The Potential Impacts of Climate Change on Great Lakes Transportation

By **Frank H. Quinn**

Introduction

The Great Lakes, shown in Figure 1, are one of North America's largest water resource systems with a basin area of about 770,000 km^2, of which about one third is lake surface. It is one of the most intensively used fresh water systems in the world, serving multiple interests including navigation, hydropower, recreation, water supply, food supply, and riparian. The outflows from Lakes Superior and Ontario are regulated by regulatory works in the St. Marys and St. Lawrence Rivers respectively. The remainder of the system is naturally regulated. Great Lakes water levels change slowly due to the large lake surface areas and constricted outlet channels which integrate short-term climate fluctuations. There is a likely potential for significant global climate change due to increased greenhouse gas

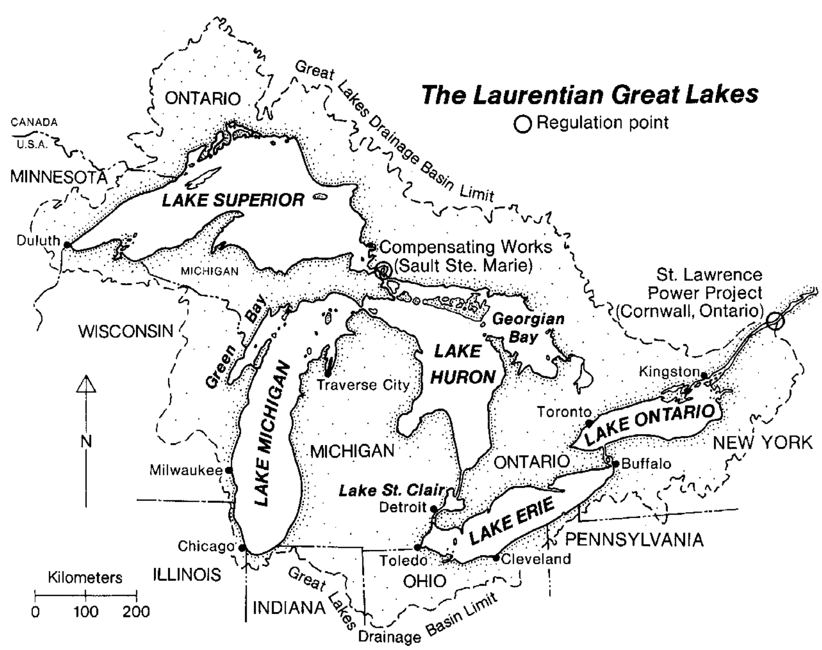

Figure 1. Map of the Great Lakes drainage basin.

concentrations in the atmosphere. The impacts of this change, when translated to the Great Lakes basin, are significant in terms of lake levels and waterborne transportation. The Great Lakes-St. Lawrence water transportation system supports more than 30,000 jobs in the U.S. and Canada with business revenue and personal income from the movement of cargo topping $3 billion per year (Stead et al., 2000). Because of the relatively small water level variability, about 1.8 meters, shipping interests have become dependent upon a relatively stable lake levels regime, resulting in sensitivity to the water level changes anticipated under climate change. Studies conducted in the U.S. and Canada since the early 1980's show an increased possibility of lake level lowering due to global warming, resulting in major changes to the water resources and lake levels.

The Great Lakes have had two episodes of low water over the past 40 years, in 1963-1966 and 1997-2001, which may provide some guidance in impact assessment. The problem with using them as a true analogue is that they were of limited duration lasting three to four years, and did not represent a long term change. During the last episode, declining water levels in the Great Lakes impacted several major industries in the region. In the year 2000, lake carriers that transport these cargoes were forced into "light loading", carrying 5-8% less goods. Although water levels increased in 2001, they are now the same level as the year 2000. The Lake Carriers Association reported that Dry Bulk Commerce decreased by 6.7 percent in 2001 compared to 2000. A tenfold increase was also noted in the dredging activity during the five year period beginning with 1963 (4,119,000 cubic yards annually) compared with the preceding five years (372,000 cubic yards annually) (Sousounis et al., 2000). Also during the recent episode cruise ships were unable to dock at Saugatuck, MI, a highly desirable stop, because of inadequate water depths in the harbor. Many small picturesque stops may not be available for cruise ships under climate change.

