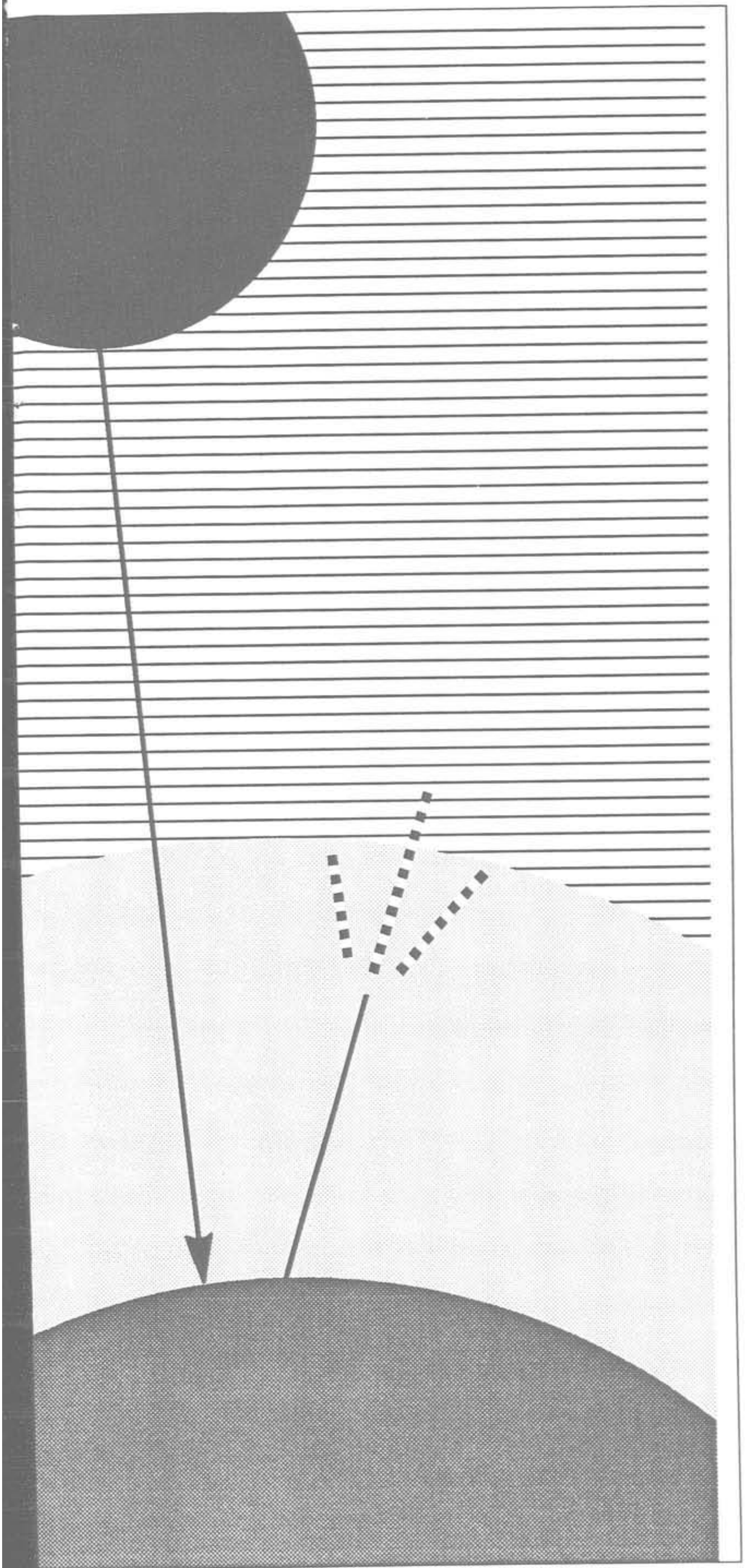

# Climate Change on the Great Lakes Basin

A compilation of papers presented at a symposium convened at the Annual Meeting of the American Association for Advancement of Science, Chicago, Illinois, February 1992.


Illinois Global Climate Change Program Office
Illinois State Water Survey
Champaign, Illinois

and

Climate Adaptation Branch
Canadian Climate Centre
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Downsview, Ontario

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# CLIMATE CHANGE ON THE GREAT LAKES BASIN

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July 1992

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# GREAT LAKES 20TH CENTURY CLIMATE VARIABILITY: IMPLICATIONS FOR FUTURE SCENARIOS?

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## INTRODUCTION

Several climate studies (e.g., Jones et al., 1986a, 1986b; Hansen and Lebedeff, 1987, 1988; Jones, 1988; Vinnikov et al., 1990; IPCC, 1990) have determined that the earth's global climate is warming. Some scientists attribute this to an increasing trend in greenhouse gases, such as $C0_2$. Doubled-$C0_2$ climate models are in general agreement that in a greenhouse-enhanced world, the Great Lakes region (interior North America) should experience wetter winters, drier summers, and an increase in temperature during both winter and summer ("Business-as-Usual" scenario, IPCC, 1990).

The models used to predict $C0_2$-induced climate change primarily deal with changes in mean temperature and precipitation due to changes in atmospheric composition, radiative processes, and feedback mechanisms. They currently do not address with any certainty shifts in large-sale weather regimes, such as depression tracks or anticyclones, nor can they resolve smaller-scale disturbances (IPCC, 1990). If future changes of climate primarily consist of a greater frequency of certain conditions within the multivariate distribution of current climatology, then we can use existing relationships to help clarify likely and unlikely scenarios of future climate.

Historical land station data from the Great Lakes regions were used to 1) assess the Twentieth Century trends in temperature and precipitation in the region, 2) determine the characteristics of historical climate variability in the region with a view toward future scenarios, and 3) assess the probable climate characteristics that would be associated with a warmer climate.

## DATA

Two types of data were analyzed in this study: climate division data and primary station data. The climate divisions in the Great Lakes region are fairly uniformly spaced and of comparable size (Figure 1). Monthly and seasonal divisional temperature and precipitation were analyzed to determine the broad regional-scale characteristics and the spatial variability characteristics within the region. Regional trends were available for the period 1895-1990, however reliable assessment of spatial variability could be made for only the 1931-90 period due to the method used to compute the divisional values.

Monthly and daily data from 23 primary stations in the Great Lakes region (see Figure 1 and Table 1) were used. The common period for all stations was 1966-1990. The parameters examined included monthly and seasonal temperature, precipitation, and snowfall, plus diurnal temperature range, difference in day-to-day mean temperatures ($T_{diff}$ = $T_{ave\{day\ 1)}$ - $T_{ave(day\ i-1)}$ number of days with maximum temperature at least 90° F, number of days with minimum temperature beyond certain thresholds (at least 50° F, at most 32° F, at most 0° F), number of days with precipitation at least 0.1 inch, number of days with no precipitation, number of days with daily snow depth at least 1 inch, number of days with measurable snowfall, mean depth of snow cover for those days having at least 1 inch of snow on the ground, greatest number of consecutive days with no precipitation, greatest number of consecutive days with snow depth at least 1 inch, and the standard deviation of daily maximum temperature ($T_{max}$), daily minimum temperature ($T_{min}$), daily mean temperature ($T_{ave}$), and daily mean temperature difference ($T_{diff}$). The standard deviations of the four temperature quantities measure the temporal variability of these quantities within the month. They were computed by taking the standard deviation of the daily values about their monthly mean value.

Table 1. Stations Used.

| | |
|---|---|
| Chicago O'Hare AP, IL | Duluth, MN |
| Fort Wayne, IN | Buffalo, NY |
| South Bend, IN | Rochester, NY |
| Alpena, MI | Syracuse, NY |
| Detroit, Metro AP, MI | Akron, OH |
| Flint, MI | Cleveland, OH |
| Grand Rapids, Mi | Toledo, OH |
| Houghton Lake, MI | Youngstown, OH |
| Lansing, MI | Erie, PA |
| Marquette, MI | Green Bay, WI |
| Muskegon, MI | Milwaukee, WI |
| Sault Ste. Marie, MI | |

## METHODOLOGY

Three statistical tests for trend were made on the seasonal regional data: the nonparametric Wilcoxon test, a parametric (least squares) test for linear trend, and the two-phase regression test described by Solow (1987). This battery of tests includes a robust test for nonzero trend (Wilcoxon test) as well as a test for a change point in linear trend (two-phase regression).

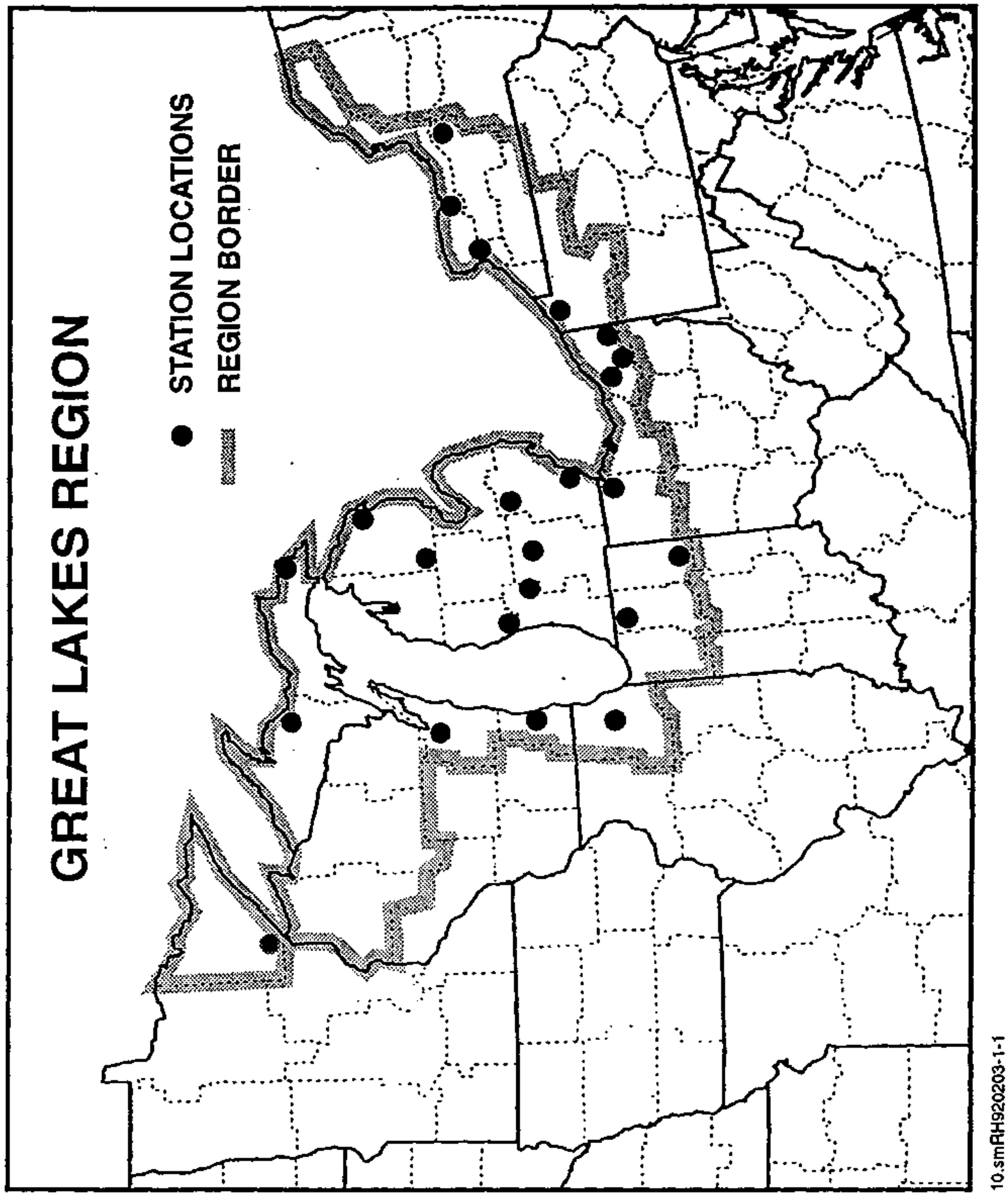



Figure 1. Location of the climate divisions and stations used in this study.

Pearson's product-moment correlation coefficient was used to describe the multivariate distribution of the current climate. The correlation coefficient determines only if a linear relationship exists between two normally-distributed variables and assesses the strength of the relationship; a strong correlation does not necessarily imply a causal relationship between the two variables. Correlation analysis is useful for determining general linear relationships between variables, but it cannot by itself determine if a nonlinear relationship exists. The correlation coefficient ranges in value from -1.0 (perfect inverse relationship) to 0.0 (no relationship) to + 1.0 (perfect direct relationship).

In this study, the seasons are defined as follows: winter = December, January, February; spring = March, April, May; summer = June, July, August; autumn = September, October, November; and annual = January through December.

