

Impacts, Challenges, and Opportunities

4. GREAT LAKES RESOURCES

study conducted by

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The Great Lakes/St. Lawrence Seaway is used for transportation, hydroelectric power generation, and recreation. Hydro-power facilities are located on the St. Marys, Niagara, and St. Lawrence Rivers and at DeCew Falls off the Welland Canal (Fig-

ure 4.1). The Great Lakes are also one of the prime recreational boating areas in the country. The three-county area around Detroit has more boating registrations than any other similar-size area in the US. The Great Lakes system contains one of the nation's prime sport fisheries as well as a smaller commercial fishery, representing billions of dollars to the economy. Because the Great Lakes Basin is an internationally shared resource, there are numerous state, provincial, county, and municipal authorities, leading to a complex jurisdictional structure.

Current Stresses

The Great Lakes have historically enjoyed a relatively small range in lake levels, approximately 6.5 feet from the recorded monthly maximum to the recorded monthly minimum (Fig-



Figure 4.1: The Laurentian Great Lakes.

ure 4.2). Superimposed upon the average levels are seasonal cycles of 10-12 inches. The lake levels for the past 30 years have been in an extremely high water level regime - the highest in recorded history, due to increased summer and fall precipitation. Record highs were set in 1973 and again in 1986. In 1997, Lake Erie rose again to near record highs. However, over the past year (to March 2000), the lake levels have experienced the second largest decline in about 100 years, second only to that during the Dust Bowl drought of 1931. The lake levels are currently near their longer term (1900-1969) mean. Impacts of the recent drop are being experienced by the shipping and hydropower industries, recreational boaters, and some individual water supplies. Many recreational boaters and marina operators around the lakes consider the current near-average lake levels to represent low-level conditions. The Great Lakes commercial navigation interests can no longer carry the same loads as they have for the past 30 years due to decreased channel depths. Revision of the existing regulation plans for Lakes Superior and Ontario is being requested by some interest groups to maintain lake levels at what they consider more accurate elevations.

There is currently an ongoing debate about the export of Great Lakes water from the basin. If the lake levels continue to decline and the current drought continues, then arguments for interbasin diversion of water into and out of the Great Lakes are also likely to intensify. A coordinated approach to policy development will be crucial for coping with lowered lake levels. The policy implications of long-term lowered lake levels are far different than the major policy deliberations during the past several years, which have emphasized coping with high lake levels. Major policy decisions will have to address the distribution of benefits among commercial, riparian, recreational, and ecological interests, between upstream and downstream interests, and finally among the many jurisdictional interests.

Previous Assessments

A number of 2 X CO₂ equilibrium climate change future scenarios have been developed [4-1, 4-2], showing that increases in

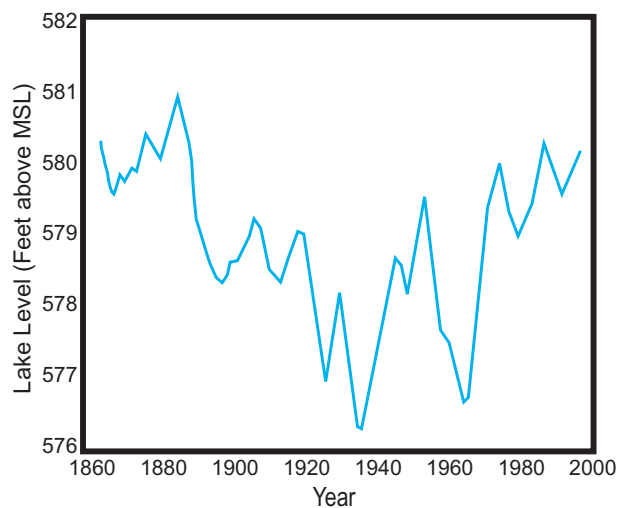


Figure 4.2: Historic Lake Michigan-Huron water levels.

atmospheric greenhouse gas concentration produce a warming effect that enhances evaporation in the Great Lakes drainage basin and over the lakes themselves. Although the general circulation models (GCMs) have produced varying results in terms of change in precipitation (both wetter and drier futures), they have agreed in showing an increase in lake surface temperature, a decrease in basin runoff, and a consequent increase in lake evaporation, resulting in reduced interlake channel flow and water levels on all of the Great Lakes. Average water level reductions ranged from 0.75-8 feet, depending on the lake and the GCM output. These model results suggested that future lake levels could be much lower than those recorded over the past 150 years. These changes would have a variety of impacts on the water resources of the system. For example, these studies showed that channel depths would decrease by 1.6-8.2 feet, necessitating extensive dredging in the connecting channels and the major harbors. In a number of areas the dredged material is highly contaminated, so dredging would stir up once-buried toxins and create a problem with spoil disposal. Lower water levels and flows would greatly reduce access to harbors and marinas, necessitating also extensive private dredging.

