Research Note/Note de recherche

The Impact of Water Level Changes on Commercial Navigation in the Great Lakes and St. Lawrence River[(1)]

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This paper estimates the impact on commercial navigation of, first, the implementation of proposed water level regulation measures for the Great Lakes and St. Lawrence River and, second, a doubling of atmospheric carbon dioxide. The impetus for the development of new water level regulations was the high water levels experienced on most of the Great Lakes in the mid 1980s. These levels resulted from almost two decades of above normal precipitation and below normal evaporation in the Great Lakes-St. Lawrence River basin. They were a major cause of flooding, erosion, and shoreline damage. The International Joint Commission was asked to examine and report on measures to alleviate the adverse consequences of fluctuating water levels. The Commission established a Levels Reference Study Board which, in proposing ways of reducing the impacts of varying Great Lakes-St. Lawrence water levels, developed a number of new water level regulation measures.

Changes in the Great Lakes and St. Lawrence River levels are important to commercial navigation. Most vessels in the Great Lakes are constructed to take advantage of maximum allowable depths; their under-keel clearances in locks, harbours, and connecting channels are often less than one metre. Thus, even small decreases in water depths can reduce vessel carrying capacities and increase unit transportation costs. The impacts of water level changes are examined by simulating a recent year's (1989) pattern of shipments in the Great Lakes and St. Lawrence River with each of the proposed water level regulation measures in place and determining the changes in variable shipping costs resulting from each measure. A similar simulation is done using the water levels resulting from a doubling of atmospheric carbon dioxide. All impacts are compared to a benchmark reflecting historic hydrologic conditions and current water management structures and procedures

The next three sections review commercial navigation in the Great Lakes- St. Lawrence system, related past research, and the water level regulation measures evaluated. Thereafter the methodology is presented, followed by sections on the results and conclusions.

Commercial Navigation

The Great Lakes-St. Lawrence River system provides a strategically placed and efficient transportation system for Canada and the United States. Stretching 4,000 kilometres from the head of Lake Superior to the Gulf of St. Lawrence the system is a convenient and low-cost means of transporting commodities through a heavily industrialized part of North America. Navigation has been facilitated by the construction of locks at Sault St. Marie, the Welland Canal, and the St. Lawrence Seaway together with various water control structures.

Bulk commodities dominate the freight moved in the system as water transport is attractive for bulk commodities while other modes compete effectively for package freight.[(2)] Grain is moved from the upper lakes to lower St. Lawrence ports for transshipment to export markets. A backhaul of iron ore is available from the Quebec-Labrador region to mills in Ontario. The major movement of coal is from American Lake Erie ports to Ontario generating plants and steel mills. Other traffic includes domestic shipments of grain, petroleum products, salt, limestone, pulpwood, and other crude materials.

Ships of the Great Lakes fleet are usually built specifically for operation in the Great Lakes-St. Lawrence system. Most Canadian vessels are built to the dimensions of the locks in the Welland Canal and Seaway. The 1989 Canadian fleet was made up of 119 ships; 56 bulk commodity carriers (bulkers), 34 bulk commodity carriers with self-unloading capability (self-unloaders), 25 tankers, and 4 others. Bulkers are primarily engaged in long-haul grain and ore movements; self-unloaders are used more for short hauls of coal, salt, and limestone; and tankers for petroleum products. Canadian ships carry most of the Great Lakes-St. Lawrence waterborne trade between Canadian ports and between Canada and the United States. Among the reasons suggested for this are higher American operating and construction costs, the improvement of the Canadian fleet with the opening of the St. Lawrence Seaway, earlier Canadian government assistance programs, and the grain-ore shipment pattern available to Canadian ship operators (US General Accounting Office 1986).