## SUMMARY OF RESULTS

Examination of historical data from the Great Lakes region indicates that, during the last 95 years, there is no statistically significant trend in temperature (for any season) or in winter or spring precipitation; however summer, autumn, and annual precipitation show an increasing trend (Figures 2-4). The least squares analysis is the only test that yielded significant results (Table 2); the Wilcoxon and two-phase regression tests yielded insignificant results for all seasons.

Table 2. Statistical tests for linear trend in the Great Lakes region, 1895-1990. Temperature trend expressed in ° F/100 years, precipitation trend expressed in inches/100 years. Trends indicated by * are significant at the 0.05 confidence level.

| | LINEAR REGRESSION TREND | |
|---|---|---|
| SEASON | TEMPERATURE | PRECIPITATION |
| Winter | -0.23 | -0.06 |
| Spring | 0.49 | 0.37 |
| Summer | -0.52 | 1.63* |
| Autumn | -0.87 | 1.80* |
| Annual | -0.22 | 3.83 |

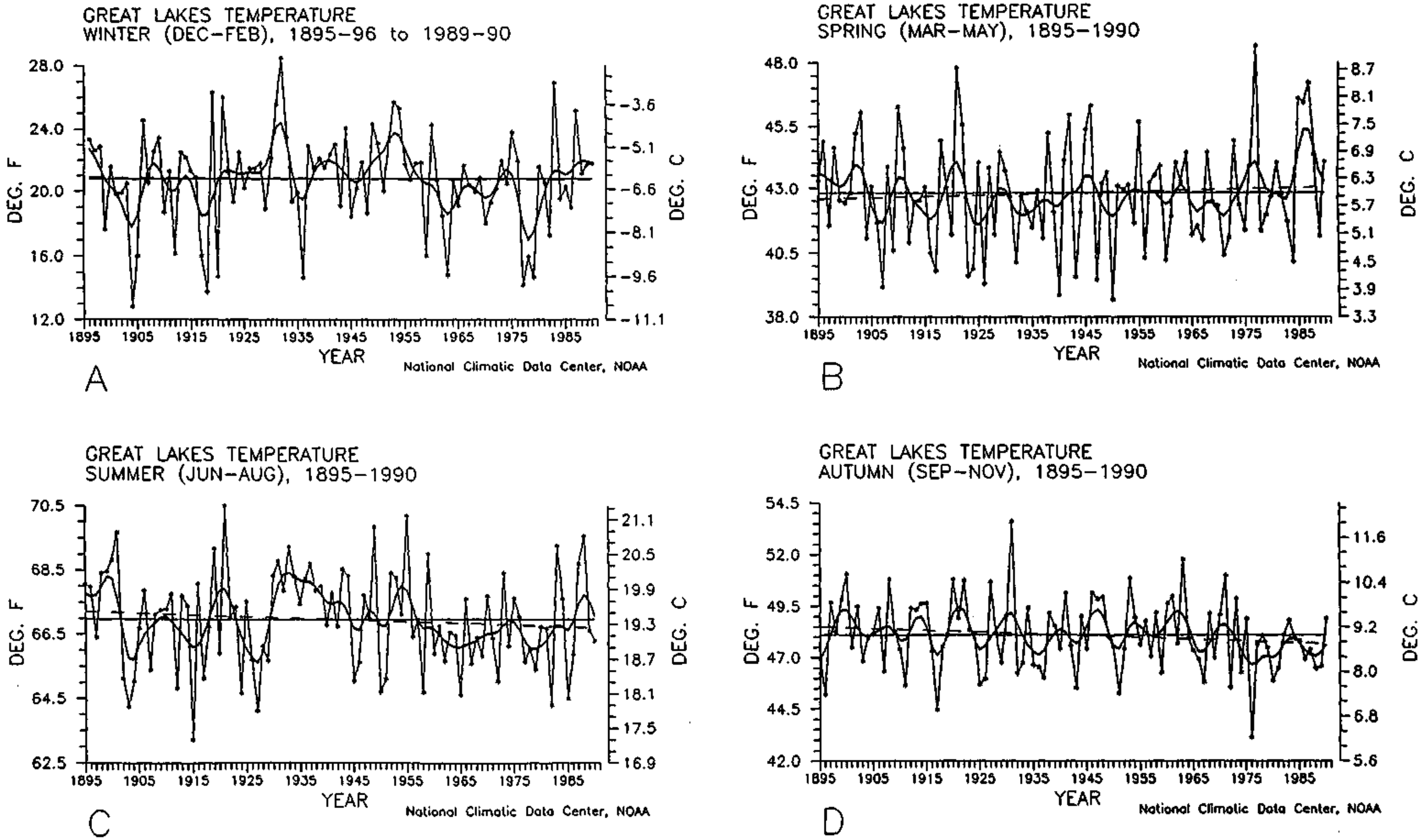



Figure 2. Seasonal temperature for the Great Lakes region for 1895 through 1990, based on climate division data. The darker smooth curve is a nine-point binomial filter designed to smooth out the year-to-year fluctuations and highlight decade-scale variations. The dashed line is the least squares linear trend.

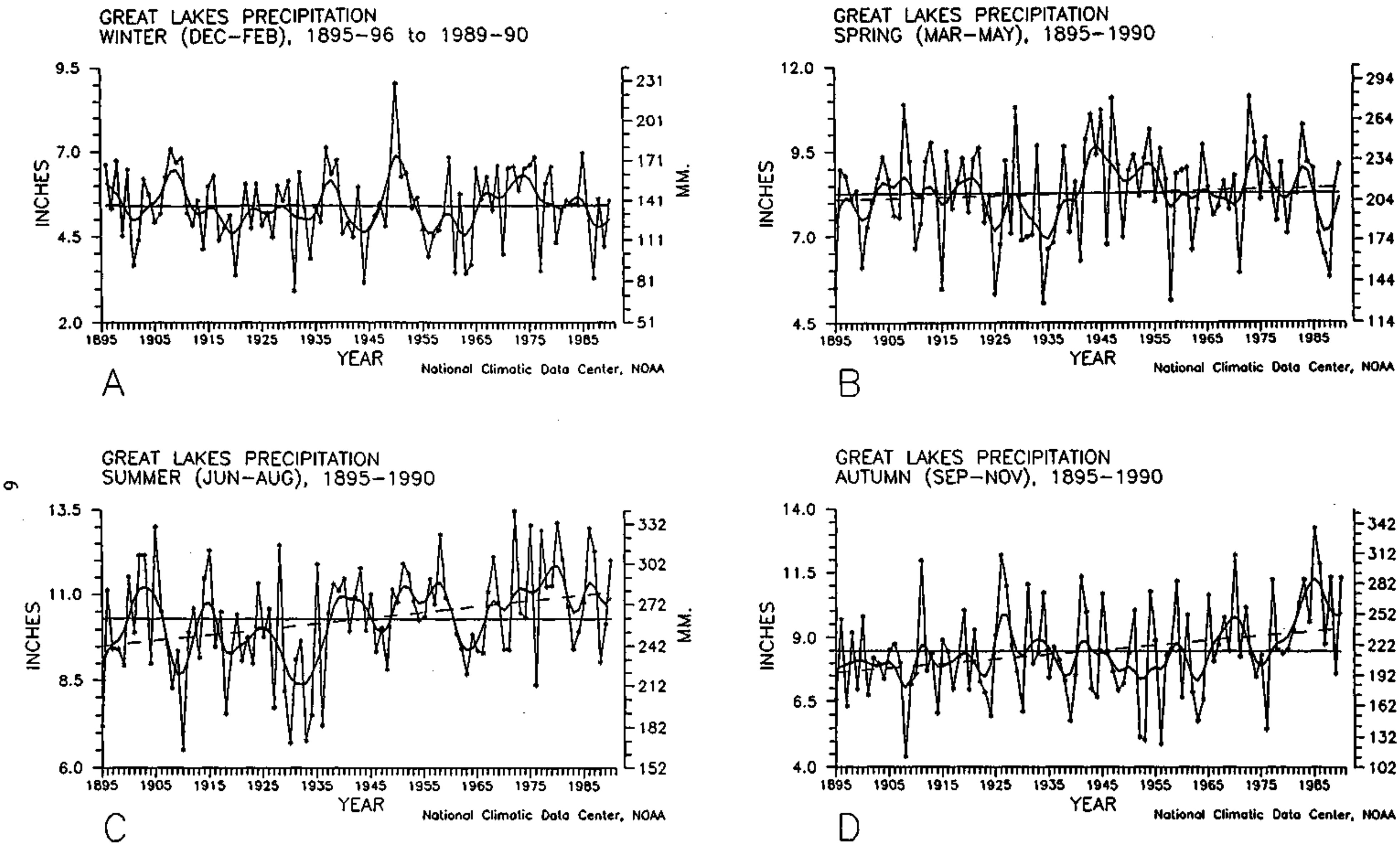
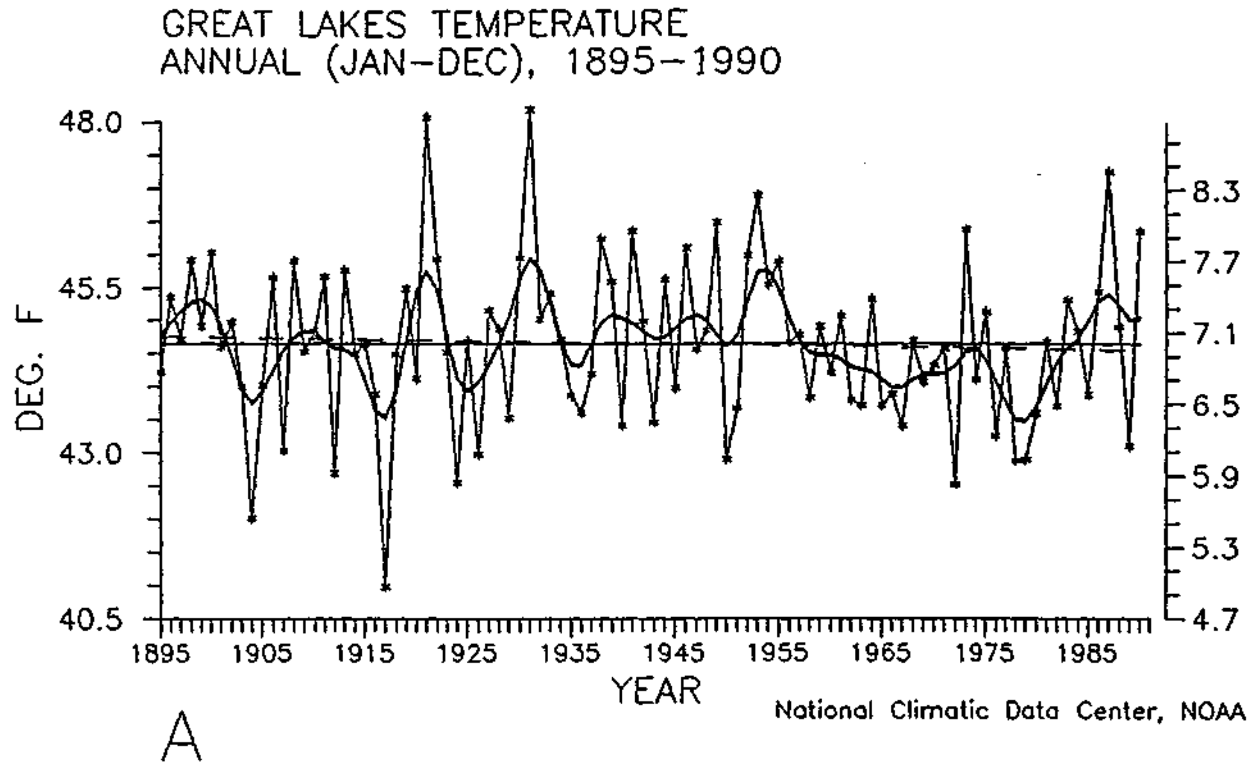



Figure 3. As in Figure 2, except for seasonal precipitation.