Such water level drops would endanger the usability of the Chicago Diversion [4-3]. Since the 1940s, when the Chicago Sanitary and Ship Canal was created by diverting Lake Michigan water to the Mississippi River, the canal elevation has been

maintained at about 2 1/2 feet below the level of Lake Michigan. An extreme drop in the average lake level would dramatically affect the flow of water from Lake Michigan across the divide and to the Illinois River. This would force the Illinois Department of Natural Resources to either reverse the flow in the canal, posing serious health risks, or to dredge approximately 30 miles of the canal system, half of which would entail rock removal at a huge cost to the public [4-4].

Faced with much lower river flows and lake levels, some hydro-power plants would be forced to shut down or dramatically reduce power production. Treaty requirements protecting the aesthetics of Niagara Falls would ensure greatly reduced electricity generation there under low flow conditions. Inexpensive, nonpolluting hydropower might have to be replaced by fossil-fueled or nuclear powered plants that would exacerbate the low water levels by increasing the amount of water consumed for cooling.

Current Assessment

Temperature, precipitation, and other atmospheric output from the HadCM2 and CGCM1 scenarios were applied to observed long-term time series as input to a hydrologic model in order to get estimates of future hydrologic changes. The hydrologic model was developed at the Great Lakes Environmental Research Laboratory. It includes lake regulation plans. It was used to calculate lake levels and flows in the connecting channels from net basin water supplies that were computed using output from both GCMs.

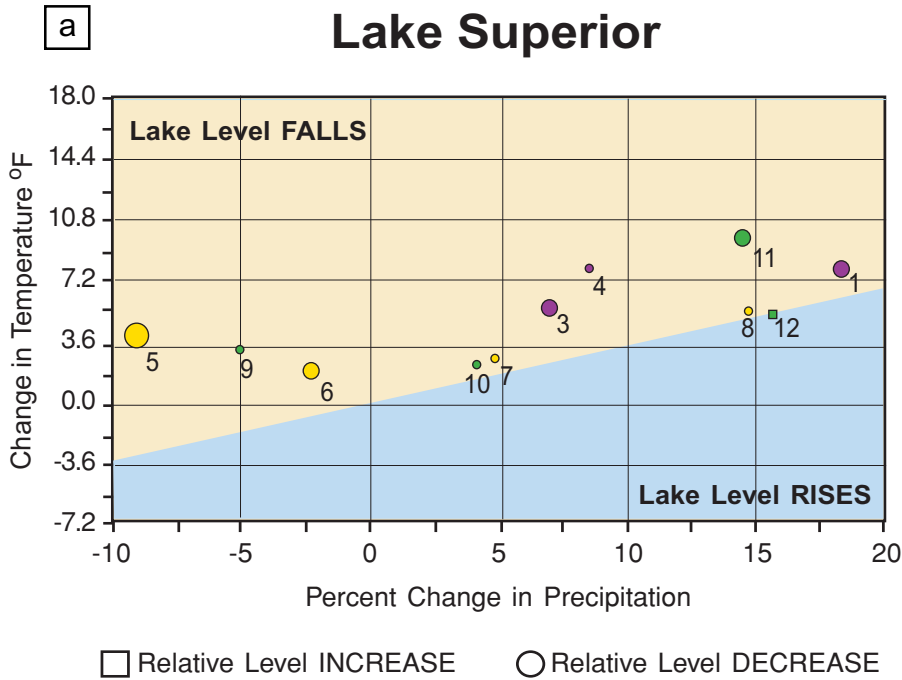
Lake Levels

The climate scenarios presented here depict a wide range in levels and flows for the Great Lakes in the 21st century. The mean annual runoff is reduced considerably by using the CGCM1 output. The reduced runoff, combined with increased lake surface evaporation due to a strong increase in lake surface temperature, yields a reduction in net basin supply (water input to the lakes by runoff from its basin plus input from

overlake precipitation minus output to overlake evaporation) that increases in magnitude with time. Corresponding lake level reductions from 0.7-2.4 feet are predicted by 2030, with greater reductions at later times, (e.g., 2-5 feet) on Lakes Michigan and Huron by 2090. The magnitude of these changes in lake levels is large enough to distinguish them from those from natural variability, except on Lake Ontario. Outflows from each of the lakes were also reduced. Lake Superior shows the smallest impact, dropping by 0.7-1.4 feet over the same time period. Flows in the connecting channels are reduced by 25-33% of base flow.

