US Army Corps
of Engineers
North Central Division

GREAT LAKES LEVELS

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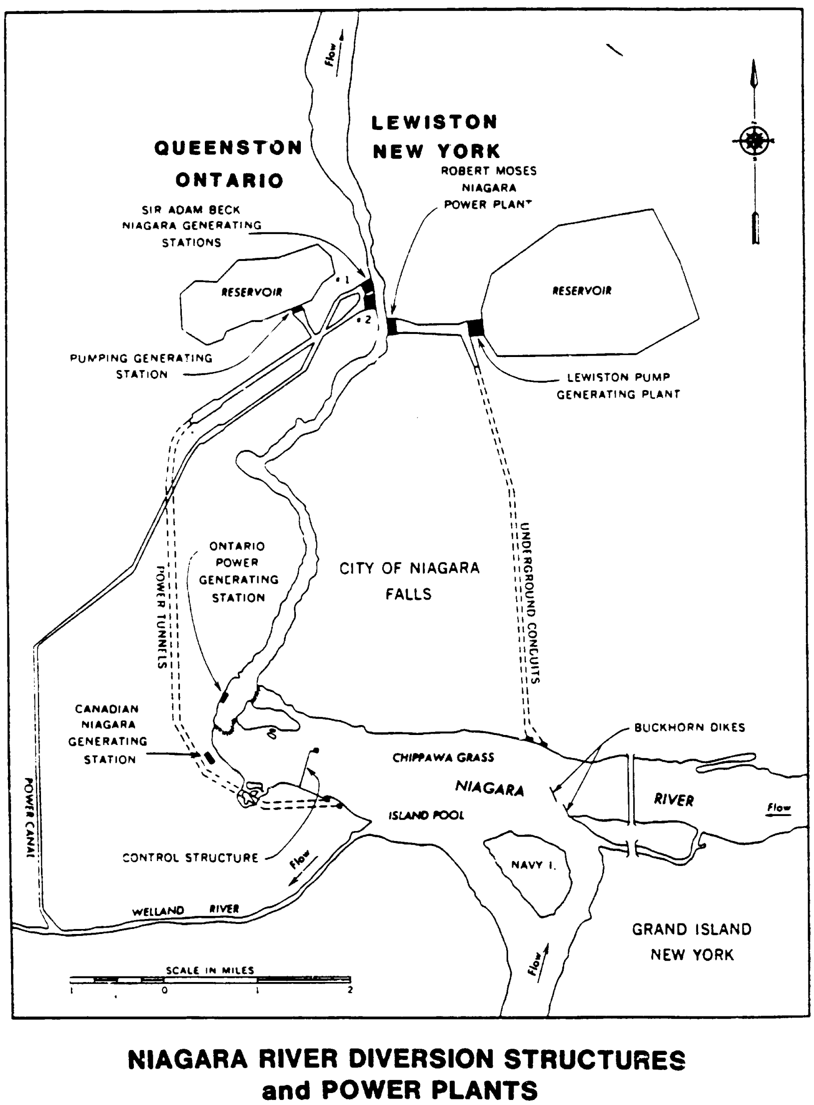
STUDY OF ICE JAMS ON THE NIAGARA RIVER

INTRODUCTION

The New York Power Authority's (Authority) Niagara Power Project, situated on the Niagara River in Lewiston, Niagara County, New York, has a generation capacity of 2,400 megawatts. It is the largest power plant among the Authority's facilities with about 35 percent of the total installed generating capacity. Water for the Niagara Power Project and the Sir Adam Beck Generating Stations, operated by Ontario Hydro, is diverted from the Grass Island Pool located on the Upper Niagara River, just upstream of Niagara Falls (Figure 1). The combined generating capacity of the U.S.



NIAGARA RIVER DIVERSION STRUCTURES and POWER PLANTS

Figure 1.

and Canadian stations is about 4,500 megawatts. Diversions for hydropower production are made in accordance with the terms of the 1950 Treaty Between the U.S. and Canada Concerning the Uses of the Waters of the Niagara River. The Treaty requires that flows over Niagara Falls be not less than 100,000 cubic feet per second (2,832 cubic meters per second) during daylight hours in tourist months and not less than 50,000 cubic feet per second (1,416 cubic meters per second) during evenings and non-tourist months. All water that is not used to satisfy the Falls flow requirement of the 1950 Treaty is available for hydroelectric power generation.

