address the right problem. As a result, adaptation strategies may need to vary from place to place. For example, experience shows that heat stress disproportionately harms the elderly, the young, the poor, and the infirm. Thus, when developing adaptation strategies, vulnerable populations should be targeted. Another complicating factor relates to distributional effects: one person's negative impact might be another person's positive opportunity. For example, while decreases in snowfall might harm the skiing industry, such an outcome would help municipalities save money on snow removal activities.

Multiple stressors. Several beneficial uses are already under stress from factors that have nothing to do with climate change, such as land use and population growth. Climate change could exacerbate or ameliorate such existing stressors, a point that needs to be taken into account when developing adaptation strategies.

Cost. Many productive activities require funding. Unfortunately, funds are scarce, so resources used for adaptation must be diverted from other productive activities. Until adaptation is recognized as vitally important, other projects will be funded first. For example, in the face of a dramatic problem like AIDS, it is difficult to get the health care community to focus on the more insidious and less visible impacts of climate change.

The effectiveness of alternative adaptation strategies. Adaptation responses vary in effectiveness from place to place or across demographic groups. Also, other stressors may impact the effectiveness of a particular adaptation strategy. Thus, care must be taken to perform a rigorous site-specific assessment of the efficacy of different strategies. In some cases, planners will find that an adaptation strategy needs to be augmented to address community-specific challenges. For example, when trying to identify the most appropriate strategy for preventing heat-stress-related deaths, community leaders might have to go beyond issuing heat advisories and set up a buddy system to ensure that the elderly are able to get out of their homes and into air-conditioned facilities.

Maladaptation. Planners must realize that, if poorly designed adaptation measures result in detrimental secondary effects, then society might be better off if such measures were not implemented. For example, the use of hatcheries to enhance natural recruitment of fish stocks could alter or impoverish biodiversity and harm the genetic pool. Another example: Many think pest populations will increase as the climate changes. Farmers could adapt by applying more pesticides, but this will adversely impact water quality.

Multiple benefits. Some "win-win" measures are sensible to undertake whether or not climate change occurs to the full extent anticipated. These can be described as the "low hanging fruit," for example: (1) improving watershed management to reduce flood and drought damage and to protect water quality; (2) removing incentives for practices that place people, investments, and ecosystems in harm's way; (3) improving water pricing to increase efficient water use; (4) fostering continued adaptation in agriculture; and (5) establishing surveillance systems for vector-borne disease.

While easy to talk about in theory, adaptation is difficult and complex to implement in practice. Efforts need to be made to build a bridge between theory and practice.

Improving Integration of Adaptation into Decisions and Policy

Development and implementation of successful adaptation strategies is imperative now. Scheraga identified five concrete activities that the Water Quality Board could undertake.

Elicit information needs from decision-makers. In order to develop successful adaptation strategies, the Board needs to know who the stakeholders are and what endpoints they hope to achieve. Workshops and discussion forums are a means to: (1) identify relevant stakeholders; (2) learn more about their needs and issues of concern; and (3) find out how they perceive climate change risks. Some such work has already been done, for example, the Great Lakes Regional Assessment Team has held five workshops with different stakeholder groups, during which participants discussed the potential impact of climate change on water levels, lake ecology, agriculture, terrestrial ecology, and recreation. The goal was to determine the type of information the stakeholders need in order to make informed decisions.

Better characterize uncertainty for decision-makers and explain the implications of different outcomes. Be clear about the uncertainties associated with climate change modeling and invest more effort to quantify uncertainties and help decision-makers understand the implications of uncertainty.

Develop better decision support tools. Many policymakers do not know how to account for climate change in their day-to-day decision-making processes. To alleviate this problem, tools need to be developed to help resource managers gain a better understanding of: (1) the potential impacts of climate change; (2) how climate change fits in within the context of other stressors; and (3) the implications and tradeoffs of different management decisions made under uncertainty. The last will help decision-makers gain a better understanding of what is at stake when they make decisions. Some tools have already been developed, for example, U.S. EPA's TEAM web-based decision-support tool and the hantavirus pulmonary syndrome risk map that is being used in the U.S. southwest to guide decisions about public health intervention.

Develop a communication strategy. The Board should develop a communications strategy with the goal to make climate change a "real" issue for Great Lakes basin stakeholders. Many stakeholders fail to see climate change as a salient issue that requires immediate attention. Others feel powerless to respond because they think climate change is too large an issue to tackle. Efforts need be made to help people understand that they have the ability to anticipate changes and implement adaptation strategies that will minimize harm and / or exploit opportunities. Efforts also need to be made to break down complex assessment findings into easy-to-understand information. Once stakeholders clearly understand projected impacts, they will be ready to sit down and talk about adaptation strategies. Examples of the types of data that could be used to make climate change "real" include (1) pictures depicting changes in ice cover in the Gulf of St. Lawrence and (2) graphs that show changes in lake ice break-up dates over time.

Foster the adoption of adaptation strategies. This process involves six steps: (1) assess and evaluate potential adaptation measures; (2) choose preferred adaptation methods; (3) develop action plans; (4) implement adaptation strategy; (5) monitor the strategy; and (6) reassess the strategy to determine whether any revisions are required.

Summary of Discussion following Presentation

The U.S. media give the **impression that many scientists do not believe that climate change is really occurring.** Scheraga indicated that, while there are skeptics, they do not represent mainstream scientific opinion - most scientists do believe that climate change is occurring and will continue. This point is rarely disputed. The debate focuses more around the rate and magnitude of the impacts that will be realized as a result of climate change and what should be done to address the issue.

The white paper lists a number of adaptation strategies. It would be useful to **add information to help decision makers better understand which adaptation strategies are the most likely to succeed,** for example, a ranking system or scale of 3 (high success), 2 (moderate success), or 1 (low success). Although it is possible to add something to help shed light on the utility of different adaptation strategies, it is not possible to provide a detailed ranking system. Not enough is known about different adaptation strategies to say - with any level of certainty - which will perform best. Other factors also make ranking adaptation strategies difficult. For example, the level of success for a particular adaptation strategy could differ by sector. Also, it is unclear how to measure success. What one person may regard as a success could be perceived as a failure to another, for example, water rights. An economist might perceive success in terms of achieving the most efficient allocation of resources, but such an approach could cause social inequities and be regarded as a failure to a farmer who depends on the water.

It is important to encourage planners to take climate change into consideration when **designing new infrastructure systems.** The white paper uses combined sewers as an example to drive home this point, but the example may be obsolete. Canada is no longer designing new combined sewers and probably neither is the United States. However, existing systems are still being revamped and expanded. The important point is that climate change (and the associated heavier rainfalls) should be taken into account when these systems are up for redesign.

It is important to **periodically reassess adaptation strategies after implementation** to determine whether they need to be tweaked or improved to increase their utility. In reality, projects are rarely reassessed because people do not want to spend money for such efforts. Reassessment should be embraced as a key element of a project's implementation strategy. It would be helpful to generate a strategic plan that provides a long-term road map that outlines a 10-to-20-year strategy and highlights key implementation steps required along the way. Reassessment could be highlighted as an important step in the process. Efforts should also be made to educate people about the importance of reassessment activities and the negative effects that could result from canceling or delaying reassessment.

Increased erosion rates have the potential to dump large quantities of nutrients and toxic materials into the Great Lakes. This should be emphasized and information added to the white paper about **adaptation measures to minimize erosion during high-intensity rainfall events.** Indeed, runoff will be a bigger problem as the frequency of high-intensity rainfalls increases. In February 2003, U.S. EPA completed a study into the effectiveness of different types of riparian buffer zones to reduce sedimentation that may be exacerbated by climate change.

A booklet, *Risk Management Guidelines for the Caribbean*, was developed to help decision makers there learn how to cope with uncertainty and risk in a systematic way. A similar **booklet that discusses risk management guidelines should be considered for the Great Lakes region.** However, it is not enough to simply create and distribute educational manuals. Decision makers also need to be equipped with tools that will help them decide on a course of action and determine how much intervention to advocate.

It is important to **develop probabilistic modeling tools** that will help decision makers gain a better understanding of the likelihood of different climate change outcomes. Canadian and U.S. modelers should work together, share data, and develop new models for the Great Lakes region. There is no such emphasis in the United States' existing Science Plan, and Canada does not even have a science plan. The director of the U.S. Climate Change Science Program is championing the effort to incorporate this modeling objective into the U.S. plan. He hopes to establish two modeling centers in the United States to perform scenario development activities. Although the topic is very much in the forefront, securing the needed dollars could prove difficult.

An army of professionals helps communities address land-use management issues, watershed management, water permitting issues, infrastructure design, and habitat protection issues. Most of these community-support professionals are poorly equipped to address climate change considerations or to promote adaptation strategies, because they have not received training and information about these issues. Thus, it is important to **train the people who are actually working with communities on a day-to-day level -** "train the trainer" as it were. Workshops and training sessions would facilitate the effort. Indeed, a communication strategy is a critical component to any adaptation strategy. It is critically important to make people understand that climate change is real and is happening now, but it can be difficult to convince people that climate change is salient.

The word "adaptation" has a connotation of incrementalism that could give the impression that the effects of climate change can be easily managed if small incremental steps are taken to adjust to the changes. Such an interpretation is false. **Adaptation strategies will not fix everything.** It is important that people understand that fundamental change, rather than incremental change, is needed to address the effects of climate change. Further, it is important to identify the endpoints that are of concern to different sectors. Once these are determined, a sensible combination of mitigation and adaptation strategies needs to be developed to protect the systems that various sectors care about. One complicating factor is that the effectiveness of regional adaptation policies may depend on what is done at the national level.

The Board and the Commission are in a unique position to examine and **publicize sustainability success stories** and "win-win" adaptation measures.

The IPCC may discuss indicators of the impacts of a changing climate in its next report, but these may only be relevant to scientists. What indicators are important to the public? It will not be easy to convince people to take immediate action to address and adapt to climate change. **Can key indicators be identified that will prompt people to care and take action?** A number of indicators might spur the public to action: deaths, beach closures, negative economic ramifications, and water shortages. As unfortunate as it may sound, the public may have to be confronted with such negative impacts before it will rally to support a coordinated adaptation strategy. Optimistically, the public may understand the relevance of climate change before dramatic negative impacts are as apparent. For example, in the United States, the public is becoming more and more knowledgeable about the issue and some states (*e.g.* Massachusetts) are suing the federal government in an effort to encourage federal officials to place high priority on climate change issues. Public skepticism and the level of emphasis on climate change highlight the importance to develop communication materials that clearly link negative impacts, such as death and economic losses, with climate change in order to grab the public's attention. The IPPC plans to write a chapter on this issue.

SUMMARY OF PLENARY DISCUSSIONS

Environmental Quality Breakout Group Report -- Day 1
Gail Krantzberg, Facilitator

Better establish the link between climate change and beneficial use impairments. The Commission must have a clear picture of how changes in hydrology, temperature, precipitation, water level, and ice cover could impact beneficial uses.

Stress the importance of watershed planning and management. Scenarios and modelling tools that look at trends over time at the watershed level will help decision makers better understand the vulnerabilities of watersheds.

Address the interconnectedness of stressors. Climate change is just one of many elements stressing the Great Lakes. Additional work is needed on land management planning and modeling to better understand how future land management decisions, and the stressors related to them, will impact watersheds in light of a changing climate. For example, communities that strive to address flash flooding and runoff issues will be better positioned to address future climate changes.

Emphasize the impact of severe storm events and severe droughts on water quality. As the frequency of high-intensity storm events increases, runoff events will increase, combined sewers will overflow more often, and sanitary infrastructure will be overtaxed, resulting in more toxins and pathogens entering the Great Lakes and possibly leading to higher bacterial counts, more beach closings, and poorer water quality.

Expect the unexpected. Do not be paralyzed by uncertainty. Communities need to develop flexible plans that can be adapted to changing conditions. Do not postpone action until the magnitude of impacts is more certain. Uncertainty is inevitable and is no excuse for inaction. "The perfect is the enemy of the good, so let's get on with it."

The term "adaptation" implies that humans will be able to live with climate change and continue business as usual, once some simple adjustments are made. This interpretation is false.

Ecosystem Health Breakout Group Report — Day 1
John Gannon, Facilitator

In addition to discussing the first-line effects of climate change, also discuss the next steps, for example, **the effects of climate change on bioaccumulation and impacts to wildlife.**

Perform more research about the **impact of climate change on beneficial uses.**

Undertake more monitoring and surveillance. Enlist volunteers to assist.

To help generate public outcry for action, **undertake more public outreach** to instruct people about the importance of the climate change issue.

Changes have already been observed. For example, the **hunting season on Walpole Island has shifted** and now coincides with when adult ducks raise their young.

More islands are appearing near Walpole Island because the water level is dropping.

Consider climate change when **planning ecological restoration activities.**

Combined Environmental Quality / Ecosystem Health Breakout Group Report — Day 2

John Gannon, Facilitator

Highlight success stories. Promote win-win sustainable success stories. Focus on systems not originally designed with climate change issues in mind. This will help community members realize that they may be able to tweak existing systems to accommodate climate change. It will convey a "can do" feeling and an understanding of how adaptation for climate change could help address other non-climate-change related stressors. Emphasis on win-win situations will help instill a feeling of power.

Train the trainers and the implementers about climate change issues.

Tap into the emergency response and the watershed planning communities to promote adaptation strategies.

Take climate change into account when developing habitat restoration programs. For example, it makes little sense to restore a wetland if climate change modeling results indicate that the area is expected to dry up in the future. Such points should be communicated to those who fund habitat restoration programs.

Better understand ecosystem function. More information about ecosystem vulnerability and resilience to change would equip decision makers to target areas that are most vulnerable to negative effects and to intervene in these situations.

Communicate research information about vulnerable areas to officials who administer environmental programs. For example, it would be beneficial if those who issue water permits had a clear understanding of which areas were most likely to experience water loss as the climate changes.

Promote monitoring programs, link the programs to specific indicators and endpoints, and identify champions for them.

Promote information sharing. The lack of communication and collaboration across the border prevents gaining a better understanding of ecosystems. Inventory available information and invest in efforts to learn more about what is happening in both countries.

Publicize lessons learned about successful adaptation efforts. Develop an adaptation portfolio, which includes tools, techniques, and real-world examples.

Human Health Breakout Group Report

Alain Bourque, Facilitator

Human health considerations extend beyond physiological concerns. Quality of life issues and psychological well being are important components.

Consider "exceedences" as well as "extremes."

Clarify whether "climate change" refers to both naturally induced and anthropogenic-induced effects or just the latter.

Better define baseline conditions. Undertake more monitoring to establish a solid baseline, without which it is difficult to predict future impacts.

Increased temperatures will increase biological activity and associated hazards, such as the spread of vector-borne disease. Consider also the impact of climate change on food-borne illnesses.

Consider the changing characteristics of air masses. Climate change impacts not only temperature but also humidity and contaminant concentrations, all of which can have significant health implications.

Discuss the concept of "ecosystem flips." Adaptation does not address fundamental changes which can result when a threshold is reached; the result may not be reversible.

Higher temperatures could lead to a more sedentary life style, which could have negative health impacts.

People might be putting too much hope in "the medical solution" as a means to address human health concerns related to climate change. People believe that modern medicine can take care of everything. When it comes to climate change, the medical community will not be able to provide for all who are impacted.

Make climate change more visible in the public eye. The public needs more information about current climate change impacts. Provide data on the number of lives and dollars lost.

Develop a marketing strategy and education materials for a variety of groups. There is a need for a variety of outreach efforts. The general public is probably best served by simple and concise messages that emphasize the importance of addressing climate change and explain what people can do to help minimize harmful effects. Win-win situations should be emphasized. For example, a slogan such as "Save energy, save money, save the environment" might be effective. A separate marketing strategy should be developed for decision makers; it would be useful to find a champion to advocate issues. For industry, emphasize business opportunities that could be realized by developing environmentally friendly products.

Develop a sound strategic plan for the Great Lakes basin. Clearly define important questions, the definitions to be used, the partnerships to be tapped into, and the philosophies and values to be adopted. In addition, take the global picture into account and consider space and time scales.

Develop better economic evaluations and better predictive tools.

Municipal / Urban Breakout Group Report

John Carey, Facilitator

Use a worst-case scenario rather than a best-case scenario when examining the risks associated with climate change. A 2 X CO_2 scenario is not overly realistic.

Provide urban managers with tools that integrate more robust spatial and temporal scales. Also provide a better understanding of how climate change will affect the frequency and magnitude of extreme events, so that they can analyze impacts beyond existing design thresholds. In turn, managers and users should provide input for the development of design scenarios, to ensure that relevant issues are taken into account.

