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GREAT LAKES SHIPPING, TRADE, AND AQUATIC INVASIVE SPECIES

Global Climate Change and Great Lakes International Shipping

Prepared for
Committee on the St. Lawrence Seaway:
Options to Eliminate Introduction of Nonindigenous Species into the Great Lakes, Phase 2
Transportation Research Board and Division on Earth and Life Studies

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INTRODUCTION

This study examines the potential impacts of climate change on Great Lakes international commercial navigation and on nonindigenous species. For the Great Lakes climate change is expected to result in lower water levels, shorter times of ice cover, and higher surface water temperatures, affecting both shipping and nonindigenous species.

Great Lakes international commercial navigation is defined here as shipping to or from an American or Canadian Great Lakes port and a country other than the United States or Canada. Great Lakes international commercial navigation includes cargo originating in the Great Lakes which moves to another country after being transshipped at ports in the lower St. Lawrence River and Gulf of St. Lawrence.

International shipping will be affected by lower lake water levels and less ice cover. Lower water levels will require that, in order to maintain sufficient under-keel clearances, vessels may have to reduce the tonnage of cargo carried on each voyage. Transporting a given tonnage of a commodity will require additional trips, thus increasing total shipping costs. This impact is estimated by simulating a typical annual pattern of cargo movements under various climate change and water level conditions. The qualifications to this analysis, typical of analyses of this type, are discussed. The second impact, reduced ice cover, could result in an extension of the navigation season. This impact is discussed in terms of the adjustments season extension may require. Currently, because of ice formation, the locks in the Great Lakes - St. Lawrence River system are closed for at least two months a year.

Higher surface water temperatures and reduced ice cover will alter the environment for all species, including nonindigenous species. The changed environment may favour nonindigenous species, compared to native species, encouraging the spread and abundance of nonindigenous species. The altered environment may also facilitate the introduction of further nonindigenous species.

After an overview of the effects of climate change on the Great Lakes, the impacts on commercial navigation and nonindigenous species are examined in detail.

CLIMATE CHANGE AND THE GREAT LAKES

Climate change, projected to occur because of increases in concentrations of greenhouse gases in the atmosphere, will likely be manifested in the the Great Lakes area by higher temperatures, causing increased evaporation and evapotranspiration, lower runoff into rivers and lakes, higher lake temperatures; and reduced ice formation with shorter periods of ice cover. Rainstorms may be more intense and, as a result of higher temperatures, more precipitation may fall as rain rather than snow. Overland evapotranspiration will increase and total runoff to the lakes will be lower due to the higher temperatures. Also, runoff may peak earlier due to a lower snowpack, changing the seasonal distribution of water levels. Overall, the average steady-state supply of water to the lakes is expected to decrease, resulting in lower lake levels and lower connecting channel flows. Any increases in precipitation are not expected to be sufficient to overcome the increased evaporation and evapotranspiration. (Hartmann 1990a and 1990b, Croley 1990, Mortsch and Quinn 1996, Chao 1999, Easterling and Karl 2001) Temperature increases may be partially offset by the cooling effects of aerosols introduced into the atmosphere. (Mortsch et al 2000)

There is evidence that the climate of the Great Lakes is already changing. Kling et al

(2005) report that winters are shorter, average annual temperatures are rising, and the duration of lake ice cover is decreasing as air and water temperatures rise. An assessment report states that over the last thirty years the maximum amount of ice forming on each of the five lakes each year is decreasing. (State of the Lakes Ecosystem Conference 2006) A recent study from the University of Minnesota Duluth reports that since the late 1970s Lake Superior has been warming faster than the regional atmosphere. This warming is due to the diminishing winter ice cover which allows increased solar radiation of the lake. (Austin and Colman 2007)

THE IMPACT OF LOWER WATER LEVELS ON COMMERCIAL NAVIGATION

The impact of lower water levels on commercial navigation is estimated by simulating international cargo movements in a recent year, 2001, first, with no climate change but allowing for seasonal and annual changes in water levels, then with various magnitudes of climate change, still allowing for seasonal and annual changes in water levels. The costs for the base case with no climate change are then compared with the costs for the climate change cases to estimate the costs imposed by the lower water levels due to climate change. In this section the data used and its sources are reviewed, the climate change scenarios described, the methodology outlined, and the results presented. Adaptation possibilities and the use of alternative modes are also discussed.

Data Used

The simulation requires data on the tonnages shipped by origin, destination, and commodity; vessel characteristics, including their capacity and changes in draught with changes in cargo tonnage; costs for vessel movements between each origin and destination; Seaway fees and port tolls; base case water depths encountered between and at each origin and destination; and water depths under various climate change scenarios. Each data requirement and source is discussed below.

Tonnages Shipped

Cargo movements by port and commodity for 2001 were obtained from Statistics Canada and the Institute for Water Resources of the US Army Corps of Engineers. Merging the data required the use of a common commodity classification. Canadian data used the Standard Classification of Transported Goods; American data were transformed to this classification system. An evaluation of the use of 2001 data may be found below.

The international cargo movements considered here are those from or to an American port or a Canadian port and a country other than the United States or Canada. The data set consists of 116 origin-destination-commodity combinations These international cargo movements are all exports or imports but exports and imports between the United States and Canada are not considered. The origin-destination-commodity combinations used here only represent part of the commercial navigation traffic in the Great Lakes - St. Lawrence system. Considerable freight also moves by way of this water transportation system between Canadian ports, between American ports, and between Canadian and American ports.

Unfortunately the American data do not provide the country of origin or destination for international shipments. Thus all shipments were assumed to move to or from the Gulf of St. Lawrence.

Table 1 presents a grouping of similar origin-destination-commodity combinations used in the analysis. The export of grains and other agricultural products takes place either through ocean going ships loading in Great Lakes ports and moving directly to overseas ports or through grain shipped by lake freighter to ports in the lower St. Lawrence River or Gulf of St. Lawrence for trans-shipment to ocean going ships. Ocean going ships which take on grain in the Great Lakes may also load additional grain in the lower St. Lawrence River and Gulf of St. Lawrence.

Two-thirds of the export and import tonnage transported in the Great Lakes is grain and other agricultural products. There are small tonnages of other exports. The major imports are base metals and articles of base metal, such as flat-rolled products of iron or steel and bars, rods, angles, shapes, sections, and wire of iron or steel. A variety of other imports make up 10.7 percent of international shipments. On a tonnage basis, exports are 70.6 percent of the total international cargo, imports are 29.4 per cent. The total tonnage of exports and imports is slightly greater for Canada than the United States.