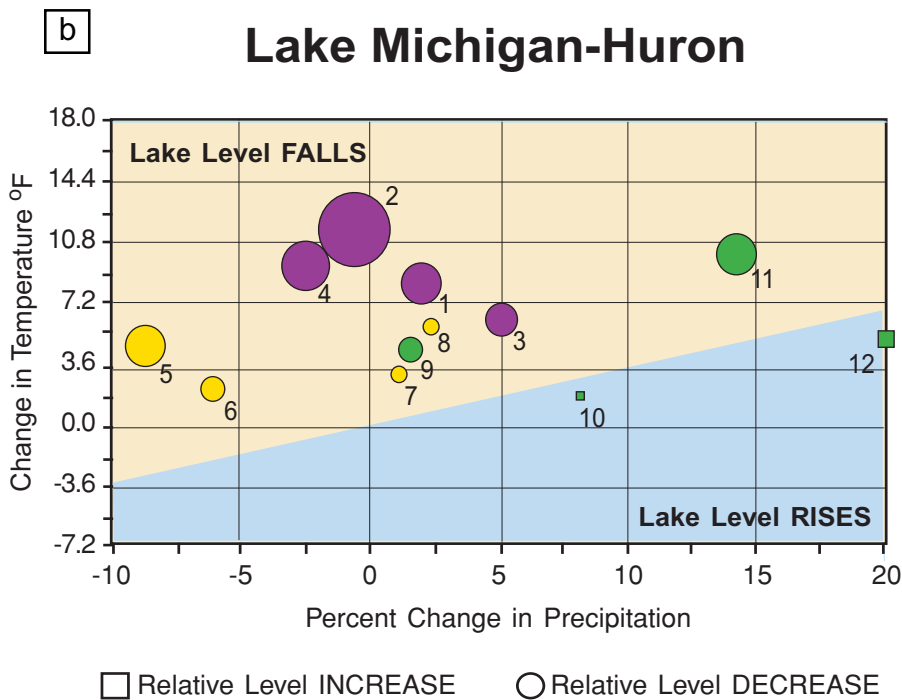
The mean annual runoff is little changed or slightly increased when using the HadCM2 output. Combined with modest changes in lake surface temperature, the result is little change or a small increase in net basin supply during each of the time periods investigated. The hydraulic routing of its wetter climate results in rises in water levels up to 1.2 feet for Lake Michigan-Huron, but none of the rises on any of the lakes exceed those expected from natural variability. Water levels on Lake Superior remain essentially unchanged. Outflows from all of the lakes also increase by about 5%. Additionally, it should be noted that due to a decrease in the annual mean runoff between 2030 and 2050 into most of the lakes, the water levels in 2050 are lower than in 2030, as are the outflows. This may indicate an artifact in using 20-year averaging periods for the GCM data in developing hydrologic scenarios, as the random variability between 20-year periods appears to exceed the long-term trend forced by greenhouse gases.

Lake level changes are shown for both the CGCM1 and HadCM2 models for 2030 and 2090, along with results from some previous studies, in Figure 4.3. Lakes Superior and Michigan-Huron were chosen because they are the least affected by changes in upstream conditions. The results from the HadCM2 scenario differ not only from the CGCM1 scenario, but also from those from all other models used in previous assessments, in that the output from all those models also result in lowered lake levels (It should be noted, though, most all of those models used equilibrium 2 X CO₂ – see box on next page).



