

2011-12 Operation of the Lake Erie - Niagara River Ice Boom



A report to the
International Niagara Board of Control
by the
International Niagara Working Committee



October 2012



Report to
The International Niagara Board of Control
On the 2011-12 Operation of
The Lake Erie-Niagara River Ice Boom
By the International Niagara Working Committee

TABLE OF CONTENTS

Cover:
Photos of Ice Boom Installation
(USACE Photos)

Paragraph	Description	Page
1	HIGHLIGHTS	1
2	HYDROMETEOROLOGICAL AND ICE CONDITIONS	1
3	OPERATION OF THE ICE BOOM DURING THE 2011-12 ICE SEASON.	3
3.1	Installation of the Ice Boom	3
3.2	Ice Boom Operation	3
3.3	Ice Boom Opening	3
3.4	Ice Boom Maintenance	3
4	POWER LOSSES, FLOODING, AND NAVIGATION DURING THE 2011-12 ICE SEASON	4
4.1	Estimated Power Losses	4
4.2	Niagara River Shore Flooding and Property Damages	4
4.3	Navigation at the Welland Canal	4
5	FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS	4
5.1	Findings and Conclusions	4
5.2	Recommendations for the 2012-13 Operation	4
	APPENDIX A - DESCRIPTION OF THE LAKE ERIE-NIAGARA RIVER AREA	11
A.1	Hydraulics and Hydrology	11
A.2	Hydro-Electric Installations and Remedial Works	12
A.3	Other Shore Installations	13
A.4	Ice Problems	13
	APPENDIX B - BACKGROUND INFORMATION ON THE ICE BOOM	14
B.1	Authorization for Placement of the Ice Boom	14
B.2	Purpose of the Ice Boom	14
B.3	Description of the Ice Boom	14

TABLE OF CONTENTS

Number	Table Title	Page
1	Air Temperature at Buffalo Niagara International Airport	5
2	Lake Erie Water Temperatures as Recorded at the Buffalo Intake (Dec. 2011-May 2012).	6
3	Observed Dates of Last Ice, 1905 to Present	7
4	Dates Water Temperature Reached 4°C (39°F) and Dates of Ice Boom Installation	8
5	Comparison of Ice Areas Near Time of Boom Opening	9
6	Estimated Power Losses Due to Ice for Period of Record 1975 to Present.	10
7	Comparative Data for Years Ice Boom Has Been In Place	11

Number	Figures
1	Great Lakes-St. Lawrence River Drainage Basin
2	Map of Niagara River Showing Water Level Gauge Locations
3	Niagara River Diversion Structures and Power Plants
4	Structural Details of the Ice Boom
5	Map of Eastern Lake Erie
6	Plan View of Ice Boom and Sequence of Removal

RELATED INTERNET SITES

International Joint Commission	www.ijc.org
New York Power Authority	www.iceboom.nypa.gov
International Niagara Board of Control	www.ijc.org/conseil_board/niagara/en/niagara_home_accueil.htm
COE, Buffalo District	www.lrb.usace.army.mil
COE, Detroit District	www.lre.usace.army.mil
Great Lakes Information Network	www.great-lakes.net
Environment Canada	www.ec.gc.ca/grandslacs-greatlakes/

1. HIGHLIGHTS

The 2011-12 winter ranks as the second-warmest in the Niagara region's recorded history and the 12th lowest snowfall amount of any season on record.

Lake Erie's water temperature, as measured at the Buffalo Water Intake, was 6°C (43°F) on 14 December 2011. As a result, installation of the Lake Erie - Niagara River ice boom's 22 spans started on 17 December 2011.

An ice cover did not form behind the ice boom during the 2011-12 ice season. The ice cover on Lake Erie for the 2011-12 ice season peaked during the third week of January at just over 12% of Lake Erie's overall area, with most of the ice occurring in the lake's western basin while the lake's eastern basin only had ice form inside Long Point Bay.

The ice boom experienced four span breaks during the 2011-12 installation season as a result of rough, open-water conditions during high wind events.