TABLE 1 Exports from and Imports to Canada and the United States, 2001
(Excludes Trade Between Canada and the United States)

Commodities and Route	Country	Metric tonnes	% of Total Exports & Imports
Grains and agricultural products exported directly overseas	Can.	2,222,235	13.66
	U.S.	2,727,768	16.76
Grains and agricultural products exported, shipped to lower St. Lawrence River for trans-shipment	Can.	3,805,869	23.39
	U.S.	2,145,535	13.19
Other exports, incl. petroleum products, forest products	Can.	436,444	2.68
Other exports, incl. forestry products, base metals	U.S.	146,098	0.90
Imports of base metals and articles of base metal	Can.	886,065	5.45
	U.S.	2,161,978	13.29
Other imports, incl. sugar, petroleum products	Can.	1,102,111	6.77
Other imports, incl. forestry products, metallic ores	U.S.	637,024	3.92
Total exports and imports		**16,271,127**	**100.00**
Total exports and imports, by country	Can.	8,452,724	51.95
	U.S.	7,818,403	48.05

Sources: Statistics Canada and Institute for Water Resources, US Army Corps of Engineers

Vessel Characteristics

Both lake vessels and ocean going vessels are used for international shipments in the Great Lakes. As mentioned above lake vessels move grain and other agricultural products from Great Lakes ports to the lower St. Lawrence River and Gulf of St. Lawrence for trans-shipment. Ocean going vessels move a variety of commodities into and out of the Great Lakes. For the commodity flows in table 1 bulk carrying lake vessels (lakers) are assumed to move all grain and agricultural products to the lower St. Lawrence for trans-shipment; ocean going vessels are assumed to move all other commodities. This is a typical allocation of cargoes by vessel type in the Great Lakes - St. Lawrence River system.

Both lake and ocean going ships have possibilities for moving cargo in both directions, into and out of the Great Lakes. Many ocean going ships will bring iron and steel products into the lakes and take out grain. Lake ships moving grain out of the lakes to the lower St. Lawrence River or Gulf of St. Lawrence will often take on a cargo of iron ore at a Gulf of St. Lawrence port for delivery to a Great Lakes steel mill.

To determine vessel capacities; immersion factors, the change in vessel draught with a change in tonnage carried; and daily operating costs data were obtained for a representative lake vessel and a representative ocean going vessel. Vessel data came from Greenwood (2002), Seaway Marine Transport, Fednav International Ltd., and US Army Corps of Engineers Detroit District (2002).

Vessels in the Great Lakes - St. Lawrence River system are often loaded so that they operate with minimal under-keel clearances, the minimum allowable clearance being one foot or 0.3 metres. Lake vessels are constructed to take advantage of the water depths normally available. The larger ocean-going vessels will often not be fully loaded in the Great Lakes because of the limited water depths. Reduced water depths can significantly reduce a vessels's cargo. If a lake vessel has to reduce its draught by one metre, its capacity is reduced by 17 percent.

Travel Times, Fees and Tolls

Sailing distances between ports were obtained from Greenwood (2002), by measuring distances on navigation charts published by the Canadian Hydrographic Service, and from Canadian Hydrographic Service sailing directions. Fees and tolls were from the St. Lawrence Seaway world-wide web internet site.

Port and Channel Depths

Water depths at potential route constraint points, connecting channels, locks, the Seaway, and ports were provided by Greenwood (2002), the St. Lawrence Seaway Management Corporation, navigation charts, sailing directions, and Schulze et al (1981). Various world-wide web internet sites provided additional port information.

Climate Change Scenarios

Estimates of the impact of climate change on the Great Lakes - St. Lawrence River system were developed from global atmospheric models coupled to hydrologic models; the atmospheric conditions created by climate change are used to determine the resulting hydrologic situations. The atmospheric models were provided by general circulation models (GCMs), numerical representations of the atmosphere and its phenomena, which produce future forecasts of weather and climate conditions for all or for regions of the Earth. Increases in the atmospheric concentrations of greenhouse gases, a cause of climate change, are introduced into a GCM and the resulting climate conditions noted. Greenhouse gases, primarily CO_2, may be instantaneously increased and the model run until the climate is in equilibrium or gradually increased and the changing climate observed. Sulphate and other aerosols, which provide a cooling effect, the opposite of greenhouse gases, may also be introduced. The resulting temperature and precipitation data can then be used to derive changes in hydrologic conditions, including evaporation, evapotranspiration, runoff, and lake levels.

For the analyses reported here several predictions of water levels, termed water level scenarios, are used. The scenarios include a benchmark case and scenarios based on various magnitudes of climate change. The benchmark, labelled the Basis of Comparison (BOC), is used as a reference or base point for assessing the impacts of any change in water levels. Taking into account normal seasonal and annual hydrologic and climate variation, the BOC is assumed to provide an indication of the water levels that would occur naturally without climate change. The BOC is the set of water levels that would have occurred each month of the 90-year period from 1900 to 1989 if all current regulation plans, structures, channels, and diversions had been in effect over that period. The hydrologic conditions or actual water supplies that occurred over these 90 years are applied to current water management procedures and structures to derive a set of monthly water levels for various locations on the Great Lakes and the St. Lawrence River.

Mortsch et al (2000) have estimated the impacts on water levels of climate change on the Great Lakes using several climate change scenarios. This study uses the following three scenarios:

CCCma 2030: Canadian Centre for Climate Modelling and Analysis, a transient run
CCCma 2050: Canadian Centre for Climate Modelling and Analysis, a transient run
CCC GCM1: Canadian Climate Centre, General Circulation Model 1, an equilibrium doubling of CO_2 run[1]

The transient scenarios (CCCma 2030 and CCCma 2050) are developed from global climate change model runs that simulate the response of the climate system to a gradual increase in greenhouse gases and sulphate aerosols. Greenhouse gases increase at past rates up to the present and then are assumed to increase by one percent a year until 2100. The cooling effects of sulphate aerosols are included in the models. The period 1961-1990 is the base climate, 2030 represents an average of 2021 to 2040, and 2050 represents an average of 2041 to 2060. Climate change is the difference between the base and 2030 and the base and 2050. A drier and warmer

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[1] The GCM Modelling component of the Canadian Climate Centre is now part of the Canadian Centre for Climate Modelling and Analysis.

climate is indicated with runoff and outflow decreasing and evapotranspiration and lake evaporation increasing, resulting in lower lake levels. (Mortsch et al 2000, pp. 156, 171-2)

For the older CCC GCM1 scenario, the atmospheric concentration of CO_2 is doubled and the climate allowed to stabilize at a new level. The cooling effect of sulphate aerosols is not considered. Water levels are lowered with less yearly runoff for all the lakes. (Mortsch et al 2000, pp. 155, 171)

The climate change scenarios used here are representative of the vast majority of similar scenarios. In a recent report Mortsch et al (2005) state that only one scenario out of the 34 constructed for the Great Lakes had shown an increase in water levels, and only a very small increase. This was the HadCM2 scenario from the UK Hadley Centre. All other scenarios indicated a decrease in water levels.

For the benchmark BOC, monthly water levels at various locations in the Great Lakes – St. Lawrence River system were provided by Environment Canada for the 1900 to 1989 period. These levels were modified by Environment Canada to provide water levels for each of the three climate change scenarios.