MODEL	PERIOD	TYPE	Δ LEVEL	
1	GISS	2XCO ₂	E	-1.54
2	GFDL	2XCO ₂	E	failed
3	OSU	2XCO ₂	E	-1.51
4	CCC1	2XCO ₂	E	-0.75
5	MOTR2	2020	T	-2.62
6	CCTR2	2020	T	-1.64
7	GFTR2	2020	T	-0.66
8	HCTR2	2020	T	-0.33
9	CGCM1	2030	T	-0.72
10	HadCM2	2030	T	-0.03
11	CGCM1	2090	T	-1.38
12	HadCM2	2090	T	+0.36

E: Equilibrium model
T: Transient model



MODEL	PERIOD	TYPE	Δ LEVEL	
1	GISS	2XCO ₂	E	-4.30
2	GFDL	2XCO ₂	E	-8.13
3	OSU	2XCO ₂	E	-3.25
4	CCC1	2XCO ₂	E	-5.31
5	MOTR2	2020	T	-4.59
6	CCTR2	2020	T	-2.95
7	GFTR2	2020	T	-1.31
8	HCTR2	2020	T	-1.64
9	CGCM1	2030	T	-2.36
10	HadCM2	2030	T	+0.16
11	CGCM1	2090	T	-4.53
12	HadCM2	2090	T	+0.16

E: Equilibrium model
T: Transient model

Figure 4.3: a) Lake Superior and b) Lake Michigan-Huron comparison from selected climate change studies. The size of the marker is keyed to the magnitude of the change in lake level. The color represents different studies: the lavender ones (1-4) were taken from previous studies at the Great Lakes Environmental Research Laboratory (GLERL); the yellow ones (5-8) were taken from a recent study by Phil Chao [4-9]; and the green ones (9-12) were done most recently – specifically for this assessment.

Clear and straightforward reasons for the relatively cool and wet conditions of the future time periods within the HadCM2 model are unknown. Nonetheless, its disagreement with the other models widens the range of potential outcomes in hydrologic response to greenhouse warming. One difference of the HadCM2 from the CGCM1 model and previously studied models [4-2] is that it includes the presence of the Great Lakes as a water surface with significant thermal inertia. It is doubtful that this is a full explanation of the increased precipitation and lesser increase in temperature, as differences of similar magnitude have been noted on portions of North America remote from the Great Lakes [4-5].

The most notable difference between these results and those from previous climate change studies is the timing of the change in lake levels and connecting channel flows. Many of the previous studies looked at the impact on the basin from a doubling of carbon dioxide in the atmosphere, which would take about 70 years given a 1% annual compounded increase. This study predicts similarly dramatic declines in water levels and flows by 2030, at least according to the CGCM1 scenario.

TRANSIENT VS. STEADY-STATE MODELS

It should be noted that many previous studies used equilibrium models. That is, simplified ocean models were allowed to come into equilibrium with an atmosphere with doubled CO_2 . In contrast, transient models are now being used in which full dynamical ocean models are coupled to an atmosphere with CO_2 content changing in time. The newer, transient, approach effects a delay in warming by bringing the thermal capacity of the oceans into play in the model. The earlier equilibrium doubled CO_2 model runs also do not include the effect of increased sulfate aerosol concentration in the atmosphere.

The different results from the two scenarios emphasizes the necessity of having policies and water management plans that are robust enough to function over a wide range of water supplies, lake levels, and flows. The Great Lakes have just experienced a 30 year regime of extremely high lake levels similar to those projected by the HadCM2 scenario. The impacts of extreme low levels and flows on the people and the environment in the Great Lakes basin are not as familiar to people as the impacts of high levels. Low records were last set in the 1960s and 1930s, too long ago for the impacts to be common knowledge. Because of our recent experience with high level and flows, the focus on impacts in this report are the less familiar low levels. A drop in the levels of Lakes Michigan-Huron of about a meter in 30 years would severely change the nature of that immense body of water. Lake St. Clair and Lake Erie, with predicted drops in average levels of about 2 feet, respectively, would also be impacted greatly. Connecting channel flows will decrease by about 25% by 2030.