Urban infrastructure is typically in place for long time. Even if there is agreement that adaptation to climate change is necessary, it could take decades to make infrastructure changes. Further, if a community has a poor management system, improvements should be made now to avoid exacerbation of problems resulting from climate change. A municipality's response to climate change could affect the private sector's willingness to invest in municipal infrastructure.

Prioritize adaptation schemes based on their likelihood of success. Schemes that aim to protect human health and property are more likely to succeed than those that aim to manage ecosystems. While ecosystems should be monitored and efforts made to minimize human impacts on ecosystems, not much can actually be done to manage them. Ecosystems manage themselves. It is unclear how realistic ecological restoration efforts are.

Consider water temperature elevations in urban tributaries.

Include information on net effects, in addition to just a list of effects. This would help people understand whether effects are additive or cancel each other out.

Further explore impacts to groundwater recharge, a major concern in urban areas. Consider the impact of major events, such as a high-intensity rain falling on frozen ground.

The political will to act is likely tied to a specific event. High-impact events, such as a catastrophic flood, raise awareness about the need for adaptation strategies. As a result, after such an event, the window of opportunity is open to implement an adaptation strategy. For this reason, it is important to have strategies well thought out and ready for implementation at a moment's notice.

Place more emphasis on identifying true vulnerabilities and actual risk. Identify vulnerable areas and estimate the actual risk of harmful results.

When developing adaptation strategies, **determine whether existing systems can be tweaked to address a community's vulnerabilities** rather than developing a new system from scratch.

Tap into already-established networks to develop adaptation strategies. Engineering professionals, health providers, bankers, and the insurance industry will all play a role to help communities address the negative impacts of climate change. Engage these sectors.

Identify communities that will be particularly vulnerable to the effects of climate change, for example, water scarcity, and work with them to develop targeted adaptation strategies.

Strengthen non-point source management programs. Non-point source pollution has been a long-standing problem and is likely to become bigger as the climate changes. Analyze existing non-point source control programs and determine how to strengthen and improve them.

Encourage relevant parties to develop probabilistic models and make clear predictions. The public requires clear and concise messages about how the scientific community thinks climate change will impact the Great Lakes basin. Such messages can be provided if probabilistic models and predictive tools are developed.

Connect existing models to better predict the effects of climate change. For example, connect the regional climate model with the water-level model.

Encourage improved data storage practices and the sharing of data. Some important historical data have been lost. Try to prevent similar losses in the future.

Develop more robust economic forecasts. When projecting the costs associated with climate change, try to calculate the cost of both inaction and action.

Resource / Resource Use Breakout Group Report

Jim Bruce, Facilitator

More clearly explain how climate change will adversely impact beneficial uses.

Incorporate recently published articles in the white paper and strengthen the information for the agriculture section. Specific references were provided.

Adaptations that are designed to address short-term events will help communities prepare for the long-term impacts of global climate change.

Climate change impacts have already been seen. Drought and extreme temperature events are occurring more frequently. At Walpole Island, there are many cloudless summer days now, a rare event years ago. The flow of the Niagara River has declined since the 1970s, impacting the hydro power industry and forcing greater reliance on coal in New York and Ontario. Seasonal changes are shifting, for example, on Lake Ontario and Lake Erie, the spring rise is occurring earlier. The recreational and tourist industries are suffering from the effects of a warming climate.

Consider changing the hunting and fishing seasons to accommodate changes being seen in the timing of seasonal events, such as spawning.

The agricultural sector is already adapting. For example, chicken farmers are placing ceramic tiles on coop roofs to reduce interior temperatures. But what is the utility of making adaptations that support already unsustainable agricultural practices? There is also a need to consider how crop selection will be impacted by climate change.

From an industry and human population perspective, ensure constant and continued access to high-quality water.

High-intensity rainfall events have larger-than-expected impacts on erosion. Data for the northeastern U.S. in a recent Soil and Water Conservation Society report suggest that the frequency of high-intensity and extreme rainfall events has increased and that, when precipitation events increase by 10%, erosion increases by 24%. The concern is the huge amount of contaminants entering the water system. Data are also available for Canada but not yet published.

Consider the potential for maladaptation. Climate change might increase agricultural pest populations. While increased pesticide usage could be an adaptation strategy, this could have negative secondary effects. Collect more information on the effects of pesticides before resorting to increased pesticide use.

Develop better regional climate models for the Great Lakes. Global-scale climate models do not provide detailed information about the Great Lakes basin. Create better regional-scale models to help people in the Great Lakes areas gain a better understanding of how climate change could impact lake-effect storms, lake levels, drought frequency, and other extreme events.

Examine how climate change will impact the ability to reuse water. How will changes in the hydraulic cycle impact water reuse programs in the Great Lakes?

Develop ready-to-go adaptation action plans. Borrowing from the disaster mitigation community's philosophy, develop adaptation plans as soon as possible, even if the political support is not in place to support the plan. There would be a public outcry for adaptation if a disaster occurs, and adaptation measures could be implemented immediately before political support for such efforts evaporates.

To convince decision makers that adaptation is important, **focus on climate change effects that are happening now rather than predicted outcomes.** This will help policy makers understand that climate change is a relevant issue and that adaptation should be initiated now rather than in the future.

When calculating the costs associated with adaptation measures, also estimate the losses that could be incurred if adaptation is not undertaken. For example, when calculating the cost of expanding an existing storm sewer system, also estimate the costs that would be incurred if the investment were not made and flooding events became more frequent.

The Great Lakes monitoring network has some weaknesses. In some parts of the basin, basic data networks are in disarray.

Develop a binational research and monitoring strategy. The Commission should direct its Science Advisory Board to develop a science plan for the Great Lakes basin.

Request government funds to fill in knowledge gaps regarding the effects that climate change could have on the Great Lakes basin. Specifically include support for student research and hydrological monitoring.

Review lake level regulation plans. Try to account for shifts in the seasonal timing of water-level change events that have been observed over the last 30 to 40 years.

Review Great Lakes policies through a climate change lens.

Develop and distribute risk management guidelines to educate policymakers about climate change and adaptation measures.

Focus more attention on erosion management and adaptation measures needed to address the increase in high-intensity rainfalls. Work with non-governmental organizations and investor groups.

Encourage governments to examine the impact of climate change on human health.

Provide strong support for an educational program.

Provide information about how likely potential climate change outcomes are in the Great Lakes basin. Use the IPPC report to help classify the outcomes of climate change as highly likely, moderately likely, or unlikely.

Walpole Island Breakout Group Report

Dave White, Facilitator

The aboriginal people of Canada have significant experience with adaptation. They have been forced to adapt to life on smaller and smaller territories and to deal with pollution from upstream sources.

Walpole Island residents have succeeded in maintaining five major ecosystems and protecting about 50 rare and endangered species.

Aboriginal people should continue to be involved in workshops and other forums.

Aboriginal people possess a wealth of information and data on ecosystems and rare and endangered species. This information is vitally important to the scientific community. In addition, they possess detailed information about their surrounding lands and have a good understanding of the vulnerabilities of different areas and which areas are most likely to be impacted by a changing climate.

Aboriginal people offer a clear vision. Humans are charged with the responsibility to preserve the balance between the earth and the sky. When this balance is destroyed, catastrophic problems can emerge.

ADAPTATION STRATEGY IMPLEMENTATION

Given the importance of implementing a sound adaptation strategy, key points made by the white paper authors are synthesized below with insight and advice provided by workshop participants.

A number of common-sense win-win adaptation options were identified, for example:

- Improved watershed management will reduce flood and drought damage and protect water quality and human health.
- Removal of incentives for practices that place people, investments, and ecosystems in "harm's way."
- Improved water pricing to increase efficient water use.
- Continued adaptation in agriculture.

However, if such actions are so sensible to reduce risk and take advantage of opportunities, why have they not been implemented? In reality, there are numerous barriers to adaptation. A formidable challenge, then, is to improve the integration of adaptation to climate change into decision-making, policy formulation, and program implementation. In addition, information and knowledge gaps - such as the impact of climate change on beneficial uses - point out the need for research into impacts and potential adaptations, in order to establish or strengthen linkages. Effective linkages require communication and dialogue, which lead to education, outreach, and marketing.

A number of approaches and tools are available. For example, in 1997 the Great Lakes-St. Lawrence Basin Project undertook consultations via a binational conference on adapting to the impacts of climate change and variability. More recently, the U.S. Great Lakes Regional Assessment Team and the Canadian Climate Impacts and Adaptation Research Network have hosted a series of sector-specific workshops and consultations (Table 3). Another approach is Ouranos, a Québec-based consortium of major stakeholders who have pooled financial, technical, and scientific resources to quantify climate change impacts and propose adaptation scenarios suited to their respective needs (see Part 5).

Table 3. C-CIARN Sectors and U.S. Great Lakes Assessment Workshops

C-CIARN Sectors	U.S. Great Lakes Regional Assessment Workshops
Health	Water levels - shipping, recreation boating, safety, infrastructure
Water resources	Lake ecology - productivity, fishing
Coastal zone	Agriculture - farming, insurance, adaptation
Forest	Terrestrial ecology - forests, wildlife, timber industry
Agriculture	Recreation - winter recreation and economy
Landscape hazards	
Fisheries	

Such initiatives, targeted at interested stakeholders and their constituencies, are intended to:

- Identify decision makers.
- Ascertain issues of concern.
- Identify stakeholder perceptions of risk, whether these perceptions are scientifically sound, and how the perceptions were formed.

These initiatives, in turn, provide an avenue to:

- Characterize uncertainties and explain implications for outcomes of concern to decision makers.
- Communicate climate change impact assessment findings.
- Identify research needs.
- Develop decision support tools.

Communication of assessment findings poses challenges:

- The issues are complex.
- Potential consequences and adaptation strategies have many uncertainties.
- Issues are not salient - there is a lag in the occurrence of impacts, and impacts are diffuse.
- There is a sense of powerlessness.

Much of the effort over the past two decades has been to convince people that climate change is an issue. As a result, only a limited number of sectors and stakeholders have effectively changed the way they do business in anticipation of future climate change. There is a continuing need to make climate change real for stakeholders. With increased awareness of the sensitivity of outcomes to climate change, stakeholders can effectively change the way they do business. Society is beginning to adapt to impacts, for example, Canadian ports, coastal zone protection, health monitoring and surveillance, wildlife migration corridors, and ski resorts.

Decision support tools would help resource managers:

- Depict potential impacts.
- Place effects of climate change into context with other stresses.
- Display implications and tradeoffs of alternative management decisions.
- Facilitate decision making under uncertainty.

For example, risk maps can be developed as decision support tools to guide public health interventions, such as for the hantavirus pulmonary syndrome outbreak in the southwestern U.S. in 1993, where high-risk areas can now be predicted in advance. U.S. EPA has developed TEAM (Tool for Environmental Assessment and Management), an interactive web-based tool to help water resource managers include considerations of climate change in their day-to-day decision making, utilizing decision criteria and objectives defined by the user.

Climate change impact assessment will never be "perfect" and without uncertainties, but existing assessments already provide timely and useful information for decision-makers and resource managers about potential consequences of climate change and possible adaptation strategies. For example, wastewater conveyance systems can be designed and constructed to take account of combined sewer overflows and effects of climate change on precipitation. Society has the opportunity to be anticipatory and proactive, rather than waiting to react in the midst of a crisis. Decisions will have to be made. Making no decision is equivalent to making a decision, and an informed decision is better than an uninformed one.

FORMULATION OF SUGGESTED BOARD ADVICE

Dave Ullrich summarized five themes that had emerged from the workshop discussions and presentations.

Promote education, outreach, communication, and marketing efforts to a variety of audiences. The messages: climate change is a serious issue, communicate success stories, train the trainer, and understand ecosystem functions.

Develop tools. Integrate climate and lake level models, develop better economic models, and enhance the modeling community's ability to predict the outcomes of global climate change.

Support science. Ensure that funds are available for student research, promote monitoring, preserve data, and identify impacts on beneficial uses.

Develop a strategy for addressing climate change issues. Have a ready-to-go implementation plan so that strategies can be immediately executed when crisis emerges, identify groups that are particularly vulnerable, prioritize restoration programs, build in philosophies and values, emphasize partnerships, and be clear about definitions and actions.

Implement strategies. Rather than regarding strategic planning simply as a paper exercise, actually implementing strategies is important. Release a list of easy activities that governments and / or individuals can undertake to address climate change.

The Water Quality Board and the Commission have the opportunity (and responsibility) to elevate climate change dialogue and to create power where there is currently a sense of powerlessness. More specifically, the Board and the Commission can help people understand that climate change is real and happening now, and help the public realize that it has the ability to act in ways that will minimize the negative impacts of climate change.

Workshop participants suggested additional points. Dave White suggested the Board explore and acknowledge the traditional ecological knowledge that First Nation people possess. In many cases, aboriginal people can provide important insight about vulnerable areas. He cited the example about the Inuit school that was buried by an avalanche -- aboriginal people knew that the school was located in an unstable location and had advised against building there. The advice was not heeded, however. White advised merging aboriginal knowledge with Western science. By collaborating, it would be possible to obtain a more complete picture of what is happening and would empower policy makers to make better decisions. Others strongly supported White's suggestion. John Carey felt that there is too much emphasis on modeling and not enough on observational knowledge, traditional knowledge, and monitoring efforts. A greater effort should be made to collect information from aboriginal communities as well as community-level emergency response managers. We should break the dependence on modeling techniques as the basis for risk assessment and planning. Jim Bruce said that the benefits offered from modeling efforts should not be downplayed. John Lenters said that observational knowledge and modeling are both very important and complement each other.

George Kuper thought that the five outlined themes did not provide an in-depth approach. He advised a focus around the idea of a robust risk assessment and risk management process. This would help risk managers make good decisions about how to address climate change issues. In the process of performing the risk assessment, a variety of stakeholders would become involved and educated about climate change and adaptation issues. Milt Clark said that that enough information is already available to move forward with decision making. Waiting for a risk assessment would delay important decision-making activities for 10 to 20 years. Others agreed.

The white paper authors - Marianne Alden, Linda Mortsch, and Joel Scheraga - were thanked for the great effort they had put into the paper's development, for the impressive product, and their clear description of the content in their presentations. Georges Beauchemin was thanked for his insight about climate change from a client or user perspective. All participants were thanked for freely sharing their views and insights over the course of the workshop. The breakout group facilitators and recorders were thanked for ensuring that the key discussion points were captured and shared with all. Lastly, Christ Hartnett of ERG, Inc. was thanked for logistical support, including recording of the workshop. All the advice received would be taken into consideration in preparing the revised white paper (the nature and scope of the changes made are described above) and to formulate the Board's advice to the Commission.