Although there was concern in the early 1980s about the ability of the system to accommodate even modest increases in traffic, traffic has declined in recent years. A major reason is the reduction in grain shipments. Canadian and American sales to Europe have decreased, shipment through the Mississippi River system is an attractive alternative, and a larger proportion of Canadian grain is now exported through west coast ports. The shift to the west is due to expanding markets in Asia and a rail transportation subsidy policy that favours movements from the prairies to the west coast (Lake and Hackston 1990). The increased use of containers, mostly handled at ports outside the Seaway; more ocean-going vessels that are too large to enter the Seaway; limitations on winter navigation; Seaway tolls; and competition from railways have also contributed to the decline.[(3)]

Past Research

Two previous studies found that reducing lake levels would increase shipping costs. Marchand et al. (1988) were concerned with the effects of climate change. Increased carbon dioxide levels are expected to reduce lake levels and river flows, impeding navigation, but also reduce ice cover, expanding the navigation season. Annual shipping costs are estimated to increase by 15 to 33 percent, depending on the assumptions made about traffic increases. A 1981 study done for the International Joint Commission on the impacts of regulating only Lake Erie water levels through reducing high water levels but maintaining average levels found increases in annual shipping costs from one to ten million dollars annually (International Lake Erie Regulation Study Board 1981).

Water Level Regulation Measures Evaluated

The water level regulation measures examined here were developed by the International Joint Commission Levels Reference Study Board as sets of actions that could be taken to reduce the adverse impacts of fluctuating water levels and flows in the Great Lakes-St. Lawrence River system. Each regulation measure is a set of water management procedures and, for some measures, proposed physical changes in the system, such as dredging or the construction of water control and protective structures. Each measure attempts to generate water levels and flows to reflect the preferences of one or more interest or user group. To generate water levels and flows, a measure's management procedures and control structures are subjected to 90 years of natural variation in water supplies. The hydrologic conditions or actual water supplies that occurred from 1900 to 1989 are applied to the regulation measure's water management procedures and structures to give a long run view of the results that can be expected if a measure is implemented. The results for each measure include monthly level and flow data for each lake and for other points for the 90 years from 1900 to 1989.

A benchmark, termed the Basis of Comparison (BOC), is used as a reference for assessing the impacts of each proposed regulation measure. The BOC is the set of water levels and flows 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 the period. The BOC reflects historic hydrologic conditions and current water management structures and procedures.

The water level regulation measures analysed are divided into three groups, those that regulate all five lakes, those that regulate three lakes (Superior, Erie and Ontario) and those that regulate two lakes (Superior and Ontario). Each measure, however, even if only directly regulating two or three lakes may result in changes in the levels of other lakes and the St. Lawrence River. The three-lake regulation measures each include the addition of structures in the Niagara River to reduce outflows from Lake Erie and the dredging of the Niagara River to increase flows, as needed. Additional structures and dredging would be carried out in the St. Lawrence River to allow for the changes in Lake Ontario levels brought about by the regulation of Lake Erie. The two lake regulation measures include changes in either or both of the current Lake Superior and Lake Ontario regulation plans. Restrictions on the current operating plans would be lifted to meet the preferences of various user groups. No water control structures would be built. Brief descriptions of each of the measures are presented in Table 1.[(4)]

Each water level regulation measure results is a series of trade-offs. Differing preferences of water user groups result in compromises. Also, annual and seasonal variations in precipitation, evaporation, and run-off must be accommodated while, at any given time, the total amount of water available in the Great Lakes-St. Lawrence River system is limited. Thus, in general, if higher water levels are generated in one area, then lower water levels must occur eslewhere. No measure can generate higher water levels everywhere.

TABLE 1 Water Level Regulation Measures

Doubling Atmospheric Carbon Dioxide

The impact of the doubling of atmospheric carbon dioxide, or global warming, on commercial navigation through changes in the Great Lakes and St. Lawrence River water levels is also estimated. This scenario is not a management plan, but a description of a possible climatic condition that could occur at some future time. The hydrological impacts on the Great Lakes Basin, based on a doubling of carbon dioxide global warming scenario, were simulated by coupling the Canadian Climate Centre Global Circulation Model results with the Large Basin Runoff Model and other conceptual modelling techniques developed at the Great Lakes Environmental Research Laboratory. These procedures simulated the moisture storage and runoff from the 121 sub-basins draining into the Great Lakes and the over-lake meteorology and thermodynamics for each of the Great Lakes. The results of these simulations indicate that runoff to the lakes will be lower due to higher air temperatures, causing greater overland evapotranspiration; runoff will peak earlier due to a lower snowpack; ice formation will be reduced; and lake evaporation will be increased. The average steady-state net basin supplies will drop by one half.(5)