Ice Cover

Simulation to assess changes in lake ice cover were limited to three basins of Lake Superior and three basins of Lake Erie; each basin is simulated separately. Average ice duration for the 1950-95 base period ranged from 11 to 16 weeks, similar to the results of an earlier study [4-6]. The CGCM1 and HadCM2 scenarios have reductions in ice duration that range from 1.7 to 6.7 weeks (2030 scenario), 2.3 to 7.1 weeks (2050 scenario) and 5.3 to 11.6 weeks (2090 scenario). The greatest reductions 37 to 81 days occur for the CGCM1 scenario. Simulation to assess changes in lake ice cover were limited to the basins of Lakes Superior and Erie; each basin is simulated separately. Average ice duration for the 1950-95 base period ranged from 11 to 16 weeks. The CGCM1 and HadCM2 scenarios have reductions in ice duration that range from 1.7 to 6.7 weeks (2030 scenario), 2.3 to 7.1 weeks (2050 scenario) and 5.3 to 11.6 weeks (2090 scenario). The greatest reductions 37 to 81 days occur for the CGCM1 scenario.

Average February ice cover for the base period exceeds 50% in area for all lake basins except eastern Lake Superior (42%). Average February ice cover for the 2030 CGCM1 scenario is less than or equal to 31% of its base period averages; for the 2030 HadCM2 scenario it is less than or equal to 75% of its base period average. For the 2090 scenarios (CGCM1 and HadCM2) the average February ice cover ranges from 2 to 11% for the Lake Superior basins and 1 to 29% for the Lake Erie basins. February is ice-free for most winters simulated under the CGCM1 scenario for Lake Erie.

Impacts

The CGCM1 scenario suggests that the lake levels will drop significantly. A one meter (3.28 feet) average drop in Lake Michigan would disable the Chicago Diversion [4-3, 4-4]. Beaches would be broad, but access to marinas and docks would be severely limited. Great Lakes commercial navigation would be crippled. Electricity generation from hydropower would decline as dramatically as the lake levels. Political discussions over costly and environmentally hazardous dredging projects would abound. Thousands of municipal water intakes and wells would have to be moved or extended. The nature of the fishery would be completely altered due to a lack of spawning ground and

warmer water. Native American and Native Canadian populations that depend on the fishery or marshland for their livelihood would be impacted. Locks would have to be re-engineered and channel walls stabilized.

A much different future is portrayed by the HadCM2 scenario. The HadCM2 predicts a slightly warmer and wetter climate that results in higher lake levels and slightly higher connecting channel flows as compared to the 1954-1995 base period. Since the high water levels of 1985-86 set records on all the lakes of approximately 3 feet above average, the effects of high water levels are still very fresh in our collective memory. High levels most directly threaten shoreline property owners. They present challenges for cities and other jurisdictions faced with maintaining sewage facilities, water supply, seawalls, and harbors.

Table 4.1 shows an interest-based regulation model developed for Lake Ontario and the St. Lawrence River [4-7] which was run for six climate scenarios (2030, 2050, and 2090 for both the CGCM1 and the HadCM2). The model uses ten interest satisfaction (IS) relationships and attempts to maximum the collective satisfaction of all interests that use the resource, thus determining the optimum outflow for Lake Ontario. Satisfaction is defined as the degree that conditions are completely ac-

Table 4.1: Satisfaction (%) Values by interest for various GCM scenarios. Satisfaction refers to the degree that conditions are acceptable or unacceptable to interests; 100% being completely acceptable, 0% being completely unacceptable. Environmental factors are considered after all years are evaluated.

Interest	Base Case	CGCM1			HadCM2		
		2030	2050	2090	2030	2050	2090
Lake Ontario Riparians	27.5	11.3	0.6	0.0	26.3	25.5	15.5
Lake Ontario Rec. Boaters	15.2	0.6	0.0	0.0	16.8	17	8.2
Comm. Nav. on Lake Ontario	57.7	20.5	3.4	0.1	61.3	60.4	53.6
Comm. Nav. - Lake St. Lawrence	99.6	100.0	100.0	99.2	99.9	99.9	53.6
Hydropower-International Reach	66.9	15.7	1.4	0.0	75.1	74.1	59.6
Lake St. Louis Riparians	79.0	41.2	24.7	6.5	78.3	77.2	74.2
Lake St. Louis Rec. Boaters	37.6	16.6	8.1	1.3	36.7	35.8	34.5
Hydropower-Canadian Reach	60.2	31.7	11.3	0.7	63.0	63.1	54.1
Montreal Harbour	70.0	9.5	1.5	0.1	63.8	63.1	74.4
Comm. Nav. - Lake St. Louis	83.5	23.9	4.3	0.0	85.4	83.9	89.7
Env. Factors based on levels range	64.7	47.6	42.9	41.9	62.8	62.3	68.1

ceptable (100%) or unacceptable (0%) to an interest. The interest-based model used outflows varying from 110,000 feet³/second (3110 meters³/second) to 350,000 feet³/second (9910 meters³/second), which are more extreme than those within the regulation plan presently used for Lake Ontario, but necessary to handle conditions resulting from the climate scenarios. The minimum outflow value is lower than the period of record (1860-1998) monthly value of 154,000 ft³/s (4360 m³/s) which occurred in February 1936.