Table 2 indicates the average change in water levels at selected locations for each of the climate change scenarios, compared to the Basis of Comparison. Except for Lake Superior the impacts are greatest for doubling the atmospheric concentration of CO_2 and least for the earlier transient scenario. The BOC data are levels above a datum in the Gulf of St. Lawrence, not depths.

Estimated Impact of Lower Water Levels

The potential impact of lower water levels was estimated by computing the operating costs for Great Lakes international commercial navigation under the Basis of Comparison and for each of the climate change water level scenarios and then comparing the costs for each climate change scenario to the costs for the Basis of Comparison. For the BOC and each climate change scenario the 2001 pattern and volume of international shipments is applied to the water levels generated by the scenario and the variable costs of moving the various commodities determined. The

TABLE 2 Average Change in Water Levels, by Climate Change Scenario

Location	Basis of Comparison Average annual level, metres	Average annual decrease from Basis of Comparison, metres		
		CCCma 2030	CCCma 2050	CCC GCM1
Lake Superior	183.34	0.22	0.31	0.23
Lakes Michigan and Huron	176.44	0.72	1.01	1.62
Lake Erie	174.18	0.60	0.83	1.36
Lake Ontario	74.84	0.35	0.53	1.30
Montreal Harbour	6.49	0.45	0.62	1.41

Note: Levels are based on International Great Lakes Datum 1985.
Source: Environment Canada

differences in variable costs between the BOC and the climate change scenarios are the estimated impacts of lower water levels. Annual shipments are evenly allocated over the navigation season to account for changes in seasonal maximum allowable vessel draughts.

The computer simulation minimizes the costs of moving the internationally traded commodities under each water level scenario, subject to the constraints listed below:

- The weight and volume of commodities to be shipped, by commodity, route, and season. The shipping costs for each scenario must include all commodities shipped during the example season of 2001.
- Vessel capacity, the maximum load the vessel can carry with no other constraints.
- Season of the year. For vessel safety the maximum allowable draught is greatest in the summer and lowest in the winter as the most severe weather is expected in the winter.
- Minimum water depth on the route. For each route the water levels and depths at the origin and destination ports, the connecting channels, and the locks and Seaway are examined to determine the minimum. The most constraining or limiting depth for each voyage is a determinant of the amount the vessel can carry. Required under-keel clearances are always maintained.
- The time required and thus the cost of a voyage.

Given the total weight of a commodity to be shipped between an origin-destination pair of ports and the available capacity for the type of vessel used, the total number of voyages required for each commodity and each origin-destination pair is computed for each of the years from 1900 to 1989. The length of each voyage, the number of vessel-days required, is a function of the number of days required for loading and unloading and for travel between the origin and destination ports, taking into account delays at the locks. The total vessel-days required for each origin-destination-commodity combination is determined by multiplying the length of the voyage in days by the number of voyages required.

Origin-destination-commodity combination variable costs are determined by multiplying total vessel-days by daily operating costs. The operating or variable costs are those which depend on operating time, the higher the number of vessel-days required the greater the total variable costs. The total variable cost for a commodity is the sum of the costs for all origin-destination pairs involving that commodity. The variable cost for a scenario is the sum of costs across all commodities.

The total variable costs by commodity and scenario are computed for each of the ninety years, 1900 to 1989, of water level data. For each scenario averages by commodity group and scenario over the 90 years are calculated and used in comparisons. The average annual costs for each climate change scenario are compared and contrasted with the average annual costs for the benchmark Basis of Comparison.

Over the ninety years for which costs are calculated for each scenario the only variable is hydrologic conditions. A fixed pattern of shipments and current daily vessel operating costs are used in computing total costs for each of the ninety years. The cost calculations for each year use the hydrologic conditions for that year but shipments and daily vessel costs are the same for all years. Thus the 1900 to 1989 average indicates the costs for average hydrologic conditions.

The percentage increases in costs for each of the climate change scenarios are presented in Table 3. The table shows the annual average costs for the BOC and the percentage increase in average annual cost over the 1900-1989 period for each of the three climate change scenarios, by commodity group and route. As expected the overall increase in cost is greatest for the doubling of CO_2 scenario, lesser for the 2050 transient scenario, and least for the 2030 scenario. But even with the 2030 scenario total costs are estimated to increase by approximately five percent. The doubling of CO_2 scenario would result in a cost increase of 22 percent.

The annual average increases vary by commodity group depending on the total amount shipped, the distances shipped, and allowable vessel loads. The other exports group has percent increases in cost greater than the overall average while the base metal imports group shows percent increases in cost below the average.

The variation by commodity group in the average annual cost data for the BOC reflects the variation in tonnage shipped for each commodity group, as presented in table 1. The implication of this is that the absolute burden of the cost increases due to climate change will not be uniformly distributed between commodity groups. The large shipments of grains and other agricultural products mean that these commodity groups together bear approximately three-quarters of the dollar value of cost increases.

TABLE 3 Climate Change Scenario Average Annual Cost Comparisons with the Basis of Comparison

Commodity group and route	Country	BOC Average annual costs, $ Can.	% increase in average annual costs over BOC, by climate change scenario		
			CCCma 2030	CCCma 2050	CCC GCM1
Grains and agricultural products exported directly overseas	Can.	17,619,824	5.31	9.76	23.47
	U.S.	23,622,519	4.95	9.30	22.62
Grains and ag. products exported, to lower St. L. R. for trans-shipment	Can.	35,657,559	5.63	10.53	26.73
	U.S.	20,355,006	4.15	7.96	21.71
Other exports	Can.	3,492,575	7.36	12.16	25.56
	U.S.	1,323,207	6.29	10.94	24.47
Imports of base metals and articles of base metal	Can.	5,856,075	3.35	5.48	14.97
	U.S.	19,711,794	3.50	6.44	16.55
Other imports	Can.	5,686,766	1.89	3.56	13.30
	U.S.	5,735,336	5.90	9.82	21.84
TOTAL exports and imports		139,060,660	4.77	8.78	22.14

The results presented are the costs using current prices for a future year when the full impact of a climate change scenario has occurred. The costs are not the present value of the future impacts of a climate change scenario. The impact of climate change will not occur immediately. It may be gradual with an increasing effect over time or it may occur more quickly with rapid changes in water levels, especially if a significant climate threshold is reached.

Historically Low and High Water Years

Natural hydrologic conditions vary considerably over the 1900 to 1989 period. Years with naturally determined high water levels allow vessels to carry greater loads and are favourable to commercial navigation; years with naturally determined low water levels limit vessel capacities and are unfavourable to shipping. Water level decreases due to climate change will compound the effects of naturally occurring low water levels.