CLIMATE CHANGE WORKSHOP PARTICIPANTS

May 28-29, 2003

Marianne Alden
Adaptation and Impacts Research Group
University of Waterloo
Waterloo, Ontario N2L 3G1
Tel: 519.888.4567, Ext. 6862
Fax: 519.746.2031
e-mail: mealden@fes.uwaterloo.ca

Doug Alley
Great Lakes Regional Office
International Joint Commission
100 Ouellette Avenue -- 8th Floor
Windsor, Ontario N9A 6T3
Tel: 519.257.6703
Fax: 519.257.6740
e-mail: alleyd@windsor.ijc.org

Alex Basiji
Great Lakes Environment Office
Great Lakes & Corporate Affairs
Environment Canada -- Ontario Region
4905 Dufferin Street
Downsview, Ontario M3H 5T4
Tel: 416.739.5981
Fax: 416.739.4804
e-mail: alex.basiji@ec.gc.ca

Georges Beauchemin
Coordonateur interministriel
pour la mission reconstruction
Ministére de la Sécurité publique
Direction générale sécurité, civile et sécurité, incendie,
2525, boulevard Laurier
6e tage B (Laurentides) Bureau B6.58
Ste-Foy, Québec G1V 2L2
Tel: 418.643.3500
e-mail: georges.beauchemin@msp.gouv.qc.ca

Jeanne Bisanz
Great Lakes Regional Climate Change Assessment
29890 West 12 Mile -- No. 908
Farmington Hills, Michigan 48334
Tel: 248. 851.2316
e-mail: bisanz@msu.edu

Alain Bourque
Coordonnateur C-CIARN-Québec
Directeur Impacts et Adaptation
Ouranos
550, rue Sherbrooke ouest -- 19ième étage
Montréal (Québec) H3A 1B9
Tél: 514.282.6464, poste 230
Fax: 514.282.7131
bourque.alain@ouranos.ca

Marty Bratzel.
Great Lakes Regional Office
International Joint Commission
100 Ouellette Avenue -- 8th Floor
Windsor, Ontario N9A 6T3
Tel: 519.257.6701
Fax: 519.257.6740
e-mail: bratzelm@windsor.ijc.org

Jim Bruce
Global Change Strategies International Inc.
1875 Juno Avenue
Ottawa, Ontario K1H 6S6
Tel: 613.731.5929
Fax: 613.731.3509
e-mail: jpbruce@sympatico.ca

Mark Burrows
Physical Scientist
Great Lakes Regional Office
International Joint Commission
100 Ouellette Avenue -- 8th Floor
Windsor, Ontario N9A 6T3
Tel: 519.257.6709
Fax: 519.257.6740
e-mail: burrowsm@windsor.ijc.org

Dr. John Carey
Executive Director
National Water Research Institute
Canada Centre for Inland Waters
P.O. Box 5050
Burlington, Ontario L7R 4A6
Tel: 905.336.4625
Fax: 905.336.6444
e-mail: john.carey@ec.gc.ca

Milt Clark
U.S. Environmental Protection Agency
77 West Jackson
Chicago, Illinois 60604
Tel: 312.886.1918
Fax: 312.886.4071
e-mail: clark.jmilton@epa.gov

Dr. John E. Gannon
Physical Scientist
Great Lakes Regional Office
International Joint Commission
100 Ouellette Avenue -- 8th Floor
Windsor, Ontario N9A 6T3
Tel: 519.257.6711
Fax: 519.257.6740
e-mail: gannonj@windsor.ijc.org

Paul A. Gray
Ministry of Natural Resources
300 Water Street
Peterborough, Ontario K9J 8M5
Tel: 705.755.1967
Fax: 705.755.1701
e-mail: paul.gray@mnr.gov.on.ca

Gary Gulezian
Director, Great Lakes National Program Office
U.S. Environmental Protection Agency
77 West Jackson Boulevard (G-17J)
Chicago, Illinois 60604
Tel: 312.886.4040
Fax: 312.886.2403
e-mail: gulezian.gary@epamail.epa.gov

Don Haley
Toronto & Region Conservation Authority
5 Shoreham Drive
Downsview, ON M3N 1S4
Tel: 416.661.6600, Ext. 5226
Fax: 416.661.6898
don_haley@trca.on.ca

Victoria A. Harris
RAP Coordinator
University of Wisconsin Sea Grant Institute
UWGB ES 105
2420 Nicolet Drive
Green Bay, Wisconsin 54311-7001
e-mail: harrisv@uwgb.edu

Chris Hartnett
Environmental Scientist
ERG
5608 Parkcrest Drive -- Suite 100
Austin, Texas 78731
Tel: 512.407.1829
Fax: 512.419.0089
e-mail: chris.hartnett@erg.com

Dr. Adele Iannantuono
Health Canada
2301 Midland Avenue -- 2nd Floor
Toronto, Ontario M1P 4R7
Tel: 416.954.6357
Fax: 416.952.0236
e-mail: adele_iannantuono@hc-sc.gc.ca

Martin Jaffe
Associate Professor
University of Illinois at Chicago
Great Cities Institute (MC-107)
412 South Peoria Street -- Suite 400
Chicago, Illinois 60607
Tel: 312.996.2178
Fax: 312.996.8933
e-mail: mjaffe@uic.edu

Greg Jenish
Policy & Decision Analyst
Environmental Commissioner of Ontario
1075 Bay Street -- Suite 605
Toronto, Ontario M5S 2B1
Tel: 416.325.0118
Fax: 416.325.3370
e-mail: greg.jenish@eco.on.ca

Kennon Johnson
Environment Officer
Walpole Island Heritage Centre
R.R. # 3
Wallaceburg, Ontario N8A 4K9
Tel: 519.627.1475
Fax: 519.627.1530
e-mail: kennon.johnson@wifn.org

Dr. Gail Krantzberg
Director, Great Lakes Regional Office
International Joint Commission
100 Ouellette Avenue -- 8th Floor
Windsor, Ontario N9A 6T3
Tel: 519.257.6715
Fax: 519.257.6740
e-mail: krantzbergg@windsor.ijc.org

George Kuper
President and CEO
Council of Great Lakes Industries
3600 Green Court -- Suite 710
Ann Arbor, Michigan 48104
Tel: 734.663.1944
Fax: 734.663.2424
e-mail: ghk@cgli.org

Beth Lavender
Climate Change Impacts & Adaptation Directorate
Natural Resources Canada
601 Booth Street
Ottawa, Ontario K1A 0E8
Tel: 613.992.1755
Fax: 613.992.0190
e-mail: blavende@nrcan.gc.ca

Ric Lawson
Great Lakes Commission
2805 South Industrial Highway -- Suite 100
Ann Arbor, Michigan 48104-6791
Tel: 734.971.9135
Fax: 734.971.9150
e-mail: rlawson@glc.org

John Lenters
Department of Geology and Physics
Lake Superior State University
650 West Easterday Avenue
Sault Ste. Marie, Michigan 49783
Tel: 906.635.2156
Fax: 906.635.2266
e-mail: jlenters@lssu.edu

Ann MacKenzie
Economics Advisor
International Joint Commission
234 Laurier Avenue West -- 22nd Floor
Ottawa, Ontario K1P 6K6
Tel: 613.947.1420
Fax: 613.995.5583
e-mail: mackenziea@ottawa.ijc.org

Dr. Jiri Marsalek
Project Chief, Urban Water Management Project
National Water Research Institute
Environment Canada
P.O. Box 5050
Burlington, Ontario L7R 4A6
Tel: 905.336.4899
Fax: 905.336.4420
e-mail: jiri.marsalek@ec.gc.ca

Bano Mehdi
Coordinator, C-CIARN Water Resources
Brace Centre for Water Resources Management
Macdonald Campus, McGill University
21 111, rue Lakeshore
Ste-Anne de Bellevue, Québec H9X 3V9
Tel: 514.398.7836
Fax: 514.398.7767
e-mail: bano.mehdi@mcgill.ca

John Mills
Regional Director General -- Ontario Region
Environment Canada
4905 Dufferin Street
Downsview, Ontario M3H 5T4
Tel: 416.739.4666
Fax: 416.739.4691
e-mail: John.Mills@ec.gc.ca

Kelly Montgomery
Physical Scientist
Great Lakes Regional Office
International Joint Commission
100 Ouellette Avenue -- 8th Floor
Windsor, Ontario N9A 6T3
Tel: 519.257.6723
Fax: 519.257.6740
e-mail: montgomeryk@windsor.ijc.org

Katherine Moore
Conference Management Group
ERG, Inc.
110 Hartwell Avenue
Lexington, MA 02421
Tel: 781.674.7348
Fax: 781.674.2906
e-mail: katherine.moore@erg.com

Linda Mortsch
Adaptations and Impact Research Group
Environment Canada
c/o Faculty of Environmental Studies
University of Waterloo
Waterloo, Ontario N2L 3G1
Tel: 519.888.4567, Ext. 5495
Fax: 519.746.2031
e-mail: linda.mortsch@ec.gc.ca

Dr. Joel D. Scheraga
National Program Director
Global Change Research Program
Office of Research and Development
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue (Mail Code 8601D)
Washington, DC 20460
Tel: 202.564.3385
Fax: 202.565.0066
e-mail: scheraga.joel@epa.gov

Dennis Schornack
Chairman, U.S. Section
International Joint Commission
1250 23rd Street N.W. -- Suite 100
Washington, D.C. 20037
Tel: 202.736.9000
Fax: 202.467.0746
e-mail: schornackd@washington.ijc.org

Katherine Silverthorne
Director, Climate Change Program
World Wildlife Fund
1250 24th Street, N.W.
Washington, D.C. 20037
Tel: 202.822.3469
Fax: 202.331.2391
e-mail katherine.silverthorne@wwfus.org

David Ullrich
Deputy Regional Administrator
U.S. Environmental Protection Agency
77 West Jackson Street -- R19-J
Chicago, Illinois 60604
Tel: 312.886.9851
Fax: 312.353.1120
e-mail: ullrich.david@epa.gov

Tim van Seters
Toronto & Region Conservation Authority
5 Shoreham Drive
Toronto, Ontario M3N 1S4
Tel: 416.661.6600, Ext. 5337
Fax: 416.661.6898
e-mail: tim_van_seters@trca.on.ca

Dr. Ellen Wall
Coordinator
C-CIARN Agriculture
Environmental Sciences -- 202 Blackwood Hall
University of Guelph
Guelph, Ontario N1G 2W1
Tel: 519.824.4120, Ext. 58480
Fax: 519.763.4686
e-mail: ewall@uoguelph.ca

Ed Watt
Department of Civil Engineering
Ellis Hall
Queens University
Kingston, Ontario K7L 3N6
Tel: 613.533.2137
Fax: 613.533.2128
e-mail: watt@civil.queensu.ca

Dr. Jordan M. West
U. S. Environmental Protection Agency
ORD/NCEA/Global Change Research Program
1200 Pennsylvania Avenue (Mail Code 8601D)
Washington, DC 20460
Tel: 202.564.3384
Fax: 202.565.0075
e-mail: west.jordan@epa.gov

Dave White
Walpole Island Heritage Centre
R.R. # 3
Wallaceburg, Ontario N8A 4K9
Tel: 519.627.1475
Fax: 519.627.1530

Enos Whiteye
Language and Consultations Expert
Tahgahoning Enterprize, Inc.
R.R. # 3
Walpole Island, Ontario N8A 4K9

Mike Williams
Walpole Island Heritage Centre
R.R. # 3
Wallaceburg, Ontario N8A 4K9
Tel: 519.627.1475
Fax: 519.627.1530

Dr. Julie Winkler
Department of Geography
315 Natural Science
Michigan State University
East Lansing, Michigan 48824-1115
Tel: 517.353.9186
Fax: 517.432.1671
e-mail: winkler@msu.edu

PART 5
CROSS BORDER TOOLS AND STRATEGIES

Presentation by Georges Beauchemin at the Climate Change Workshop May 28, 2003

BIOGRAPHY

Georges Beauchemin has been a public servant with the province of Québec for 25 years. He began his career in 1977 as an urban planner with the Ministère des affaires municipales. He is very familiar with the issues and the impacts of climate change. In 1996, as the assistant secretary for the Conseil executif, Georges served as the inter-departmental coordinator for the reconstruction and the economic recovery of the Saguenay flood disaster area. In 1999, he was given the task of responding to the ice storm that hit eastern Ontario and western Québec and, in 2000, he was called upon to respond to the avalanche in the Inuit village of Kangiqsualujjuaq, Québec. Georges is currently the director general of municipal affairs in the Québec Department of Public Security. He is also the chair of Ouranos, a consortium created in 2002 by the province of Québec, Hydro-Québec, and the Meteorological Service of Canada to promote the acquisition of expertise to advance the understanding of regional climate change and of its environmental, social, and economic impacts. The consortium brings together government ministries, universities, associations, foundations, and other organizations in order to develop the expertise and the strategies necessary to mitigate the impacts of climate change. Georges' presentation looks at climate change from a client or user perspective and, as such, provides insight for the organization of governance structures to address the issue. For information about Ouranos, see: http://www.ouranos.ca .

INTRODUCTION

When I received the invitation to address this workshop, I was perplexed. The invitation asked me to do a presentation on extreme events. However, upon reflection, I concluded that the climate change adaptation issue -- this story line -- is not event based. Climate change is an extreme situation which we are facing and must focus on. In reading all the IPCC (Intergovernmental Panel on Climate Change) reports and other climate change reports, I found that most of the adaptation issues that we have to deal with relate one way or another to water, that water is the common denominator.

In August 2002, Montréal city officials who manage the potable water intake for the city called Ouranos in a panic. The Montréal water system is old and outdated, and it leaks. The official figure is that around 30 to 40% of the water is lost to the ground. But the panic was not about this issue. Rather, the water level in the St. Lawrence River was so low that they could not get the bulk of the water into the plant, and the emergency pipe was inoperable. The officials responsible for Montréal's infrastructure debated whether to advance an emergency water intake project or to repair the leaky pipes. Finally, they decided to do neither. With the water level in the St. Lawrence today, we would probably need precipitation 200% above normal during the coming months just to avoid this happening again. Before, they had to instruct Canada Packers and others to close down. And it will happen again.

RISKS

Climate change is not a question of in the future -- it is already there. One of the basic ideas in the white paper (in Part 3) is risk. Consider information that has become available since IPCC's latest report, such as this report by the Hadley Climate Centre. Scientists are telling stakeholders like myself what we read in Figure 1. There will be damage and it will be long-lasting. Greenhouse gas emissions are on the rise, basically because we have not uncoupled economic growth with energy consumption, which produces a lot of greenhouse gases.

Figure 1

Physical commitment to climate change

Even if atmospheric greenhouse gas concentrations were stabilised immediately, we could still experience a changing climate and sea-level rise for more than 1,000 years into the future due to past emissions. Furthermore, the greenhouse gases we emit today and in the near future will initiate changes in climate that will be felt far into the future.

Predictions of climate change when CO2 concentrations are stabilised in the future

Reducing CO2 emissions so that concentrations approach stabilisation will delay the amount of climate change we experience over the next 100 years and more.

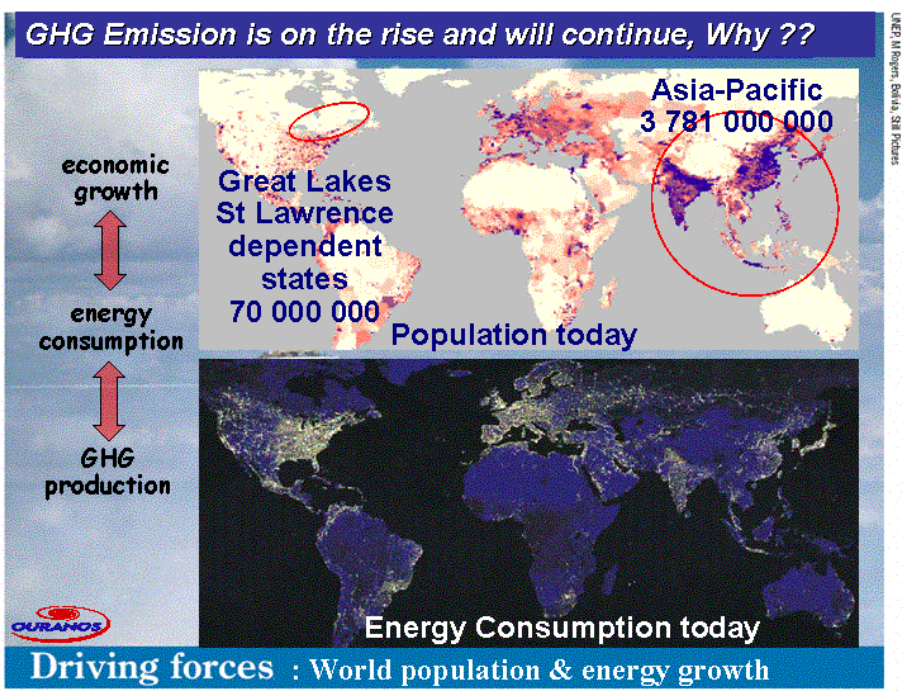
However, any realistic future stabilisation level is likely to result in some damage.

OURANOS

Scientific results from the Hadley Centre
October 2002
Met Office

Today's world is depicted in Figure 2. Our region -- the Great Lakes / St. Lawrence community -- has around 70 million people connected to the watershed. The top shows where people in the world live today. The bottom is the night-time energy picture today. It is only natural that, during the coming years, people in Asia would like to shine as much in the dark as we do at night. That is a big issue for the world.

Figure 2



The U.S. Department of Energy's latest outlook, just published, has a chapter that shows CO_2 emissions for the next 25 years. Figure 3 shows that levels are very high and are going higher.

Figure 3

In the *International Energy Outlook 2003* (*IEO2003*) reference case, world energy consumption is projected to increase by 58 percent over a 24-year forecast horizon, from 2001 to 2025. The strongest growth is projected for developing Asia, where demand for energy is expected to more than double over the forecast period.