The operation of the Niagara Power Project and the Canadian generating stations has at times been hampered by ice generated in the river or by ice transported into the river from Lake Erie. On occasion, severe conditions have led to ice jams and flooding of the low-lying areas along the upper Niagara River. Ice has also caused losses in power production when it has been necessary to pass water over the Niagara Falls to meet treaty requirements. These losses, which are shared equally by the Authority and Ontario Hydro, have averaged about 66,000 megawatt-hours annually over the last ten years (1980-1990). At a replacement power cost of $30 per megawatt-hours (1988 $ U.S.), the lost benefits to the residents of New York State and Ontario amount to about two million dollars per year. (NOTE: The Authority and Ontario Hydro jointly divert water from the Grass Island Pool to the generating stations and the Falls. They are jointly responsible for meeting the water level regulations applicable to the Grass Island Pool and the Falls flow requirements in the Treaty.)

The Authority is upgrading its hydroelectric generating facilities at the Niagara Project to provide additional generation capacity during peak periods. This undertaking required that the Authority apply for an amendment to its operating license issued by the Federal Energy Regulatory Commission (FERC). The application for the amendment was approved by FERC, but included several conditions. The FERC required the Authority to develop and implement a study plan (Plan) aimed at evaluating the relationship between project design and operations, with the formation of ice jams in the upper Niagara River, and the impacts on power generation losses and shoreline flooding.

Specifically, the Authority was required to "undertake an ice model study, either mathematical or physical, of the Upper Niagara River." In addition, FERC required the Authority to "retain a board of qualified, independent, engineering consultants (Board) experienced in ice engineering, physical modeling, and mathematical modeling to assess the potential for the possible solution to ice jam conditions on the upper Niagara River, as such conditions affect the operations of the project and shoreline flooding." The Board members are: Robert Ettema, Iowa Institute of Hydraulic Research, Iowa City, Iowa; David Andres, Alberta Research Council, Edmonton, Alberta, Canada; and Richard Carson, Acres International, Winnipeg, Manitoba. This Board assisted the Authority in developing the Plan and review the results, develop conclusions, and recommendations for remedial measures. Lastly, the Authority was required to "survey the scientific community regarding the practicality of developing a physical ice model for the upper Niagara River." Over 30 responses to the survey were received.

GENERAL STRATEGY FOR THE PLAN

The objectives of the Plan are: 1) to determine whether and/or how the Authority's intake and its appurtenant structures or physical features affect ice transport, ice jam initiation, and ice jam development in the upper Niagara River; 2) to investigate whether there are measures, either physical, structural, and/or operational, that will significantly reduce the likelihood of ice jam formation and resulting flooding and power generation losses; and, 3) to investigate whether there are measures that will ensure that intake operation will not exacerbate the problems related to ice jam progression once a jam is initiated in the vicinity of, downstream of, or upstream of the intake.

After reviewing the background material, it was concluded that appropriate physical and numerical modeling, and careful interpretation of the modeling results, could be used to address these three objectives with the understanding that the first objective is a necessary, diagnostic precursor to the second and third objectives. It

Table 1 Potential Improvements That May Reduce the Frequency and Severity of Ice Stoppage and/or Ice Jams in the Upper Niagara River

Grass Island Pool

Type of Change	Description	Priority for Consideration
Physical	Deepen and extend excavation in front of Authority's intake	Medium
Physical	Excavate to redirect portion of flow from the Chippawa Channel to the Authority's intake	Medium
Physical	Excavate portions of the Grass Island Pool to decrease size of ice island	High
Physical	Modify ice escape channel	Medium
Structural	Modify or remove the Buckhorn Dikes	High
Structural	Install ice deflector structures or ice booms in the Grass Island Pool	Medium
Structural	Modify the Authority's intake	Low
Structural	Relocate the Authority's intake	Low
Structural	Modify the International Control Structure	Low
Operational	Modify International Control Structure operation	High
Operational	Revise diversion procedures	High
Operational	Increase icebreaker operations and number of icebreakers	High
Operational	Modify Grass Island Pool water level limits	High
Operational/ Structural	Install temporary, removable structures, such as ice booms or barges	Medium

Upstream of Grand Island

Physical	Excavate to increase proportion of flow into Tonawanda Channel	Low
Physical	Excavate to decrease proportion of the ice discharge into the Tonawanda Channel	Low
Structural	Install a permanent ice retention structure in Lake Erie	Low
Structural	Increase ice-retention performance and capacity of the Lake Erie - Niagara River ice boom	Medium
Structural	Install permanent ice-deflector structure in the river upstream of Grand Island to deflect ice into the Chippawa Channel	Medium
Operational/ Structural	Use temporary ice-deflector structure in the river upstream of Grand Island to deflect ice into the Chippawa Channel, e.g., ice booms or barges	High

Tonawanda Channel

Physical	Excavate to reduce the potential for hydraulic thickening of ice covers that raise water levels	Low

was also concluded that it is not possible to completely eliminate the occurrence of ice jams in the river, especially in the complex Grass Island Pool reach. There are potential combinations of hydraulic and hydrometeorologic conditions that will produce ice discharges of such severity that jams will occur irrespective of any action taken by man.

