REGIONAL CLIMATE CHANGE AND FRESH WATER ECOLOGY[1]

John J. Magnuson
University of Wisconsin, Madison, WI

Dr. John Magnuson, Director of the Center for Limnology at the University of Wisconsin at Madison, Wisconsin talked about the potential impacts of climate change on lakes in the Great Lakes region. Below is a summary of his talk.

Dr. Magnuson first noted the importance of the ecology in the region. Besides the Great Lakes themselves, which have a surface area of 244,160 km^2 and a volume of 23 x 10^{15} liters, the region has numerous other (smaller) lakes and streams. For example, Wisconsin alone, has 12,500 lakes covering 14,000 ha, 2,000,000 ha of wetlands, and 53,000 km of streams. The region includes the Laurentian Great Lakes and a diverse collection of smaller glacial lakes, streams and wetlands located south of permanent permafrost and extending towards the southern extent of Wisconsin glaciation.

Dr. Magnuson then described briefly the paleoclimate of the region, in order to set the stage for a description of the current climate and future climate scenarios. He noted that the region was mainly drier than present, except for a brief period around 9,000 YBP (years before present). Between 12,000 and 7,000 YBP, the region was cooler by up to 7 °C. Between 7,000 and 3,000 YBP, the region was up to 3 °C warmer. Since then, the climate has been less than 2 °C cooler than present.

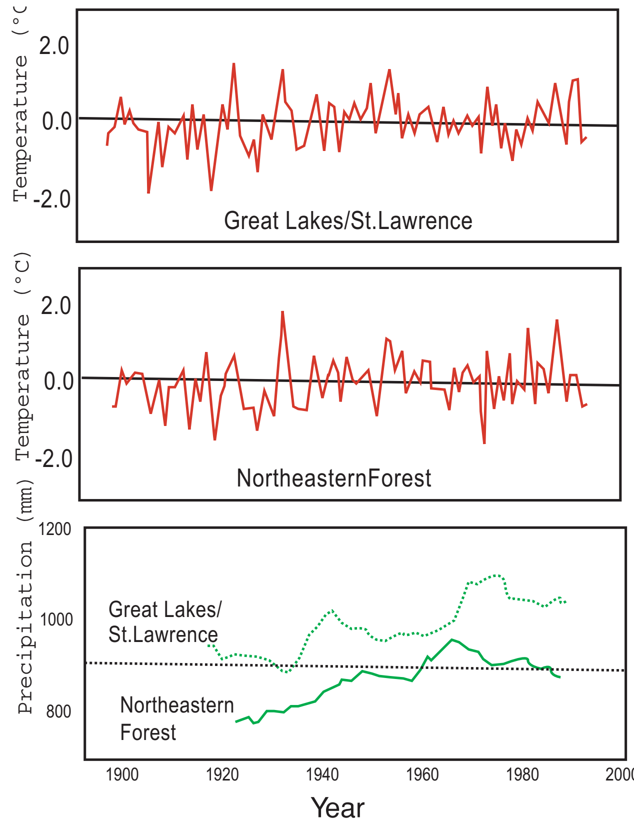

Figure 1: Departure from 1951-1980 average temperature (solid line) and linear trends (dashed lines) for (a) Great Lakes basin/ St. Lawrence lowlands, and (b) Northeastern Forest, (c) Annual precipitation (9 year running mean) amount for these two regions. Source: Magnuson et al. 1997.

Overall, the region is warmer and wetter now than it has been over most of the last 12,000 years. More recently, specifically since 1911, observed air temperatures have increased by about 0.11 ºC per decade in spring and 0.06 ºC in winter; annual precipitation has increased by about 2.1% per decade (cf.Figure 1 and 2). Additionally, ice thaw phenologies since the 1850s indicate a late winter warming of about 2.5 ºC.