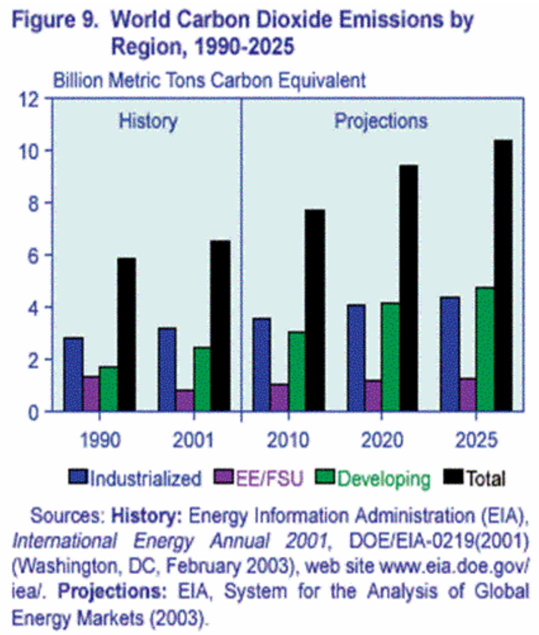
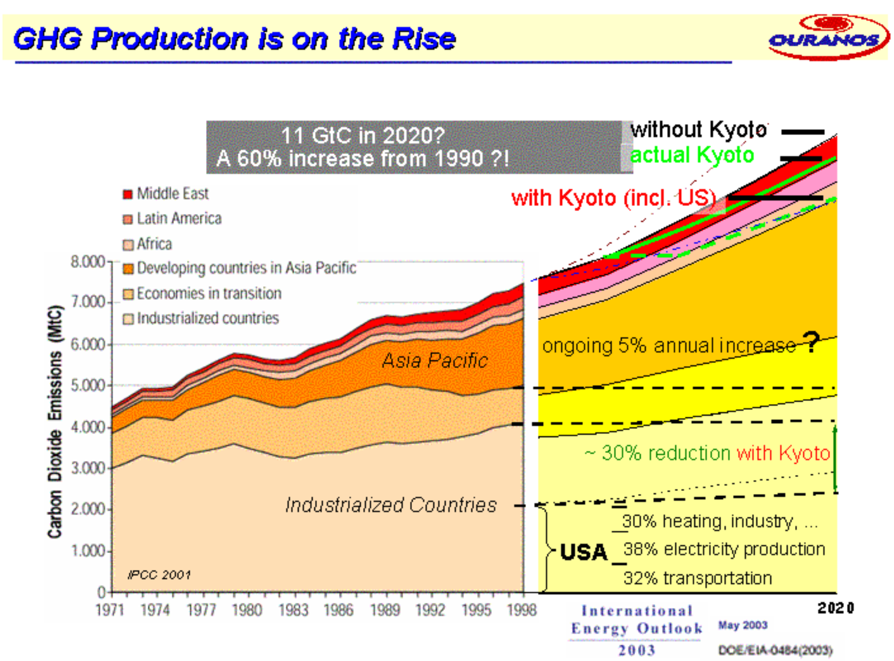


Figure 4 gives an idea of the picture from 1971 to 2020. People argue about greenhouse gas mitigation. Look at the graph without Kyoto, with Kyoto, and with Kyoto should the U.S. join. The main story is that most of the greenhouse gases will not come from North America. Rather, the big issue is that they will come from south-east Asia and China over the coming century.

Figure 4

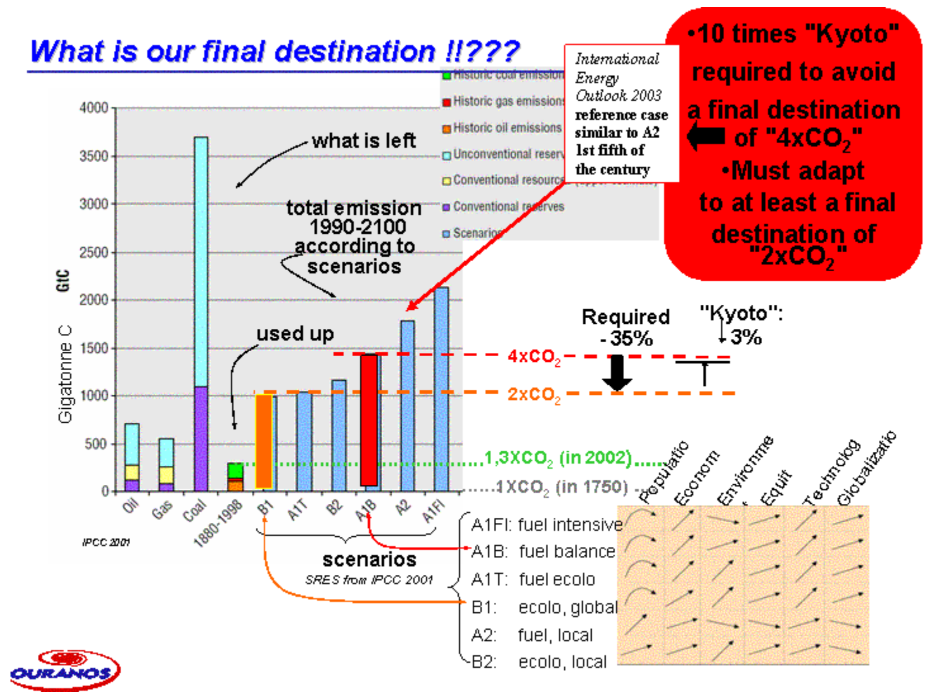


The bar charts in Figure 5 are very useful to understand what is coming. I have captured the issue by asking, What is our final destination? If we think about mitigation as doing 1, 2 or 3 Kyoto's, we are actually not sending an amount of carbon into the atmosphere. The bars on the left show how much proven coal, gas, and oil reserves we have. Should we, as a species, wish to burn it, the bars indicate the amount that we would actually put into the atmosphere, compared to what we have released so far. It is what we call 1 X CO_2, basically, the natural level around 1750. One can argue whether it is 1800 or 1750, but it does not matter very much.

Today we are basically at 1.3 X and the scenarios on the right side of Figure 5 -- the IPCC report calls these stress scenarios -- show story lines for what the future might look like. Consider these story lines and the driving forces behind them. Should we decide that we are not going to argue about this issue as a species and as countries, the bars indicate the best and worst scenarios we would reach. These bars indicate the amount of CO_2 we can release into the air. These story lines incorporate population, economic, environment, equity, and other scenarios. The best-case scenario is 2 X CO_2. When we look at the International Energy Outlook, that is exactly the scenario which we are on track for today. So, doing mitigation actions on greenhouse gases -- whether inside Kyoto or outside Kyoto -- does not matter. It is simply irrelevant. It is the amount that counts.

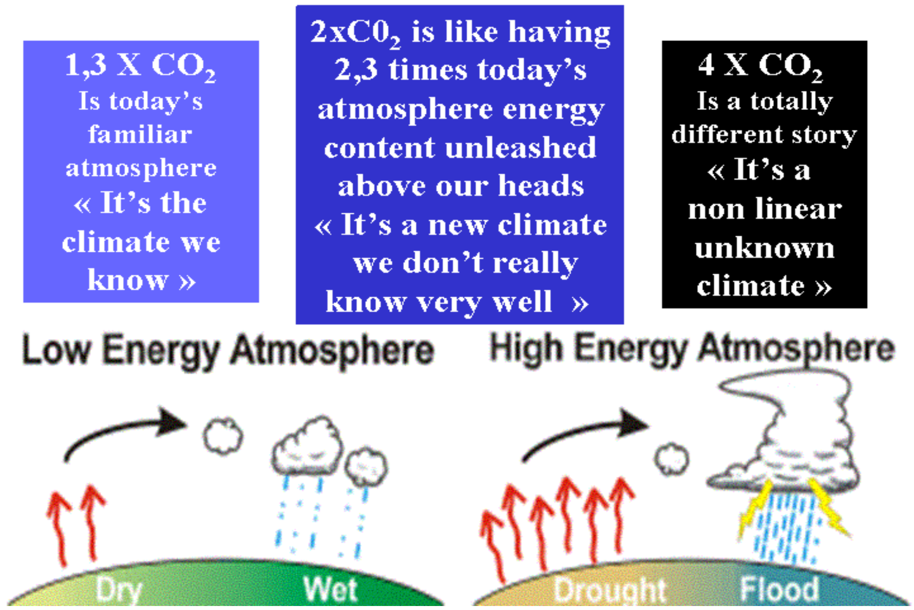
An analogy. Should you wish to NOT go to a particular destination, understand that because of the long life of greenhouse gases, once you have taken the subway from station No. 1 you will reach station No. 2 and then No. 3. If you want to stop at No. 3 you will have to hold it back at No. 1 for quite a long time. It is not the actual concentration over 100 years. It is 120 years later, and it does not matter there. So, the global picture is basically doing at least 10 times the reduction in Kyoto with the United States included, and those who manage those kinds of issues are who win. And it is a certitude that we are going to have to adapt, too.

Figure 5



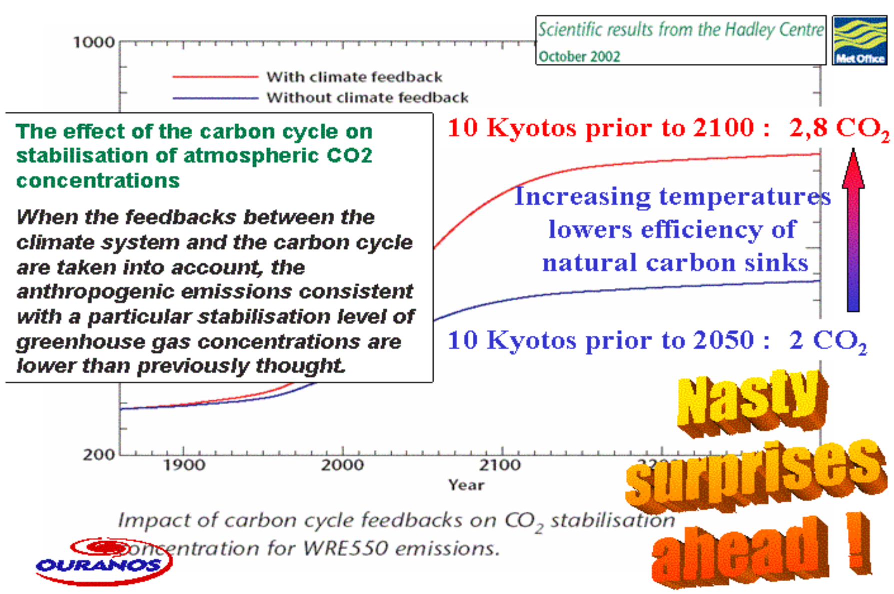
What does that mean? I work for public security. I address all sorts of things, like climate change, disasters, avalanches, and now al-Qaida has been added to our plate. But basically we are risk managers. When we look at risk, we want to understand the assumptions that scientists are making. What do you know and what are you not telling me that I should know and need to know? This is what is most important to us. Consider the atmospheres in Figure 6. 1.3 X CO_2 is today's familiar atmosphere. It is the climate we know or, rather, we think we know. If the story line projects 2 X CO_2, it is like having 2.3 times today's energy content unleashed over our heads. It is the new climate that we do not really know very well. 4 X CO_2 is a totally different story. It is non-linear, unknown. Do not ask a professional climate modeller to model 4 X CO_2. He will say, you're crazy. It is non-linear. I do not know what's going to happen. It is the black box.

Figure 6



We are learning more about carbon cycling. This will be a topic in the next IPCC report. Figure 7 is a British carbon cycle modelling study published in October 2002. Basically, it says that temperature has a very high influence. Temperature determines the amount that the oceans will take in as a carbon sink, and the biggest sink is not the Amazon forest, not the boreal forest, not the pasture land. It is the ocean. And it slows down. What it means for us is, we thought that if we did 10 Kyoto's in the next 100 years, we would reach 2.8 X CO_2. In fact, we have to do it in 50 years to reach the target of 2 X CO_2. That is an even bigger challenge to stop arguing about and start doing something about.

Figure 7



The catch 22 is captured in Figure 8. 2 X CO_2 is the best case scenario. But a risk manager does not want to plan with the best case scenario. Because of that, it is a very risky scenario. If I believe what scientists write and what I read, and I ask questions, worse climate scenarios are in the making. They may well be more probable, but they are a lot riskier. What kind of strategy should we adopt in view of such risks, and what strategy for the Great Lakes and the St. Lawrence River?

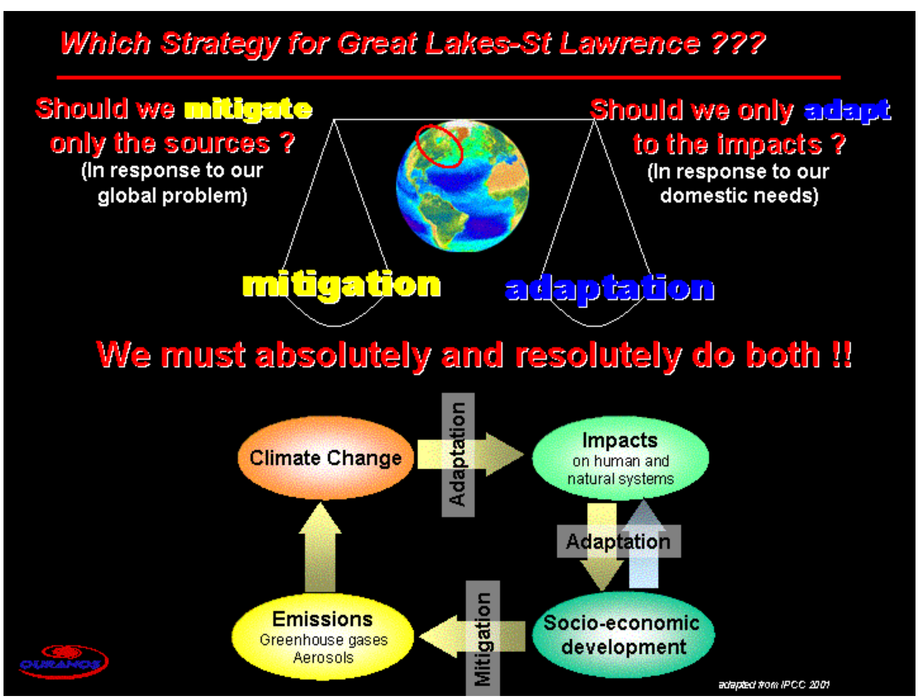
Figure 8

The « catch 22 » thinking about today's knowledge on climate risks…

- 2 X CO_2 is the best case scenario
- Because of that fact, it's a risky scenario
- Worst climate scenarios are in the making and may well be more probable, but they are riskier …
  so what strategy should we adopt in view of such risks !

We have wrestled with this inside the Québec government for the last year and half. Ouranos was asked to do the opening at the parliamentary commission on how to implement Kyoto. We were successful in having the government recognize that Québec's strategy will have to be to do both (Figure 9). Stop the argument about mitigation or adaptation. These two different crowds will have to talk to one another and will have to act together because one interacts with the other. From what we see coming from scientists, there is no other choice.

Figure 9



OPPORTUNITIES

Luc Crépeault makes two key points:

1. "The key element for adaptation strategies is knowledge."

2. "The poorer you are, the more you need to know."

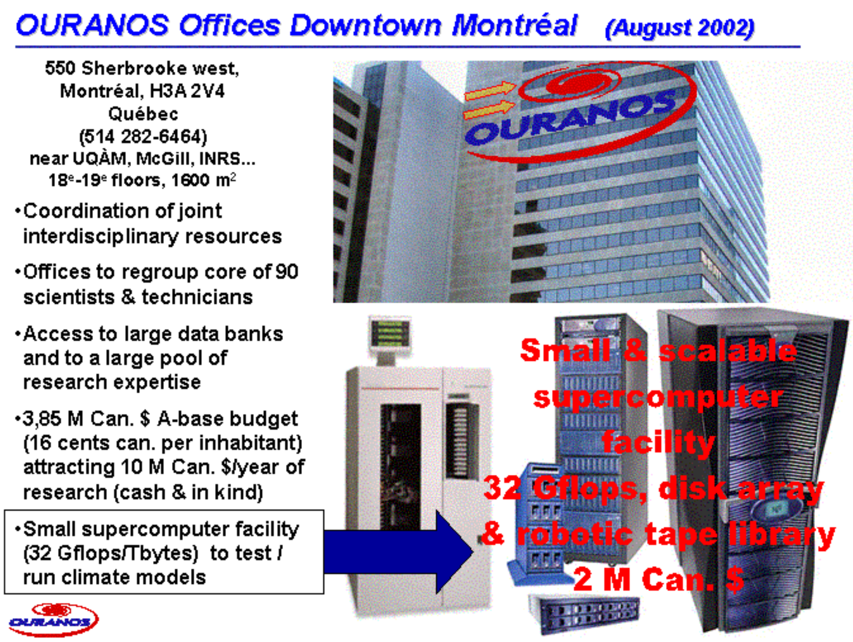
He is my boss and he believes it. Ouranos would not have gone as far as it has without him pushing us in the right direction. We need to direct more resources to knowledge and expertise because we are going to need it as users and stakeholders.

Ouranos is a consortium of major stakeholders Figure 10 that brings together financial and technical resources, and technical includes people. Eight Québec government departments put money where their mouth is, along with Hydro-Québec; Environment Canada, both headquarters and the Québec region; VRQ which, like CFCAS, provided some seed money; UQÀM which does the Canadian regional climate model; McGill University; Université Laval; INRS. Ouranos has a new financial collaboration with British Columbia. In an agreement with Meteo France, they will, free of charge, provide regional scenarios for North America using their model. This will allow us to compare their projections with the Canadian regional model. Through CFCAS, Ouranos is working with other stakeholders on future partnerships.