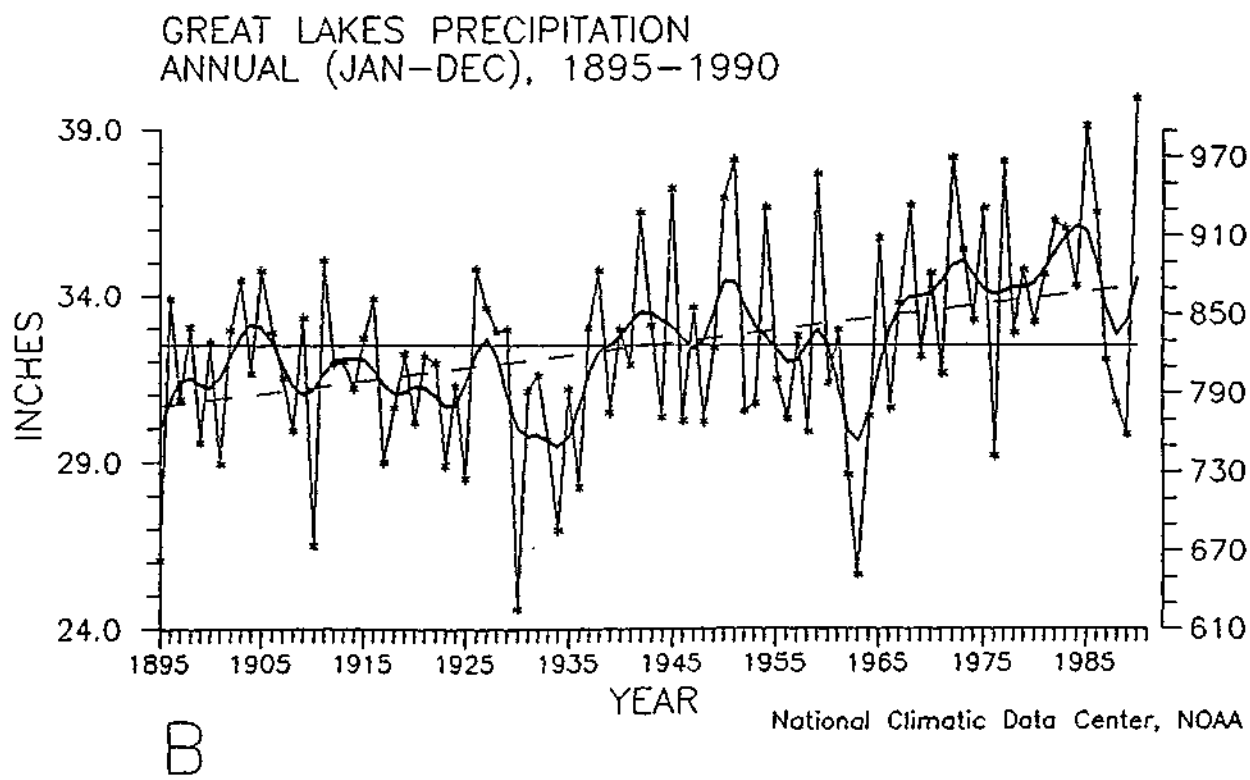




Figure 4. As in Figure 2, except for annual temperature and precipitation.

Assuming that the enhanced-Greenhouse climate models are correct and that past warm episodes can serve as an analog for a future warm climate in the Great Lakes region, the historical data can be used to determine the multivariate characteristics of such a warmer climate. The analysis indicates that past warmer-than-normal episodes have the following characteristics. Warmer winters in the Great Lakes region are wetter overall but have more days with no precipitation (implying heavier precipitation events when they occur), have a greater variability in monthly mean temperature from place to place, have a lower variability in day-to-day temperatures (except a higher variability in daily maximum temperature during late winter), have a lower average diurnal temperature range, have fewer days with extremely cold temperatures, and are less snowy. There is also weak evidence suggesting a greater variability in monthly total precipitation from place to place.

Warmer springs have a greater variability in day-to-day temperatures, a greater average diurnal temperature range, fewer days with extremely cold temperatures, and are less snowy. Early spring is wetter overall. Mid-to-late spring is drier overall and has more days with no precipitation, more days with warmer minimum temperatures, and more days with hotter maximum temperatures.

Warmer summers are drier overall and have more days with no precipitation, more days with hotter maximum temperatures, and more days with warmer minimum temperatures. There is greater variability in monthly mean temperature from place to place. There is weak evidence for greater variability in monthly total precipitation from place to place and weak evidence for lower variability in day-to-day temperatures.

Warmer autumns have fewer days with extremely cold temperatures, more days with hotter maximum tempatures and warmer minimum temperatures, and are less snowy. Mid-autumn has more days with no evidence for greater variability in daily maximum and minimum temperatures during mid-to-late autumn.

While this study has concluded that warmer-than-normal temperatures are associated with less snow, notable associations were determine between the station snow indices. To wit, greater monthly snowfall totals are associated with: (1) more days with measurable snowfall (strongest correlations in late autumn to mid-winter); (2) more days with at least 1" snow cover (the correlations were strongest during late autumn to early winter, and early spring, and only moderately strong during mid to late winter); and (3) greater daily snow depth (the correlations were strong during all months except February).

Notable associations were also determined between the station precipitation indices. Lower monthly precipitation totals are associated with (1) fewer "wet" (precipitation at least 0.1 inch) days (the relationship is strong across the region throughout the year); (2) more dry (no precipitation) days (strongest relationship during the summer months); and (3) longer dry spells (consecutive number of days with no precipitation).

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# EFFECTS OF CLIMATE CHANGE ON THE WATER RESOURCES OF THE GREAT LAKES

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## ABSTRACT

The Great Lakes contain about 95 percent of the U.S.'s fresh surface water supply and 20 percent of the world's fresh surface water supply. These water resources serve many uses including hydropower, industrial, navigation, municipal, recreational, and fish and wildlife habitat. Recent studies on possible impacts of climate change, using general circulation model outputs coupled with hydrologic simulation models, indicate a 23-51 percent reduction in Great Lakes net water supplies. Potential lake level changes range from -0.4 meter for Lake Superior to as much as -2.5 meters on Lakes Michigan and Huron. These results have major environmental and socioeconomic implications and will require new paradigms in water resource management for the Great Lakes.

## INTRODUCTION

The Great Lakes system, Figure 1, is one of the world's major water resources. It contains approximately 23,000 km$^3$ of water, representing 95 percent of the U.S. and 20 percent of the world's fresh surface water. It is also one of the most intensively used fresh water systems in the world, serving multiple interests including navigation, hydropower, recreation, and riparian. Some significant uses of the Great Lakes have become dependant upon small variations in water levels, resulting in system sensitivity to even small changes in the lake levels. Climatic change, represented in this study by global warming, could have a significant effect on the Great Lakes and the surrounding region.

Examples of the regional climatic responses to large scale climate change are demonstrated by the warming and cooling trends of the northern hemisphere during this century. The warming over the northern hemisphere between the 1920's and the 1960's is well documented in the records of the Great Lakes. The mid-century northern hemisphere cooling trend is also reflected in the Great Lakes region. The annual mean of the air temperatures around the Great Lakes for the period 1960-1980 is 0.8° C cooler than the prior 30 year period. The precipitation from 1966-1986 was been extremely high with very little variability. For the upper Great Lakes, 17 out of 21 years of this period had above average precipitation. The cooling trend combined with the high precipitation regime to give exceptionally high water supplies to the basin. The mid 1980's brought record high lake levels, flooding in low lying areas, and extreme erosion damages along the lake shore bluffs.

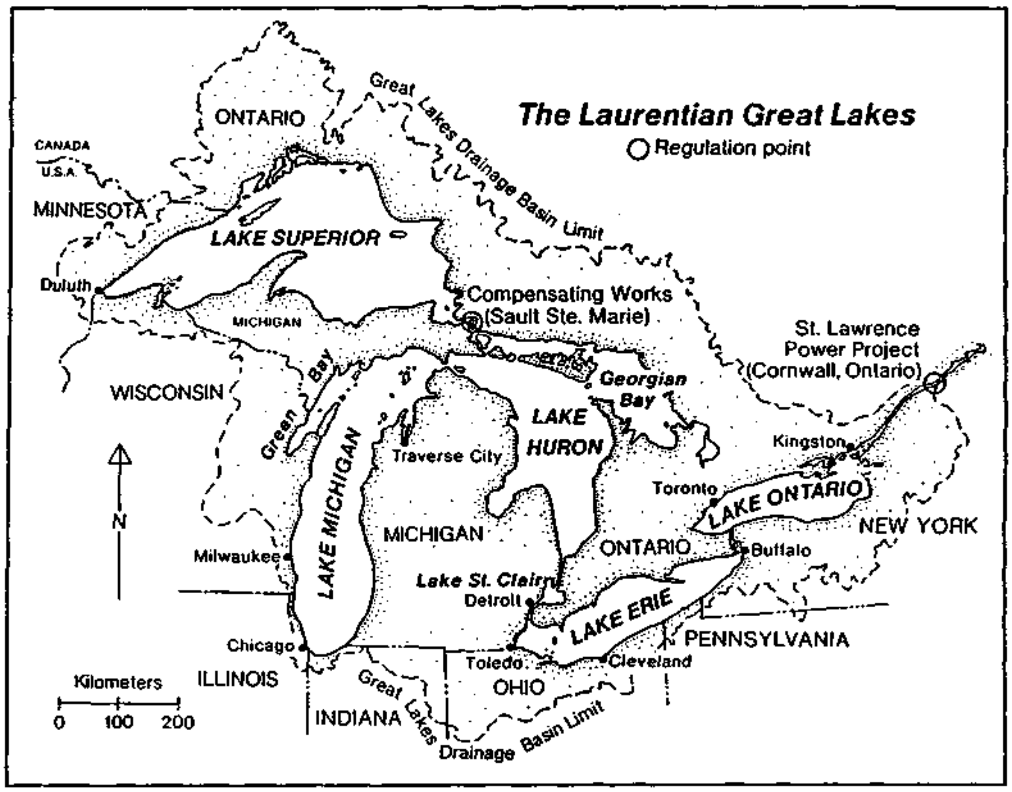


Figure 1. Great Lakes System

The current concern is that climatic warming, resulting from increases of greenhouse and other gases, could result in major changes to the hydrologic cycle and water resources of the Great Lakes. The main climatic impact would be a potential temperature rise of between 3° C and 7° C over the Great Lakes region. This could be accompanied by changes in the amount and seasonal distribution of precipitation. The basin has not been widely affected by low water supplies for an extended period in the past 50 years. This could likely change as a result of the scenarios possible in the future. The importance of potential climate warming on the water resources of the Great Lakes has been recognized for the past decade (Quinn and Croley, 1983; Quinn, 1987; Cohen, 1986; Cohen, 1987; Hartmann, 1990; Croley, 1990). This assessment uses the data from Croley (1990) and Hartmann (1990) to examine the sensitivity of Great Lakes water resources to potential climate change.

## IMPACTS ON WATER SUPPLIES AND LAKE LEVELS

This study assesses impacts on Great Lakes net basin water supplies using the outputs of three general circulation models (GCMs): the Oregon State University Model (OSU), the Goddard Institute for Space Studies Model (GISS), and the Geophysical Fluid Dynamics Model (GFDL), which were to assess potential effects of global climate change on the United States (U.S. Environmental Protection Agency, 1989). The detailed methodology of going from the GCM climatic outputs to relevant Great Lakes basin values was presented by Croley (1990). The primary changes in basin air temperature and precipitation for an equivalent doubling of $CO_2$ which were used to drive the hydrologic models are given in Table 1.

Table 1. Differences in Meteorological Variables for a Doubling of $CO_2$.*

| Basin | Air Temperature (° C) | | | Precipitation (mm) | | |
|---|---|---|---|---|---|---|
| | GISS | GFDL | OSU | GISS | GFDL | OSU |
| Superior | 4.3 | 7.2 | 3.4 | 148 | -36 | 58 |
| Michigan | 4.7 | 6.2 | 3.5 | 16 | -8 | 42 |
| Huron | 4.6 | 6.4 | 3.3 | -43 | 28 | 46 |
| Erie | 4.7 | 5.7 | 3.4 | -53 | 48 | 54 |
| Ontario | 4.6 | 5.9 | 3.2 | -66 | 27 | 74 |

* Mean of 3 GCM's from Croley (1990)

Many GCM output variables have a high degree of uncertainty associated with them. For example, the Great Lakes have a major impact on the climate of the basin but the GCMs do not recognize the existence of the lakes due to their large spatial scales. This can affect seasonal temperature distribution, snowfall, humidity, and wind speed. For the Great Lakes region the GCM's present climate does not replicate the observed climate including hydrologic variables such as runoff and soil moisture. The GCM outputs do, however, provide data for examining the potential sensitivity of the system to climate change.

The GCMs meteorological outputs are used to drive a series of hydrological models to estimate the hydrologic system response in terms of soil moisture, runoff, evapotranspiration, and evaporation from the lake surface. The sum of the precipitation and runoff minus the evaporation yields the net basin water supply to the system. The water supplies are then input into a hydrologic response model, (Quinn 1978), including the existing regulation plans for Lakes Superior and Ontario, to provide the lake level and connecting channel responses to the climate change scenarios. The overall water supply data are given in Table 2, and the resulting lake levels are given in Table 3. Additional information is available from Hartmann (1990). The Lake Ontario regulation plan failed under all scenarios, while the Lake Superior regulation plan failed under the GFDL scenario. Both regulation plans have recently been modified in an experimental mode to handle the reduced water supplies from the climate change scenarios without failing (Lee, personnel communication).