Removal of the ice boom spans began on 28 February 2012 and was completed on 2 March 2012. 28 February 2012 marks the earliest opening of the ice boom spans since it was first installed in the winter of 1964-65.

Since no measurable ice formed in the eastern basin of Lake Erie during the 2011-12 ice season, the Board's International Niagara Working Committee cancelled both helicopter flights typically carried out during the season to measure ice thickness and did not perform any fixed-wing ice observation flights leading up to the removal of the boom.

Data in this report are in metric units followed by approximate customary imperial units (in parentheses). The latter are provided for information purposes only.



2. HYDROMETEOROLOGICAL AND ICE CONDITIONS

During the 2011-12 winter, the International Niagara Working Committee continued its program to collect data and information related to ice boom operations. This data is used to monitor conditions of the ice boom and Lake Erie, as well as to determine the installation and removal dates of the ice boom. As part of the usual program, satellite imagery and mapping were analyzed and meteorological data from the U.S. National Weather Service Station at Buffalo were collected.

The average monthly air temperature data for November 2011 through April 2012, as measured by the National Weather Service at the Buffalo Niagara International Airport, are displayed in Table 1. The average temperature for the six-month period was 3.2°C (5.8°F) above average. The 2011-12 winter ranks as the second-warmest in the Niagara region's recorded history with the 12th lowest snowfall amount of any season on record.

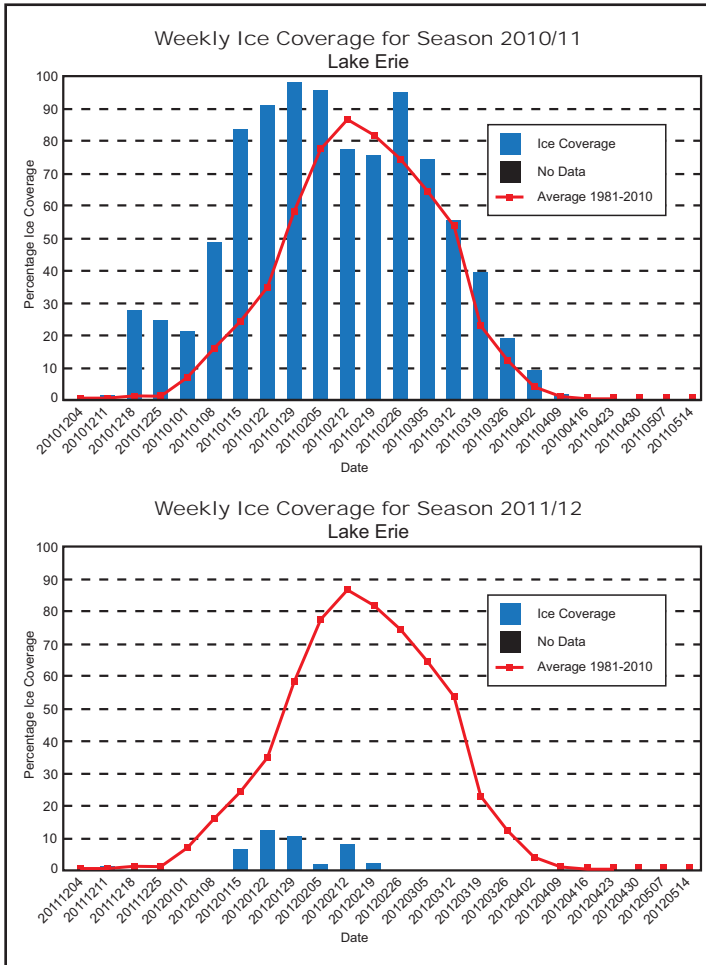
The number of days with snow on the ground is a very telling measure of a winter's severity. On average, the number of days with an inch or more of snow on the ground for the region is 72 days. Only 15 days of snow cover on the ground were observed during the 2011-12 season, breaking the previous minimum record of 29 days set back in 1918-19.