Figure 10

We are located in Montréal. No, there is no sign on the building, as implied in Figure 11. At the beginning, we discussed whether Ouranos should be virtual or real. We decided that it has to be real for people to believe in. We need a physical place for people to meet and talk, because at least of the business is done in the corridors -- not done in the computer room, not in the office, in the corridors. We need corridors in order for people to interact with one another. It is informal, it is non-aggressive -- that is how people interact.

Figure 11



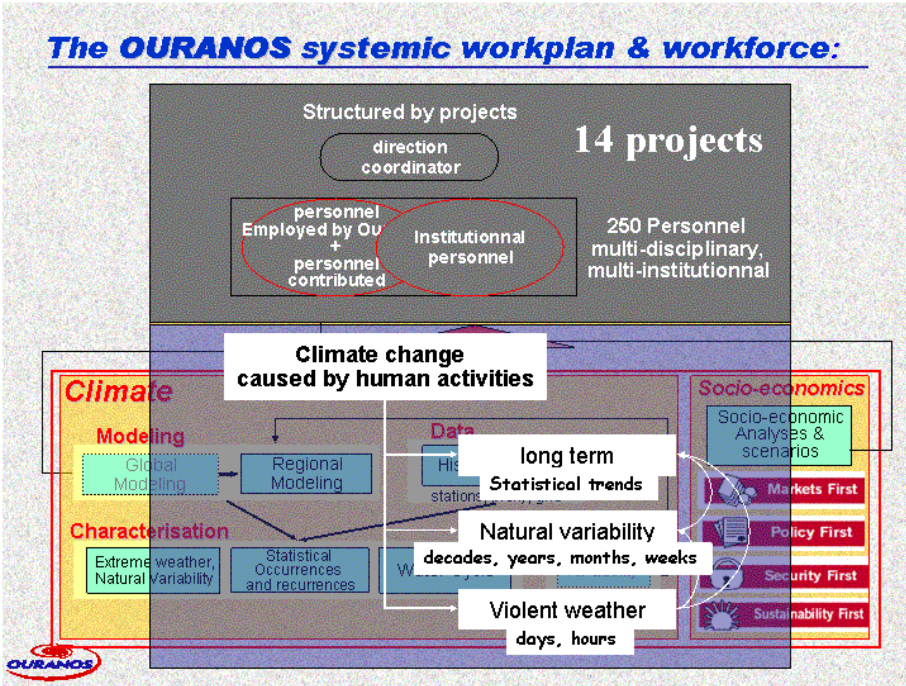
Ouranos today has a facility of around 65 - 70, and next fall we will reach capacity at around 90. Ouranos has a small super-computer facility running the Canadian regional climate model. The meteorological office has a faster computer, but it is used for weather and is shut down twice a day. We need a dedicated computer, and we have our corridor for discussion.

Ouranos invests in science in order to get tools for decisions. We try our best to invest in our own people but, if they cannot do the job and we need the answer, we will buy it, wherever it is. We were asked, why should we invest in the Canadian regional climate model if you turn to Hadley or another one? That's the bottom line. We will get the answer wherever it is, because we need the answer.

We need tools and we need scenarios, because that is the way that Ouranos plans and acts. We discuss with stakeholders, based on assumptions and scenarios. We are risk takers, so that is the usual way of doing business. We are interested in both climate change and climate variation, because that is how climate change is going to behave. Changes in natural variability will occur. We have to understand that. If it results in an avalanche, it matters not whether it is related to climate change or climate variation. It is still an avalanche, and it still kills people. My job is to get them out of there.

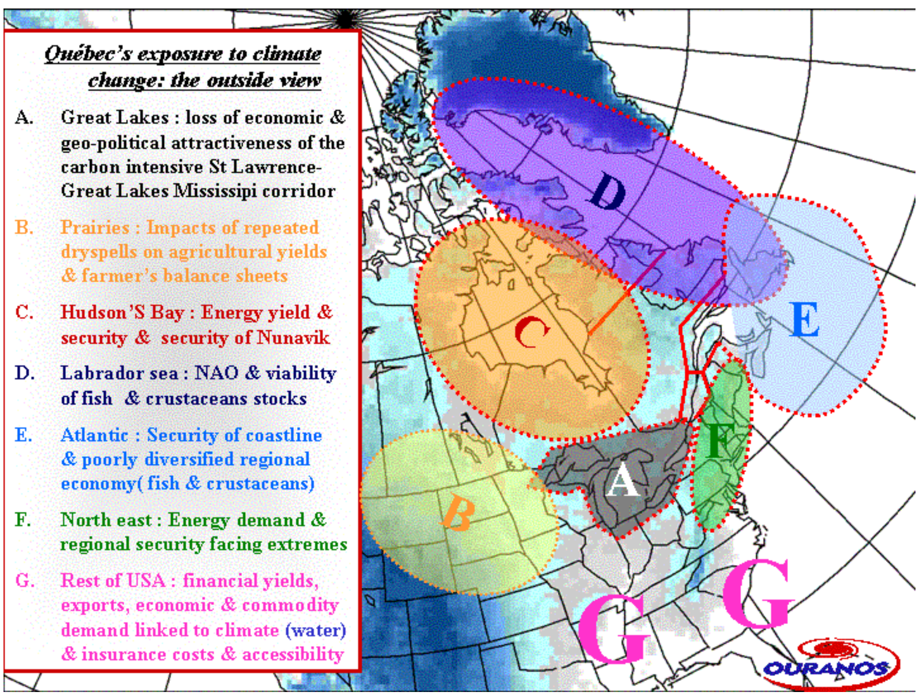
As shown in Figure 12, Ouranos is structured by projects. That means a coordinator who we call the champion. For an issue, find a natural champion who everybody is looking at and convince him to undertake leadership. Ouranos will supply some paid personnel. We ask the stakeholders, if they believe in the project, to provide their own dedicated personnel for the project, also institutional personnel from universities. Ouranos has started 14 projects since last September, with a workforce of around 250 people. This looks huge, but it is actually only 10% of what we feel will be needed. We will need a tenfold increase just to try and understand what kind of risk we will have to decide upon.

Figure 12



We were talking about the box -- outside the box, inside the box, the black box. Consider Québec's exposure to climate change outside of the box, depicted in Figure 13. First, the loss of economic and geopolitical attractiveness of the carbon-intensive St. Lawrence / Great Lakes / Mississippi corridor.

Figure 13



Consider the Prairies. The price of corn went crazy last summer because of the drought. The people doing agricultural insurance for Québec did not see it coming. Québec produces a lot of pork -- pork is actually corn on feet -- if we cannot predict drought, the insurance cost will go crazy, because there is no magic bucket for money.

Hudson's Bay is a huge issue. Nobody understands Hudson's Bay future behaviour. This is an inland sea the size of the Gulf of Mexico. The last time a scientific team studied this body of water was in the 1960s. There is a report that will get the attention of leaders and lobbyists over the coming years. The report proposes the Grand Canal. The main assumption is that there is no biological life in Hudson's Bay, so it is not worthwhile protecting. The Grand Canal would raise the water level of the Great Lakes by diverting water, then pumping or pushing water out of the Great Lakes and down the Mississippi River. This is a solution in the minds of some people, and they are ready to put their money on it.

The Labrador Sea, contrary to normal wisdom about climate change, is cooling. We have over fished the cod, but salmon are dying because of cooler water. For Québec, this means that we are a peninsula surrounded by water with a very cold signal at our doorstep. This is a big issue and I would like to know the consequences.

The Great Lakes do not have coastal erosion and rising sea levels, but Québec does. In fact, Québec seems to capture just about everything about climate change.

The issue in the northeast is energy demand and weather extremes. Last year, we negotiated and signed a compact of mutual assistance in times of disaster among the premiers and the governors of New England, Québec, New Brunswick, Nova Scotia, Prince Edward Island, and Newfoundland. This is the type of new thinking the decision-makers have to rely on. The compact gives me the authority to call the National Guard of New York or Maine to come into Québec and help us with an ice storm or whatever. The compact went through the U.S. Congress. We in Québec get called to go to Massachusetts and repair hydro lines. Why? Because Hydro-Québec has 800 teams ready to roll anytime. My main line of business is security and, if we are going to have more major events, it would make sense to sign more such agreements, and we are considering such an expansion with Ontario.

Lastly, with the rest of the United States, we have other climate-related issues -- water, insurance costs going up -- because of the increasing number of big events.

Let us look now inside the box of Québec. We have divided the province into four sub-regions, as shown in Figure 14. In the Arctic, we have polar bears and Inuit. The Inuit eat polar bears -- sometimes the polar bears eat the Inuit. They need an ice shelf to capture the seals. The avalanche in Ungava was a freak event that killed nine people. The community was having its New Year's party in the school gym, the only facility big enough. The gym was built beside a cliff. When the avalanche struck after midnight, we were lucky because half of the people had already left. The gym was filled with two metres of snow with people buried underneath. If that school had been hit on a school day, we would have lost 100 kids. The next summer, we moved of the village. Twelve thousand truckloads just to do new streets, $35 million just for one freak event. We never thought that we would have avalanches in Québec. We have hills, not the Rockies or the Alps. We had to find experts for these kind of hills in Russia and Norway just to understand why "gentle slopes" are actually more dangerous to avalanches because people are not aware of how far the snow will go.

The vast central area is where Québec produces power and timber. In the maritime region we are seeing coastal erosion like crazy. The shore is sand or clay. We have people calling and telling us that the shore moved 30 feet during a storm and that it is now so close to the church or whatever. We have to start doing something. If the sea level is rising, perhaps the answer is to move some of the villages, because we will not win against rising seas. We have to plan ahead and start educating mayors and politicians to understand the issues. In the south of Québec, it is just like in the Great Lakes -- every issue that you can imagine.

For climate change or variability, we must consider the economy, health and safety, environment and conservation, and system dynamics, as shown in Figure 15. Apart from the Arctic, everything we are trying to put together is very useful, because a lot of economic assets are vulnerable to climate change (Figure 16). Regarding the fishery, the cod are already gone, and the next in line are shellfish, because of colder water and bad management. Water temperature plus bad management can create havoc on a resource.

Figure 14

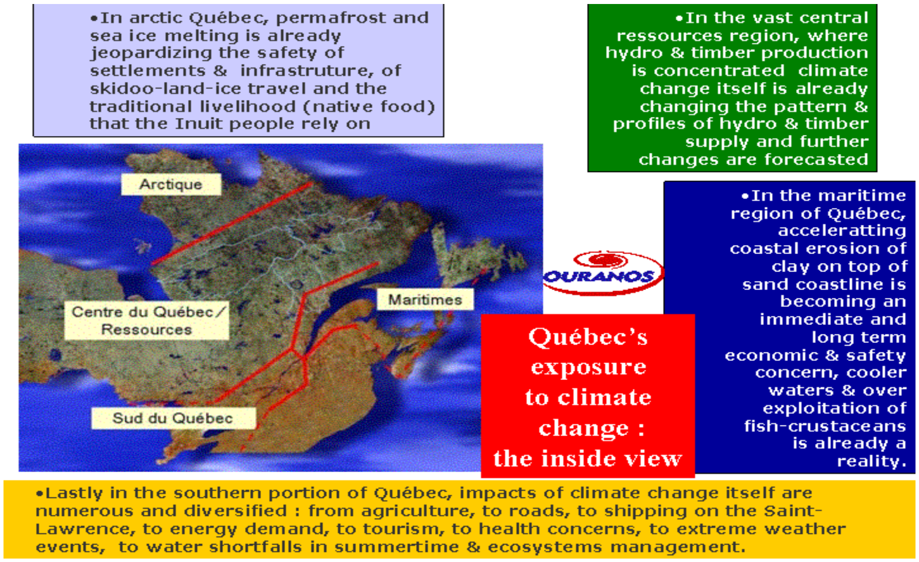


Figure 15

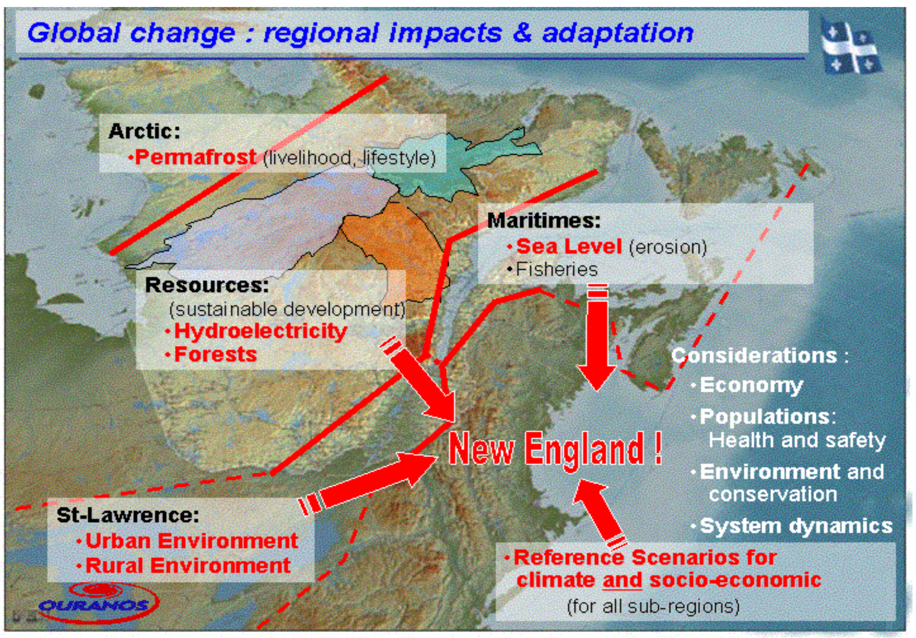
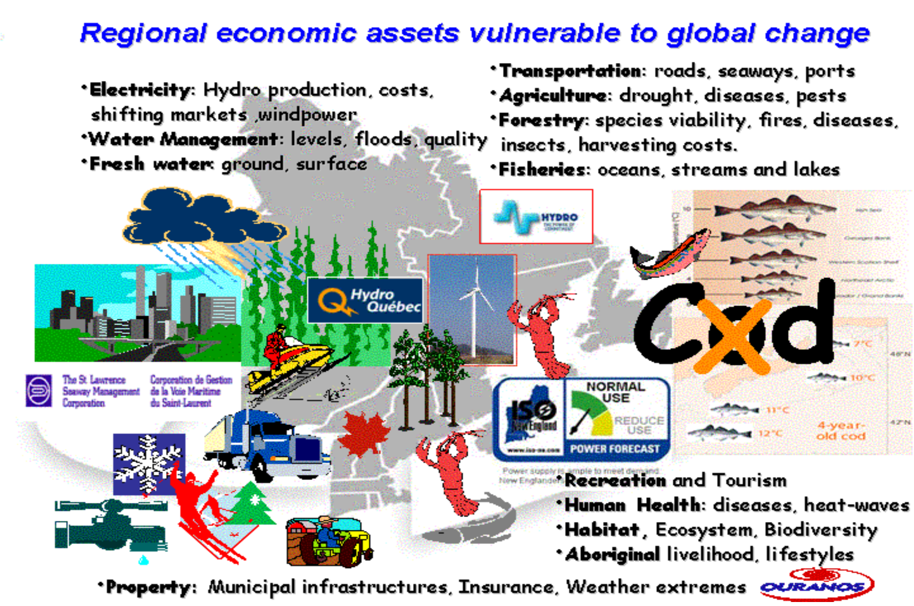


Figure 16



Québec shares concerns about impacts and adaptation with its neighbours (Figure 17).