Great Lakes Transportation System

U.S. Fleet. The transportation system comprises bulk cargo carriers, ocean going vessels and smaller cruise ships. Predominant players are the bulk lake carriers with lengths up to 1000 feet. In recent years there have also been two or three small cruise ships running from Montreal or Quebec City with a number of port calls throughout the Great Lakes. Ocean going vessels have plied the Great Lakes since the construction of the St. Lawrence Seaway in the late 1950s. This presentation will concentrate primarily on the lake carriers. The U.S.-Flag Lakes fleet consists of approximately 65 large self-propelled vessels and tug/barge units in the dry- and liquid-bulk trades; another 20 smaller tug/barge units are engaged primarily in moving liquid-bulk products (Lake Carriers Association, 2002). Thirteen of the ships are the 1,000-foot-long super carriers which can routinely carry as much as 70,000 tons of iron ore or coal. In May of 2002 there were 43 dry bulk carriers, three cement carriers, and five tankers in operation (Lake Carriers Association, 2002).

U.S. Cargo. The Great Lakes-St. Lawrence Seaway is a 1270-mile transportation route that handles approximately two billion tons of commercial shipping. Sixty percent of the seaway traffic travels to and from overseas ports such as Europe, the Middle East and Africa. Eighty percent of cargoes shipped each year include iron ore, coal, grain or steel. The following cargo data are from Lake Carriers Association (2002). Iron ore averages nearly 58 million tons each shipping season, twice that of the next largest commodities, stone or coal. The ore is loaded at ports on Lakes Superior and Michigan and delivered to lakefront steel mills, or to transfer facilities where the iron ore is then railed to inland furnaces. The iron ore trade begins out of Escanaba, Michigan, in early March. When the locks at Sault St. Marie, Michigan, open on March 25, loading resumes at the six ore docks on Lake Superior and continues until the federally-mandated closing of the Soo Locks on January 15. Depending on demand for iron ore, shipments will continue from Escanaba until early- or mid-February. Since it has the longest shipping season, the iron ore trade is the most dependent on icebreaking by the U.S. Coast Guard. Early- and late-season sailing tests the ships' and crews' endurance, but steelmakers must minimize stockpiling costs to remain competitive with foreign suppliers.

Limestone has the most diverse customer base. The steel industry uses "flux-stone" as a purifying agent in the steelmaking process. The flux-stone is either added directly to the blast furnace or mixed in with the iron ore at the mine to produce "fluxed pellets." The construction industry uses "aggregate" as a base for highways, parking lots and sewer systems. The chemical and paper industries also use limestone. When all the applications for limestone are combined, it is estimated that each American uses 8,000 pounds every year. The annual stone float for U.S.-Flag lakers is approximately 23 million tons. The development of fluxed pellets has actually increased the stone trade for U.S.-Flag lakers above pre-recession levels. The Great Lakes region is blessed with an almost inexhaustible supply of limestone and the quarry at Rogers City, Michigan, is the largest in the world. Since stone is somewhat high in moisture content and is often "washed" before loading into vessels, the trade is a bit more weather-sensitive than other cargos. The stone trade generally resumes in early April and finishes by late December.

Coal rounds out the "Big 3" trades for U.S.-Flag lakers. Shipments generally top 20 million tons in a typical navigation season. There are two types of coal hauled on the Lakes: Metallurgical or "met" coal for steel production, and steam coal for power generation. There is another distinction: Eastern and Western coal. Eastern coal is mined in West Virginia, Pennsylvania, Kentucky, Ohio and Illinois and is shipped from Lake Erie and Lake Michigan ports. Western coal is mined in Montana and Wyoming and then railed to Superior, Wisconsin, for loading into vessels. The coal trade begins in late March and generally wraps up by year's end. The coal trade perhaps best exemplifies the benefits of inter-modalism. There is not a single large coal mine anywhere near a U.S. port on the Lakes. American railroads, in other instances fierce competitors for cargo carried by lakers, deliver the coal to Lakes ports for final shipment by vessel to the customer.