Table 2. Percentage change in water supply variables resulting from a doubling of $CO_2$*

| Scenario | Basin runoff | Over-lake . precipitation | Over-lake evaporation | Net basin supply |
|---|---|---|---|---|
| GISS | -24 | +4 | +27 | -37 |
| GFDL | -23 | +0 | +44 | -51 |
| OSU | -11 | +6 | +26 | -23 |

* From Croley (1990)

Table 3. Changes in lake levels due to a doubling of $CO_2$.*

| | Lake Level (m) | | |
|---|---|---|---|
| Lake | GISS | GFDL | OSU |
| Superior | -0.46 | - | -0.47 |
| Michigan-Huron | -1.31 | -2.48 | -0.99 |
| Erie | -1.16 | -1.91 | -0.79 |

* From Hartmann (1990)

The Great Lakes have historically enjoyed a relatively small range in lake levels, approximately 1 meter from the average annual maximum to the average annual minimum. Superimposed upon the average levels are seasonal cycles of 40-45 cm. Thus, the probable impacts of climatic warming are (1) decreasing the water supplies through increased evapotranspiration from the land surface resulting in smaller runoff into the lakes, (2) increasing the evaporation from the lake surfaces and (3) changing the precipitation patterns. These impacts will likely result in lake levels much lower than those recorded over the past 150 years. These changes would have a major impact on the water resource management of the system.

## WATER RESOURCE CONSIDERATIONS

The decreased water supplies and lake levels would have major impacts on navigation, hydropower, fisheries, recreational boating, and the ecosystem. The Great Lakes/St. Lawrence Seaway is a major freshwater transportation system. This system depends upon adequate depths in the connecting channels and harbors to function at full capacity. Under the climatic warming scenario, channel depths would decrease by .5-2.5 meters, necessitating extensive dredging in both the connecting channels and the major harbors. Much of this area has not been dredged in the past 20 years. In a number of areas the dredged material is highly contaminated, creating a problem with spoil disposal. On the other hand, a decreased ice season could lead to an extension of the current navigation season, contributing to better vessel utilization and a decrease in stockpiling.

The waters of the Great Lakes are extensively used for hydropower production. Facilities range from low head plants in the St. Mary's River to high head facilities in the Niagara and St. Lawrence Rivers. A climatic warming would result in decreased flows and water surface elevations which would contribute to lower hydropower production. This could be important as hydropower is cheap and nonpolluting when compared to its primary alternative, fossil fuel. Fossil fueled and nuclear power plants sited around the lakes use lake water for cooling. A climatic warming could produce increased consumptive use of water which would further exacerbate the anticipated low lake levels.

The Great Lakes system contains one of the nation's prime sports fisheries, as well as a smaller commercial fishery, representing billions of dollars to the economy. A climatic wanning could result in a change in the species composition of the fishery with cooler water species giving way to warmer water species. This could have a significant impact on the value of the fishery. As an example, whitefish, a valuable commercial species, apparently depends upon ice cover for adequate spawning and survival. Climatic change could drastically reduce the ice cover in prime spawning areas.

The Great Lakes system is one of the prime recreational boating areas in the county. The three county area around Detroit has more boating registrations than any other area in the U.S. The lower water levels in the lakes and connecting channels resulting from climatic change would greatly reduce the areas currently accessible to small craft, including the small passenger vessels that are operating in many areas at the present time. This could require extensive private dredging and the rebuilding of ramps.

Finally, a long term climatic warming would adversely effect the valuable Great Lakes ecosystem. Currently existing wetlands would be eliminated, and the diversity of species would probably be decreased. The complex food web would also be disrupted with a major change in species composition. Decreased water supplies would also impact water quality by increasing the flushing times for the lakes and perhaps contributing to oxygen depletion in Lake Erie. The changed climate could also induce circulation changes affecting sediment, biological, and contaminant transport. Changes to the pelagic and nearshore ecosystem dynamics and species composition could also be expected.

From a downstream perspective the flows in the lower St. Lawrence River would be greatly reduced impacting recreation, navigation, wetlands, and hydropower. In addition the reduced flows could result in increased tidal effects and salt water intrusion in the lower river.

The debate over interbasin diversion of water into and out of the Great Lakes is also likely to intensify. There will be demands to increase the amount of water diverted into Lake Superior through existing diversions as well as new potential diversions. At the same time, efforts will likely be taken to divert additional water into the Mississippi River basin. Simultaneously the Great Lakes response would likely be to curtail the water diverted out of Lake Michigan at Chicago.

The Great Lakes are a shared resource between the United States and Canada. There are also numerous state, provincial, county, and municipal jurisdictions leading to a complex jurisdictional structure. This will require a coordinated approach to policy development for coping with lowered lake levels. The policy implications of long term lowered lake levels are far different that the major policy deliberations during the past several years which have emphasized coping with high lake levels. Many recreational boaters and marina operators around the lakes consider the current near average lake levels to represent low conditions. Extensive revision of the existing regulation plans as well as the possible regulation of Lake Michigan-Huron and Lake Erie will be required to maintain lake levels at desirable levels. This will result in low flows in the connecting channels and in the St. Lawrence River. Major policy decisions will have to address the distribution of benefits between commercial, riparian, recreational and ecological interests, between upstream and downstream interests, and finally between the many jurisdictional interests.

## CONCLUSIONS

Global warming will likely have severe implications for the Great Lakes water resources. Studies to date indicate inadequate water supplies to maintain the historical water level and flow regimes. The decreased lake levels of 0.5-2.5 m will require major adaptation by all interests as well as lead to increased regulation of the system. These changes will require a new paradigm of how the lakes will be viewed from social, economic, and ecological perspectives. New policies will have to be developed and implemented to balance the competing interests.

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# CLIMATE CHANGE IN THE GREAT LAKES BASIN: IMPACTS, RESEARCH PRIORITIES AND POLICY ISSUES

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## CLIMATE CHANGE IN CANADA

The threat of global warming has been recognized as an important issue in Canadian environmental management and policy. Preliminary impact assessments based on a doubling of carbon dioxide ($2xCO_2$) General Circulation Model (GCM) scenarios suggest that adverse effects would be felt in all regions of the country (Canadian Climate Program Board (CCPB), 1991). These include problems of coastal flooding associated with sea level rise on Canada's three ocean coastlines (Atlantic, Pacific, Arctic) (CCPB, 1991). The risk that the continental interior of North America will become hotter and drier is a threat to Canada's major grain export region — the southern Prairie provinces (Arthur, 1986; Williams, 1988). The impacts are likely to be more varied in central Canada (Great Lakes-St. Lawrence Basin) (see Section 2 below) but prominent among them is the risk of a fall in the level of the Great Lakes with loss of draught for Great Lakes shipping and reduced hydro-electric power production, for example, at Niagara (Howe, 1986).

There would be major impacts on agriculture and forestry as climate and vegetation zones move north (Smit, 1989; Wheaton et al., 1987). While human intervention and deliberate adaptation might mitigate the impacts in agriculture, forests with longer crop cycles are likely to be more seriously affected. Natural ecosystems and wildlife may be especially at risk since it will be difficult to adapt or migrate at a rate fast enough to keep pace with the anticipated rate of climate change (Wheaton et al., 1987; Intergovernmental Panel on Climate Change (IPCC), 1990). The region of largest relative warming is likely to be the Arctic where changes in permafrost may have significant impact on infrastructure cost and design. Native peoples, in particular those relying directly on hunting and fishing for their livelihoods, might also be strongly affected (Roots, 1986).

Even in urban, industrial Canada climate change is likely to have substantial impact if changes occur in extreme event distributions and in incidence of expected maxima. This suggests that design of buildings, transmission towers, dams, and other infrastructure will have to take climate change into account. There may be adverse effects on human health as more people are exposed to heat stress and as the distribution of disease vectors changes (IPCC, 1990).

The news is not all bad, however. Canada has a cold and harsh climate over much of its territory for long periods, and warming is likely to bring some benefits in terms of longer growing seasons, reduced heating costs, and longer ice-free navigation (Arthur, 1986; Williams, 1988; Smit, 1987; Howe, 1986).

It is recognized that these conclusions are very preliminary and that great uncertainties remain, both with respect to the rate and magnitude of climate change, especially on a regional basis, and the likely impacts. Most impact studies have imposed a future climatic scenario on a present-day economy. It is clear, however, that once climate change impacts begin to be felt, considerable adaptation is likely to take place, including private and spontaneous adaptation requiring little or no government intervention.

To help reduce the uncertainties associated with climate change, the Canadian federal government has adopted an approach containing three main elements. First, there is an expanded program of scientific research on the atmosphere to reduce scientific uncertainties. It is likely that this will include efforts to build regional models of climate change, nested in the CCC GCM. Second, studies are being undertaken on the limitation of greenhouse gas emissions including $CO_2$, methane and oxides of nitrogen. So far, Canada has announced a policy target of stabilizing greenhouse gas emissions by 2000 at 1990 levels. A third area of study concerns preparations to respond to climate change. The Canadian Climate Centre now has a Climate Adaptation Branch which is examining options for adapting to climate change and variability.

These three pillars — scientific research on the atmosphere and the development of limitation and adaptation strategies — form the main structure of the National Action Strategy for Global Warming which is being developed by the federal government in association with the provinces (Canadian Council of Ministers of the Environment (CCME), 1990).

Attention has been directed toward the work of the IPCC and the negotiations of an international framework convention on global warming (CCME, 1990). While these activities will continue, it seems likely that in future the focus will shift more to the regional level, to the analysis of climate change and variability, and to the development of adaptive responses. In this connection, the project on responding to the impact of climate change in the Great Lakes-St. Lawrence Basin being developed by Canada in association with some U.S. partners assumes greater importance.

## CLIMATE CHANGE IN THE GREAT LAKES-ST. LAWRENCE BASIN

### Physical Implications of Climate Change

Our socioeconomic activities such as driving cars, burning fossil fuel, deforestation and other land use practices are altering the chemical composition of the atmosphere. There is a high probability of major climate change in the Great Lakes-St. Lawrence River Basin in the next 100 years due to increases in greenhouse gases. This change could significantly affect the Great Lakes-St. Lawrence Basin ecosystems and hydrologic cycle.

GCM modelling results have projected a global mean temperature rise between 1.5° C and 4.5° C based on a doubling of the current carbon dioxide concentration in the atmosphere. Also, changes in the amount and seasonal distribution of precipitation would likely occur. At the regional level of the Great Lakes-St. Lawrence Basin, modelling results for temperature and precipitation from the Canadian Climate Centre (CCC), Goddard Institute for Space Studies (GISS), Geophysical Fluid Dynamics Laboratory (GFDL), and Oregon State University (OSU) GCM's are intercompared in Tables 1 and 2. For the four models, temperature increases range from 3.4 (OSU) to 9.1 (CCC) ° C in winter while summer increases range from 2.7 (GISS) to 8.6 (GFDL) ° C. Precipitation is more variable; in winter, precipitation varies from 90% (CCC) of the $lxCO_2$ normal to 130% (GFDL) of $lxCO_2$ normal. In summer, precipitation in the Basin ranges from 70% (GFDL) to 130% (CCC) of $lxCO_2$ normal. Some of the potential climatological and hydrological implications or "first order" changes due to global warming scenarios for the Basin are summarized in Table 3. Croley (1990) has applied $2xCO_2$ scenarios from several GCMs to a runoff model developed for the Great Lakes Basin. Declines in the net basin supply of the Great Lakes Basin range from -23% to -51%. Although the climate model projections are too uncertain to accurately predict regional biophysical and socioeconomic effects of global warming, the modelling results can be used as plausible scenarios to assess the sensitivity and resilience of nature and society to climate changes (Hengeveld, 1991). Some of the potential socioeconomic implications of climate change in the Great Lakes-St. Lawrence Basin, summarized from numerous impact studies, are highlighted below.

**Socioeconomic Impacts and Policy Implications of Climate Change**

Water Resources. In the Great Lakes-St. Lawrence Basin, demand for water would increase in a warmer world; at the same time, lake levels would decline and streamflow would be reduced due to increased evapotranspiration and decreased runoff. Typical scenarios suggest that water levels in the Great Lakes could fall by 0.5 to 1.0 meter or more on average while water flowing out of the St. Lawrence River could be reduced by 20% (Sanderson). Water supplies would become less reliable and potential conflicts over water could increase.