Examining "several months individually, Buffalo's weather in November 2011 was mild with only trace levels of snow. The average temperature for November was 3.2°C (5.8°F) above normal. The 5th of November was the only day of the month to fall below freezing at -1.6°C (29°F). The lowest recorded temperature for December fell on the 29th at -8.9°C (16°F). On average, January is the region's coldest month. Temperatures dropped into single digits only five times throughout the month and the average temperature for January was 3.0°C (5.4°F) above average. The National Weather Service office at the Buffalo Niagara International Airport reported 108 km/h (67 mph) winds on 17 January 2012, one of several severe wind events throughout the season.

The mild winter was also reflected in Lake Erie's water temperature. The daily Lake Erie water temperatures, as measured at the Buffalo Water Intake, for the period December 2011 through May 2012 are provided in Table 2. For the 2011-12 winter (December, January and February), the average lake temperature was tied for the second warmest on record. The lowest water temperature during that period was 0.6°C (33°F), recorded on 13 and 14 February 2012.

The following plot of the weekly ice coverage on Lake Erie as reported by the Canadian Ice Service shows the contrast between the limited ice coverage on the lake during the 2011-12 ice season and the significant coverage experienced during the winter of 2010-11. The ice cover on Lake Erie for the 2011-12 ice season peaked during the third week of January at just over 12% of Lake Erie's overall area, with the ice occurring in the lake's western basin and inside Long Point Bay. This compares to a peak of 90% ice cover for that same time last year. As indicated by the graph, the Canadian Ice Service reported less than 2% ice coverage on 19 February 2012 and less than 0.2% coverage on 26 February 2012. Based on a comparison of available satellite-based information, it is estimated that the date of last observed ice in Lake Erie during

this winter season was 1 March 2012. Observed dates of last seasonal ice coverage in Lake Erie for the period 1905 to the present are shown in Table 3.

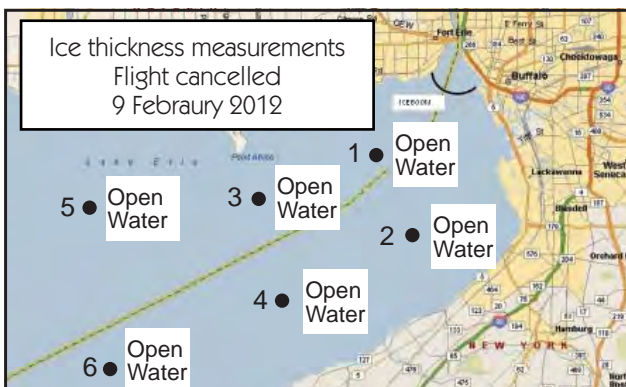
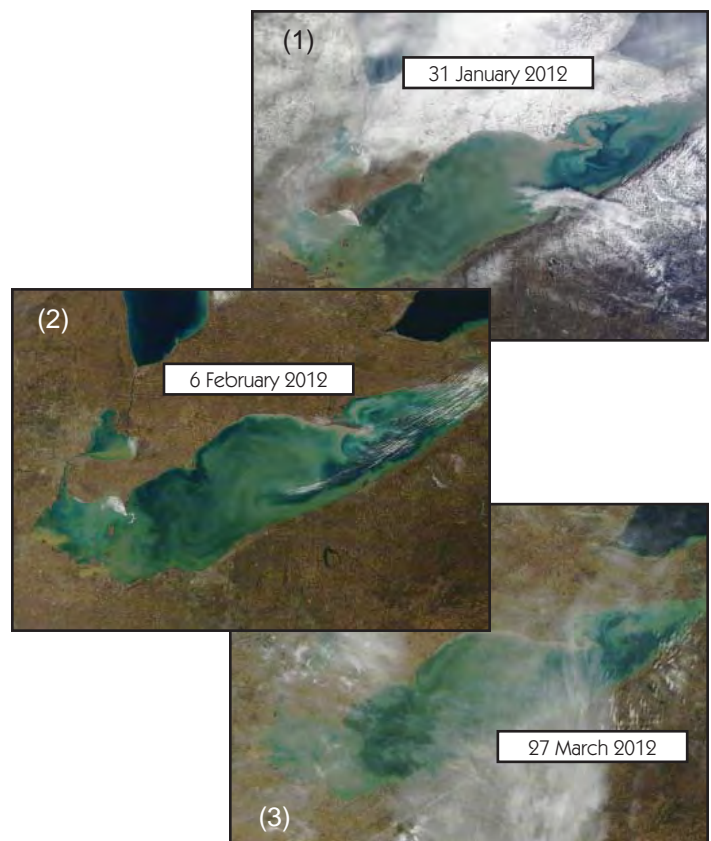