To examine the worst and best case situations years with abnormally low water levels and years with abnormally high levels were used to compute costs for the BOC and each of the water level change scenarios. The lowest and highest years are not consistent for all lakes and locations; 1964 was the lowest year for Lakes Michigan, Huron, and Erie and Montreal Harbour; 1965 was the lowest year for Lake Ontario. Considering the highest years, 1986 was the highest year for Lakes Michigan, Huron and Erie, 1987 for Lake Ontario, and 1973 for Montreal Harbour. The year 1973 was also extremely high on Lakes Michigan-Huron and Erie. After 1986 it was the second highest year on record for Lake Erie and was tied for the second highest year on record on Lakes Michigan-Huron.

Table 4 presents comparisons of the highest and lowest average level years with the 1900 to 1989 average annual costs, by scenario. The percentage differences indicate the extent to which naturally occurring low water levels compound and naturally occurring high water levels offset the effects of climate change.

As expected the cost increasing impact of climate change would be even greater in naturally occurring low water years. For a low water year similar to 1964 the 2030 scenario generates a 13.34 percent further increase in cost over the average decrease in cost for the 2030 scenario. The 2050 and doubling of CO_2 scenarios result in even greater cost increases over the average increases for these scenarios.

TABLE 4 Cost Comparisons for Historically Low and High Water Years

Year		**% change in cost from 1900-89 average total cost, by climate change scenario**			
		BOC	**CCCma 2030**	**CCCma 2050**	**CCC GCM1**
Low water level years (increase in cost)	1964	5.19	13.34	15.49	18.12
	1965	2.08	9.10	10.90	12.88
High water level years (decrease in cost)	1973	1.22	-1.47	-4.41	-6.22
	1986	-0.64	-4.89	-8.17	-14.21
	1987	-0.52	-1.89	-4.69	-5.26

In the naturally occurring high water years the cost increasing impacts of climate change are ameliorated by higher water levels, with one exception. A high water year similar to 1986, for example, would result in the cost increase due to climate change being 4.89 percent less under the 2030 scenario. Under the 2050 and doubling of CO_2 scenarios there are even further offsetting effects for the high water years. The exception is the BOC for 1973, a year of high water levels for Montreal harbour but not necessarily everywhere in the Great Lakes - St. Lawrence River system. Some areas other than Montreal harbour experienced low water levels resulting in an overall small increase in cost for the BOC in 1973.

Adaptation

The estimation assumes that shippers and vessel operators take no adaptation, remedial, or avoidance measures. The model does not allow for reductions in amounts shipped, shifts to alternative modes, or suspension of shipments for routes when low water levels make shipping uneconomic. Such actions are difficult to predict.

Both short run and long run adaptations to lower water levels are possible. In the short run, with no change in the fleet or facilities, vessel loads are reduced with the consequent increases in the number of trips and shipping costs estimated here. On average the low levels predicted for 2030 have been experienced in the past and the shipping industry appears to react as predicted. Under the headline “Shallow Waters Lighten Loads” a business publication recently reported:

> “Record low water levels for this season on the Upper Great Lakes are creating concern for commercial shipping lines. ... [The] president of the Lake Carriers Association, estimates that 75 per cent of their ships are carrying less cargo than they could if they had appropriate water levels. ... Lightening loads leads to a big inefficiency in the system. It requires more trips using more fuel, manpower and time.” (Northern Ontario Business, November 6, 2006)

In the long run further adaptation may occur. If average water levels were to permanently drop or be lower for a significant part of most navigation seasons, cost-effective remedial measures would be carried out. Lake regulation policies could be used to offset lower water levels, diversions into the Great Lakes could be increased, and diversions out of the lakes decreased. Specific lake levels could be raised by limiting outflows through sills and narrowing outlet channels. Harbours and connecting channels could be dredged, although many will have contaminated material which is costly to handle or rock bottoms requiring drilling and blasting. Vessels specially designed for more efficient operation with lower water levels could be constructed and dock facilities adapted for lower water levels.(de Loe, Kreutzwiser, and Moreau 2001; Quinn 2001)

Various changes in vessel operation could also be used to avoid or minimize low water situations. Shipments could be rerouted to ports less affected by low water levels. Part of a vessel’s cargo could be unloaded at a deep water port and the reminder unloaded at a port with shallower water. Similarly, a vessel could begin loading at a shallow water port and continue loading at a deeper water port. Many ocean going vessels now handle their outgoing grain cargos in this way, part loading in the lakes and finishing loading at the deep water ports on the St. Lawrence River and Gulf of St. Lawrence. One technique used by self-unloading lake vessels, which have a long conveyor boom for unloading, is to hold the vessel off the dock where shallow water may be present and bridge the gap by swinging the end of the boom over the dock.

Alternative Modes and Routes

For many commodities alternative modes and routes are available and would become more competitive as the cost of Great Lakes water transport increases. Grain exports are a prime example of this. Grain shipments can avoid the Great Lakes - St. Lawrence River system by rail shipments to lower St. Lawrence River ports, western Canadian ports, the port of Churchill, Manitoba, or, possibly in combination with barge transportation, Gulf of Mexico ports.

The cost of shipping grain by various routes was estimated by Sparks Companies in a 2000 report for Transport Canada. They present the following cost comparisons for shipping a tonne of wheat from Winnipeg to Egypt, one of the example overseas markets used:

Route	$Can/tonne	% above lowest
Rail to Thunder Bay, ocean-going vessel (lowest cost)	69.06	-
Rail to Churchill, ocean-going vessel	70.76	2.5
Rail to T. Bay. laker to lower St. L., ocean-going vessel	73.70	6.7
Rail to Quebec city, ocean-going vessel	77.40	12.1
Rail to New Orleans, ocean-going vessel	79.34	14.9
Rail and barge to New Orleans, ocean-going vessel	87.64	22.6

Source: Sparks Companies Inc. (2000)

Shipments out of Thunder Bay on ocean-going vessels were the lowest cost when the study was done (1999). Ocean going vessels have several cost advantages; they are usually foreign-registered, allowing them to use lower cost foreign crews and pay lower taxes and capital costs. Most of these vessels bring cargo into the Great Lakes and thus can offer attractive rates on their return journey. Also, with an ocean-going ship there is no need to trans-ship all the cargo in the lower St. Lawrence River, as with a laker, thus avoiding some elevator costs.

The route through Churchill, Manitoba is shown as attractive economically but has capacity limitations and, currently, a shorter shipping season, July to November, than Thunder Bay with its late March to late December season.

These costs were computed in 2000 and give an approximation of competitive routes and modes. They were based on the currency exchange rates, transportation technology, and degree of climate change then prevailing. It is unlikely the same ranking exists today and most unlikely the same ranking will exist in the future.

QUALIFICATIONS

Any analysis of this type is subject to a number of qualifications. Some arise from the assumptions used in the computer simulations, other arise because of possible future changes.

Assumptions

Use of 2001 Data

The analysis is based on the 2001 pattern and volume of shipments exported from and imported to the Great Lakes. The validity of using this data may be assessed by comparing 2001 with other recent years. Table 5 gives total transits and tonnage shipped through the Montreal-Lake Ontario section of the Seaway; for both international and domestic trade. The year 2001 appears to be representative of recent years, with total tonnage just 4.6% below the 2000 - 2006 average.