If this scenario does occur, water management procedures will no doubt be implemented to minimize its impact. The water levels used in this scenario are a combination of estimates based on the doubling of carbon dioxide and those from the Basis of Comparison. The BOC levels are used to simulate offsetting water management procedures. The levels used for Lakes Michigan, Huron and Erie and for Pointe Claire and Montreal Harbour are based on the doubling of carbon dioxide; all other levels are from the Basis of Comparison.

Methodology

The impact of each water level regulation measure is estimated by simulating the 1989 pattern of shipments in the Great Lakes-St. Lawrence River system under the Basis of Comparison, each of the water level regulation measures, and the doubling of carbon dioxide scenario. Each 1989 shipment is simulated for each of the 90 years of water level data to determine if low water levels requiring a reduction in the ship's load are encountered. The impacts of the low water levels on shipping costs are then estimated.(6)

The shipments examined are those by the Canadian Great Lakes fleet and include shipments between Canadian ports and between Canadian and American ports in the Great Lakes-St. Lawrence River system. Shipments of the major bulk commodities, grains, iron ore, coal, limestone, salt, other ores and crude non-metallic minerals are analysed. Together these commodities comprise over ninety percent of the total tonnage shipped in 1989. The 1989 shipping season is representative of recent commercial navigation experience in the Great Lakes-St. Lawrence system. Shipments in 1989 were reasonably close to recent average annual shipments.(7) Also, 1989 water levels for most of the lakes were close to their long term averages (Yee and Shoots 1990).

Individual shipments are simulated to ascertain if the water levels encountered, as given by the BOC, regulation measure, or scenario, restrict the amount which can be loaded and shipped. Water levels are checked at the origin port, the destination port, and the connecting channels and locks on the route. The impact of water level depends on the vessel, the cargo, and the time of year. Every vessel and cargo has different loading characteristics and maximum allowable drafts vary with the season of the year, being greatest in the summer and least in the winter. Required underkeel clearances are always maintained.

The shallowest depth encountered for each shipment is found. If the vessel cannot clear this limiting depth then the amount of cargo which must be removed to clear the depth is computed using the vessel immersion factor (the relationship between a change in a vessel's load and a change in its draft). An additional trip or trips are then necessary and the costs of these trips are estimated. These additional shipping costs are the costs to commercial navigation of the implementation of that particular water level regulation measure. Only changes in the variable costs of operation are considered; variable costs being those costs which change as a result of operating time, vessel class, and type of activity. Shipments are simulated and any additional costs estimated for each of the 90 years of water levels given for the BOC, each regulation measure, or scenario. Annual average cost changes for the Basis of Comparison, each water level regulation measure, and the doubling of carbon dioxide scenario are then computed, by commodity and route. Regulation measures and global warming average cost changes are compared with the average cost changes associated with the BOC.[(8)]

The data used are from a variety of sources. Shipment data are from Sta-tistics Canada. *Greenwood's Guide to Great Lakes Shipping (1989 and 1991)* provided detailed information on the Canadian Great Lakes fleet and ports in the Great Lakes-St. Lawrence system. Water depths at potential route constraint points, connecting channels, locks, and the Seaway were provided by the St. Lawrence Seaway Authority and the U.S. Army Corps of Engineers. Vessel operating costs are from the U.S. Maritime Administration, the U.S. Army Corps of Engineers, the Lake Carriers' Association, and Transport Canada.