The model was able to evaluate both the dry and wet forecasted conditions as shown in Figure 4.4. In the dry case, extremely low levels were experienced throughout the system becoming most extreme in the 2090 scenario. As such, satisfaction values, which are averages over the entire 42-year period (compared to a base of 1954-1995), decreased over time. For 2030, all interests are generally satisfied less than a third of the time. However, for 2090, total dissatisfaction is experienced by all. The extremely low outflows are below the minimum required for hydropower and adequate depths for commercial navigation can not be maintained. In the wet case, the discomfort felt by riparians was offset by the higher satisfaction scores of the

hydropower and commercial shipping sectors in the 2030 and 2050 scenarios. However, the incidence of higher outflows results in spillage of water at hydroplants and also in higher river velocities impacting navigation. In the 2090 case, extensive flooding would occur throughout the system.

Both high and low levels present challenges for those that regulate Lake Superior and Lake Ontario. The outlets of Lake Superior and Lake Ontario are regulated by the International Joint Commission to promote the stability of lake levels and to balance the interests of those affected by changing lake levels. Neither of the computer models currently used to guide regulation decisions was robust enough to handle the extremely low supplies predicted by the CGCM1 model. The lake level and outflows reported in this study were obtained using the upper lakes regulation and routing model, altered in 1998 to permit extreme high or low supplies. The Lake Ontario operational regulation model also needed alteration to successfully run under these low supply conditions. A modified version of the model designed to flow “pre-project” flows below a specified level (74 meters, IGLD 85) was used and performed satisfactorily.

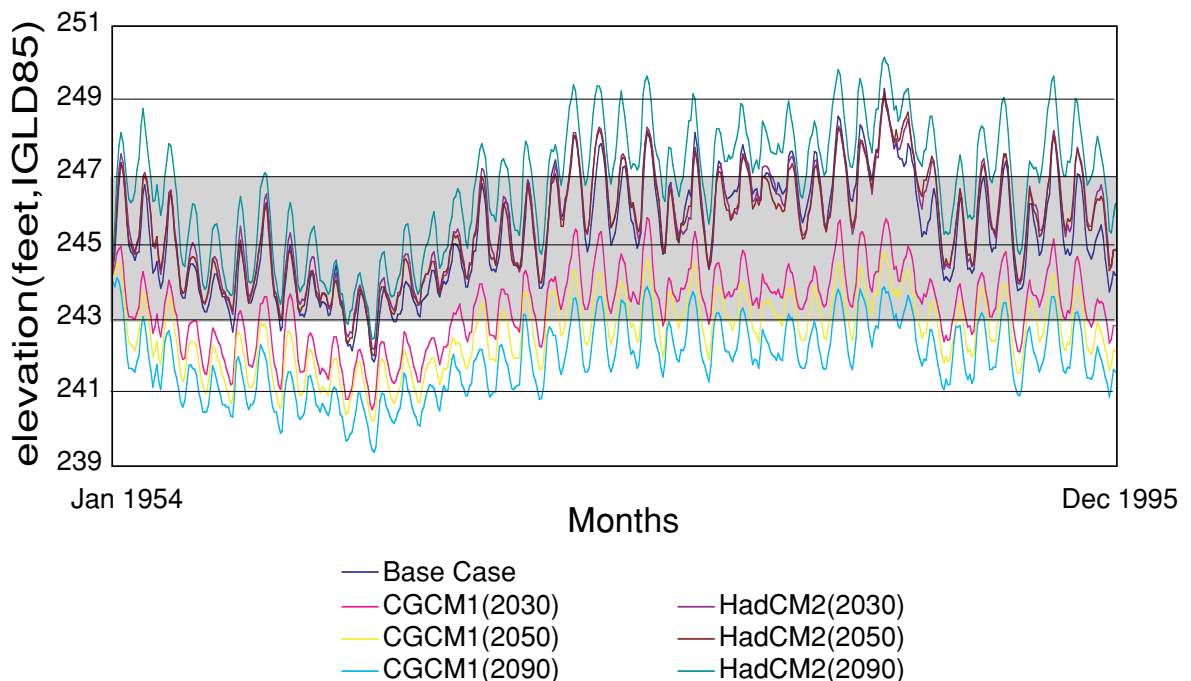


Figure 4.4: Lake Ontario levels using the IS model for various GCMs.