Dr. Magnuson described in some detail the climate change scenarios that were used in a recent study (cf. Magnuson, et. al 1997). Four general circulation models (listed in Table 1)

[1] *Much of this summary is extracted from a recent paper, Potential Effects of Climate Changes on Aquatic Systems: Laurentian Great Lakes and Precambrian Shield Region, J.J. Magnuson, K.E. Webster, R.A. Assel, C.J. Bowser, P.J. Dillon, J.G. Eaton, H.E. Evans, E.J. Fee, R.I.Hall, L.R. Mortsch, D.W. Schindler and F.H. Quinn. Hydrological Processes, Vol.11,825-871 (1997).*

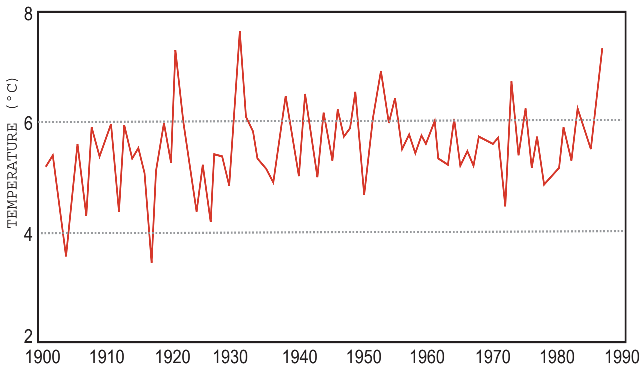

Figure 2: Annual temperatures for the Great Lakes basin (1960-1990). Source: Magnuson et al. 1997.

were examined. All showed temperature increases from 2-5 ºC (summer) to 4-8 ºC (winter). All showed precipitation changes from -20 to +10% in summer and -10 to +20% in winter (cf. Magnuson, et al 1997). Additionally, climate change scenarios were created by transposing climates from areas which represent now what the Great Lakes region climate is expected to be in the future (cf. Table 1).

Such changes in climate have altered and would further alter hydrological and other physical features of lakes. Warmer climates, i.e., 2 x CO_2 climates, are expected to lower net basin water supplies, stream flows, and water levels owing to increased evaporation in excess of precipitation. Lake levels are expected to drop 0.5-2.5 m. Reductions in lake levels would be most dramatic where increases in temperature and decreases in precipitation are greatest – in the southern half of the basin. Small inland lakes may completely disappear or at best shrink so much that salinities and nutrient and pollution concentrations increase to dangerous levels. Figure 3 shows the observed 20-year trend for inland lakes in northwestern Ontario (lake 240 basin). Note that decreasing precipitation and increasing evapotranspiration (ET) have led to dramatic decreases in basin discharge.

Additionally, a warmer climate would decrease the spatial extent of ice cover on the Great Lakes. Ice-on dates would come later in the fall or winter season and ice-on dates would come earlier in the winter or spring season. Such changes have already been observed. Ice-off dates for Lake Mendota, Wisconsin and Grand Traverse Bay, Michigan have increased by 8 and 12 days, respectively, since the late 1800s.

Table 1: Average, annual, steady-state Great Lakes basin hydrology under base (1XCO_2), transposition and 2 X CO_2 scenarios Values in italics are the percentages change form the the base case.

Scenario	Overland precipitation	Evapotranspiration (m^3/s)	Basin runoff (m^3/s)	Over lake precipitation (m^3/s)	Over lake evaporation (m^3/s)	Net basin supply (m^3/s)
1 X CO_2 (Base case)	13855	7814	6206	6554	4958	7803
Transposition scenarios:						
#1 6ºS x 10ºW	14643 +6%	10201 +31%	4674 -25%	6767 +3%	7394 +49%	4048 -48%
#2 6ºS x 0ºW	17167 +24%	11198 +43%	6154 -1%	8169 +25%	6615 +33%	7708 -1%
#3 10ºS x 11ºW	16236 +17%	11563 +48%	4877 -21%	7379 +13%	8699 +75%	3556 -54%
#4 10ºS x 5ºW	20095 +45%	13907 +78%	6308 +2%	9482 +45%	8364 +69%	7426 -5%
2 X CO_2						
CCC*	13637 -2%	7727 +22%	6090 -32%	6499 0%	5352 +32%	7237 -46%
GISS†	13871 +2%	9317 +21%	4658 -24%	6747 +4%	6821 +27%	4584 -37%
GFDLø	13725 +1%	9176 +19%	4714 -23%	6501 0%	7685 +44%	3530 -31%
OSU¶	14438 +6%	9204 +19%	5438 -11%	6903 +6%	6745 +26%	5596 -23%