An ice cover did not form on Lake Erie behind the ice boom this season as a result of the mild winter. This is only the fourth time in the past 60 years that an ice cover did not occur.

Helicopter flights are typically carried out during early February and March to gather ice thickness data. However, as illustrated on these maps, no measurable ice formed in the eastern portion of Lake Erie beyond the small amount noted inside Long Point Bay during the 2011-12 ice season. As a result, the helicopter flights scheduled for 9 February 2012 and 8 March 2012 were cancelled by the Board's International Niagara Working Committee.



The following MODIS satellite images from the U.S. National Oceanic and Atmospheric Administration (NOAA) Coast Watch Great Lakes program show the eastern portion of Lake Erie on 31 January 2012, 6 February 2012 and 7 March 2012, respectively.



3. OPERATION OF THE ICE BOOM DURING THE 2011-12 ICE SEASON

because of high winds. The splice repair of the broken span was rescheduled and subsequently completed on 21 February 2012.

3.1 Installation of the Ice Boom

A video system is used to monitor the ice boom. The Internet address for information on the ice boom, as well as current images, is:

www.iceboom.nypa.gov

On 22 November 2011, the junction plates were raised from the bottom of the lake and 12 buoy barrels were attached. The remaining 11 buoy barrels were installed 29 November 2011, completing phase 1 of the ice boom installation. From 1 to 7 December 2011, boom spans were pulled from their storage area at 100 Katherine Street, Buffalo, NY, located about 3 kilometres (2 miles) upstream on the shore of the Buffalo River, and placed inside the Buffalo Harbor break wall, completing phase 2.

In accordance with Condition (d) of the International Joint Commission's 5 October 1999 supplementary Order of Approval, installation of the Lake Erie-Niagara River ice boom by the power entities (New York Power Authority and Ontario Power Generation) may begin when the Lake Erie water temperature reaches 4°C (39°F) or on 16 December, whichever occurs first. As noted above, Lake Erie's water temperature, as measured at the Buffalo Water Intake, was 6°C (43°F) on 14 December 2011. As a result, installation of the ice boom's spans were planned to begin on 16 December 2011, weather conditions permitting. However, strong winds and high wave action on 16 December 2011 prevented crews from proceeding with ice boom installation. Favorable weather conditions on 17 December 2011 allowed for ice boom installation to begin. Starting from the Canadian side, 9 spans (V through N), or 41% of the boom spans, were installed. The final 13 spans (M through A) were placed on 18 December 2011, completing the ice boom installation in just two days.

Table 4 provides the dates from 1964 to the present year when the Lake Erie water temperature as measured at the Buffalo Water Intake reached 4°C (39°F) and the dates of ice boom installation. As indicated in both Tables 2 and 4, the Lake Erie water temperature reached 4°C (39°F) on 28 December 2011.

3.2 Ice Boom Operation

Typically an ice sheet will form behind the ice boom stabilizing the structure for a significant portion of the ice season. However, this season ice did not form behind the boom and the ice boom was subsequently stressed by rough open waters during high wind events. On 24 January 2012, span D was noticed to be trailing in images provided by the ice boom camera mounted atop the First Niagara tower (formerly the HSBC tower) in Buffalo. The broken span was removed and replaced by a repair crew on 25 January 2012. While replacing span D, the repair crew noticed a single trailing pontoon on span F. Span F was replaced with the final spare span. On 30 January 2012, span E was noticed to be trailing. Since all spare boom spans were in use, a splice repair was necessary and completed by 3 February 2012. Another high wind event occurred and resulted in a break of span I observed on 16 February 2012. The initial attempt to repair the span on 17 February 2012 was suspended

3.3 Ice Boom Opening

Given the lack of ice accumulation in the Maid-of-the-Mist Pool below Niagara Falls, and the risk of continuing damage to the ice boom caused by open water conditions, the International Niagara Board of Control issued a media advisory on 27 February 2012 stating that, with favorable conditions, removal of the boom was about to begin.