Other cargoes, including cement, salt, grain, sand and various liquid-bulk products in total represent roughly 10 percent of the U.S.-Flag float each year. In many instances, these commodities are "backhaul" cargos, which help keep freight rates as low as possible. Salt cargos top 1 million tons each year. Many Great Lakes communities get the salt they need to keep streets and sidewalks ice-free in U.S.-Flag lakers. Cleveland and Fairport Harbor, Ohio, are the two U.S. salt-loading ports on the Lakes. Roughly 500,000 tons of wheat move between Duluth/Superior and Buffalo each year in U.S.-Flag lakers. Grain is the one trade where "straight-deckers" (non self-unloading ships) are still active. Other commodities carried by U.S.-Flag lakers include sand, gypsum, taconite tailings and coke breeze. The cargo statistics for the last four years are given in Table 1.

There are 15 major international ports and about 50 smaller regional ports on the Great Lakes-St. Lawrence River System. The location of many of these ports is shown in Figure 2.

Climate Impacts

A review of various Great Lakes studies, and their rationale, is given by Quinn (1999). In the late 1980s a major study was undertaken by the United States Environmental Protection Agency to assess the potential effects of global climate change (Environmental Protection Agency, 1989). As part of this effort a detailed assessment of the impacts on Great Lakes water supplies was undertaken using an integrated suite of daily rainfall-runoff models for the 121 basin watersheds and lake evaporation models for each of the lakes (Croley, 1990). This assessment used a pre-selected set of double CO_2 scenarios from the Goddard Institute of Space Sciences (GISS), Geophysical Fluid Dynamics Laboratory (GFDL), and Oregon State University (OSU) general circulation models (GCMs). For the first time, as part of this study, the climate change impacts on each of the lakes and on the water management for

Table 1. *U.S.-flag cargo carriage: 2001-1998 navigation seasons (net tons). Source: Lake Carriers' Association: June 2002.*

Commodity	2001	2000	1999	1998
Iron Ore, Total	**47,277,306**	**58,519,597**	**59,086,414**	**62,800,734**
Iron Ore, Direct Shipments	44,182,574	53,242,963	53,182,571	56,988,970
Iron Ore, Transshipments	3,094,732	5,276,634	5,903,843	5,811,764
Coal, Total	**21,394,115**	**21,108,263**	**21,969,064**	**21,937,047**
Coal, Western	13,350,523	12,878,253	13,471,049	13,515,846
Coal and Coke, Eastern	8,043,592	8,230,010	8,498,015	8,421,201
Limestone and Gypsum	27,334,146	27,933,432	28,392,094	31,618,104
Cement	4,215,357	4,125,542	4,373,812	4,286,049
Salt	876,392	838,017	1,309,894	1,312,157
Sand	625,094	427,070	249,238	234,300
Grain	350,719	351,398	346,814	352,083
Total, All Commodities	**102,073,129**	**113,303,319**	**115,727,330**	**122,540,474**