MITIGATION SCHEMES

Following a review and synthesis of the background material, three principal mitigation schemes were identified to address the second and third objectives of the Plan. However, before the schemes can be investigated, several baseline studies need to be conducted pursuant to the first objective of the Plan. Baseline information (studies to establish a set of data and observations for use in evaluating potential changes to existing conditions) is needed for assessing the effectiveness of measures identified for evaluation. Five types of studies are prescribed; these include: technology assessments, historical data analyses, field observation and measurement programs, numerical modeling, and physical modeling.

A physical model of a portion of the Grass Island Pool was built to be used as the primary tool in evaluating the first mitigation scheme. The physical model was constructed by the Alden Research Laboratory, Holden, Massachusetts, under contract to the Authority. This model is being used to investigate the effects of structural, physical, or operational changes on ice discharge capacities. Concurrent numerical (computer) modeling of the ice processes in the Grass Island Pool will also be conducted to compensate for shortcomings in the physical modeling and to evaluate impacts on the remainder of the river. These models will also be used to assess any potential impacts on operations and/or ice jamming potential in the Grass Island Pool from any measures evaluated under the second mitigation schemes.

The second mitigation scheme involves reduction of ice discharges and is to be investigated in two aspects. One is improvement in the design of the Lake Erie - Niagara River ice boom to further reduce the frequency and severity of lake ice runs. The other is diversion of ice from the Tonawanda Channel to the Chippawa Channel. The goal of the latter is to alter the temporal and spatial distributions of ice in the river system to improve ice transport past the hydropower intakes in the Grass Island Pool. It would also encourage utilization of the full ice discharge capacity of the river, rather than just that of the Tonawanda Channel.

The evaluation of potential improvements in the Lake Erie - Niagara River ice boom may involve three phases of study. Current ice boom technology will be assessed to determine if any alternative designs appear to be applicable to the situation. If so, laboratory (physical) modeling of the prospective designs and the current design may be done to assess performance. If an alternative design demonstrates superior performance, then one or two test sections may be installed and monitored during several winter seasons. If successful, a new or improved boom may be installed to replace the existing boom.

The feasibility of diverting ice from the Tonawanda Channel will be investigated initially by using a numerical (computer) model of flow and ice drift in a portion of the river upstream of Grand Island. Use of a physical model will also be considered if numerical modeling indicates that structural measures may reduce ice discharge into the Tonawanda Channel. The design of the physical model will be guided by the outcome from numerical modeling, primarily because it is not practical to physically model the large general area in which a structural measure might be located.

The third mitigation scheme is largely operational in nature and involves the improvement of ice transport conditions within the river. This scheme requires analysis of operational procedures in response to particular combinations of hydraulic, ice, and meteorological conditions. These operational procedures for mitigating ice jamming will be evaluated by a combination of physical and numerical modeling. Operational procedures may be identified through sensitivity analyses of a wide range of hydraulic and ice conditions, as well as operational actions. Operational actions, which may be determined to yield possible mitigation strategies for particular combinations of hydraulic and ice conditions, may be adopted for winter operations.

Several potential improvements initially hold promise for reducing ice jamming in the upper

Niagara River. The improvements are of three primary types; physical, structural, or operational. Potential improvements to specific areas of the river are listed in Table 1. Those with a medium to high priority are included in the Plan. The highest priority measures will be studied first. Priority will be based on preliminary, practical, and economic considerations, as well as the likelihood of success. If the studies reveal that they will not be practical, consideration of lower priority improvements may be needed.

There are no obvious simple "solutions" that will significantly reduce the likelihood of ice jamming in the upper Niagara River. Moreover, there are no simple modeling methods to determine with assurance that potential improvements will be effective. Though the three mitigation schemes are straightforward, and a sizeable list of alternative mitigation measures can be identified, the complexity of the system and the number of different interests involved require that any improvements or combination of improvements be carefully evaluated.