* Canadian Climate Center GCM (Croley, 1993)
† Goddard Institute for Space Studies GCM (Croley, 1990)
ø Geophysical Fluid Dynamics Laboratory GCM (Croley, 1990)
¶ Oregon State University GCM (Croley, 1990)

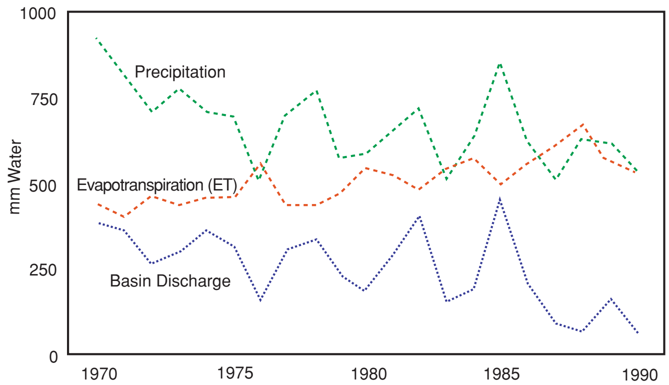

Figure 3: Hydrological changes observed for the lake 240 basin during the 20-year period of warmer and drier conditions at ELA (Experimental Lakes Area in northern Ontario). Adapted from Schindler et al., 1996a). Source: Magnuson et al. 1997.

Ice-off dates have decreased by 14 and 20 days respectively at these two sites. Small lakes, especially those to the south, would no longer freeze over every year. Simulations using output from several general circulation models show that stratified lakes are 1-7 ºC warmer for surface waters, and 6 ºC cooler to 8 ºC warmer for deep waters (cf. Figure 4). Thermocline depth would change (4 m shallower to 3.5 m deeper). A decreased thermocline depth would occur from the temperature changes alone, which would stabilize the surface layer and reduce mixing. An increased thermocline depth, however might occur owing to increases in light penetration which would occur because of the reduced input of dissolved organic carbon (DOC). Dissolved oxygen would increase below the thermocline.

These physical changes would in turn affect the phytoplankton zooplankton benthos and fishes. Annual phytoplankton production may increase but many complex reactions of the phytoplankton community from altered temperatures, thermocline depths, light penetrations and nutrient inputs would be expected. Zooplankton biomass would increase, but, again, many complex interactions would be expected. Generally, the thermal habitat for warm-, cool-, and even cold-water fishes would increase in size in deep stratified lakes, but would decrease in shallow unstratisfied lakes and in streams. Less dissolved oxygen below the thermocline of lakes would further degrade stratified lakes for cold water fishes.