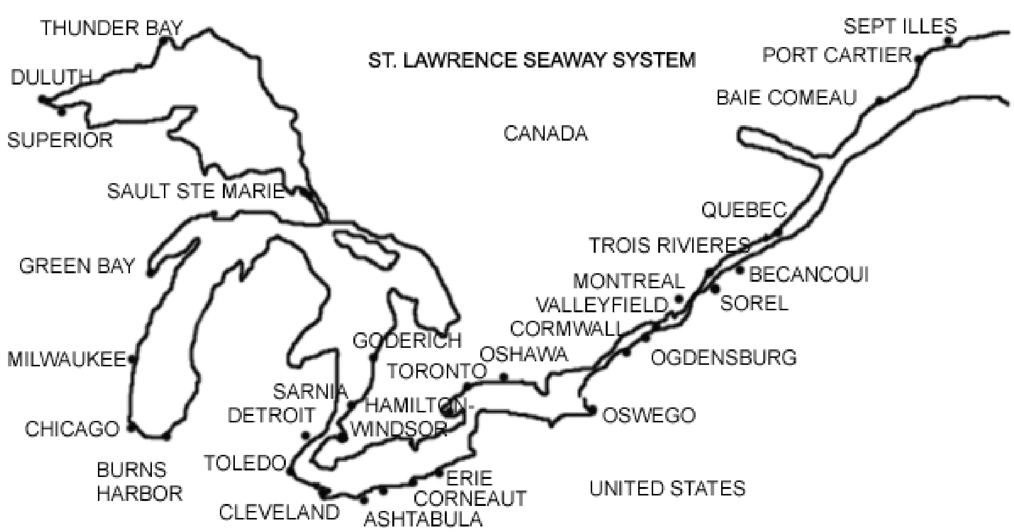

Figure 2. *Map of Great Lakes-St. Lawrence Seaway ports. Source: http://www.canadainfolink.ca/glks.htm.*

Lakes Superior and Ontario were determined (Hartmann, 1990). The net basin supply components were used in conjunction with the operational regulation plans and hydraulic routing models of outlet and connecting channel flows to estimate water levels on Lakes Superior, Michigan, Huron, St. Clair, Erie and Ontario. The Lake Superior regulation plan failed under the GFDL scenario and the Lake Ontario regulation plan failed under all scenarios. A large reduction in lake ice cover was also noted (Assel, 1991).

The International Joint Commission (IJC) Water Levels Reference Study (Working Committee 3, 1993) used the methodology developed for the EPA study with GCM scenarios from the Canadian Climate Centre to continue the assessment process. For this assessment the lake regulation models were adjusted to make them more robust to changes in water supplies, while retaining the same basic management framework (Lee et al., 1994). All of the GCM scenarios previously discussed did not include aerosols or the Great Lakes as a physical feature in the GCMs.

During the course of the last 10 years, climate assessments were also developed using historical analogues and climate transpositions, moving climates from the southeast and southwest U.S. to the Great Lakes (Mortsch and Quinn, 1996; Quinn et al., 1997), and stochastic simulations (Lee et al., 1994). These assessments allowed the consideration of changes in variability as well as changes in the extremes and the mean. While the historical analogues show relatively little change to the existing lake level regime, the transpositions show a wide range in impacts depending upon the particular climate used in the transposition.

The U.S. National Assessment[1] is the first Great Lakes study to use GCM scenarios with aerosols. The study uses transient scenarios developed from the recent Canadian Climate Centre model (CGCM1) and the Hadley Center model (HadCM2), the latter of which includes a rudimentary Great Lakes. The two scenarios focus on time slices representing the years 2021-2030 and 2081-2100. This work is progressing also using the basic framework established for the EPA study. This study focuses on the CGCM1 scenario for the 2030 time slice (Lofgren et al., 2002). The impacts for the CGCM1 scenarios are summarized in Table 2. The HadCM2 scenarios gave lake levels very

Table 2. *CGCM1 scenarios - Annual mean levels, base and differences (Δ) from the base for various time slices (Lofgren et al., 2002).*

Levels	**Base (ft)**	**Δ 2030 (ft)**	**Δ 2050 (ft)**	**Δ 2090 (ft)**
Superior	601.80	-0.72	-1.02	-1.38
Michigan-Huron	579.23	-2.36	-3.31	-4.52
Erie	571.78	-1.97	-2.72	-3.71
Ontario	245.45	-1.15	-1.74	-3.25

similar or slightly higher than the base case so the impacts on transportation would be the same as the base case. It is my understanding that HadCM3 gives similar results as the CGCM1 model. Good summaries of the hydrologic and lake level impacts of all the various studies are given in Lofgren et al. (2002) and Mortsch and Quinn (1996). *It should be noted that, unlike the seacoasts, the Great Lakes levels fall instead of rise under the influence of climate change*.