The total tonnage shipped through the Montreal - Lake Ontario section of the Seaway in 2001 and classified as international cargo was 16,271,127 tonnes, 53.7% of the total tonnage shipped through the Montreal - Lake Ontario section in 2001. This is the cargo shipped to and from outside Canada and the United States. The remainder of the cargo for the Montreal - Lake Ontario section is shipped within and between Canada and the United States.

A considerable proportion of the shipments within and between Canada and the United States would also be part of the export and import process. Some Canadian and American shipments would be inputs for industries exporting at least part of their production; some may be combined with imported inputs during production.

TABLE 5 Montreal-Lake Ontario, Transits and Cargo, 2000-2006

Year	Transits	Cargo, tonnes
2000	2,977	35,406,212
2001	**2,588**	**30,277,824**
2002	2,612	30,002,292
2003	2,579	28,900,440
2004	2,683	30,800,380
2005	2,695	31,273,322
2006	2,953	35,546,000
Avg. 2000-2006	2,727	31,743,781

Source: St. Lawrence Seaway

Operational Efficiencies

The costs presented here are estimates only and are primarily presented for comparison purposes. They are underestimates of actual costs as certain operational efficiencies are assumed but may not always be achieved. The analysis is based on the operating costs for a series of one-way voyages, hauling the current volumes, and operating within the current navigation season. The costs of empty return or positioning trips are not included since, in some cases, the return trips are made with revenue-producing cargo. Otherwise, return or positioning trips are made empty. When lower water levels necessitate additional voyages to move a given amount of cargo between an origin and destination more empty return or positioning trips may also be necessary, an additional cost of lower water levels. Not including these additional trips without cargo leads to an underestimate of the impacts of lower water levels.

The simulations assume vessels are always loaded to their available capacity, which, for reasons other than water depths, may not always occur. The study does account for seasonal variations in water levels but vessel operators may be able to take advantage of these by scheduling additional shipments during seasonally high water levels. Capital costs of vessels are not included, only those costs which vary as the result of the number of days operated are included. If additional trips are necessary fleet additions may be necessary but, as discussed below, the current fleet could handle additional voyages if an extended navigation season is allowed by reduced ice cover.

The estimates presented in the paper are estimates of the cost of transporting various commodities. The price vessel operators charge to shippers will depend on this cost but will also be influenced by the volume shipped, the possibility of a back haul, the availability of competitive modes, and other contract conditions.

Future Traffic Patterns

Freight traffic patterns could be considerably different in the future. Relative shipping costs for alternative modes and routes may change resulting in commodity shipments switching modes and routes. The normal evolution of firms and industries will, no doubt, result in changes in the transportation of bulk commodities. Markets for agricultural products may grow or diminish, sources of raw materials may change, and technological developments may alter the inputs required by various industries. General economic growth should increase the demand for water transport.

The future will also see widespread impacts of climate change, affecting not only Great Lakes shipping but other modes and routes and the demand for and supply of those commodities now shipped on the Great Lakes. The total production of grain and the location of its production may change, thus changing the demand for grain transportation. Individual routes may become more or less attractive. For example, with less ice in the north, the port of Churchill, Manitoba, from which some grain is now exported, may become more active, taking traffic from the Great Lakes.

Increase in Surface Water Temperatures

With higher lake water temperatures the specific gravity of lake water will fall and, due to thermal expansion, the volume of water in a lake will increase. Both of these impacts, however, will be relatively small. When the temperature of fresh water increases from 5 degrees C. to 10 degrees C. the density of water decreases about 0.03 percent, the thermal expansion of water is about 0.1 percent.[2] Also, with respect to their effects on the under-keel clearances of ships, the two effects will offset each other. With a decrease in density ships will float lower; with thermal expansion ships will float higher.

Because of their very small and offsetting effects these two effects were not included in the analysis. Also, the estimates of climate change impacts and the projected increases in costs due to lower water levels are not so precise that these effects would change the significance of the estimates.

Fleet Composition

As discussed above the analysis uses standard vessel sizes; a standard bulk carrier or laker for the trans-shipment of grain to the lower St. Lawrence River and a standard ocean-going vessel for all other shipments. The standard laker closely represents nearly all the vessels used for these grain shipments. Practically all lake vessels in the Great Lakes - St. Lawrence River system are built to take maximum advantage of Seaway lock dimensions; they are as large as allowed by the length, width, and depth of the Seaway locks.

There is a wider variety of ocean-going vessels coming into the Seaway. Many approach Seaway lock dimensions but many are somewhat smaller. The standard ocean-going vessel used in the analysis is regarded as appropriate for Seaway and open ocean use. The vessel was recently constructed, launched in 2005, and its design is based on extensive experience with vessels operating in the Great Lakes and open oceans. The design is regarded as an excellent compromise between the needs to successfully handle open ocean conditions, fit overseas dock restrictions, and carry a large cargo in the Seaway. To be suitable for ocean voyages and overseas ports the length and width of this standard vessel are less than allowed by Seaway lock dimensions. The size of the example vessel was 20,661 net tons, based on the International Tonnage Convention (ITC) . Smaller and larger vessels, however, are engaged in international trade in the Seaway. To the extent that smaller and larger vessels are used, the standard vessel does not represent all ocean-going vessels using the Seaway.

The distribution of the sizes of ocean-going vessels using the Seaway in 2006 is presented in Table 6. Vessels over 15,000 tons in size made 54 percent of the transits, but the transits of these vessels represented 76 percent of the total tonnage of vessels using the Seaway in 2006. While a number of smaller vessels engaged in international trade are using the Seaway, the majority of cargo tonnage is carried by larger vessels. The smaller vessels, having shallower draughts, are less likely to be affected by lower water levels due to climate change. Thus, to the extent that smaller vessels carry commodities for international trade, the estimates of the cost increases due to lower water levels will overstate the impacts. Conversely, to the extent that

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[2] Croley (2003) presents data on the impact of climate change on surface water temperatures for each of the Great Lakes under several climate change scenarios. The base temperature varies between 5.8 and 11.0 degrees C.; the largest average steady-state increase in surface water temperature is 4.2 degrees C.

larger vessels carry commodities for international trade, the estimates of the cost increases due to lower water levels may understate the impacts. The smaller vessels will likely have higher costs per tonne-nautical mile than larger vessels but may be more suitable for specialized or low volume cargo.

Other Potential Impacts of Climate Change on Commercial Navigation

The impact of climate change on commercial navigation has been estimated by examining the effects of the reductions in water levels due to climate change. There may, however, be other impacts of climate change on commercial navigation, not analysed in this report. Extreme weather events may become more intense and/or more frequent, forcing vessels to delay voyages; short sea shipping within the lakes may become more attractive because of its environmental benefits; crop production patterns may change, possibly increasing grain production and the demand for shipping capacity; and vessels may be forced to control engine exhaust emissions, an additional expense.