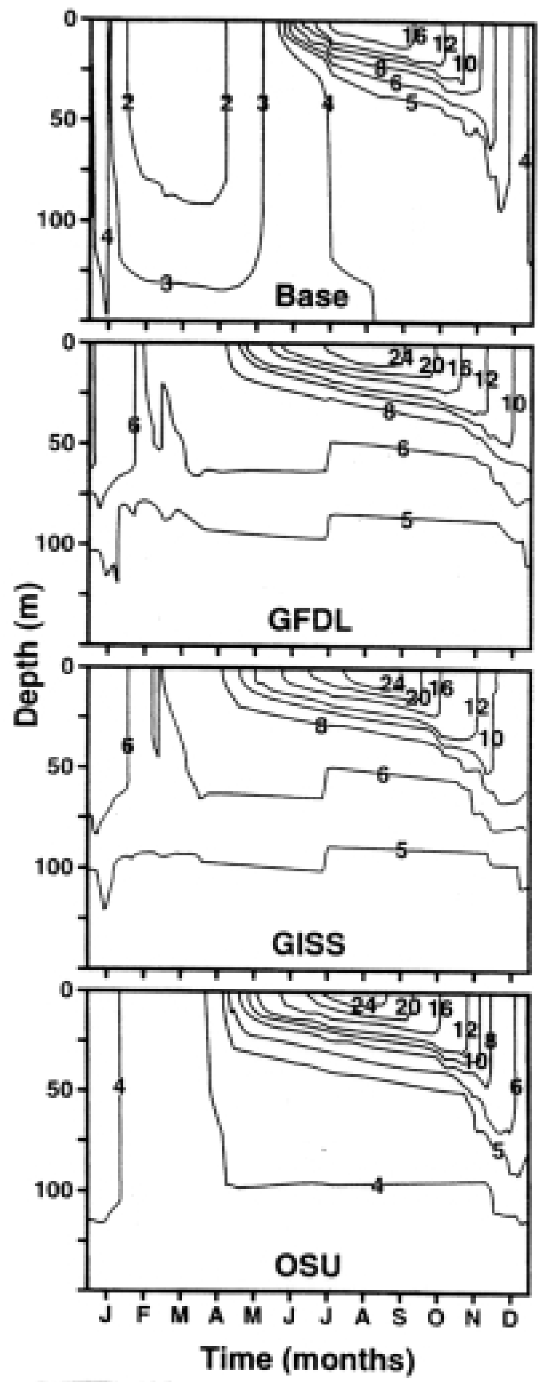

Figure 4: Simulated temperature isotherms (ºC) for Lake Michigan under base and 2 X CO_2 scenarios from three global climate models (modified from McCormick, 1990). Source: Magnuson et al. 1997.

Growth and production would increase for fishes that are now in thermal environments that are cooler than their optimum, but decrease for those that are at or above their optimum, provided they cannot move to a deeper or headwater thermal refuge. The zoogeographical boundary for fish species could move north by 500-600 km; invasions of warmer water fishes and extirpations of colder water fishes should increase. Assuming a 5 ºC temperature increase, approximately three new species would inhabit inland lakes in Ontario, nearly doubling in some cases, the varieties of fish in any given lake. The largest increase in variety would occur midway between the north and south boundaries of tertiary watersheds (cf. Figure 5). Limitations along the northern boundary would still be temperature limited, while limitations along the southern boundary would exist because there are already a large variety of species.

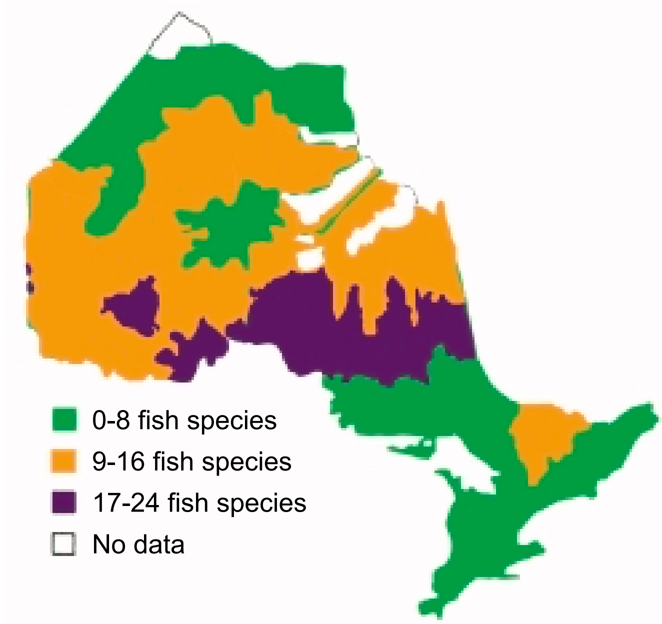

Figure 5: Tertiary watersheds in Ontario where 0-8, 9-16 and 17-24 of the 33 freshwater fish species with temperature-determined boundaries are predicted to be able to invade following climate warming of 4.5-5.5 ºC (modified from Minns and Moore, 1995). Source: Magnuson et al. 1996.