Municipal water supply systems could be stressed because of reduced water intake capacities caused by lower lake levels and less streamflow. For example, in the low water level period during the mid 1960's, numerous municipalities had to extend intake pipes and increase pumping capacities while at the same time curtailing use of water. During the drought of 1988, high rise apartments in areas of northern Toronto were without water for short periods of time because there was not enough pressure in the system. How are our water supply agencies going to respond to potential increases in demand for water at a time when sources are declining and costs increasing?

Instream pollution assimilative capacities could decline due to a reduced streamflow and serious environmental degradation could occur. Municipalities and industry would have to upgrade their effluent treatment with significant capital expenditures. Regulatory agencies whose water quality criteria were not being met would have to evaluate their water quality criteria; perhaps change them; and decide what to do with pollution offenders.

Table 1. Comparison of GCM Models - Temperature (2x$CO_2$)

| | GENERAL COMMENTS | WINTER | SPRING | SUMMER | AUTUMN |
|---|---|---|---|---|---|
| CCC | GREATER TEMP INCREASE THAN OSU; LESS THAN GFDL OR GISS<br>SHARPEST RISE IN WINTER (of all GCMs) | Greatest increase of all seasons<br>N and W parts of basin show greatest rise<br>(4.0 C to 9.1 C) | SW part of basin shows sharp increase<br>(3.3 C to 8.3 C) | SW part of basin shows sharp increase<br>(3.9 C to 6.2 C) | Smallest increase of all seasons<br>Increase in temp as move S in the basin<br>(2.7 C to 4.7 C) |
| GISS | WARMEST IN WINTER & AUTUMN | Warmest in N part of basin<br>(4.5 C to 6.6 C) | Warmest in S part of basin (near L. Erie)<br>(3.8 C to 4.8 C) | Steady increase in temp as move N to S in basin<br>(2.7 C to 3.8 C) | Increase in temp as move NE to SW<br>(3.0 C to 6.0 C) |
| GFDL | GREATEST TEMP INCREASE OF ALL GCMS (all seasons)<br>VERY STEADY AND SHARP INCREASE IN SUMMER | Sharp increase as move N in the basin<br>(5.0 C to 8.7 C) | Similar rise in winter<br>(4.4 C to 8.0 C) | Very sharp rise as move E to W in basin<br>(5.6 C to 8.6 C) | Season with smallest rise as move E to W in basin<br>(5.6 C to 7.0 C) |
| OSU | SMALLEST TEMP INCREASE OF ALL GCMS (all seasons)<br>TEMP RISES EQUALLY IN ALL SEASONS | Greatest increase of all seasons (but only slightly)<br>Temp increases as move NE to SW in basin<br>(3.4 C to 4.2 C) | Warming gradually as move E to W in basin<br>(2.9 C to 3.5 C) | Temperature increase as move E to W in basin<br>(3.0 C to **4.0** C) | Very gradual increase as move S in the basin<br>(2.6 C to 3.3 C) |

Table 2. Comparison of GCM Models - Precipitation (Ration of 2 x $CO_2$:1 x $CO_2$)

| | GENERAL COMMENTS | WINTER | SPRING | SUMMER | AUTUMN |
|---|---|---|---|---|---|
| CCC | WETTER IN SPRING, WINTER IN THE N-NW PART OF BASIN; DRIER IN S PART OF BASIN IN SUMMER AND AUTUMN | Wetter in N-NW part of basin; drier in SW part (0.9 to 1.2) | Sharp rise in precipitation as move N in basin (0.9 to 1.4) | Generally drier than normal except for NE part of basin (0.75 to 1.1) | Sharp drop in precipitation as move S in the Basin; increase in N part of basin (0.65 to 1.3) |
| GISS | WETTEST OF ALL GCMs WETTER AS MOVE N IN THE BASIN (all seasons, esp. winter and summer) SHARP DROP IN AUTUMN PRECIPITATION | Progressively wetter as move N in the basin (1.0 to 1.2) | Wetter as move NE in the basin (1.0 to 1.1) | Increase in precipitation as move N in basin (1.0 to 1.3) | Sharp decrease in precipitation as move NW to SE in basin (0.65 to 1.2) |
| GFDL | VERY WET WINTER DRIER IN SPRING, SUMMER AND AUTUMN (esp. NW part of basin) | Sharp rise in precipitation throughout basin (1.1 to 1.3) | Precipitation increase as move NW to SE in basin (0.95 to 1.15) | Sharp decrease in precipitation throughout basin (0.7 to 0.9) | Precipitation declines NW from L. Superior; increase in precipitation in SE part of basin (0.8 to 1.1) |
| OSU | PRECIP INCREASES AS MOVE SE TO NW IN WINTER AND AUTUMN | Precipitation increases as move SE to NW in basin (1.0 to 1.15) | Precipitation decreases as move NE to SW in basin (0.9 to 1.1) | Decrease in N part of basin; increase in S portion of basin (0.9 to 1.1) | Sharp increase as move SE to NW in basin (1.0 to 1.25) |

Table 3. Global Warming Impact Scenarios for the Great Lakes Region.

| PHYSICAL VARIABLE | CHANGE |
|---|---|
| Air Temperature | increase |
| Overland evapotranspiration | increase |
| Snowmelt | decrease in snowpack, earlier seasonal peak |
| Soil moisture | decrease |
| Runoff/streamflow | decrease, earlier seasonal peak |
| Lake surface temperature | increase |
| Lake evaporation | increase |
| Ice cover | decrease |
| Net basin supply | decrease, earlier seasonal peak |
| Lakes levels | decrease, earlier seasonal peak |

Pressure for diversions of water within the Basin and outside the Basin would increase. Many towns in Southern Ontario currently view a pipeline to one of the Great Lakes as a solution to their water supply problems. Outside the basin, arid areas such as the Southwest and California look to the Great Lakes as a motherlode of water. Large-scale diversion schemes such as the GRAND Canal do not seem farfetched under potentially severe water shortage conditions. Will the current Canadian policy on no water diversions out of the basin be changed in the face of the external pressure?

Natural Ecosystems. Temperature, growing season, precipitation, and soil moisture changes could lead to a significant alteration of the composition and viability of natural ecosystems in the Basin. For example, Rizzo (1990 in Hengeveld, 1991) has modelled significant shifts in vegetation regions in Canada. His results indicate a northward movement of the Temperate forest zone within the Great Lakes-St. Lawrence Basin and the replacement of the Boreal forest. Potential changes in the composition and distribution of natural ecosystems has serious implications for management of National and Provincial Parks, National Wildlife Refugia and Natural areas. Climate change could also influence the continued viability of rare and endangered wildlife and vegetation species as well as the sustained diversity and health of all species. Will our policy be to manage existing ecosystems in their current state or allow them to change to a new state?

Wetlands, for example, are the only natural ecosystems that are recognized and protected by an international convention, the RAMSAR convention. Wetlands are diverse, highly productive ecosystems that are disappearing at a rapid rate due to urban encroachment and agricultural land drainage. These ecosystems are vulnerable to water supply changes since they occur along the land-water continuum. Inland wetlands are particularly vulnerable. While many Great Lakes shoreline wetlands would be affected by water level declines and changes in the seasonal water level cycle, certain wetlands would be able to migrate lakeward while more enclosed wetlands would "dry" out. Water supply alteration could cause major changes in vegetation communities within wetlands and hence affect diversity and number of waterfowl, furbearers, fish, and other wildlife that could be supported by the wetland ecosystem (Mortsch, 1990).

The Great Lakes system has a prime sports fishing industry as well as a smaller commercial fishery, representing billions of dollars to the economy. The cold water fishery in some of the Great Lakes could decline because warmer water temperatures would reduce their thermal habitat. Cooler water species would give way to warmer water species. This could have a significant impact on the value of the fishery. Spawning would also be affected by warmer water temperatures, reduced streamflow and poorer water quality. Whitefish, a valuable commercial species, depends upon an adequate ice cover for spawning and survival. Climatic change could drastically reduce the ice cover in prime spawning areas (Meisner et al., 1987).

Recreation and Tourism. Many recreational activities are seasonal and have strict climatic requirements for the activity to take place and to be enjoyed. For example, cross country and downhill skiing require certain snow cover conditions while swimming and camping have preferred water and air temperature comfort requirements.

Winter recreational activities such as downhill skiing, particularly in southern Ontario, could be eliminated or severely curtailed in a warmer climate. Of particular importance are the snow covered conditions during the peak Christmas and Spring break period. Technological measures might overcome some of the problems. However, winter recreation complexes should diversify to other activities to reduce their vulnerability.

Climate warming could enhance or lengthen the season for summer recreational activities such as camping, hiking, boating, sightseeing. The increase in recreation opportunity would occur in the "shoulder" period of the season, the spring and fall, when temperatures were previously not as favorable to the activity. More use of recreational properties and natural areas could lead to over-use problems, environmental deterioration and serious resource management problems (Wall, 1990).

Lower water levels on the Great Lakes and smaller inland lakes could reduce the aesthetics of shoreline recreation and cottage sites. Recreational boating access could be severely curtailed at private docks, marinas, and in connecting channels. Extensive dredging of channels and rebuilding of docks and ramps might be required. Who will pay for the costly improvements?

Agriculture. Nearly 25 percent of the total Canadian agricultural production and seven percent of the American production are located in the Basin. Changes in temperature, growing season duration, precipitation and moisture stress could affect the crops that are viable in the Great Lakes-St. Lawrence Basin and the yield derived from these crops. Horticultural crops such as fruits, vines, and vegetables could become more important in Southern Ontario while soybeans, corn and other corn-belt crops could become viable in northern portions of the Basin where soil conditions are suitable.

Drought stresses could increase in southern parts of the Great Lakes-St. Lawrence Basin and farmers could expand their demand for irrigation to maintain their cropping practices and yields. Irrigation has significant costs, environmental implications and increases the potential for conflicts with other water users.

Farmers will have to make significant adjustments to the new agroclimatic conditions or face serious losses. What programs will assist them in new crop selection, tillage practices, provide new drought and pest resistant strains? Smit (1987) showed that the potential for profits was high in ideal conditions but that there was also a higher risk of years with poor productivity and decreased returns. Without adjustments to new conditions, climate warming could cost Ontario farmers over $100 million per annum in lost production.

Transportation. The Great Lakes-St. Lawrence Seaway is a major freshwater transportation system. It depends upon adequate depths in the connecting channels and harbors to function at full capacity. Under climatic warming scenarios, channel depths could decrease 0.9 to 1.5 meters, necessitating extensive dredging in both the connecting channels and the major harbors. The dredged material can be highly contaminated, creating a problem with disposal of the spoil. A shorter ice season on the Great Lakes could lead to an extension of the current navigation season, contributing to better vessel utilization and a decrease in stockpiling.

Energy. Climate affects both energy supply and demand. Water availability such as water levels and streamflow affect the production and supply of hydroelectric power. The reliability of flows through the Great Lakes is one of the factors that make the Great Lakes hydro-electric stations so valuable to the energy grid. Climate change could lead to a decrease in power generation capacity due to reduced flow and head. The shortfall would have to be augmented by a more costly mix of fossil fuels and nuclear power. The switch to other energy sources has environmental implications; burning of fossil fuels increases $CO_2$ emissions.

Climate warming would also affect the demand for energy. Warmer winter temperatures would reduce the demand for space heating while warmer summer temperatures would increase air conditioning demand. Sanderson (1987) calculated the net effect would be a small reduction in energy requirements in Ontario.

## CANADIAN PROPOSAL FOR AN INTEGRATED STUDY

The potential biophysical, social, and economic impacts described in this paper are summarized from numerous climate impact assessments studies in the Great Lakes Basin. These studies had certain general characteristics. They focused on one sector such as navigation agriculture; emphasized negative impacts; identified few responses to or ways of adapting to the potential impacts or benefits; did not assess the policy implications of climate impacts; and did not integrate results. However, these impact assessments played an important role in identifying some of the impacts of climate change, alerting us to the possible consequences and demonstrating the complexity of the problem. However, in order to develop effective policies and response strategies on a regional scale, we need to conduct "second generation", integrated impact assessments. These assessments will consider the interaction of various economic sectors within a region under a scenario of a warmer climate and explore possible adaptation strategies to deal with climate change and variability.

As part of the Canadian Federal Green Plan Initiative "Reducing the Uncertainties", the Canadian Climate Centre is developing projects to conduct such "second generation" impact assessments and adaptation studies on those regions where there is a high likelihood of major climate change. One such region to be examined is the Great Lakes-St. Lawrence River Basin (see Figure 1).

A Canada-U.S. symposium, "The Impacts of Climate Change on the Great Lakes Basin", held in Chicago in 1988, recommended that a binational, integrated study of the Great Lakes Basin be developed as a regional pilot project (U.S. National climate Program Office and Canadian Climate Centre, 1990). A subsequent November 1989 workshop "Responding to Climate Change in the Great Lakes Basin" identified important policy issues in the energy, agriculture, and water sectors (Canadian Climate Centre and U.S. National Climate Program Office, 1991). The following describes a Canadian project proposal for a Great Lakes-St. Lawrence River Basin Pilot Project on responses to the impacts of climate change.