One or more fixed-wing reconnaissance flights to determine the extent and condition of the ice cover on the eastern basin of the lake and in the Maid-of-the-Mist Pool are typically carried out near the end of the ice season to help decide if the ice boom can be removed. Given the lack of ice cover, a fixed-wing flight was deemed unnecessary prior to this year's decision to open the ice boom.

Removal of the ice boom began on 28 February 2012, with seven spans tied to the break wall by the end of the day. Eight more spans were removed and tied off to the break wall on 29 February 2012. Removal operations were cancelled on 1 March 2012 as a result of high winds. All 22 spans were secured to the break wall by 2 March 2012, completing phase 1 of the removal process.

28 February 2012 marks the earliest opening since the ice boom was first installed during the winter of 1964-65. Previously, the boom's earliest opening date was 5 March in 1998. A comparison of historical ice coverage area at the time of the ice boom opening and the ice boom opening dates is shown in Table 5. On 27 February 2012 only a trace amount of ice remained in the eastern basin inside of Long Point Bay; this amount of ice was negligible and the eastern basin was deemed ice-free.

The process to remove the buoy barrels began on 5 March 2012. Late on 5 March 2012, the removal crew experienced an issue with a cable on the crane that was used to remove the buoy barrels. Procurement and installation of a new cable on the crane did not occur until 9 March 2012. Although the crane was repaired, operations were once again cancelled for a few days as a result of high winds. Finally on 12 March 2012, the general maintenance crews removed the remaining 14 buoy barrels, completing phase 2 of the removal process.

Crews began towing the 152 metre (500 ft) long ice boom spans to the Katherine Street storage site, where they were pulled onto shore, on 14 March 2012. Five spans were towed and pulled onto shore each day on 14, 15, 16 and 19 March 2012. The final spans were brought to the storage site on 20 March 2012, completing the ice boom removal for 2012.

3.4 Ice Boom Maintenance

As a result of the stresses experienced during the 2011-12 season from the combination of open-water and rough conditions during storm events, it was anticipated that a significant amount of hardware would need to be replaced as part of the Power Entities' annual ice boom maintenance program. In addition, one anchor cable was found to be

damaged during ice boom removal and was replaced on 23 and 24 May. Closer inspection may reveal other damaged cables that will require replacement or repair.

4. POWER LOSSES, FLOODING, AND NAVIGATION DURING THE 2011-12 ICE SEASON

4.1 Estimated Power Losses

Some reduction in hydropower generation occurs virtually every year due to ice problems. The Power Entities estimate that the use of the ice boom results in an average annual savings to the hydropower facilities of approximately 414,000 Megawatt Hours (MWh) of electric energy.

The power entities experienced zero loss of hydroelectric power generation due to ice during the 2011-12 ice season. This occurrence is noted to be only the fourth year that no power losses were observed as a result of ice since 1975. A summary of estimated loss of energy due to ice for the period of record 1975 to present is shown in Table 6.

4.2 Niagara River Shore Flooding and Property Damages

The New York Power Authority's Flood Warning Notification Plan in the Event of Ice-Affected Flooding on the Upper Niagara River was tested on 12 December 2011. A drill was conducted that simulated a flood event along the U.S. shoreline in the vicinity of the North Grand Island Bridge, which was triggered by an ice jam upstream of the NYPA intakes. No ice-affected flood watch or flood warning alerts were issued under the flood warning notification plan during the 2011-12 ice season.

There were no reports of damages to shore properties due to ice or flooding along the Niagara River during the 2011-12 ice season.