Figure 17

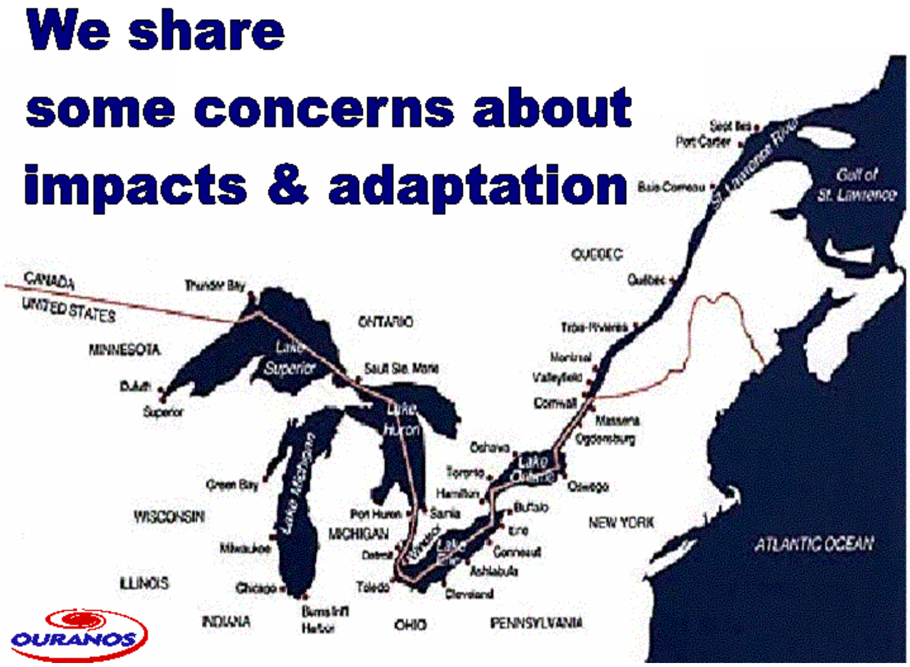
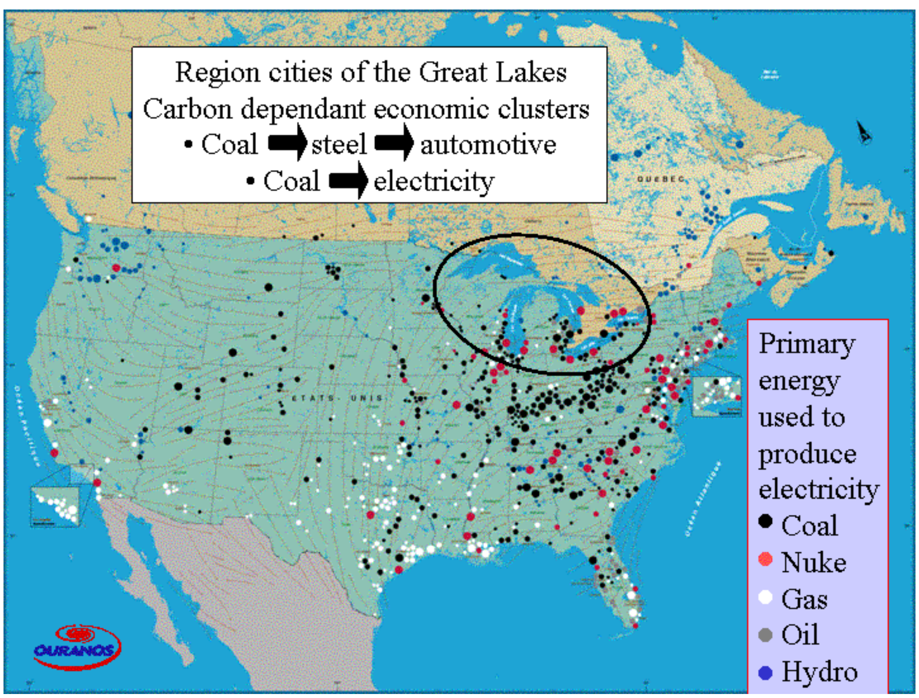


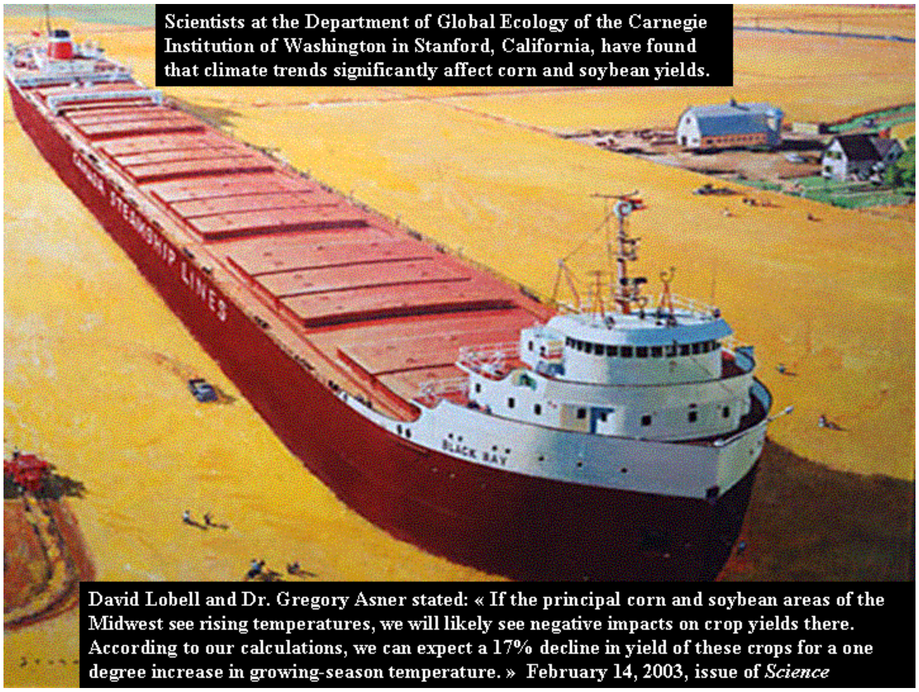
Figure 18 shows how electricity is produced in North America. The black, white, and grey are CO_2 based. The red is nuclear and the blue is the hydro. We use a lot of coal to produce electricity. Regardless of one's opinions, the Great Lakes region is basically a region of cities with very carbon-dependent economic clusters. We use coal, we use steel so we can have cars which, in turn, use petroleum. There is a huge issue on CO_2 management that will impact the Great Lakes region. Whether one likes it or not, it is there.

Figure 18



The picture in Figure 19 is in the Canada Steamship Lines lobby. Agriculture is how they pay for the ship. We can expect a decline in the amount of cargo available for carriage. With a one degree increase in temperature, there will be at least 17% decline in corn and soybean crop yields in the United States. And look at how the grain belt in Canada has been impacted by repeated droughts over the several last years.

Figure 19



If one is a stakeholder managing the assets of a company and is concerned about exports and imports, you have an issue with climate change policies, climate change itself, and lower water (Figure 20).

Figure 20

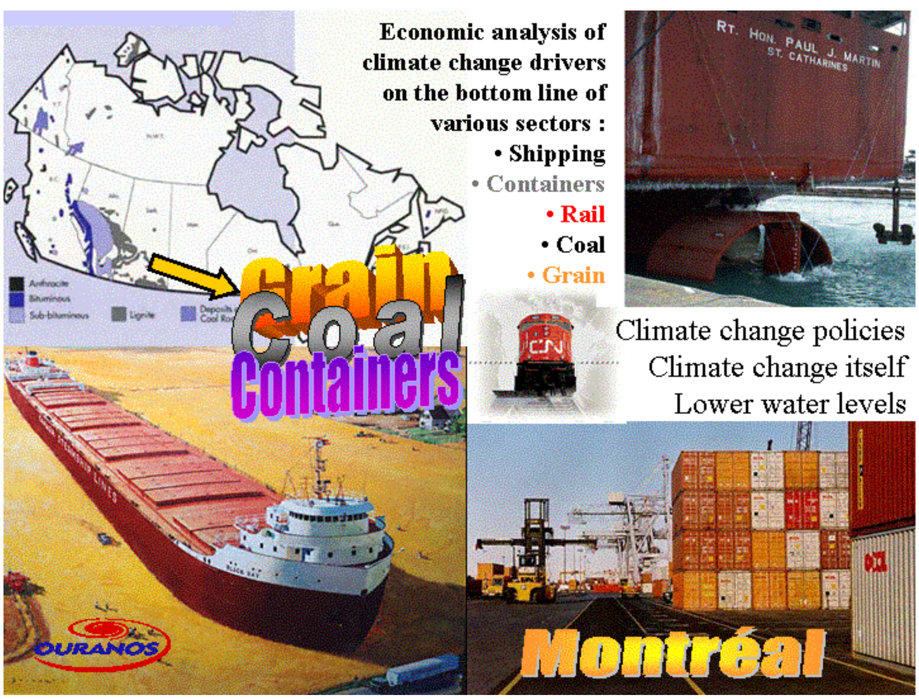


Figure 21 depicts the exposure of the U.S. side of the Great Lakes and Seaway to climate change. Note that salt is used to melt the ice off the roads, so is climate related. Grain is climate related, but it represents only 5 - 6% of shipping. Basically, the driver is CO_2 policies, which will impact the Great Lakes, and everybody is going to be impacted by the same thing -- water levels.

Figure 21

Exposure of Great Lakes-Seaway (US side) activity
to climate change (policy, climate itself & lower water levels)

Comparison of Tonnage

COMMODITY	2000	1991	CHANGE
STEEL	5,047	2,424	2,624
GENERAL CARGO	1,025	458	567
GRAIN	6,814	5,399	1,415
ORE	87,796	65,132	22,665
COAL	42,245	24,677	17,568
CEMENT	5,372	2,187	3,185
STONE/AGGREGATES	23,187	14,931	8,257
PETROLEUM	4,653	3,437	1,216
OTHER DRY BULK	11,255	4,054	7,201
OTHER LIQUID BULK	621	1,079	(458)
SALT*	3,953		
TOTALS	191,969	123,776	68,193

* Included with Dry Bulk in 1991

5,5 % of tonnage is exposed to climate change itself
75,5 % of tonnage is exposed to climate change policies
100 % of tonnage is exposed to lower water levels

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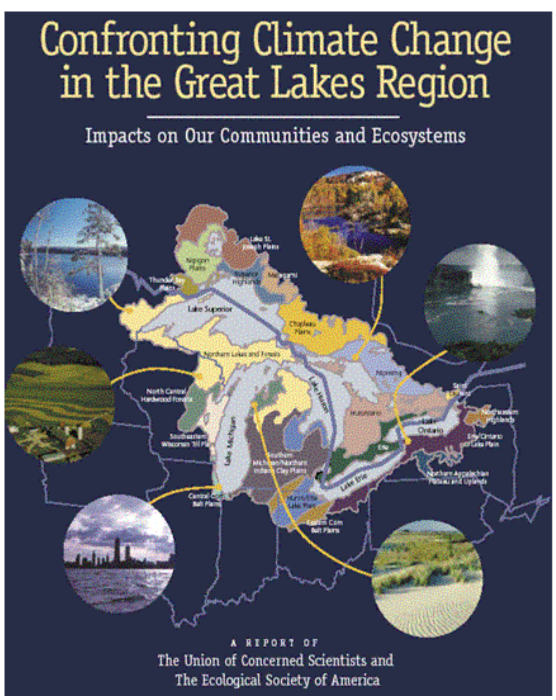
Inside the white paper and in the report by the Union of Concerned Scientists and the Ecological Society of America are a lot of important issues (Figure 22). I am not suggesting that we focus on only one issue. Quite a number of them are important. My point is that the water level of the Great Lakes is probably the one that captures most of them, indirectly or directly.

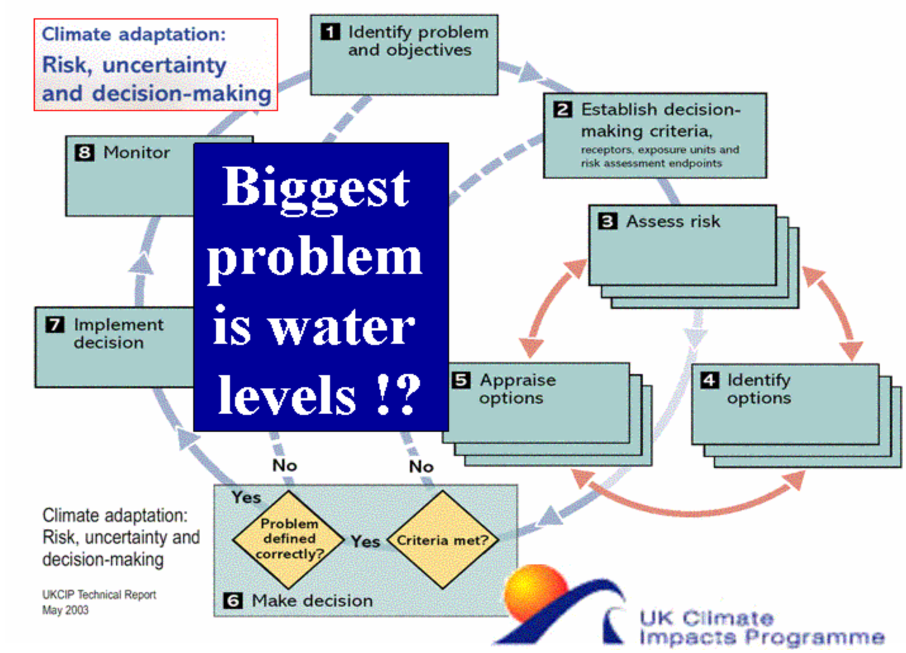
Figure 22



Other important issues are also at stake…heatwaves, fauna, tourism but water levels of the Great Lakes & of the St Lawrence river also by the way… seem to capture the bulk of & the deep & far reaching impacts of CC.

The United Kingdom's climate impact program has published a paper which describes how decision-makers plan and work, if it is to be done in a professional mode (Figure 23). One needs to identify the problem and establish the criteria by which one will reach a decision. To do that, one will do a merry-go-round quite a few times. If that has been well done, then the decision will be implemented, followed by monitoring and starting over again. If the biggest problem is water levels, we will have to focus on that.

Figure 23



RESPONSES

I am personally convinced that our only true added value in what we do is with brains and data, will and expertise, that is, our responsibility to put together the impetus and start talking to decision-makers that it happened.

When we talk about adaptation, there are three kinds of audiences (Figure 24), but one cannot produce the same material for all of them, and putting everyone under the same cover does not work. Nobody is satisfied with the product, because of that. It is a basic marketing issue.

Figure 24

Ouranos is basically focusing on the third group (Figure 25) because these are the people who want to know. It matters not to them whether it is climate change or variability, whether it is Kyoto or something else, what they want is the bottom line. Can you get your act together and give me the bottom line? To do that, one must do a quantitative assessment (Figure 26).

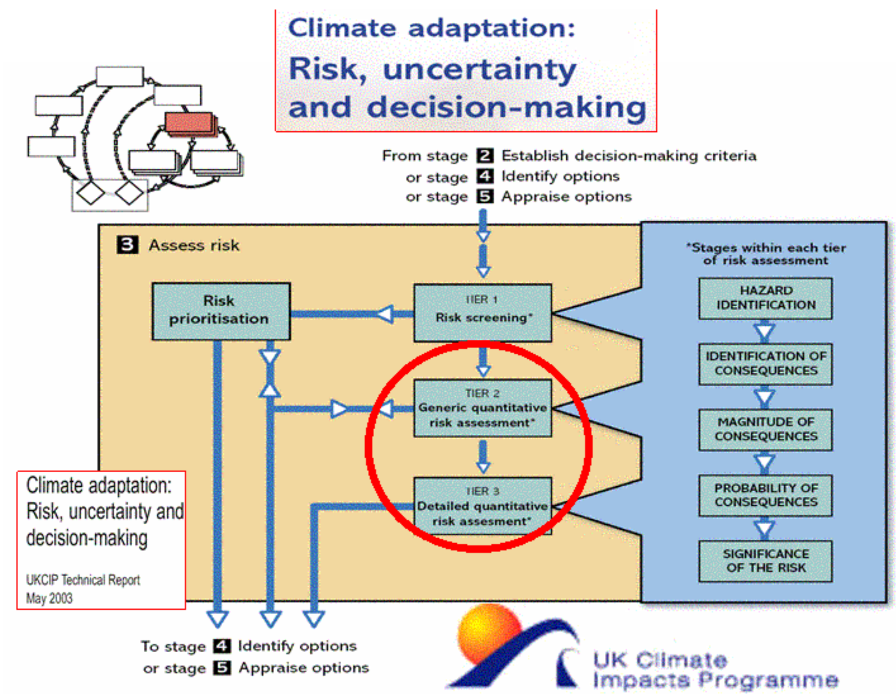
Figure 25

Ouranos is responding mainly to questions coming from the third group

What these users want & need is a quantified, integrated & combined picture of their exposure (i.e :balance sheet, health, safety & other issues) to climate change itself & incoming climate policies consequences on their bottom line