### Research Objectives

The goal of the GLSLB Pilot Project is to undertake multi-disciplinary, integrated studies on the physical, biological, social, economic and political impacts of climate change in the Great Lakes-St. Lawrence Basin which will improve the understanding of the complex interactions between climate and society so that informed regional responses can be developed for the Basin. It will focus on a few key policy issues since it will be possible to identify all climate related impacts. The objectives of the GLSLB Pilot Project are to:

i. identify some of the major threats to the region and determine the areas of greatest vulnerability;

ii. identify the opportunities that may arise and examine their potential benefits;

iii. identify and assess the possible regional responses to these threats and opportunities;

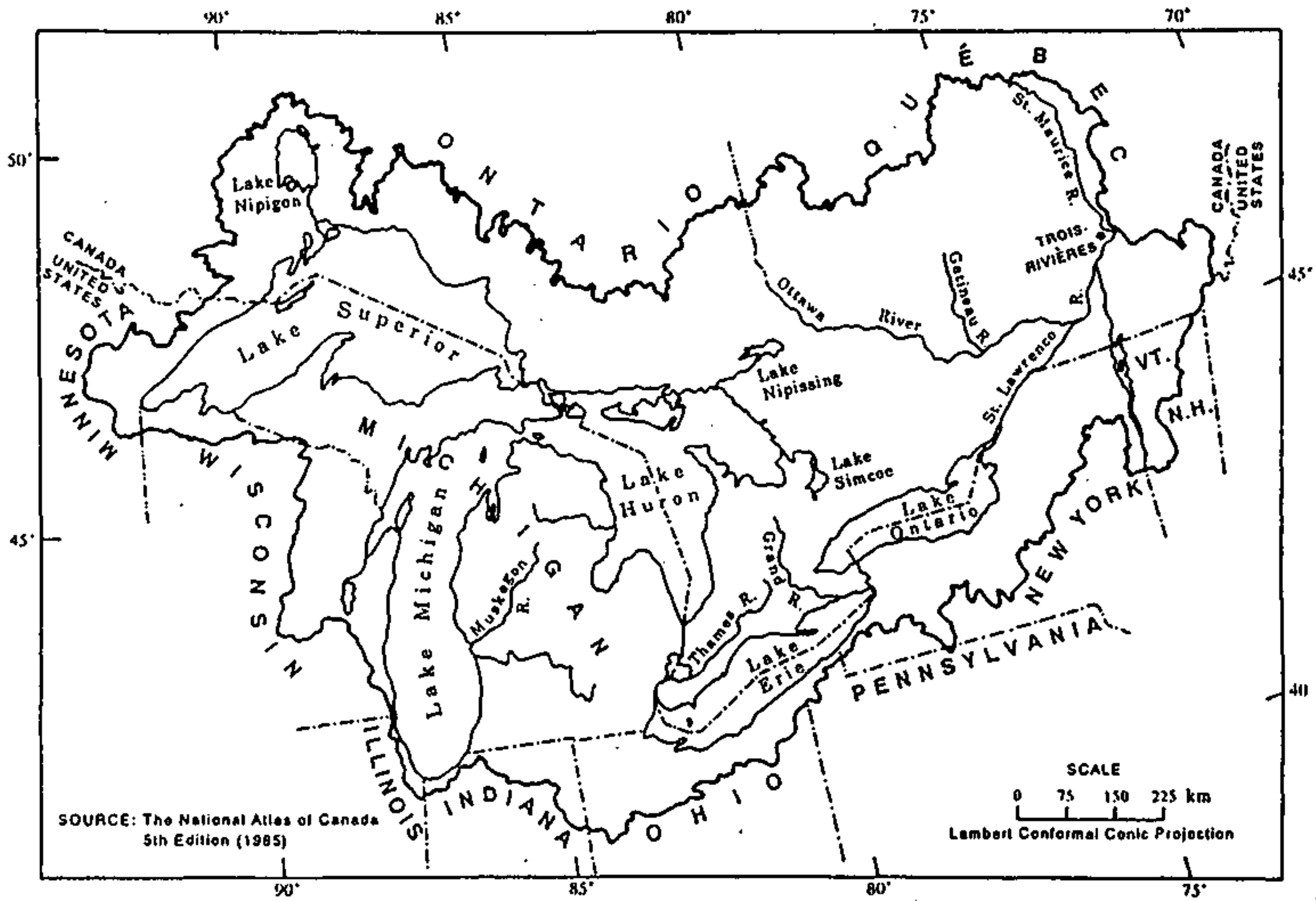


FIGURE 1. STUDY AREA

iv. examine linkage between the regional responses and actions taken at the international, national, and local levels (including individual behavior);

v. identify and assess policy options; and

vi. develop partnerships, and facilitate debate and information exchange among a wide range of decisions-makers, stakeholders and the public.

**Research Strategy and Framework**

The GLSLB Pilot Project will assist in the development of adaptation responses that will minimize the impacts of climate change and take advantage of the opportunities afforded by climate change in the Great Lakes-St. Lawrence Basin. It will try to identify climate sensitive activities and biophysical systems and develop linkages between climate and these sectors. Therefore, the Pilot Project will support a combination of "policy-driven" research and "science-driven" research. It will offer the opportunity to explore a wide range of climate interactions but ultimately the GLSLB Pilot Project must provide the opportunity to re-examine the methods and assumptions of socioeconomic research in the climate field and to test and demonstrate new ideas in some concrete, empirical studies focused within the Basin.

It is proposed that the Pilot Project will employ five implementation strategies:

i. It will **focus on a limited number of key policy issues** since it is not possible to identify all the climate-biophysical-society linkages and to address all the potential impacts and benefits.

ii. It will **build upon existing climate impact assessments** in the Basin. A substantial body of research has accumulated in Canada and the U.S. on the implications of climate change for natural systems and human activities in the Great Lakes-St. Lawrence River Basin. The GLSLB Pilot Project will attempt to fill some gaps in impact assessment methodology and gaps in climate-biophysical-socioeconomic links.

iii. It will **coordinate with and draw upon ongoing research** in the Great Lakes-St. Lawrence Basin such as the International Joint Commission Water Level Reference Study and the Great Lakes Water Quality program. Those activities that could contribute to the research agenda for the pilot project will be identified in order to incorporate research results and to avoid duplication.

iv. It will develop **partnerships** which involve Canadian and American interests, government agencies, academia, and industry. The purpose will be to enhance the profile of the climate change issue and to secure expertise, data, models, and funding from other sources.

v. It will **share experience and techniques with other ongoing impact** assessments in the Mackenzie Basin and the Prairies. Also critical is the development of a collaborative research agenda with the U.S. so that a binational effort can be undertaken.

It is proposed that the research framework for the study be organized into four major tasks:

Project Design. The goal of this portion of the project is to develop the key research components, the management and coordination structure and, most importantly, to develop the consultation process which will garner support and collaboration from interested and committed partners. Two committees will be organized in Canada to manage the GLSLB Pilot Project. Regional workshops will be held to identify areas of interest and expertise; identify target areas for research; and to provide input to the research proposal.

Background Framework. A study will inventory and summarize the previous climate impact assessments in the GLSLB. It will also identify ongoing research in the Basin which might contribute models, data, ad results that would be relevant to the research agenda. This review will identify the past research focus, the information and data gaps and assist in identifying target areas for impact assessments.

A climate scenario is a plausible representation of future climate without any statistical probability of occurrence provided. Climate change scenarios will be developed for the Great Lakes-St. Lawrence River Basin. One scenario will be the $2xCO_2$ "run" from the Canadian Climate Centre General Circulation Model. There are several other climate scenarios that could be developed using analogues and transpositions. Paleoclimate information could provide analogues for a warm and wet period and a warm and dry period; instrumental records could be used to develop an historical warm analogue. It is critical that these scenarios are well documented; replicatable; and meet the data requirements of the impact assessments. The climate change scenarios will be applied to a baseline, current climate derived from the 1951 to 1980 normals.

A view of the future socioeconomic character of the Great Lakes-St. Lawrence River Basin must be developed rather than assessing future climate impacts on current socioeconomic conditions. The feasibility of incorporating population demographics, technical change, energy use patterns, land availability or suitability, transportation, urban structure, and economic development will be assessed.

Integration, combining parts into a whole, is a key concept for the GLSLB Pilot Project. What method(s) could be used to bring together diverse climate impact assessments to obtain an assessment of the combined impacts or the cumulative effects? What are the opportunities for a multi-disciplinary team to exchange data and results; to transfer impacts; to incorporate novel methods and concepts; and finally to combine the impacts into an assessment of the policy implications? A Geographic Information System (GIS) will be used to organize data. The Council of Great Lakes Research Managers has developed the Great Lakes-St. Lawrence Ecosystem Model Framework; this framework will be considered as an integration method.

Integrated. Multi-disciplinary Impact Assessment. Some candidate areas for research are water quantity and quality, agriculture, energy, transportation, forestry, human health and fisheries. Partners will be consulted through the Inter-agency Task Group and in the regional workshops.

A key goal of the project is to develop multi-disciplinary research teams that are integrated throughout the study. For example, a study of the impact of lower lake levels on navigation would evolve to assess the impacts of reduced cargo carrying capacities of the number of ship trips; changes in the type of ship cargo; implications for fleet configuration; implications for lock expansion, harbor and channel dredging and spoil disposal; potential shifts in cargo transportation to other modes such as train or road; the capacity of those systems to respond as well as the financial, employment and environmental implications.

A policy inventory would document the current policy instruments that affect the GLSLB region such water policy, agriculture policy, energy policy. It would identify the institutions, regulations and programs in place to implement the policy. Initially, one sector would be chosen for a preliminary assessment of the policy mechanisms to respond to climate change and to document strengths, weaknesses and missing links.

Project Synthesis. The final phase of the GLSLB Pilot Project will be to summarize the research results into a final document. Also, a pilot "policy learning" exercise will be initiated to explore new methods of incorporating impact assessments, uncertainty and policy development.

## Current Activities

A draft project proposal has been prepared and will be finalized at a Steering Committee meeting in May. At that time, the Committee will select the key policy issues that will receive detailed climate impact assessment.

To date, two contracts have been let for the GLSLB Pilot Project. One contract is a review of Canadian and American impact research in the Great Lakes-St. Lawrence Basin. The intent of the study is to review the following items: sectors studied, research methodologies, sensitivity analyses, climate scenarios used, models, data sources, information gaps, integration methods, adaptation recommendations, and policy analyses. An attempt will be made to link findings and methods between studies and to provide a review of the status of climate impact research. Other current research efforts such as the International Joint Commission Water Levels Reference Study and the Great Lakes Water Quality Program will be reviewed for activities that could contribute to the research agenda for the pilot project. The results expected are: an annotated bibliography on a Personal Computer (PC) with query capabilities; a synthesis of the research results and identification of gaps; a contact list (on PC); and results from telephone interviews on current research.

The second activity is to enhance an economy-environment framework (EEF), developed under contract to Ontario Ministry of the Environment, to incorporate and integrate climate impact assessment results from the GLSLB Project. The EEF links an input-output (I-O) model which describes intersectoral purchases and sales of material and labor within a region, usually a province or country, for a "snapshot" of the economy with environmental data bases such as land capability, wastes generated by production, and forestry and agricultural productivity. One of the benefits from this phase of the work should be feedback to the climate impact assessment community on the data that they would have to provide for an input-output economic assessment of their results within the economy-environment framework. Information such as timesteps, units of measurement, and spatial scale would be invaluable information for them in designing the output of their models.

## POLICY ISSUES AND ADAPTIVE STRATEGIES

Canada is committed to the development of new environmental policies under its Green Plan (Government of Canada, 1990). This provides *inter alia* for an evolution of the way in which environmental policy is developed, including a much stronger integration with policy in other fields: economics, as well as forestry, fisheries, water resources, transport and others. The broad policy direction is towards sustainable development, and is to be made consistent with the general thrust of the Bruntland Report Our Common Future (World Commission, 1987).

The development of adaptation strategies in this policy climate is a broad and challenging task. It involves much more than the traditional fine-tuning described as "climate applications", in which climate information and advice is used in building and infrastructure design and some agriculture, forestry, and water management decisions. Now the whole future direction of society, its values and priorities, is seen to bear a relationship to climate as never before. This both because of the potentially costly impacts of climate change and because the actions needed to stabilize greenhouse gases call into question our energy-intensive economy and our high materials consuming, high mobility life style.