Dr. Magnuson emphasized it is important that aquatic ecosystems across the region will not necessarily exhibit coherent responses to climate changes and variability, even if they are in close proximity. Lakes,wetlands, and streams will respond differently, as will lakes of different depth or productivity. Differences in hydrology and the position in the hydrological flow system, in terrestrial vegetation and land use, in base climates and in the aquatic biota can all cause different responses. Additional complications will occur because climate change effects interact strongly with effects of other human-caused stresses such as eutrophication, acid precipitation, toxic chemicals, and the spread of exotic organisms. Additionaly, aquatic ecological systems in the region are sensitive to climate change and variation.

In closing, Dr. Magnuson highlighted some of the expected impacts related to water resources as a result of climate change. Changes in lake levels, recently observed or simulated in 2 X CO_2 scenarios, exceed those observed or simulated for sea level changes. Human responses to such large changes would be costly, particularly those related to shipping, dredging, and replacement or refurbishing of shoreline structures in the Great Lakes. Changes in ice cover also influence shipping costs. In addition, higher demand and usage of water from the Laurentian Great Lakes would probably occur following a decrease in net basin water supplies.

For shipping at simulated water levels 0.5-1.5 m lower than base levels, dredging costs would be incurred or ships would have to carry lighter loads . If lighter loads are carried, then the costs per ton transported in 2 X CO_2 scenarios will increase from 1.6 to 33% depending on the harbor (Duluth/Superior, Two Harbors, and Whitefish Bay on Lake Superior, and Toledo, Cleveland, and Buffalo on Lake Erie) and the scenario (GISS, GFDL and OSU). Cargoes would have to be reduced by 1.6-2.7% to get into the harbors without additional dredging. Dredging costs can be as high as $ 31 million per harbor not including the costs associated with shipping-related facilities. For the 101 km Illinois shoreline of Lake Michigan including Chicago, \$138-312 million would be needed over a 50-year period for dredging harbors to compensate for a 1.25-2.5 m decline in lake level. The cost of sheeting, and bulkheads slips, and docks was estimated at an additional \$113-203 million. Taken together, these shipping costs for the Illinois shoreline total \$251-515 million over a 50-year period. Increased dredging activities would also have implications for destruction of benthic habitats and resuspension of toxics in harbor sediments.

Even with lighter loads, the same amount of goods could be shipped over a season if the ice-free season were longer (see section on ice, below). For Buffalo, an increase in the shipping season of 99 days would be sufficient to compensate for the need for lighter loads with a 1.5 m decline in water level; simulated increases in the ice-free period more than compensated for the need for lighter loads in two (GISS and OSU) of the three climate scenarios. For Lake Superior ports, a slightly shorter increase in the ice-free season would be sufficient based on all GCM scenarios. The bottom line projection for shipping costs for ports on Lakes Superior and Erie, as a consequence of reduced water levels plus the longer shipping season apparent in 2 X CO_2 scenarios, was 1-7.5% above present costs or about one half of the increases in costs from water level reductions taken alone.

Additional costs, unrelated to shipping, have been estimated for the Illinois shoreline of Lake Michigan by Changnon et al. (1989) for 2 X CO_2 scenarios. These included costs to extend water intake structures for city water supplies (\$16-17 million), to relocate beach facilities (\$1-2 million) and to extend and modify storm water outfalls (\$2-4 million). These costs are less than those associated with shipping. Historical responses to lower water in the Chicago area include relocation and encroachment to take advantage of the new beach areas. Damage to these structures was extensive when water levels returned to higher levels.

Generation of electricity from hydroelectric facilities in the Great Lakes Basin would also be reduced in a drier and warmer climate. Presently, the capacity of the Great Lakes electric generation system is about 3.2 million kW for Ontario, 1.7 million kW for Quebec and 3.1 million kW for New York. The costs of replacing the hydroelectric power generated at Niagara and along the St. Lawrence River following a 0.6 m decline in water level in Lakes Erie and Ontario is high. Long-term annual costs of replacing this capacity with nuclear or fossil fuel plants were estimated to be in the range of U.S. \$169 million in 1988 for New York and Canadian \$1 billion for Ontario. The combined output from these hydropower facilities is of the same magnitude as that of the Tennessee Valley Authority.