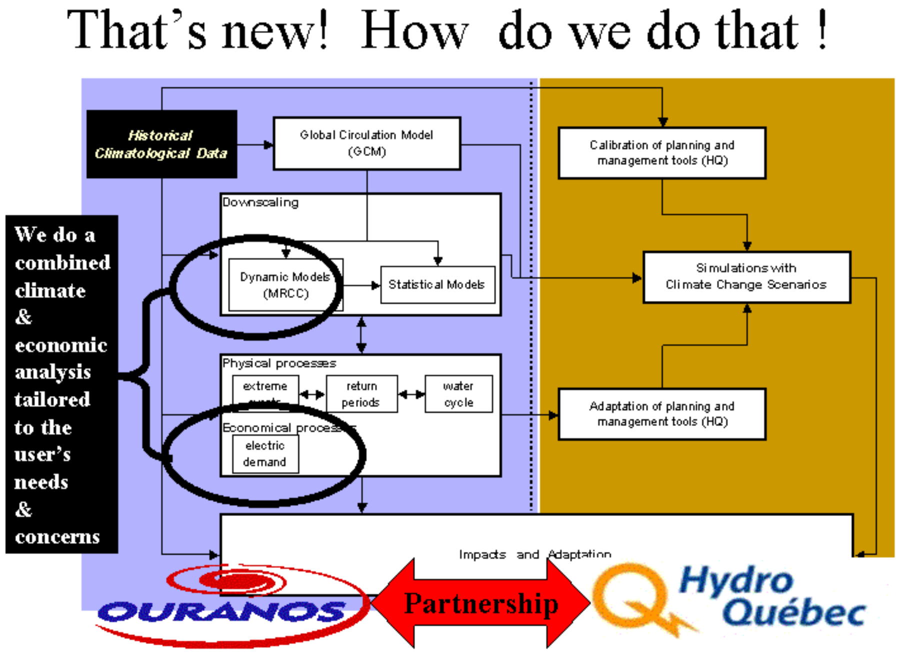
OURANOS

Figure 26



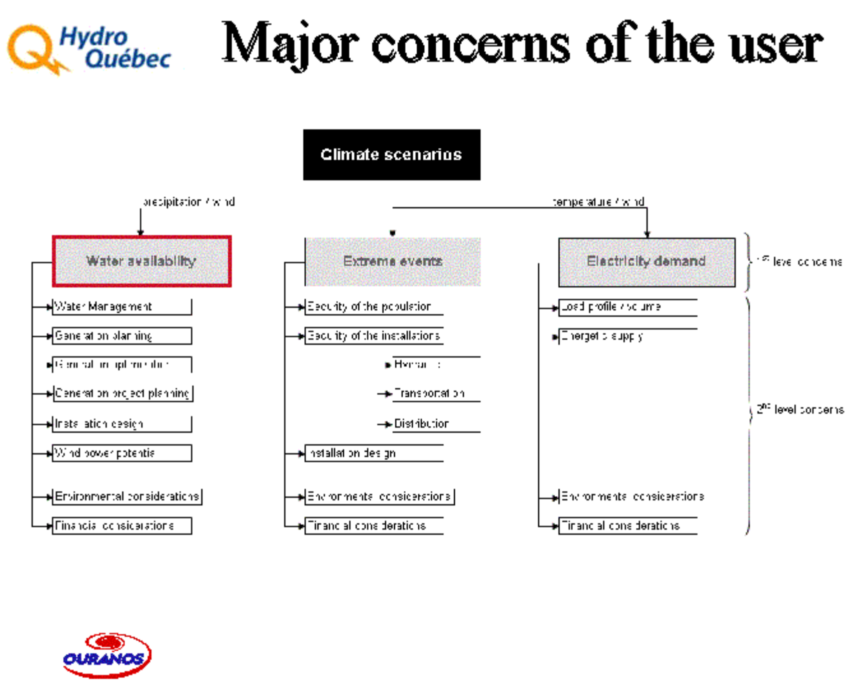
The way we are doing it with Hydro-Québec is with the dynamic Canadian region climate model, which is a downscaling technique of global circulation models (GCMs) (Figure 27). For example, one will to have to do an economic analysis of electric demand, tailored to their needs and it will not be public.

Figure 27



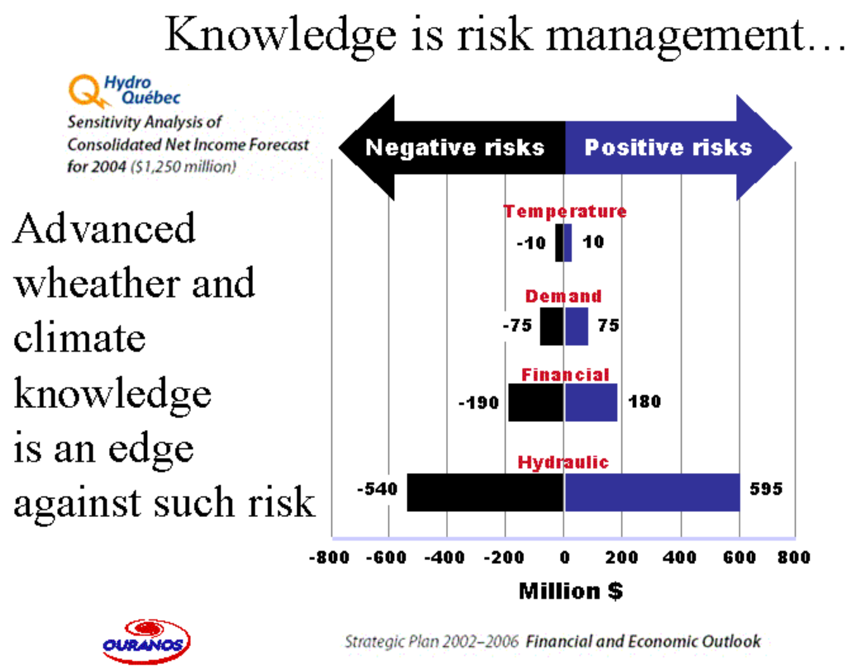
Accept and live by the standard that some of this work will not reach the public stage. If we do not provide what they want, they will buy it from somebody else who will. There are people in the re-insurance business or Standard & Poors asking these questions of all the hydro utilities. Are they going to have the water they say they are going to have? This means that we have to understand the concerns of the user, and that can only be done with a partnership (Figure 28).

Figure 28



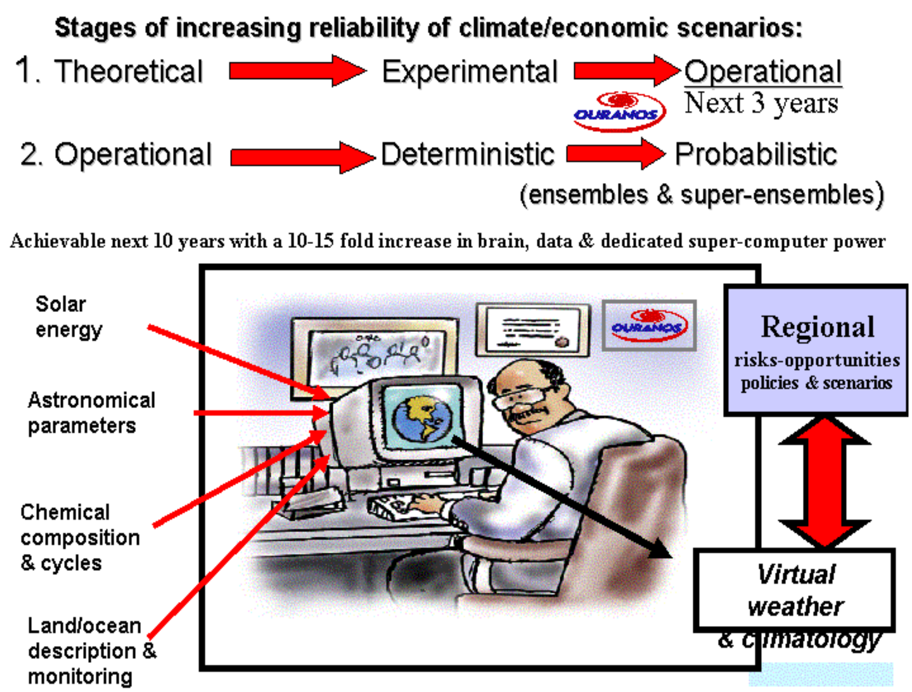
We know that water levels are our biggest risk in terms of financial exposure in Québec. Advance weather and climate knowledge is a hedge against such risk, so it makes sense to invest in climate modeling (Figure 29).

Figure 29



We have gone from the theoretical to the experimental on climate scenarios with the Canadian regional climate model (Figure 30). Ouranos is trying to move to the operational stage over the next two years. Operational means that we will do multiple runs, check them, put them into users' hands and tell them the truth about the model. They need to know whether it is good, bad, grey, what shade of grey. Europeans are already doing probabilistics. We can as well, but we will need a 10-year time lapse, a 10-15 fold increase in brains, people, data, and dedicated super-computer. The computer is the least of the worry and not an issue, as they have become a commodity and are becoming cheap.

Figure 30



Only two consortiums are investing in nested models and dynamical downscaling -- Prudence in Europe and Ouranos. Figure 31 shows the window each is modeling. Perhaps one day the two will merge. Some future partnerships are going into that direction. One drives inside the box with the data from a GCM -- whether it is Canadian, Hadley, or another does not matter (Figure 32). The model has its own climatology inside the box, and the model is high resolution. To date, it has been 45 by 45 km, but it can set it at any level, if one is ready to pay. Figures 33 and 34 are the windows that Ouranos is modeling. In order to understand the climate in one particular area, which is my main concern, scientists tell me I need to model a much larger area, so I am doing part of the job for Canada and the United States.

Figure 31

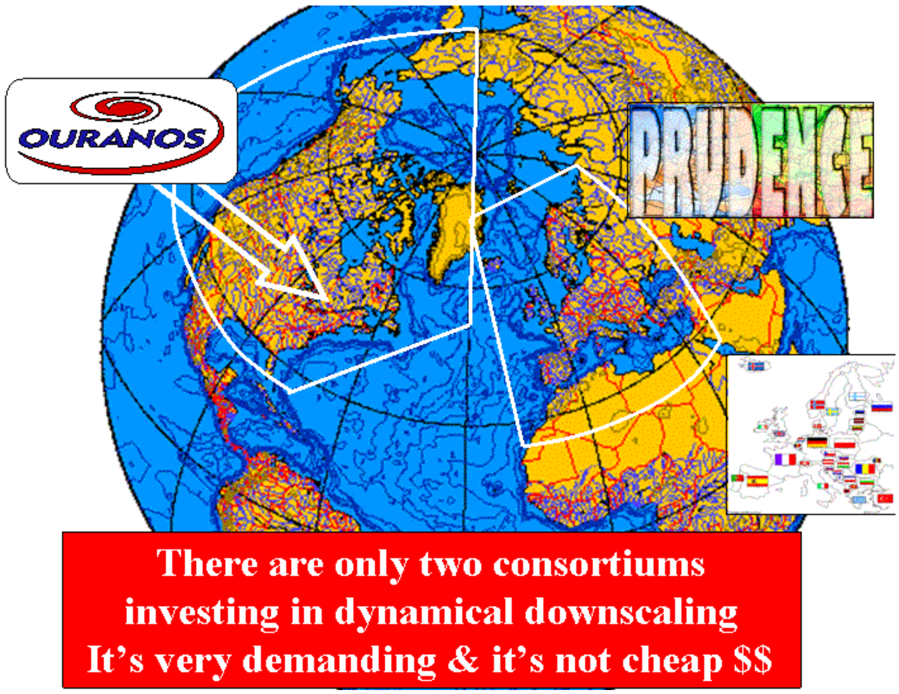


Figure 32

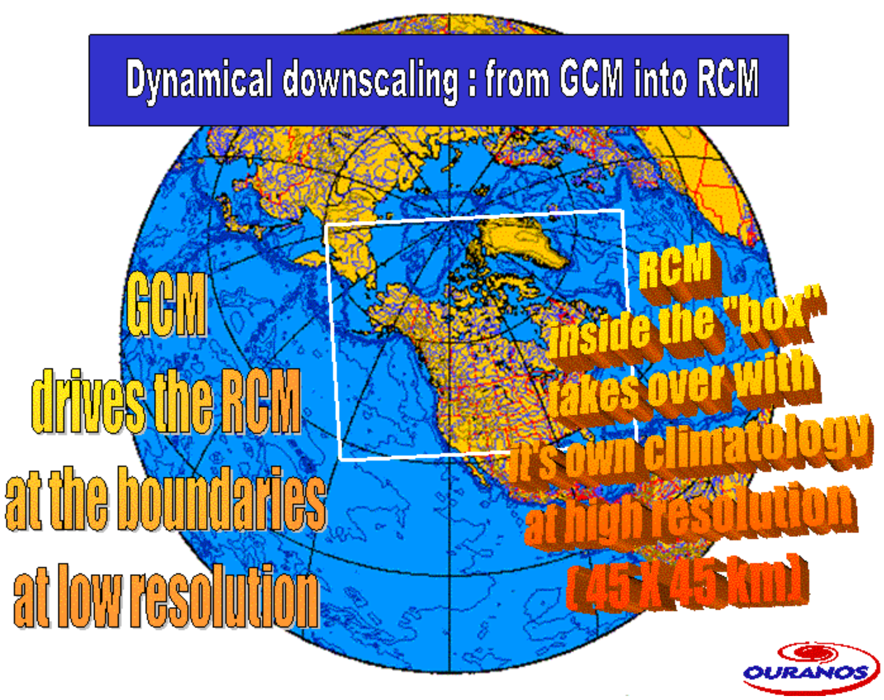


Figure 33

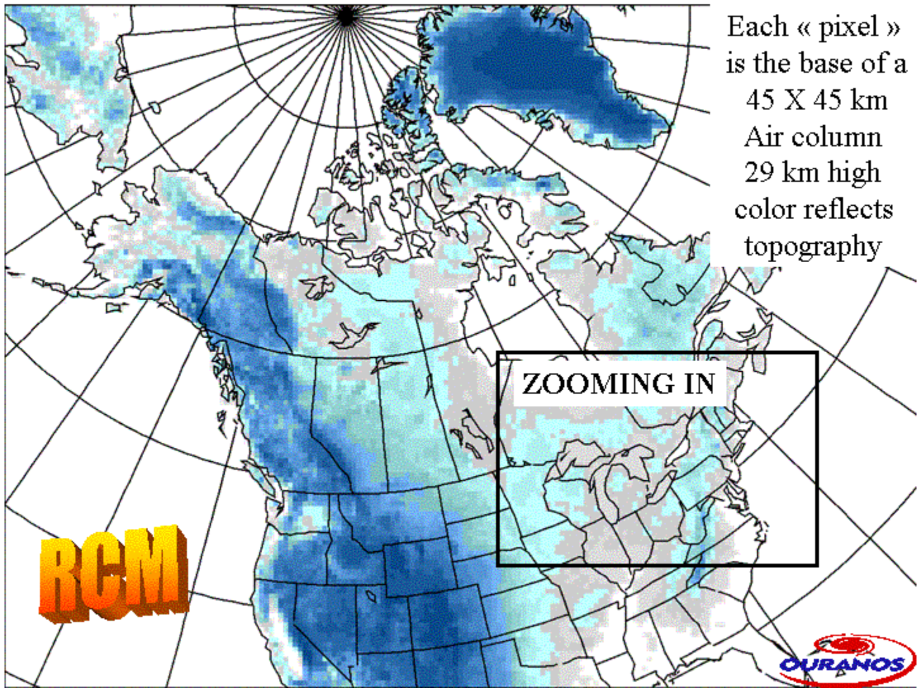


Figure 34

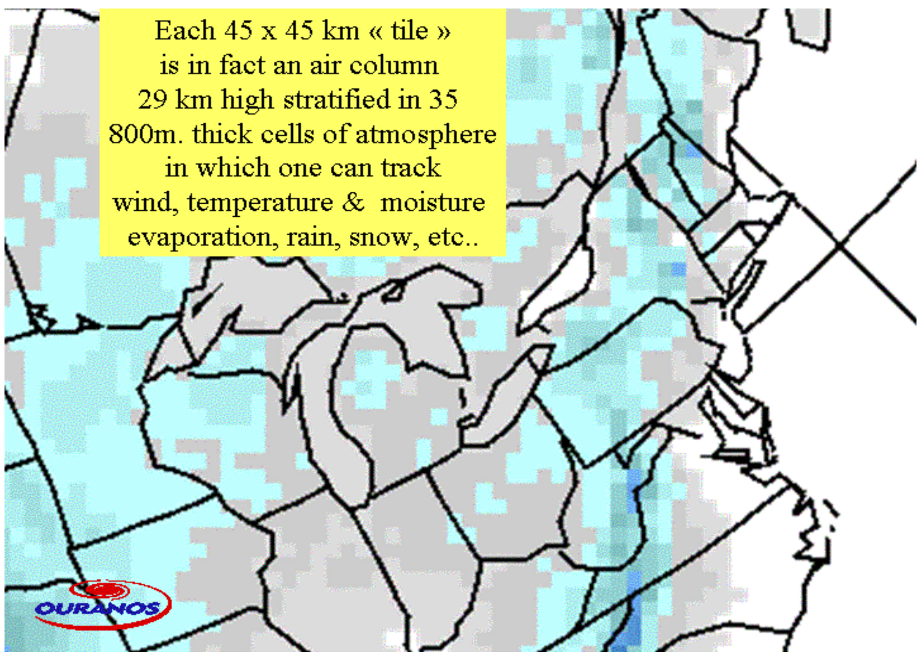
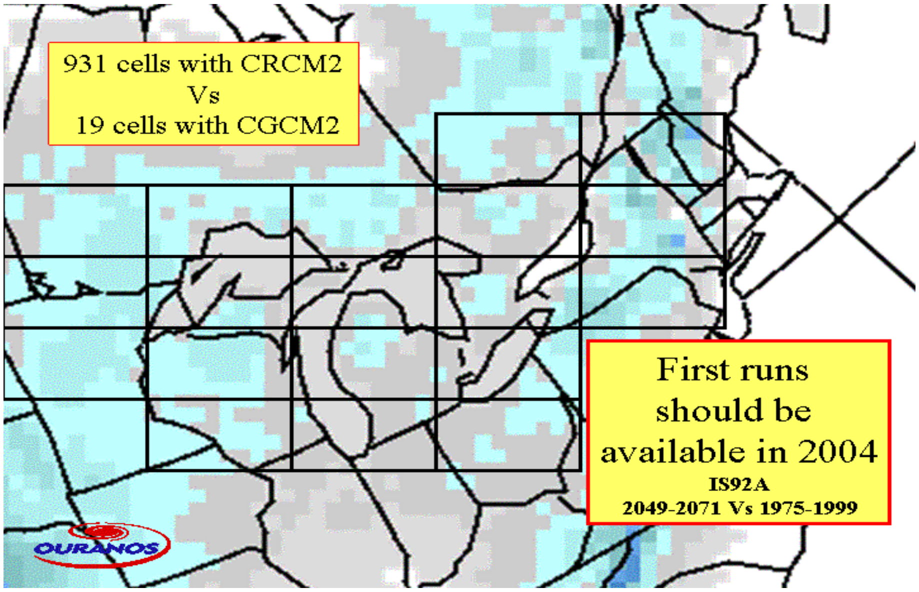


Figure 35 shows the size of every cell that Ouranos is modeling. Each is 29 km high and stratified to 35 layers. Compared to the GCM we will have a lot more detail, the first of which should be available in 2004. Ouranos is modeling with the previous stress scenario because the data were available in IS92A. It will take 15 months of computer time to get the results.