Various methods of evaluation were considered. These are as follows: technology assessment; analysis of historical information; field measurements and observations; physical modeling; and, numerical (computer) modeling. Further details of these methods of evaluation and schedules can be obtained from the New York Power Authority.

CONCLUSION

A strategy for studying and, hopefully, mitigating the processes that can lead to the occurrences of ice stoppages and ice jams on the upper Niagara River has been developed and set forth in a comprehensive plan of study and is being implemented. The principal intent of the strategy and plan is to determine whether or not there are practicable measures to reduce the frequency and severity of such occurrences on the upper Niagara River. The studies prescribed in the plan will lead to advances in the state-of-the-art of understanding and modeling of river ice hydraulics.

This article is an excerpt from a paper titled, "A Plan for Studying Ice Jamming on the Upper Niagara River." The authors are Randy D. Crissman, Senior Hydraulic Engineer, New York Power Authority, Niagara Falls, New York; Robert Ettema, Research Engineer, Iowa Institute of Hydraulic Research, Iowa City, Iowa; Robert L. Gerard, Professor, University of Alberta, Edmonton, Alberta; and, David Andres, Research Officer, Alberta Research Council, Edmonton, Alberta.

IJC Levels Reference Study Final Report

A draft final report on the Great Lakes - St. Lawrence River Levels was distributed to interested parties in mid-February, 1993. A series of public meetings were held during February 23-25 at Sault Ste. Marie, Michigan; Chicago, Illinois; Buffalo, New York; and Dorval, Quebec. The public meetings were well attended. The Board will meet on March 16-17, 1993, to finalize the report and submit its report to the IJC by March 31, 1993.

High Water Levels

The International Joint Commission, United States and Canada, on February 18, 1993, instructed its International St. Lawrence River Board of Control to invoke Criterion (k) of the Commission's Order of Approval for the Regulation of Lake Ontario. Criterion (k) provides that in the event of excess water supplies, "the works in the International Rapids Section (of the St. Lawrence River) shall be operated to provide all possible relief to the riparian owners upstream and downstream."

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Commanding

Great Lakes Basin Hydrology

Below average precipitation and net basin supplies in February brought some needed relief to the Great Lakes basin. The February monthly mean lake levels compared to the February long-term averages (1900-1992), show Lake Superior slightly above average; Lakes Michigan-Huron 6 inches above average; Lake St. Clair 21 inches above average; Lake Erie 24 inches above average; and Lake Ontario 22 inches above average. Based on the above information and in anticipation of the normal spring rise, shoreline residents of Lakes St. Clair, Erie, and Ontario continue to be alerted to possible extreme lake levels. Water level setups and wave actions caused by storm conditions can often be very serious and may require residents to protect their property. Should conditions worsen, the Corps of Engineers will provide further information and advice to shoreline residents through these Update Letters.

The precipitation, water supplies, and outflows for the lakes are provided in Table 2. Precipitation data include the provisional values for the past month and the year-to-date and long-term averages. The provisional and long-term average water supplies and outflows are also shown.

Table 2
Great Lakes Hydrology[1]

BASIN	FEBRUARY				YEAR-TO-DATE			
	1993*	AVG.**	DIFF.	% OF AVG.	1993*	AVG.**	DIFF.	% OF AVG.
Superior	0.4	1.5	-1.1	27	2.2	3.4	-1.2	65
Michigan-Huron	0.8	1.7	-0.9	47	3.5	3.8	-0.3	92
Erie	1.8	2.1	-0.3	86	5.9	4.5	1.4	131
Ontario	2.1	2.4	-0.3	88	5.7	5.0	0.7	114
Great Lakes	1.0	1.8	-0.8	56	3.7	3.9	-0.2	95

LAKE	FEBRUARY WATER SUPPLIES***		FEBRUARY OUTFLOW[3]	
	1993[2]	AVG.[4]	1993[2]	AVG.[4]
Superior	-60,000***	10,000	83,000	67,000
Michigan-Huron	18,000	86,000	175,000[5]	154,000
Erie	26,000	35,000	229,000[5]	188,000
Ontario	34,000	37,000	268,000	223,000

*Estimated **1900-91 Average ***Negative water supply denotes evaporation from lake exceeded runoff from local basin.

[1]Values (excluding averages) are based on preliminary computations.
[2]Cubic Feet Per Second (cfs) [3]Does not include diversions [4]1900-89 Average (cfs)
[5]Reflects effects of ice/weed retardation in the connecting channels.

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