Results

The results for each regulation measure in Tables 2 and 3 are presented as annual average differences with the Basis of Comparison, the BOC representing the situation without any new water level regulation measure. The cost changes for each measure are subtracted from the cost changes for the BOC. Positive values for a plan indicate that the plan is more favourable to commercial navigation than the Basis of Comparison; that is, the regulation measure provides benefits to commercial navigation, compared with the BOC. A negative result suggests the measure does not improve the situation for commercial navigation. The annual average additional costs which would have been incurred if BOC conditions existed over the 1900 to 1989 period are also presented.

Table 2 presents comparisons with the BOC, by commodity group and overall. Measure 1.11, reflecting the preferences of navigation interests, is, not surprisingly, the most favourable to commercial navigation. This measure, however, has very high capital and operating costs and the benefits for commercial navigation do not justify implementation of this measure. Several two- lake regulation measures, 1.4, 1.5, 1.19, and 1.21, have positive benefits for commercial navigation and can be implemented with no additional costs. The least favourable is measure 1.20, where the variance of Lake Superior levels is increased while the variance of Lakes Michigan and Huron levels are decreased, followed by measure 1.15, which reflects the preferences of environmental interests.

Grain, coal, and crude materials are the commodities showing the greatest impact. Grain is the commodity shipped the longest distances and thus will be affected by any low water levels in the system. Since coal and crude materials are commodities with a high weight to volume ratio, the capacity of the vessel is usually not a constraint on the amount of these commodities that can be carried. These ships will normally be loaded to their maximum possible draft and thus changes in water depths are more likely to have an impact.

TABLE 2 Regulation Measure Comparisons with the BOC, by Commodity Group ($, annual averages)

The impacts of any measure may not be uniform. For example, even for measure 1.11, which reflects the preferences of commercial navigation, an adverse impact is shown for the shipment of other crude materials. This is due to the complex interactions of the water level regulation measures, the patterns of shipments for each commodity, and natural events. No regulation measure can provide higher water everywhere, commodities follow different routes, and precipitation and evaporation show significant annual variation.

The doubling of carbon dioxide scenario has a very significant negative impact on commercial navigation. The annual average impact, compared with the BOC, would be over two million dollars. Over 90 percent of this impact is felt in the shipping of grains and coal.

Table 3 presents comparisons with the BOC by area, dividing routes into those wholly within the upper lakes (Lake Erie and all higher lakes); those between the upper and lower parts of the system; and those wholly within Lake Ontario, the St. Lawrence River, and the Gulf of St. Lawrence. The navigation measure, 1.11, is again the most beneficial measure, particularly in shipments between the upper and lower lakes. Measures 1.4, 1.5, 1.19, and 1.21 also show benefits to commercial navigation. Again the largest impact is due to the doubling of carbon dioxide scenario, with the largest effect on the upper lakes.

The results are presented as annual averages, which means that, for a given year, the impacts of any of the regulation measures could be larger. As annual averages, the regulation measure impacts are a relatively small percentage of total annual operating costs, but they provide useful information on the direction of the impacts of each measure. The benefits and costs to other water users are not included. Water levels have impacts on hydroelectric generating plants, recreational boaters, and riparian landowners. Including other water users may increase or decrease the benefit of a water level regulation measure.

The Levels Reference Study Board has recommended that no further consideration be given to five-lake and three-lake regulation and that the regulation plans of Lakes Superior and Ontario be modified to achieve water levels and flows similar to those described in Measure 1.21 (Levels Reference Study Board 1993b). This measure has a positive impact on commercial navigation and thus would be compatible with commercial navigation interests.

Conclusions

A detailed examination of the impacts of proposed water level regulation measures on commercial navigation in the Great Lakes-St. Lawrence River system suggests that implementation of several of the measures would be favourable to commercial navigation. Some of the measures beneficial to commercial navigation can be implemented with no additional capital or operating costs as they only involve modifying the regulation of flows from Lake Superior and/or Lake Ontario. The benefits are measured by comparing each of the water level regulation measures with a set of water levels representing historic hydrologic conditions applied to current water management procedures and structures. A doubling of carbon dioxide, however, would have a severe detrimental impact on commercial navigation. There is evidence that the results presented here are under-estimates of the true impacts.