In this sense adaptation has a very broad meaning. It involves the creation of an economy and a lifestyle that is sustainable. As the Bruntland Report so convincingly demonstrates, and as we realize more and more, day by day as the UNCED negotiations proceed, sustainability is indivisible. It involves all nations and it involves all aspects of society.

It was recognition of these dimensions of the global warming problem that led to the proposal to develop a joint Canada-U.S. project on climate change in the Great Lakes-St. Lawrence Basin. The need for the study increases with time. As the economies of the region on either side of the Great Lakes become more strongly integrated under the pressure of global competition and as facilitated and encouraged by the Canada-U.S. Free Trade Agreement, questions involving harmonization of environmental and economic policy will become more salient. The prospect of global warming is one factor among many that are driving this process and it is important that we develop great understanding and foresight of the role of climate change and variability so that we may take anticipatory action now and avoid, or at least minimize, the cost and conflicts that otherwise await us.

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# CLIMATE AND GLOBAL CHANGE: THE RESPONSES AND POLICY ISSUES RELATED TO CLIMATE CHANGE IN THE GREAT LAKES BASIN

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## INTRODUCTION

I am here on behalf of the Great Lakes Commission to address the policy issues associated with climate change in the Great Lakes Basin. It is always a welcome opportunity - albeit a rare one - to analyze the policy implications of an issue in the anticipatory mode. The history of resource management in the Great Lakes Basin and, I suspect, in most other regions of North American and beyond reflects a bias toward crisis management at the expense of anticipatory endeavors such as planning, forecasting and proactive policy analysis. The prospect of reversing that bias is an exciting one, and in light of this symposium's topic; a most necessary one.

The preceding papers have done a commendable job in reviewing the major hydrologic and socioeconomic implications of climate change in the Great Lakes Basin. I will embellish upon their findings by exploring the preset and prospective policy response to such changes. Due to the nature of this issue, this can be at once a highly speculative yet highly significant venture. I say significant because the climate change issue is illustrative of a host of current and emerging issues in the Great Lakes Basin.

It is a fascinating issue from a policy standpoint. It is an issue that involves anticipatory rather than reactive attention. It is an issue at the center of public policy debate. It is an issue that defies precise quantification. It is an issue that has a multi-dimensional character and demands multi-disciplinary, multi-jurisdictional responses. And it is an issue where the complexity of scientific inquiry is exceeded perhaps only by the prospective complexity of the institutional arrangements and responses that may be developed to address it. Our ability to formulate scientifically sound and politically acceptable and implementable policies, on this topic, may well pave the way for enlightened public policy on other troubling issues that share similar characteristics.

I will touch upon several topics that focus on climate change as it relates to Great Lakes water resources and water resources policy:

- An introduction to the public policy significance of the Great Lakes as both a natural and socioeconomic resource;

- A review - for illustrative purposes - of a couple climate change studies as they relate to Great Lakes water levels;

- A review - in general terms - of prospective policy responses associated with impacts on various sectors of economic and socioeconomic activity; and

- Finally, I would like to share some "lessons learned"; some "rules of thumb" that warrant consideration in the public policy development process in responding to climate change or any other complex multi-faceted public policy issue.

## GREAT LAKES COMMISSION

By way of background, I would like to introduce you to the Great Lakes Commission. The commission is an eight-state compact agency formed in 1955 by joint action of the legislatures through a Great Lakes Basin Compact that was later ratified in 1968 by the U.S. Congress. Three to five delegates from each Great Lakes State serve the Commission - all are legislators, state officials or governor's appointees. The goal of the Commission is broad: to strengthen the region's economy and protect its environment by encouraging sound resource management practices. The Commission has three principal functions: 1) it serves as an information clearinghouse on pertinent regional economic development and environmental issues; 2) as a coordinator of state positions on these issues; and 3) as an advocate for those positions on which the states agree. Advocacy activity is directed primarily at the federal and Congressional levels.

## AN INTRODUCTION TO THE GREAT LAKES HYDROLOGIC SYSTEM AND ITS PUBLIC POLICY SIGNIFICANCE

When one describes the hydrologic characteristics of the Great Lakes system, it is difficult to avoid the use of superlatives. As an expansive, intensively used freshwater system the Great Lakes enjoy global prominence. The system contains some 65 trillion gallons of fresh surface water: a full 20% of the world's supply and 95% of the U.S. supply. Its component parts - the five Great Lakes - are all among the fifteen largest freshwater lakes in the world. Collectively, the lakes and their connecting channels comprise the world's largest body of fresh surface water. The United States and Canada share a resource with a surface area of 95,000 square miles and a drainage area of over 250,000 square miles. The system extends some 2,400 miles from its westernmost shores of Duluth, Minnesota to the Atlantic: a distance comparable to a trans-Atlantic crossing from the east coast of the United States to Europe. Recognized in federal legislation as the nation's fourth seacoast, the Great Lakes system includes well over 10,000 miles of coastline.

The coastal reaches of the basin jurisdictions are population centers and the locus of intensive and diverse water-dependent economic activity. Twenty percent of the U.S. population and 40% of the Canadian population reside within the basin. One-fifth of U.S. and more than one-half of Canadian manufactured goods are produced along the shoreline. The sport fishery is valued at 4 billion dollars per year. Almost 40 billion gallons of water are withdrawn daily to satisfy domestic, commercial and industrial needs. And, the Great Lakes/St. Lawrence Seaway transportation system contributes $3 billion dollars a year to the regional economy.

It is critical to note that economic uses of the Great Lakes have become dependent on the small variation in lake levels, typically 12-24 inches in seasonal variation each year. Even a modest departure from long-term averages is translated into terms of millions of dollars in economic benefit or loss. The loss of but an inch translates into reduced hydropower capacity and can compromise the efficiency of interlake and ocean-going vessels that typically use every inch of the 27 feet of shipping channels. Conversely, modest increases in levels can and have had devastating effects on shoreline erosion and property damage. So clearly, even subtle and gradual impacts of climate change will have major economic and policy implications.

Since setting record lows in the mid-1960s, Great Lakes water levels rose by some seven feet by 1986 and at that time were 3-5 inches higher than their long-term averages since 1900. Records dating back to 1860 were being broken on a monthly basis for all lakes except Ontario. The dramatic rise in the Great Lakes water levels in 1985-86 was due, in large part to above average precipitation in the Great Lakes Basin over the previous two decades. The magnitude of the basin, and the constrained flow of connecting channels in relation to total volume, accentuates the lake level rise.

In the last 20 years we have seen record highs and record lows set since records have been kept. I have in my office two newspaper articles. One is dated 1965 and titled "They Hope to Have High Lake Levels." It describes U.S. Army Corps of Engineers plans to address what was termed a critical low level situation. I also have a 1987 article titled "Congress Seeks to Reduce Great Lakes Water Levels." It also documents a critical situation from the other end of the spectrum. Together, they illustrate the policy implications of lake level fluctuation in an intensively used resource.

## FINDINGS AND PROJECTIONS FROM RECENT STUDIES OF CLIMATE CHANGE AND GREAT LAKES WATER LEVELS

Despite variations in Great Lakes water levels and associated uncertainties, there is one certainty: the sensitivity of the Great Lakes Basin's response to global climate change. While precise forecasting is not possible, it is generally agreed that climatic warming due to increased concentration of $CO_2$ and other greenhouse gases could have major hydrologic and ecosystemic impacts. Interestingly, the projected impact is the converse of that anticipated for sea levels. In the Great Lakes Basin, the probable impact of climatic warming is a decrease in water supplies due to increased evapotranspiration from land surfaces, evaporation from lake surfaces, and changes in precipitation patterns.

Two recent studies are illustrative. At the NOAA Great Lakes Environmental Research Laboratory, alternate scenarios were developed based on the National Research Council's projection of a 4 degree temperature increase in the Great Lakes Basin latitudes over the next 100 years due to a doubling of concentrations of $CO_2$ and other greenhouse gases. Under Scenario One, in which a 15% decrease in net basin water supplies is realized, the Great Lakes Hydrologic Response Model found that levels of Lakes Michigan and Huron would drop by almost 28 inches on average, and Lake Erie by 20 inches. Under Scenario Two, in which net basin supplies are reduced by 30%, levels of Lakes Michigan and Huron would drop by over 61 inches on average, and Lake Erie by 42 inches. These scenarios are not unrealistic: the low water level years of the mid-1960s were accompanied by approximately a 30% drop in average net basin supplies.

Studies at the Great Lakes Institute in Windsor, Ontario yielded similar results, based on the Goddard Institute of Space Studies model projecting 4.4 degrees increase in average Basin temperatures and 6.5% increase in precipitation with a doubling of $CO_2$ concentration. For example:

- North of Lake Superior, it is suggested that the number of months with average temperatures below freezing will decrease from five to three.

- Areas south of Lake Erie now have three, but would have none, making the climate of northern Ohio similar to that of Southern Kentucky.

Despite the imprecision of existing General Circulation Models and the many other variables, these projections clearly have profound economic, environmental, and policy implications.

## ECONOMIC, ENVIRONMENTAL AND POLICY IMPLICATIONS

The impacts and policy implications of climate change are found at two levels. The first level is fairly straightforward and intuitive, at least on a qualitative basis. For any given sector of water use activity, any long-term adjustment to lake level patterns is going to generate some positive characteristics and some adverse consequences. The net impact in both direction and magnitude will shape the public policy debate and the nature of alternate policy responses.

A climate change-induced lowering of water levels, at least to a point, would likely be welcomed by riparians who have endured years of shoreline erosion, flooding and property damage. On the negative side, researchers have documented the adverse impacts on hydroelectric power generation efficiency; impediments to commercial and recreational navigation; alteration of near shore aquatic habitat; prospective deterioration of near shore water quality; an alteration of coastal development pressures and patterns; alteration of the agricultural and forestry industries; and reduced access to water resources for in-stream or withdrawal purposes.

When one looks more closely at a given water use sector, the trade-offs become more apparent. For example, disbenefits to navigation interests in terms of reduced cargo capacity and increased maintenance dredging costs may be offset in part by the prospect of ice-free or reduced ice conditions and, therefore, an extended navigation season.

The multi-billion dollar water-based tourism industry would also benefit from an extended warm weather season, but would suffer from the anticipated deterioration of near shore water quality and the reduced access for recreational boaters.

The second level of anticipated impacts and policy responses transcends the boundaries of any single water use sector. At this level questions of regional significance arise that challenge the very foundation upon which Great Lakes water resource policy has been based. For example:

- Climate change scenarios are not Great Lakes-specific; they will reduce water supplies in non-basin areas as well. One likely consequence is increasing pressure for diversions of Great Lakes water to other basins. Even if Great Lakes water levels were reduced, on average, by several feet the Great Lakes may still be viewed, in relative terms, as an abundant and available source by other regions.

- The current emphasis on prohibition of out-of-basin diversion may also face challenges within the region, if low water crisis conditions generate political pressure for diversions into the basin, such as the Grand Canal scheme so vehemently approved at present.

- The philosophical and legal basis of Great Lakes water policy is not one of managing for scarcity and attendant conflict; but one of managing for abundance. If this should change, it would require a fundamental and unprecedented revision to, or outright rejection of long established institutional arrangements and agreements.

- Such a scenario would also force the issue on some long-standing-and troubling policy questions where a sense of urgency has been obscured by years of relatively high lake levels. For example, maintenance dredging requirements in commercial navigation channels could be staggering, raising questions of "who should pay", and "how best to dispose of dredged materials, both clean and contaminated?"

- Finally, the policy response to climate change would not be limited to governmental jurisdictions along, it would ultimately impact all Basin residents. For example, water conservation practices never before introduced successfully on a large scale in the Great Lakes Basin may need to become the status quo. This is unquestionably a major socio-economic adjustment.

## LESSONS TO BE LEARNED; THE CURRENT AND PROSPECTIVE POLICY RESPONSE

What can we learn from the lessons of our past? How can we draw upon past experiences with lake level changes as well as the future scenarios that climate change might bring? I offer several observations and then conclude with a set of specific recommendations.

The climate change issue in the Great Lakes Basin will never be adequately addressed until some concerted leadership at the regional, national and binational policy levels is exhibited. This is not a case of pin-pointing the problem, rallying support, responding in force and laying the issue to rest. Climate change is not an issue we call all see and touch - like algal blooms, or fish kills, or zebra mussels or oil slicks. It's not a crisis at present; it doesn't overtly affect the public's economic health or well being; and it lacks the compelling evidence, the unassailable data, to prompt action. And finally it's a global problem; if the average citizen can't get his or her arms around it they are unlikely to embrace it as an issue.

In a 1987 policy report titled "A Matter of Degrees" Mintzer (1987) makes an excellent point. He states, "The longer the delay before preventive policies are identified, agreed upon, and implemented, the more extensive the policies imposed to stay within prudent bounds will have to be." This, I believe, is the path we seem to be headed down in the Great Lakes Basin.