Coping Strategies

The CGCM1 and HadCM2 scenarios have provided two divergent futures on the availability of Great Lakes water resources under climate change. Water resource strategies/policies should be developed which are robust enough to cope with either the high or low water supplies projected for the future by the two models. The relative priorities for various interests must be left to the political process, but all of the interests should be recognized in the development of comprehensive lake regulation plans. In addition, sound public policy has to be determined relative to shoreline development, municipal and industrial infrastructure, environmental considerations, public health, consumptive uses and withdrawals, and other uses of the waters of the Great Lakes.

At a recent binational symposium on climate change in the Great Lakes/St. Lawrence Basin (GLSLB), scientists, politicians, and stakeholders labored to summarize a plan of action [4-3]. All working groups identified a critical need for better communication of any scientific conclusions that have been reached relative to climate change impacts and adaptive responses. Effective communication must be tailored to each of the many diverse audiences that comprise the user community. The public needs to become familiar with probabilistic data in order to understand and react to climate change information. Deterministic forecasts encourage users to focus on the midpoint of the forecast range of levels, often with no knowledge of the risks involved. Risk assessment using probabilistic water level forecasts can contribute to the decision-making process by providing more information to the user about the possible range of outcomes, permitting the user to decide how much risk is acceptable [4-8].

The Great Lakes/St. Lawrence Basin study [4-3] concluded that the issue of climate adaptation will receive little attention until there is more direct involvement of local stakeholders in setting priorities for public action. If the focus is shifted away from

experts' and scientists' views and more toward what climate change can do/is doing to the lives and livelihoods of individuals, then people will be more likely to hear and personalize the message. The messages of the inevitability of change and the necessity of adaptation will be accepted more readily if these are disseminated by established and trusted sectoral organizations than if they come from the scientific community.

Information & Research Needs

More robust regulation models are needed for Lakes Superior and Ontario. The existing operational regulation models for Lakes Superior and Ontario have severe limitations, including failure, when used under climate change conditions. They are primarily based upon economic considerations of the first half of the 20th century and do not take into account such relatively recent interests as the environment and recreational boating. The operational guides currently used for regulating Lakes Superior and Ontario were developed in 1990 and 1963, respectively. However, Lake Superior regulation is primarily based upon Orders of Approval issued in 1914, which used lake levels from 1860-1914.

The ability to translate GCM outputs into Great Lakes basin hydrology and water resource assessments is dependent upon our suite of hydrologic models. Second generation runoff models for the Great Lakes basin watersheds are required to take into account the land surface processes in changing climates as well as changes in land use and cover. These models are required to assess changes in vegetation, evapotranspiration, and runoff due to climate variability and change. Improved lake evaporation models are also required to better assess the changes in lake evaporation under a changed climate. A two-dimensional model that can be run in a forecasting and simulation mode for long time periods is needed. These models will provide better hydrological estimates of climate change which can be used, in turn, to provide input to the social, environmental, and economic sectors impacted by climate change and variability.

Conclusions & Lessons Learned

There have been three significant findings so far that are unique to this study. The first is that using the transient models for the year 2030 shows that significant changes to the Great Lakes water resources could come sooner rather than later. The use of the HadCM2 has also indicated for the first time that there is a potential for slightly higher water levels under climate change. The prior nine model runs for the Great Lakes water resource studies, including the current CGCM1 have all indicated a major lowering of lake levels and a reduction of water supplies. Finally, through the use of the interest satisfaction regulation

model for Lake Ontario, we have the ability to assess impacts on specific interests using a variety of regulation scenarios.

This study reaffirmed that no one method of impact assessment is completely adequate. Many of the shortcomings of our method are noted in this report. It would be very useful to have the National Assessment of Climate Change as an ongoing project, thus maintaining interest and effort in relevant issues, ensuring continuity in research efforts and the development of many alternative methodologies for comparison and increased knowledge on which to base a judgment of the accuracy of the output.