TABLE 3 Regulation Measure Comparisons with the BOC, by Area ($, annual averages)

References

Greenwood, J.O. (ed.). (1989 and 1991). *Greenwood's Guide to Great Lakes Shipping*. Cleveland: Freshwater Press.

International Lake Erie Regulation Study Board. 1981. *Lake Erie Water Level Study*. Submitted to the International Joint Commission.

Lake, R. and D. Hackston. 1990. *The Great Lakes and St. Lawrence Seaway System, Commercial Attractiveness and Priorities for Policy Development*. Toronto: Ontario Ministry of Transportation.

Levels Reference Study Board. 1993a. *Commercial Navigation Work Group Report*. Submitted to the International Joint Commission.

_______. 1993b. *Levels Reference Study, Great Lakes-St. Lawrence River Basin*. Submitted to the International Joint Commission.

Marchand, D., M. Sanderson, D. Howe and C. Alpaugh. 1988. "Climate Change and Great Lakes levels: The Impact on Shipping". *Climate Change*, 12: 107-133.

St. Lawrence Seaway Authority. 1990. *Annual Report 1989-1990*. Ottawa.

_______. 1995. *The St. Lawrence Seaway, Traffic Report - 1993 Navigation Season*. Ottawa: St. Lawrence Seaway Authority.

Statistics Canada. 1991. *Shipping in Canada, 1989*. Ottawa: Statistics Canada.

_______. 1995. *Shipping in Canada, 1994*. Ottawa: Statistics Canada.

U.S. General Accounting Office. 1986. *U.S. Flag Share of the U.S. Canada Trade on the Great Lakes*. Washington.

Yee P. and W. Shoots. 1990. *A Report on 1989 Water Levels of the Great Lakes*. Burlington: Inland Waters Directorate, Environment Canada.

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2. Bulk cargo is any commodity handled as a continuous flow during loading and unloading. Package freight or general cargo is any commodity handled in discrete units, such as crates or containers.

3. The St. Lawrence Seaway was originally viewed as a way of allowing ocean-going ships to enter the Great Lakes, but this movement of general cargo and containers has not met expectations. The Seaway, however, has allowed Great Lakes vessels to leave the lakes, carrying grain east and iron ore back.

4. Complete descriptions of the water level regulation measures are available in Levels Reference Study Board (1993a). The numbers and titles are those assigned for the Levels Reference Study, on which this study is partly based.

5. See Levels Reference Study Board (1993a) for a complete description of this scenario.

6. Higher water levels may allow greater loading. The available data, however, do not allow a distinction between cases where greater loading is possible and situations when a vessel is purposely not fully loaded. Due to incomplete data and purposeful under-loading, it is likely that the impacts of low water levels are greater than indicated here.

7. The total tonnes of cargo transiting at least one lock in the St. Lawrence Seaway (including the Welland Canal) in 1989 was 2.3% higher than the 1985-1993 average (St. Lawrence Seaway Authority and Saint Lawrence Seaway Development Corporation 1995).

8. The Basis of Comparison, which uses current management procedures and control structures, may generate increased shipping costs due to past years of low water levels.

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TABLE 1 Water Level Regulation Measures

FIVE LAKE WATER LEVEL REGULATION MEASURES	
1.11:Commercial navigation	Preferences of navigation, would maintain levels above low water levels on all lakes. Control structures placed on St. Clair, Detroit, Niagara, and St. Lawrence rivers. Capital cost $5.5 billion, annual operating cost $21.8 million.
1.15: Environment	Preferences of environmental interests, releases similar to those before regulation. No additional costs.
THREE LAKE WATER LEVEL REGULATION MEASURES	
1.2: Superior, Erie, and Ontario optimized	Levels and flows optimized to satisfy all users on Lakes Superior, Ontario, and Erie and St. Lawrence River. New water control structures in Niagara River. Capital cost $800 million, annual operating cost $4 million.
1.18: Erie outflow regulation added	Lessens high water levels on Lakes Michigan and Huron, lessens high and low water levels on Lake Erie. New water control structures and dredging on Niagara River. Capital cost $726 million, annual operating cost $23 million.
TWO LAKE WATER LEVEL REGULATION MEASURES	
1.4: Flexible Superior regulation	More flexibility allowed in balancing levels between Lakes Superior and Michigan-Huron. Higher outflows from Lake Superior would occur. No additional costs.
1.5: Pre-regulation conditions	Use of existing water control structures in the St. Mary's and St. Lawrence River to control releases to simulate pre-regulation conditions. No additional costs.
1.6: Improved Ontario regulation	Modifications to the current operating plan for regulating the outflow from Lake Ontario to better satisfy all users, balance the needs of