Impacts on Transportation

Lake Level Impacts. The Great Lakes transportation system is very sensitive to both changes in economic conditions and to climate change issues such as lower water levels and reduced ice cover. The lower lake levels due to climate change would result in reduced tonnage per trip, because of decreased draft, with the resulting need for additional trips to carry the same volume of cargo. For example, a 1000 foot bulk carrier loses 270 tons of capacity per inch of lost draft. An average ocean going vessel of about 740 feet loses 100 tons of capacity for each inch of lost draft. In addition, the greater number of trips, coupled with the possible increase in the number of vessels in operation, could result in traffic backups at the Soo Locks and perhaps at the Welland Canal. The connecting channels and harbors are dredged to provide a 27 foot project depth. Sanderson (1987) and Marchand et al.(1988) estimated Great Lakes shipping costs would increase by about 30 percent due to decreased lake levels.

The U.S. Government maintains a 27 foot depth, below low water datum (LWD) for navigation channels in the St. Marys, St. Clair, and Detroit Rivers as well as in Lake St. Clair and the Great Lakes ports. There is basically no impact on navigation in the open lakes because of their great depths, up to 1300 feet. The only problems would be in shoal areas where sufficient depths currently exist but could be problematic under a 1.3-5 feet levels decline. In the connecting channels and harbors, the projected levels declines would be below the project datum much of the time. Table 3 shows the average drop below the low water datum for each lake using the CGCM1 Scenario and the 2030 time slice. Thus by 2030 the average monthly lake level will be below the LWD for Lakes Superior and Michigan-Huron, at the LWD for Lake Erie, and above the LWD for Lake Ontario. This indicates a major loss of government guaranteed capacity for the transportation systems as early as 30 years from now.

Ice Effects. The Great Lakes ice cover is a natural feature of the Great Lakes. Its concentration and duration are a function of

Table 3. *CGCM1 scenarios - Monthly mean average levels, ft. (International Great Lakes Datum 1985).*

Levels	2030 (ft)	Low Water Datum (ft)	Difference (ft)
Superior	601.08	601.1	-0.02
MI-Huron	576.87	577.5	-0.63
Erie	569.81	569.2	+0.61
Ontario	244.30	243.3	+1.00

climate variability. The ice duration for a 1950 to 1995 base period ranged from 11 to 16 weeks (Lofgren et al., 2002). Under the CGCM1 scenario for 2030 the ice duration is reduced by about 12 to 47 days. Also the percent of ice-free winters will increase by about 2 percent for Lake Superior and 31-61 percent for Lake Erie, dending upon the basin. The ice cover restricts the shipping by blocking the navigation lanes, the ports, and the locks in the system. Historically, generally prior to the 1970s, the Great Lakes navigation season ran from mid-April through mid-November. At the present time the Soo Locks remain open for traffic through January 15 for inter-lake shipping. Intra-lake shipping continues throughout the winter at several locations. The U.S. and Canadian Coast Guard provide ice-breaking support for extended season navigation. The climate change scenarios indicate higher winter temperatures and reduced ice leading to a potentially longer shipping season on the Great Lakes. It is estimated that reduced ice cover will increase the shipping season by one to three months (Sanderson, 1987). This would increase vessel utilization and reduce the need for stockpiling commodities through the winter. It could also have the additional benefit of reduced ice-breaking costs. The extended season due to decreased ice cover could offset some of the costs resulting from lower lake levels.

Lake Regulation. The design and operation of the Lake Superior and Lake Ontario regulation plans will have a direct effect upon the shipping in the Great Lakes-St. Lawrence Seaway. By controlling the outflows from both lakes the regulation affects both upstream and downstream levels. The present Lake Ontario Regulation Plan does not function as designed under most climate change scenarios. The balancing between Lake Ontario and the lower St. Lawrence River, represented by the Port of Montreal, will be particularly important under climate change.