REDUCED ICE COVER AND SEASON EXTENSION

The second impact of climate change examined here is the effect of reduced ice cover leading to the possibility of extending the navigation season. The current situation is reviewed, the potential for season extension examined, and the implications of season extension discussed.

TABLE 6 Upbound Transits by Vessels Engaged in International Trade, Montreal - Lake Ontario, by Vessel Size, 2006

ITC Tonnage Class	Number of Transits	Average Vessel ITC Tonnage	Total Vessel ITC Tonnage	% of Total ITC Tonnage
20000 and over	148	21,797	3,226,029	39.90
15000-19999	165	17,687	2,918,381	36.10
10000-14999	41	11,844	485,623	6.01
5000-9999	195	6,883	1,342,214	16.60
1102-4999	31	3,623	112,324	1.39
Total	580	13,939	8,084,571	100.00

Source: St. Lawrence Seaway Management Corporation

Current Navigation Season

Currently the Seaway and Soo locks are closed for over two months every winter. Ice conditions make use of the locks very difficult, time is required for lock maintenance, and winter navigation in restricted channels presents environmental problems. Reduced ice cover, a predicted impact of climate change, may allow the navigation season to be extended. The conditions allowing for opening of the navigation season would occur earlier and conditions requiring closing the locks would occur later. This type of season extension would avoid the navigational and environmental problems associated with winter navigation.

Presently the opening and closing dates for the St. Lawrence Seaway, both the Montreal - Lake Ontario section and the Welland Canal are somewhat flexible. The dates are set taking into account ice conditions, the demand for service, and maintenance requirements. The opening also depends on the availability of ice breaking services as ice breaking is usually needed immediately before the opening and for a short period afterwards. Opening and closing dates are announced by the Seaway five to six weeks in advance although vessel operators and shippers know the approximate dates from past practice. In 2006 the Welland Canal opened on March 21 and the Montreal-Lake Ontario section of the Seaway opened on March 23; both closed on December 30.

The Soo locks, between Lake Superior and the other lakes, have set opening and closing dates, opening on March 25 and closing on January 15, dates which are published in the US Federal Register. Some flexibility is possible on the closing date depending on the demand for service and ice conditions. But a short extension in 2004 was not successful as a ship became stuck in ice. The setting of fixed dates arose because of difficulties when the season was extended in the past. From 1974 to 1979 the Soo Locks were open year-round but, because of environmental concerns, a fixed closed period was adopted.

Season Extension in the Future

Neither the St. Lawrence Seaway nor the Soo Locks have plans to extend the season, but season extension could evolve if permitted by ice conditions. There has been a gradual increase in the length of the navigation season for the Seaway. For the five years from 1982 to 1986, the average open period for the Montreal - Lake Ontario section of the Seaway was 269 days; for the five years 2002 to 2006 the average open period was 279 days, an increase of 10 days. In 2006 the Montreal - Lake Ontario section was open a record 283 days.

Winter navigation is opposed by a number of environmental groups, including Great Lakes United, an international coalition of environmental organizations, municipalities, unions, and individuals “dedicated to preserving and restoring the Great Lakes-St. Lawrence River ecosystem.” (Great Lakes United, p. 6) In 1984 the organization achieved “its first major victory by persuading Congress to defeat an Army Corps of Engineers proposal for winter navigation on the Great Lakes. Nine years of feasibility demonstration projects had clearly shown that ice-breaking to keep winter shipping lanes open was not only economically impractical, but also responsible for severe damage to fish and wildlife habitats.” (Great Lakes United, p. 13) Opposition to winter navigation also comes from Save the River, a grass roots organization established in 1978 to oppose winter navigation then proposed for the St. Lawrence Seaway; The International Water Levels Coalition, a bi-national citizens’ group; the Clean Water Alliance of

Minnesota; and the Save Lake Superior Association.[3]

All-winter navigation is no longer being seriously considered but some environmental groups and others have expressed concern about the impacts of ice breaking at the start of the navigation season, arguing that navigation should only commence when there is no need for ice breaking. Save the River "opposes a longer shipping season because of the dangers posed to the delicate ecosystem of the River … The opening of the Seaway should not take place until ... no icebreaking should be needed on the River to allow for ship passage. ... Ship generated wave energy can result in premature ice break up and cause ice scouring damage in wetland habitats adjacent to the shipping channel."[4] In February 2005 Congressman John M. McHugh, representing the district bordering the St. Lawrence River, expressed concerns about opening the Seaway when parts of the river are still covered in ice. (McHugh 2005)

This is opposition to winter navigation or early navigation which involves extensive ice breaking. If there is a shorter period of ice cover, allowing the navigation season to be lengthened with a decrease in ice breaking, then there will likely be less opposition to a longer season. It appears that any extension of the navigation season will only be publicly acceptable if the period of ice cover is reduced and there is, at least, no increase in ice breaking.

In past years aboriginal groups along the St. Lawrence River have expressed concerns about the impacts of the Seaway, particularly ice-breaking during the beginning of the navigation season. Their concerns include environmental impacts, disruption of wildlife and wildlife habitats, shoreline erosion, and the inability to travel on ice to hunting and fishing areas. In 2006 a Memorandum of Understanding was signed between the Canadian and U.S. Seaway Corporations and the Mohawks of Akwsesane describing procedures to be followed by all parties prior to the annual opening of the Seaway. Information will be exchanged, notification will be given of ice-breaking activities prior to the opening of the Seaway, and ice-breaking will be jointly observed. A common study of the impact of ice-breaking activities will be done over three years. Additional procedures will be followed and discussions undertaken if the season is to be opened before March 15 or closed after January 10.[5]

For the 2006 navigation season the Seaway announced on November 14, 2006 that the Montreal - Lake Ontario section would close on December 29, 2006 and that the Welland Canal would close on December 30, 2006. Passages in the last few days of the season could only be done with prior written agreement with the Seaway. The opening dates for the 2007 season were announced on February 20, 2007. The Montreal - Lake Ontario section opened on March 21, 2007, the Welland Canal opened on March 20, 2007, a record early opening date. The Seaway's press release on the opening states that "The decision to open on the 20th stems partially from Seaway clients requesting an earlier start, and was made after carefully reviewing maintenance schedules and environmental considerations." Also "Opening and closing and closing dates are set after careful deliberation, taking into account a host of factors and the interests of a diverse group of stakeholders."[6]

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[3] Information on these organizations may be found at the following world-wide web sites:
http://www.savetheriver.org
http://www.iwlc.org/events.html
http://www.cleanwateraction.org/mn/about.html http://www.cpinternet.com/~kritchie/slsa/slsa.html

[4] http://www.savetheriver.org/documents/STRopeningcriteriawhitepapermarch07.pdf

[5] Further information is available at http://www.greatlakes-seaway.com/en/news/pr20060629.html

[6] http://www.greatlakes-seaway.com/en/news/pr20070220.html

Lock Maintenance

The closed season is used for lock maintenance, mechanical overhauls, and replacement of machinery and other parts. Some period of closure is required every year for regular maintenance and inspection. Maintenance engineers suggest this regular annual maintenance could be done in one month, providing no major problem is encountered. Every three to five years, however, major maintenance, replacement and upgrading of lock machinery, and possibly resurfacing of lock walls is necessary, requiring at least two months. Thus, for many years a maintenance closure of one month would suffice but every third to fifth year a longer closed period would be required. Maintenance procedures and schedules would have to be rearranged and possibly more outside contractors hired to accommodate the shorter closed periods. Aging of the locks is increasing maintenance requirements. The Montreal - Lake Ontario locks are approaching 50 years of age, the Welland Canal locks will be 75 years old this year.