	upstream and downstream users, and reduce downstream flooding. No additional costs.
1.19: Flexible Ontario regulation	Fewer constraints on Lake Ontario's regulation plan to reflect the preferred ranges of levels and flows for riparians, recreational boating, commercial navigation, and environmental interests. No additional costs.
1.20: Superior variance increased	Increase in the allowable range of Lake Superior levels, resulting in a reduction of the variance around the mean level of Lakes Michigan-Huron. Dredging required. Initial cost $262 million, annual operating cost $20 million.
1.21: Modified Superior and Ontario regulation	Improved balancing of Superior and Michigan-Huron levels. Modification of the Lake Ontario operating plan to maintain water levels for upstream and downstream recreational boating and commercial navigation and reduce spring flooding in Montreal area. No additional costs.

TABLE 2 Regulation Measure Comparisons with the BOC, by Commodity Group ($, annual averages)

Regulation Measure	COMMODITY GROUP						Total
	Grain	Iron Ore	Coal	Limestone	Salt	Crude Materials	
1.11	21,069	638	8,999	1,793	900	-3,086	30,313
1.15	-1,457	-106	-1,474	-126	-247	-107	-3,518
1.2	3,965	257	3,574	493	347	1,989	10,624
1.18	-723	253	2,298	332	304	-2,221	242
1.4	782	90	1,241	109	106	178	2,505
1.5	1,337	144	2,064	267	166	331	4,309
1.6	0	0	0	0	0	-5	-5
1.19	1,337	144	2,064	267	174	312	4,297
1.20	-4,732	-80	-791	-81	-67	101	-5,652
1.21	1,337	144	2,064	267	174	326	4,312
DCO^2	-884,632	-271,643	-915,947	-59,513	-88,179	-87,716	-2,307,631
BOC	222,093	668	20,548	2,381	963	1,216	258,668

Notes:

1. Crude materials include other ores and crude non-metallic products.
2. The results for each measure are comparisons with the BOC; positive results indicate that the measure is more favourable to commercial navigation, negative results indicate that the measure is less favourable.
3. DCO^2 is a doubling of carbondioxide.
4. The results for the BOC are the average annual additional shipping costs if BOC conditions occurred.

TABLE 3 Regulation Measure Comparisons with the BOC, by Area ($, annual averages)

	ROUTES		
Regulation Measure	Between Upper Lake Ports	Between Upper Lake and Lower Lake/ St. Lawrence Ports	Between Lower Lake/ St. Lawrence Ports
1.11	8,326	22,095	-107
1.15	-1,719	-1,736	-63
1.2	6,323	4,358	-56
1.18	847	-363	-242
1.4	1,602	902	2
1.5	2,768	1,527	15
1.6	0	0	-5
1.19	2,768	1,534	-5
1.20	-827	-4,823	-1
1.21	2,768	1,534	10
DCO^2	-1,181,190	-1,120,128	-6,314
BOC	35,318	223,180	171

Notes:

1. Upper lake ports are those on Lake Erie and higher.

2. The results for each measure are comparisons with the BOC; positive results indicate that the measure is more favourable to commercial navigation, negative results indicate that the measure is less favourable.

3. DCO^2 is a doubling of carbondioxide.

4. The results for the BOC are the average annual additional shipping costs if BOC conditions occurred.