It should be noted, however, that even though the policy response to climate change has been limited and has been subtle, it does exist. Eugene Stakliv and James Hanchey of the Institute for Water Resources of the Corps of Engineers made an important observation to this effect at a 1988 symposium. They argued that policy responses to climate change can be made at two levels. The first level, they explain, does not demand scientific precision. "General policy and strategy development for human adaptation to climate change," they state, "may be conducted with a relatively vague knowledge of the direction and consequences of change. These include priorities for resource allocation, emerging water management measures, water pricing, conservation measures, flood warning and evacuation, flood plain and coastal zone, etc." Even a cursory review of planning documents and water management strategies within the basin will find some reference to, and acknowledgement of, climate change as a potential factor in shaping management decisions.

The second level of policy response to climate change is notably more problematic. The authors explain, "Site specific actions, such as designing flood protection levees or reservoirs, or sizing and electric utility or water supply pumping station, require specific information about the likelihood magnitude and variability of both the resource availability under the selected climate scenarios as well as the future demand for the resources."

As noted by the other authors, this level of certainty simply does not exist at present, and only a small cadre of policy makers may be willing to fully incorporate climate change scenarios into the planning and forecasting activities.

For example, George Ryan, President of the Lake Carriers' Association, has said "With all due respect... I could never recommend that my members base their long term planning on weather and climate forecasts for 1995 or 2005. In fact, I'm glad no one made economic decisions based on lake level forecasts of two years ago (1988). For, if I may remind you, just two years ago we were being warned that the record high water levels could very well prove to be just a prelude of what was to come. There were those who believed that 1986's peaks were just the foothills of an even higher plateau." This dose of skepticism, I believe, is shared by many, and will unquestionably temper the extent to which policy responses to climate change are incorporated into the decision-making process.

Climate change issues have enjoyed concerted attention within the research community and prompted much discussion and debate within policy circles, but, in the final analysis, have yet to be reflected to any degree in Great Lakes-specific policy initiatives or behavioral changes. Progress that has been made is largely attributable to dramatic fluctuations in lakes levels - fluctuations that are consequences of factors other than climate change - at least at present.

From my vantage point several specific policy responses are in order over the short term to better prepare us for climate change impacts over the long term:

1) First, our political leadership - both in the binational Great Lakes Basin and nationally - needs to acknowledge - publicly and forcefully - that scientific certainty is not an absolute precondition to formulating policy responses to this issue. In the final analysis, it is infinitely more comforting to be well prepared for a crisis that never materialize than to be unprepared for one that does.

2) Second, the political jurisdictions in the Great Lakes Basin are in desperate need of getting their collective "house in order." A Great Lakes charter was signed with much fanfare in 1985 by the Great Lakes Governors and Premiers in the name of informed, responsible and consistent water management. The development of a Great Lakes Water Resource Management Program was endorsed but never pursued. Such a program needs to be established in the short term to address water use conflicts, diversion threats, climate change impacts and other eventualities over the long term.

3) Third, the ongoing Lakes Levels Reference Study of the International Joint Commission provides another tremendous opportunity to reflect climate change implications in guidance to be provided to the two federal governments next year.

4) Fourth, we need to develop and implement a U.S.-Canada integrated study of the Great Lakes Basin as a regional pilot project for an international response to global climate change. This recommendation was the featured outcome of a U.S.-Canada symposium conducted in Chicago in 1988, and it is still relevant today. The Great Lakes are often touted as the world's largest freshwater laboratory and the bellwether of scientific investigation. It is time to put that claim into action on this issue.

5) Fifth, it is essential that resource policy in the Great Lakes Basin, especially as it relates to lake level management, be driven by principles of sound planning rather than political expediency. The high water levels of 1985-86 brought forth the "quick fix" advocates. Proposed "solutions", and I use that term loosely, included increased out of basin diversion, massive dredging and diking of the St. Lawrence River, and maximizing flows through all connecting channels via regulatory works. Some such measures - beyond the questionable economic and environmental impacts - are essentially irreversible. When we consider the additive effects of climate change on the hydrologic characteristics of the Great Lakes system, it is clear that many such measures would have devastating consequences during low water level periods. Our elected officials and policy makers need to be challenged to diligently pursue sound legislation while we're in the "calm before the storm", rather than fall victim to political expediency and crisis response after the "storm" has arrived.

6) Sixth, the notion that Great Lakes water levels can be fine-tuned to some single Utopian level is clearly ill-advised. Our present ability to regulate the lakes is measured in inches, while natural fluctuations are measured in feet. The anticipated impact of climate change on water levels reinforces this statement. We have three basic choices: 1) we can attempt to regulate the levels through elaborate engineering schemes; 2) we can armor our shorelines to protect current and future developments; or 3) we can learn to live with fluctuating water levels. The latter approach is ultimately the soundest one; a fact that is being increasingly recognized among Great Lakes jurisdictions. Congressman John Dingell of Michigan sums it up best. He said "God put the water there an Congress is a somewhat weaker institution."

7) Finally, we must remember that our water management institutions and institutional arrangements are here to serve us; they are vehicles to anticipate, ameliorate or otherwise accommodate the types of problems and challenges associated with climate change. If they are unable or unwilling to do so, new options must be pursued. I would recommend that this diversion of the climate change issue - one of institutional analysis and evaluation - receive additional emphasis in the months and years ahead.

In conclusion, despite the challenges ahead, I remain optimistic that the Great Lakes region can successfully adapt to climate change - and help mitigate economic and environmental turmoil. Indeed, we have little choice. However, adaptation will be facilitated if our institutions can foster rather than fight new management principles; adopt a Basin Water Management Program sensitive to projected impacts of climate change; and nurture the development of policy responses that are anticipatory, preventive and adaptive in nature, and not merely reactive.

# A PROPOSED U.S. RESEARCH PROGRAM TO ASSESS CLIMATE CHANGE IN THE GREAT LAKES

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## INTRODUCTION

The concept of a program to assess the effects of climate change on the Great Lakes Basin has developed during a period of rapidly growing international concern over the potential global problems associated with future climate change due to increased $CO_2$ and other trace gases in the atmosphere. These concerns have led to the development of large national research programs in the United States and Canada. Two major areas of concern over climate change have been the potential impacts on our physical and social systems, and how to adapt to and/or mitigate the effects.

Research has shown that meaningful studies of climate impacts and human/institutional responses are best done at the regional scale (Kates, 1985). The Great Lakes Basin, with its diversity of activities and wealth of data on biophysical and economic conditions, has been viewed by many as an ideal site for a multi-disciplinary, binational program to assess the biophysical effects, socioeconomic impacts, and potential responses to a range of future climatic conditions (Smith, 1990).

## BACKGROUND

The foundation for a multi-disciplinary, binational program of research into the impacts and responses to climatic change on the Great Lakes Basin has been established over the past seven years. The concept of such a program was first formulated at a meeting of the United States and Canada (Hare, 1985; Changnon, 1985). The scientists focused their attention on the need for climate impact research on the Great Lakes Basin, seen as the most ideal of all possible binational study areas.

In 1987, the U.S. National Climate Program Office and the Canadian Program Office convened a planning meeting of policy makers and scientists at the Great Lakes Environmental Research Laboratory/NOAA to assess potential shared activities relating to the climate change issue. This group selected the Great Lakes Basin as the primary study area for binational activities, and as a first action, called for a workshop involving scientists and representatives of impacted sectors to explore the Great Lakes and climate change.

The two nations' climate program offices, in concert with the Midwestern Climate Center, convened a symposium in Chicago in 1988. The representatives of the potentially impacted communities and sectors present assessed the issue of climate change in the Great Lakes Basin. They evolved a major recommendation, "to develop a U.S.-Canada integrated study of the Great Lakes Basin as a regional pilot project for an international response to global climate change" (Changnon, 1989a).

This recommendation led to a fourth meeting convened in Toronto in November 1989. Present were representatives of provincial, state, and federal agencies of both nations plus scientist who described the climate change issue. The concept of using the Great Lakes Basin as a site to perform an assessment of the impacts of global climate change was considered, and strongly supported by this group (National Climate Program Office, 1990). A major recommendation of this meeting called for development of an in-depth plan of scientific research as a basis for launching a multi-year research program to assess climate impacts on the Great Lakes Basin (Changnon, 1989b). Please note that this meeting occurred more than two years ago.

Other allied events were occurring. The International Joint Commission (JJC) was involved during the late 1980's in a multi-year assessment of the high water levels problems on the Great Lakes. As part of this endeavor, the issue of future climate change came under consideration. Future climate scenarios were designed to examine the effects of such changes on lake levels (Quinn and Changnon, 1989).

Subsequently, the U.S. Environmental Protection Agency, under a directive from the U.S. Congress, selected the Great Lakes Basin as one of four regions in the United States in which to perform preliminary assessments of the possible range of impact of future climate change. This one-year series of assessments indicated many diverse potential impacts of climate change on the Great Lakes Basin (Smith, 1990; Croley, 1990; Hartmann, 1990; Changnon et al., 1989).

These four meetings, the UC studies, and the series of one-year studies funded by the USEPA identified several major reasons for conducting a comprehensive study of climate change and impact assessments on the Great Lakes Basin, as opposed to comparable regional studies elsewhere. First, the Great Lakes Basin already has experienced a greater amount of climate change research and policy attention than any other share area of the two nations.

The basin, with 20% of the world's freshwater and 1/7 of North America's population, is well recognized as a highly climate sensitive area. Recent aberrations in climate leading to extremes in the levels of the Great Lakes have led to enormous problems (Changnon, 1987a, 1989c), and to the launching of major studies by the International Joint Commission to address and manage the lakes' aberrations under recent climate conditions. Global climate models have indicated the basin would be an area of extensive drying under greenhouse-induced future climates.

The Great Lakes Basin has other attributes for such a study. The region has an extensive database on climate conditions, on its biophysical systems including the lakes, on the economy, and the basin's demography. Many of the leading impact scientists of both nations have focused their attention on various sectors within the Great Lakes Basin and are committed to further studies of how the climate relates to its physical systems and economic conditions (Cohen, 1990). These scientists have identified that the Great Lakes Basin is a "manageable sized" region for studying the effects and responses to climate change (Hare, 1985). The 1988 and 1989 meetings of representatives of impacted sectors and government agencies concluded with clear recognition that such a long-term program had high likelihood of success, and would serve as a pilot project to illustrate globally how two nations can study together the impacts of climate change. At the scientific level, there is a continuing need to develop improved methods and models for assessing impacts of climate change (Kates, 1985, Cohen, 1990), and the program is seen as an excellent vehicle for further development of methodology for impact assessment.

In sum, the regional constituencies, government officials, and leading scientists needed to perform the research have **all agreed that the study of the Great Lakes Basin offers an outstanding opportunity to quantify the range of effects of climate change and to assess potential responses and means to adapt and/or mitigate undesirable future impacts.** More than a year ago we were at a point where a comprehensive plan of research could be intelligently prepared. Review of the seven years of efforts, including the four major meetings, indicates that sufficient input has been received so that the research community can now effectively address a defined plan of research.

During 1990 U.S. attention to the development of a research plan languished because the National Climate Program Office was disintegrating under the force of the U.S. Global Change Program. This resulted in a lack of U.S. leadership for planning a Great Lakes Research Program.

In early 1991 the nation's six regional climate centers, which are affiliated with the National Weather Service (NWS) through the Climate Analysis Center (CAC), and funded by NWS and by the states, pushed to get the U.S. research planning initiated. They, the Director of CAC, and the leaders of GLERL began a series of discussions. Members of NOAA's economist office have subsequently become involved. To date this group of representatives from different elements of NOAA have been unable to resolve their differences about the objectives and dimensions of the future U.S. program. In the meantime the Canadian government has launched its studies.

## RESEARCH PLAN

Adequate background work has been conducted concerning the study of the climate change in the Great Lakes Basin, and these endeavors could form the basis for the U.S. plan of research. The plan is seen as a blueprint for a five-year or longer research program which would embrace studies of how future climatic change would 1) affect hydrologic and biological systems, 2) create socioeconomic impacts, 3) lead to social and institutional responses, and 4) affect policy. Interactions among the United States and Canadian scientists, representatives of weather-impacted sectors, and government policy-makers, conducted over the past six years, have established the need and dimensions of such a binational investigation of climatic change.

Developing the research plan should involve a small team of nationally-recognized scientists with experience in both the study of climate effects and their impacts on society, and in the planning of scientific research. This team would develop, using an interactive process involving policy makers and leading regional scientists, a consensus-based plan of research for the envisioned five-year research program. This plan would provide the basis for implementing the oft-recommended U.S. Great Lakes Research Program. However, and unfortunately, the planning effort has yet to be launched.

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