If year-round navigation is ever permitted by a drastic reduction in ice over, complete closures for maintenance could be avoided if all locks were twinned. Presently only three of the eight Welland Canal locks are twinned. Plans have been developed but no funds allocated to twin the Poe lock at Sault Ste. Marie.

Ice Breaking

Some ice breaking is usually required at the start and the end of the navigation season, particularly the start after ice has formed over the winter. Ice breaking on the Great Lakes is a cooperative effort of the US Coast Guard, the Canadian Coast Guard and private operators. Liaison between the two Coast Guards is strengthened by the stationing of US Coast Guard officers in the Canadian Coast guard office in Sarnia, Ontario during the ice season. One American and two Canadian large ice-breakers are stationed in the Great Lakes. These are multi-purpose vessels which can also be used for maintaining navigation aids, search and rescue, law enforcement, and oil-skimming at spills. The U.S. Coast Guard also has two ice-strengthened buoy tenders and five tugs for local ice breaking. Private operators of tug boats are involved in ice breaking in harbours, assisted by ice breakers when thicker ice is present.

Ice breaking capability would not appear to be a problem with an extension of the navigation season. The times when ice breaking was necessary would be earlier in the year if the locks open earlier and later in the year (or early the following year) if the locks stay open longer. The times of ice breaking would shift and adaptation to a longer navigation season would be straight forward. If ice in harbours became more prevalent it is likely private operators would build or buy additional tug boats to handle this ice.

Navigation in ice and ice breaking may have some environmental impacts. Vessels moving in ice in channels may result in ice scouring channel banks and bottoms disrupting vegetation and aquatic organisms. Vessels' propeller wash may also disrupt vegetation and aquatic organisms. Fish habitat, activity, and spawning could be affected. Shoreline structures may be damaged. Ice breaking may also disrupt human and animal movements on ice. These impacts may occur at the beginning and end of the navigation season. Extending the season with reduced lake and river ice cover will move these potential impacts to earlier and later time periods. As mentioned above the early season environmental impacts are of concern to environmental organisations and others.

Other Implications of Season Extension

The longer annual time of utilization of ships and loading and unloading facilities, less need for stockpiling, and lower ice-breaking costs may offset some of the increased costs due to lower water levels. Possibly the additional trips necessary because of lower water levels could be carried out in an extended season without any increase in total fleet size. The longer navigation season with a reduction in ice cover will likely also influence the pattern of shipments and may result in other traffic being attracted to the system.

The extended season could not only be used by international shipping movements but will also be used by inter-lake and intra-lake shipping. Some of these movements are now occurring when the locks are closed, often with ice-breaker assistance, and will likely expand with a longer ice-free season. One issue may be the suitability of cargo handling equipment if operations take place during colder weather. Some of the current equipment may not be cold weather-capable but could be modified for cold weather operation.

POTENTIAL IMPACTS OF CLIMATE CHANGE ON NONINDIGENOUS SPECIES

Besides the impacts on commercial navigation, climate change, by its broad impact on the environment, will affect the indigenous and nonindigenous fish and other species found in the Great Lakes. Conditions for all species will be altered, with climate change favouring some and negatively affecting others. With a mixture of climate change impacts, some uncertainty about the extent of these impacts, and a wide variety of indigenous and nonindigenous species, predicting the impacts of climate change on nonindigenous species is complex. Changing environmental conditions could result in further invasions of nonindigenous species and the expansion of the habitat of others. With the introduction of nonindigenous species native species are now forced to compete with the nonindigenous species.

Mandrak (1989) provides an estimate of the possible invasions of fish species into the Great Lakes as a result of climate change. Comparing the ecological characteristics of species which had already invaded the Great Lakes with the ecological characteristics of potential invaders, he estimates that 27 of 58 common, widely distributed species were potential invaders, either from the lower to the upper lakes or from outside the Great Lakes. As background to the study he notes that changes in Great Lakes fish communities over the last 200 years had made the Great Lakes more susceptible to invasions. As a result of overfishing, eutrophication, habitat destruction, and fish introductions the dominant Great Lakes fish species went from large, long-lived species to small, short-lived species characterized by decreased diversity and increased population fluctuations.

The higher Great Lakes water temperatures arising from climate change are expected to have a variety of biological effects on the Great lakes, including changes in water quality, the food web, the length and timing of reproductive and growing seasons, and species composition and distribution. (Baskin 1998) Water temperatures are crucial to species’ survival, reproduction, and spread. The effects of water temperature on species’ growth and abundance is demonstrated by a study of the effects of increases in Lake Ontario water temperatures. An increase in open-water temperatures in the Bay of Quinte over the last 50 years provided an opportunity to observe the effects of temperature change. Warm water fish species were enhanced and a decreased recruitment of cold water fish species and, to a lesser extent, cool water fish species observed. The climate change implications of this are that rising temperatures in the Great Lakes will expand the suitable habitats for warm water and some cool water fish species and reduce cold water and cool water fish species' habitat. (Casselman 2002)

Not only will increases in water temperatures alter the environment for fish species but for all species, including nonindigenous species. The warming of the lakes will favour those species that grow and multiply in warmer waters. Nonindigenous species, many of which have come from warmer waters and are thus well adapted to these temperatures, may have a competitive advantage over cool water and cold water species in the Great Lakes. Casselman notes that "Evidence already exists that the invasion of many warm water species throughout the Great lakes Basin has been correlated with abnormally warm periods ..." (Casselman 2002, p. 56)

The impact of water temperature on the abundance of nonindigenous species is substantiated by a study of Lake Superior. Lake Superior receives considerable ballast water discharges, a known pathway for the spread of nonindigenous species, but the abundance of nonindigenous species is less than expected. The lower water temperatures of Lake Superior are likely one of the factors inhibiting the growth and spread of nonindigenous species, particularly those from the warmer waters which are a major source of these species. The limited availability of nutrients, lower biological productivity, and habitat homogeneity also limit the species able to survive in Lake Superior. (Grigorovich et al 2003)