Figure 35



Consider the two sides of the border (Figure 36). The United States has decided to undertake greenhouse gas mitigation outside of Kyoto -- no problem with that for me. However, I am concerned about Canada. The U.S. has a science plan -- whether one likes it or not -- scheduled for June 25, 2003. Canada does not, and Canada signed Kyoto, which requires us to have one (Figure 37).

Figure 36

Figure 37

KYOTO PROTOCOL

TO THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

Canada's science & adaptation commitments

Article 10

All Parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances, without introducing any new commitments for Parties not included in Annex I, but reaffirming existing commitments under Article 4, paragraph 1, of the Convention, and continuing to advance the implementation of these commitments in order to achieve sustainable development, taking into account Article 4, paragraphs 3, 5 and 7, of the Convention, shall:

(b) Formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change and measures to facilitate adequate adaptation to climate change

(d) Cooperate in scientific and technical research and promote the maintenance and the development of systematic observation systems and development of data archives to reduce uncertainties related to the climate system, the adverse impacts of climate change and the economic and social consequences of various response strategies, and promote the development and strengthening of endogenous capacities and capabilities to participate in international and intergovernmental efforts, programmes and networks on research and systematic observation, taking into account Article 5 of the Convention;

Canada has another problem -- insufficient data. Figure 38 shows weather and climate stations. When one thinks about the size of the window to model, we will need data. There are stakeholders who say that we do not need a meteorological office because we have the weather channel -- and they believe it. Some of the issues we have to address with major stakeholders is that some of the assumptions are totally wrong and it is our responsibility to address them. In the meantime, we can try alternative solutions such as small airplanes (Figure 39). There is also the need to monitor vertically (Figure 40). Figure 41 depicts the size of the network needed to do a good job. The Great Lakes are going to be acting like a heat sink (Figure 42). We will have to monitor water temperatures. It can be done very inexpensively.

Figure 38

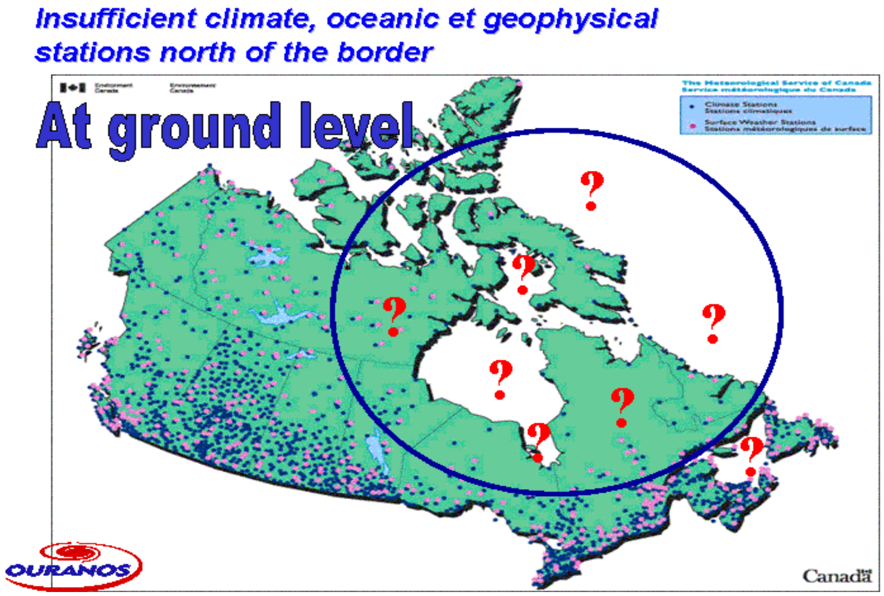


Figure 39

Figure 40

Figure 41

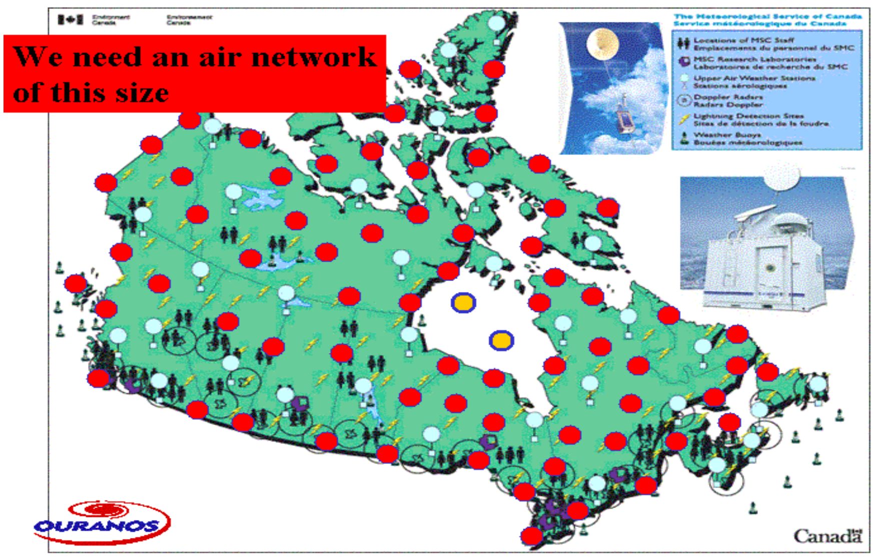


Figure 42

IN A NUTSHELL

Figure 43 indicates that there are some climate-independent decisions, and there are some climate-influenced or climate adaptation decisions. In my view, the Great Lakes / St. Lawrence system falls in the latter for a number of issues. We also know from past studies that climate variations do not move in a very linear pattern (Figure 44). The variations move in steps. One of our biggest issues is that we are managing the Great Lakes on a weekly basis, which is not bad, but we should be looking on a yearly basis, because that is where the added knowledge for adaptation truly lies. In my view, we would all benefit from cross-border strategic thinking for the next 5-10 years as to where we would want to be regarding practical climate science (Figure 45). In my view, users will be pushing for probable rather than deterministic and for combined adaptation (Figure 46). The International Joint Commission may be a suitable mechanism. Ouranos and others are ready to start linking resources, models, computers to do this. Thank you.

Figure 43

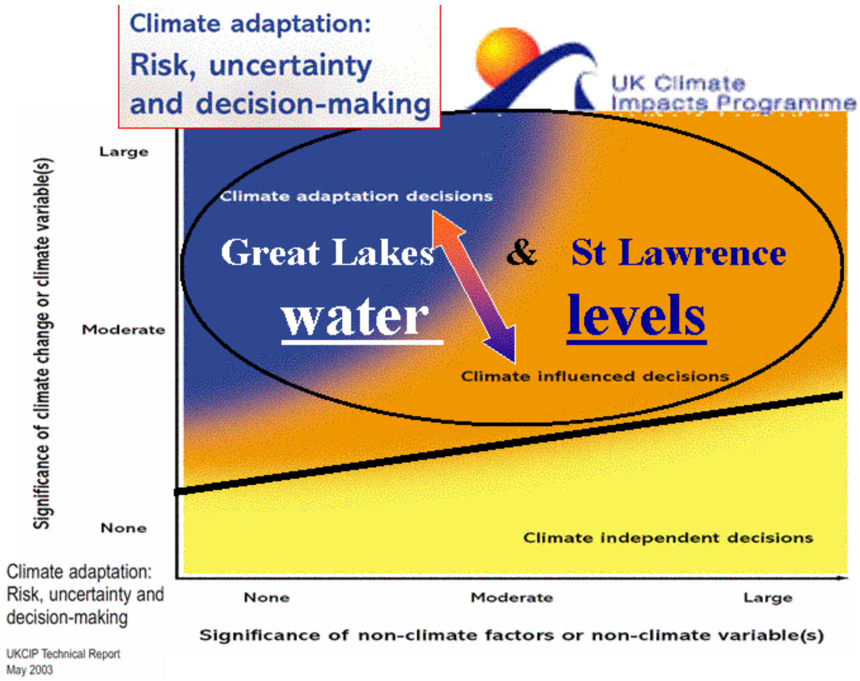


Figure 44

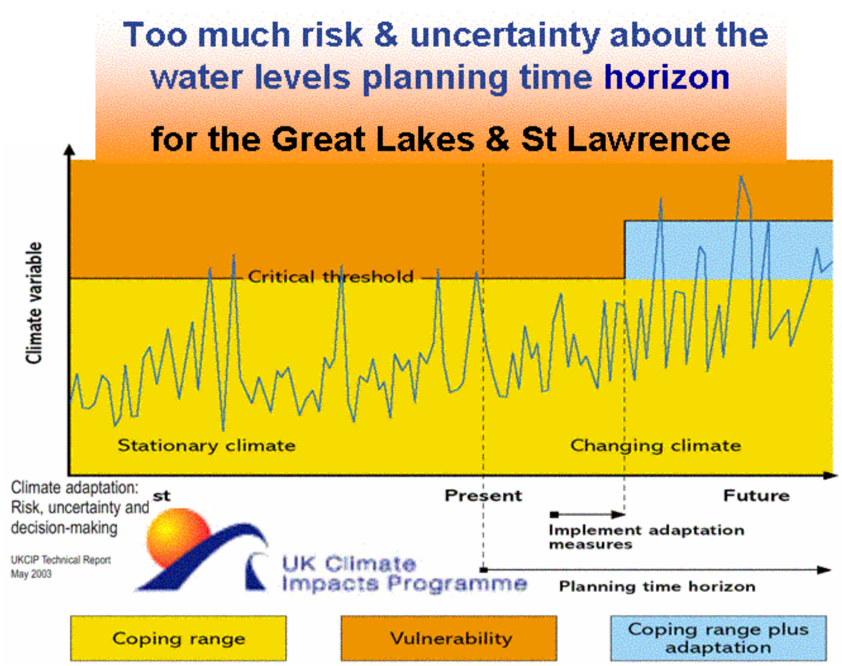


Figure 45

We would obviously all benefit from

a cross border strategy (5-10 years)

1. on practical climate science (brains & data):

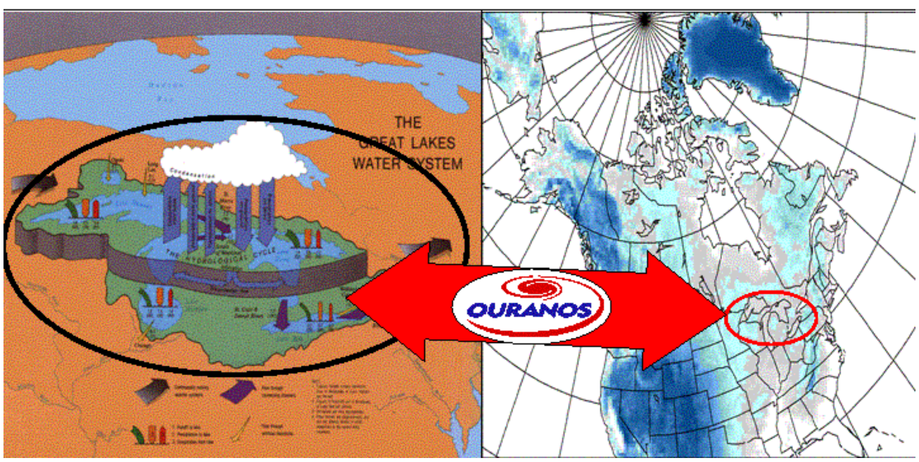
Supply stakeholders with credible regional scenarios of probable evolution of water levels (climate-economic risks-opportunities)

2. on combined adaptation (will & expertise) :

Develop & deliver timely knowledge tuned to stakeholders needs/concerns

Figure 46

Is anybody interested in coupling a catch-basin & run-off model of the Great Lakes basin with the dynamical downscaling model, as a practical first step towards a cross-border strategy ?



DISCUSSION

Question. What was the situation or context in Québec that allowed the Québec government to take action?

Beauchemin. Part of it was timing and part was people. By timing, we had the Saguenay flood, the ice storm, and the avalanche. The Prime Minister asked, How are you managing the Saguenay flood? Do you need any more help? Do you have everything you need? He was also tacitly asking, Why did it happen? Manitoba was struck by massive floods in 1970. The basic line of reasoning was the responsibility to do something, and that it was up to civil servants to take up the challenge to meet the leaders and tell them what to do. Here is where it is coming from and this is what we should be doing.

The other assumption was that we would have water in the hydro reservoirs for ever, but it is not there. The GCM story line was that we would have 20% more water, but we actually have 40% less. Then what good is that model? The only way to answer the question is to invest time and money into understanding what these things are all about. It was a coming together of basic interests and also the fact that we have to think outside of the box. Like smashing airplanes into buildings to produce a mass effect, we are not used to this kind of thinking but, as stakeholders, we are challenged to start thinking in that mode. When one reads the story line behind climate -- I have to address climate and I have to, as a department, tell Environment and Natural Resources to stop quarreling and work together in my own government.

Question. Can we attribute the loss or the recovery of the fishery to climate change?

Beauchemin. One never sees an official statement but, if you ask the person who is doing the study, there is no doubt that over-fishing killed the industry, and it still is. An article in a recent issue of *Nature* or *Science* reported that 90% of the big fish were over-fished. Nobody is managing the resource sensibly. But hardships are never alone. The story behind water temperature is also there, and that has basically erased all possibility of that species getting back on its feet because, in those areas, the fish are so stressed by water temperature that they do not grow enough, and other species are moving in, but basically we're managing on images. The next in line to go will be shellfish. We are over-fishing shellfish. We know what the water temperature is, and water temperature is crucial for such species, but we are not used to thinking in that mode. We invest money in aquaculture. We have focused on fisheries and not on oceans. Europe is monitoring the Atlantic temperature-wise on an operational basis. We should be doing the same with our waters.

Question. One could characterize many of your examples as low probability and high impact, which are likely impossible to model. Yet, are any projections or comparisons possible?

Beauchemin. So far, we have been operating in an emergency mode, but we are not getting our dollar's worth so that -- if the story line is true -- we need to move into a prevention mode. What risk do I take in putting $3 million a year into prevention, compared to money spent on an emergency where money does not count? As a stakeholder, are you willing to make this investment? Sewer design is already outdated, based on the old assumptions that we are presently using. If we are to spend wisely, the money that we are putting into infrastructure should be based on larger values.

Question. The issue of combined sewers is a good example of designing for a given capacity such as a 100-year event. If, indeed, with climate change we will have less frequent but more intense events, how can we predict the volume and how do we design sufficient capacity?

Beauchemin. I do not know the technical answer, but people do know how to do it, and we will have to undertake that kind of process. As decision-makers, we have to identify our criteria and the level of confidence in those criteria to meet the challenges before us. That is the decision-makers' responsibility. What we are designing today is based in part on what people are whispering in our ear. That is no good. If we design a car or a chemical that goes into the human body, are you liable? It is the same kind of issue here. You will be liable.

Moderator. Thank you again for a thought-provoking and challenging presentation.