Mitigation. The mitigation required for climate change is the same as that required for extremely low lake levels. The usual form of mitigation for low lake level conditions is to dredge the harbors to maintain adequate depths for the ships to come in. However, deepening the connecting channels for a greater than 27-foot project depth will require an authorization and appropriation from Congress. Thus the 27-foot project will be the major impediment for navigation under a changed climate. Dredging in the harbors and connecting channels also has serious environmental impacts. Many of the harbors and channels have concentrations of mercury, PCBs, and heavy metals buried in their sediments. This material tends to be resuspended in the water column when disturbed. An environmentally friendly way of removing this material must be undertaken. There will also need to be a system of confined disposal areas designed to handle the dredged material. An associated problem is the geology underlying many of the harbors and connecting channels. The lower Detroit River and the Welland Canal have limestone bottoms, which will necessitate a multi-year effort of blasting the rock to increase the project depths. It should be noted that channel dredging in the connecting channel will have to be compensated for by constructing dikes or control structures in order to prevent additional lowering of the lakes due to increased capacity of the channels. In 1999 Congress provided a broad-range authority to review the feasibility of improving commercial navigation on the Great Lakes/St. Lawrence Seaway navigation system, including locks, dams, harbors, ports, channels, and other related features. The study will report on important factors affecting commercial navigation; such as evolving transportation technologies, inter-modal linkages, characteristics of the Great Lakes fleet and changes affecting demand sectors. The study will identify factors and trends that affect commercial navigation on the Great Lakes/St. Lawrence Seaway and it will project future trends, commodity flows and the external factors that affect them.

Adaptation. There are several things that might be considered in adapting to climate change. The first would be to extend the navigation season, perhaps year-round, to take advantage of the decrease in ice cover. The savings from vessel utilization, reduced stockpiling and increased trips may offset to some extent the impacts of the lower water levels. Also lake regulation plans should be evaluated as per their navigation-related performance under climate change. New additions to the Great Lakes fleet could be designed taking into account shallower navigation channels. It would however probably be prudent to wait until better estimates of the changed regional climate are available before making this type of economic decision.

The Water Resources Development Act of 1986 (P.L. 99-662) authorized, among other projects, a new large lock at Sault Ste. Marie, Michigan. Non-federal cost sharing for navigation construction projects was required by the law. The proposed new lock would be designed to replace two old and outmoded small locks. This lock design should consider the potential impacts of climate change by perhaps designing a wider and deeper lock than would be warranted under the present climate. It is much easier to design for climate change than to do a retrofit.

Conclusions

Climate change, as currently envisioned, could have a major impact on the Great Lakes-St. Lawrence Seaway transportation system. There are two counteracting impacts, lower water levels leading to reduced draft and increased transits, and reduced ice cover and duration leading to a greatly extended navigation system. The mitigation measures of the past, primarily channel and harbor dredging, are likely to be the first line of defense in the future. This will have to be balanced by strict environmental standards to protect the quality of the Great Lakes water. Prudent planning should include the evaluations of existing regulation plans and the design of the new lock at the Soo Locks. It is also important to update the earlier work on this subject by assessing costs and impacts with the newer climate scenarios and current economic conditions. It is essential that the industry be involved in this assessment relating to the shipping and the port infrastructure, which was not addressed in this paper. It would also be interesting to have the Coast Guard evaluate the impact of climate change on their Great Lakes activities.

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[1]The National Assessment of the Potential Consequences Of Climate Variability and Change (http://www.gcrio.org/NationalAssessment/) is a major effort to understand what climate change means for the U.S. Its purpose is to synthesize, evaluate, and report on what we presently know about the potential consequences of climate variability and change for the U.S. in the 21st century. Projections of climate change from the Hadley Centre (HadCM2) and the Canadian Centre for Climate Modeling and Analysis (CGCM1) served as primary resources for this assessment.

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