Besides the enhancing effect of warmer temperatures on nonindigenous species now in the Great Lakes, warmer water temperatures are also expected to encourage the migration of nonindigenous species between and into the Great lakes. A northward movement of warm water nonindigenous species is likely, with species in the southern lakes moving into the northern lakes. (Beeton 2002; Chu, Mandrak, and Minns 2005; Dukes 2000) Warmer temperatures may also facilitate the invasion of nonindigenous species that have established themselves in adjacent waters. (Baskin, 1998). In the past nonindigenous species have used the Chicago canal system to enter Lake Michigan from the Mississippi River system. Warmer Great Lakes waters are expected to encourage such migrations. (Kolar and Lodge 2000)

Climate change may have its greatest impact on nonindigenous species through changes in maximum and minimum temperatures and the length of time warmer temperatures prevail, rather than changes in annual average temperatures. Earlier warm temperatures may give nonindigenous species an earlier start, possibly making them more competitive with native species (Stachowicz et al, 2002) If the winter climate is less severe then few winter kills of thermally ill-adapted nonindigenous species may be expected. (Mills et al 2005) Also, nonindigenous species may have higher growth rates at maximum annual temperatures than native species. (Stachowicz et al 2002)

Higher temperatures could increase the probability of nonindigenous species achieving minimum viable population sizes before the onset of seasonal lower temperatures. For a zooplankton species the development time for eggs is inversely related to temperatures, the higher the temperature the shorter the development time. Higher temperatures would allow faster development of nonindigenous zooplankton eggs and thus the development of more generations before seasonal lower temperatures restricted development. Even if the impact of this effect is small, it may be critical in a nonindigenous species achieving a minimum viable population size before the occurrence of unfavourable winter conditions.

While temperature change is significant, Jones et al (2006) suggest that predicting the possible effects of climate change on both indigenous and nonindigenous species requires an examination of all the effects of climate change on habitat, not just a consideration of the effects of higher water temperatures. Positive impacts at an early life stage may be countered by negative effects at a later life stage or vice versa. The authors model the impacts of river and lake temperature changes, river discharge, lake winds and currents, lake water levels, and lake thermal and light regimes on Lake Erie walleye. The results suggest that only considering the effect of higher water temperatures would give different results than considering the multiple effects of climate change. For example, higher lake temperatures result in an increased habitat area and volume for juvenile and adult walleye but lower lake levels reduce the habitat resulting in a net decrease in habitat area and volume.

The conditions of competition between indigenous and nonindigenous species may change. For example, patterns of thermal stratification in the lakes may be altered, reducing fish habitat and oxygen concentrations for fish and their prey. This negative impact on indigenous species may allow populations of nonindigenous species to expand. Even if the nonindigenous species are not good competitors, the nonindigenous species may grow as a result of deteriorating conditions for indigenous species. Some nonindigenous species may gain advantages over native species; nonindigenous species may be faster to adapt to local conditions. (Baskin 1998)

There are also detrimental effects of reduced water levels. Lower water levels combined with warmer surface waters and a shortened ice season may provide shallow water areas more suitable for nonindigenous species. (Taylor et al 2006) Mortsch et al (2006) assessed the impacts on Great Lakes coastal wetlands of lower water levels and higher temperatures, predicting the effects on wetland vegetation, bird, and fish communities. They conclude that species with the ability to accommodate to environmental changes will adapt to changing hydrologic conditions. Other species with narrow environmental tolerances and limited reproductive capacity are at risk from the consequences of climate change. The authors predict “these hydrologic stresses will likely result in reductions to the distribution of rare, specialist species and the expansion of generalist and invasive species.” (p. 249) Invasive plant species in Great Lakes coastal wetlands are also enhanced by land use changes. Frieswyck and Zedler (in press), examining recent vegetation changes in several areas of Great Lakes coastal wetlands, find that invasive species growth in these areas is related to urbanisation in the wetland watersheds.

SUMMARY

The possible impacts of climate change on Great Lakes international shipping and on nonindigenous species are examined. The expected higher temperatures of climate change are predicted to increase evaporation, lower runoff, reduce ice formation, and raise surface water temperatures in the Great Lakes, resulting in a fall in lake levels. The increased precipitation will not be sufficient to completely offset the reduction in lake levels.

For international commercial navigation in the Great Lakes the impact of lower lake levels will be restrictions in vessel draughts and tonnages carried, thus increasing the number of trips and the total costs to move a given tonnage of cargo. Estimates of these impacts are derived from a simulation of international cargo movements from and to the Great Lakes in a recent year.

Four water level scenarios are used, a base case with only seasonal and annual variation in water levels and three climate change scenarios, each representing different degrees of climate change.

The simulation minimizes the cost of transport subject to a number of constraints, including the depth of water available. In the climate change scenarios water depths are reduced thus restricting vessel loads and increasing costs over the base case. The impacts of climate change on total transportation cost vary from approximately five percent for a climate change scenario representing the possible climate in 2030 to over 22 percent for a climate change scenario representing a doubling of atmospheric carbon dioxide. The analysis of specific commodities and routes show some variation in these percentages. When years of naturally occurring low water are examined, the impacts are up to thirteen percent higher for even the most moderate climate change scenario. For year of naturally occurring high water climate change impacts are reduced.

Several qualifications apply to the results of the simulations. The analysis is based on one year's pattern of shipments which, with shifting demand and supply conditions, will likely change in the future. No adaptation, remedial, or avoidance measures are included. No doubt, with lower water levels a variety of adaptation measures would be instituted to lessen the impacts of lower water levels. The analysis is based on the characteristics of typical lake and ocean going vessels, representing the majority of vessels used. But the example ocean going vessel does not represent all ocean going vessels and, to the extent larger and smaller vessels are used, the impacts of lower water levels will change.

Climate change may also result in a shorter time of ice cover leading to the possibility of extending the navigation season. Seaway and lock managers now have no plans to extend the season but a longer season may evolve if allowed by ice conditions. Currently the Seaway sets opening and closing dates based on ice conditions and demand and has been gradually lengthening the season. The closed time of over two months during the winter is now used for lock maintenance. There is a possibility of reducing the time required for this maintenance, which would facilitate a longer navigation season. Regular maintenance could be done in one month but major maintenance and machinery replacement, requiring over two months, would have to be done every third to fifth year.

Ice breaking on the Great Lakes is a cooperative effort of the US Coast Guard, Canadian Coast Guard, and private tug boat operators. If the season is extended because of a shorter time of ice cover, the ice breaking done at the start and end of the season would move to earlier and later dates, respectively.

Climate change is generally expected to encourage the spread and abundance of nonindigenous species in the Great lakes. Higher water temperatures may alter the length and timing of reproductive and growing seasons which will likely positively affect nonindigenous species. Warm water species, including warm water nonindigenous species, are expected to be enhanced, becoming more competitive with cold water and cool water species. A northward movement of nonindigenous is predicted. If minimum winter temperatures are no longer as severe there will likely be fewer winter kills of thermally ill-adapted nonindigenous species. The lower water levels associated with climate change may also be of advantage to invasive species.

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