4.3 Navigation at the Welland Canal.

The Welland Canal opened to commercial shipping this season on 22 March 2012, for its 183rd consecutive year of service, with the passage of the Alouette Spirit barge, pushed by the tug Wilf Seymour. A comparison of the dates of boom opening and the commencement date of navigation at the Welland Canal for the period 1965 to 2012 is shown in Table 7.

5. FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Findings and Conclusions

The winter of 2011-12 was unseasonably warm, resulting in limited ice coverage on Lake Erie. Ice did not form behind the ice boom at any time during the boom's 2011-12



installation period. However, 2011-12 should not be assumed representative of future ice seasons.

The ice boom experienced four breakages during its 2011-12 installation period, as a result of rough, open-water conditions behind the boom. Spare spans were available to replace the first and second broken spans; however, splicing repairs were needed for the third and fourth breaks. Adequate materials are needed to facilitate repairs, particularly during years with open water behind the boom.

The use of satellite images alone to monitor ice conditions was adequate during the winter of 2011-12 because of very limited ice coverage that developed over Lake Erie. However, during more typical future ice seasons, helicopter (thickness) and fixed-wing (area) observation flights will still be conducted by representatives of the working committee to supplement the ice information available from remote sensing technology.

5.2 Recommendations for the 2012-13 Operation

The International Niagara Board of Control and its Working Committee should continue to monitor and assess the performance of the ice boom.

The Power Entities should ensure they continue to have adequate materials to repair multiple breakages if they occur.

Utilization of Great Lakes ice cover maps prepared by the Canadian Ice Centre in Ottawa, ON, and the United States National Ice Center in Suitland, MD, supplemented by ice thickness measurements and fixed-wing aerial ice surveys to evaluate ice conditions throughout the winter as required, should continue.

The Working Committee should continue to store ice area maps that are produced following aerial ice reconnaissance flights or determined from the composite ice maps. The computer generated maps are maintained in a storage and retrieval database structure for future use of the data.

The Working Committee should continue to liaise with both the United States and Canadian Coast Guards regarding ice boom installation and removal operations.

Table 1 Air Temperature at Buffalo Niagara International Airport

Month	°C (Celsius)			°F (Fahrenheit)		
	Normal* 1971-2000	Recorded 2011-12	Departure	Normal* 1971-2000	Recorded 2010-11	Departure
Nov. 2011	4.8	8.1	3.2	40.7	46.5	5.8
Dec. 2011	-1.1	1.9	3.0	30.1	35.5	5.4
Jan. 2012	-3.9	-0.9	3.0	24.9	30.3	5.4
Feb. 2012	-3.2	-0.2	3.0	26.3	31.7	5.4
Mar. 2012	1.1	8.6	7.5	34.0	47.4	13.4
Apr. 2012	7.7	7.3	-0.4	45.9	45.2	-0.7
Average	0.9	4.1	3.2	33.7	39.4	5.8

* Official U.S. National Weather Service Normals are based on 30 years of record, 1971-2000



Table 2 Lake Erie Water Temperatures as Recorded at the Buffalo Intake (Dec 2011-May 2012)

Month	December		January		February		March		April		May	
Date	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
1	7.8	46	3.9	39	1.1	34	1.7	35	4.4	40	7.8	46
2	8.3	47	3.9	39	2.8	37	1.7	35	4.4	40	7.8	46
3	7.2	45	3.9	39	2.8	37	1.7	35	4.4	40	8.3	47
4	7.8	46	3.9	39	2.2	36	1.7	35	4.4	40	8.3	47
5	8.3	47	3.9	39	2.2	36	1.7	35	5.0	41	9.4	49
6	8.3	47	3.9	39	2.8	37	1.1	34	5.6	42	8.9	48
7	7.8	46	3.9	39	2.8	37	1.7	35	5.6	42	9.4	49
8	8.3	47	3.9	39	2.2	36	1.7	35	5.6	42	8.9	48
9	7.2	45	3.9	39	2.2	36	2.2	36	6.1	43	10.0	50
10	6.7	44	3.9	39	2.2	36	1.7	35	6.7	44	10.6	51
11	6.7	44	3.9	39	1.7	35	1.7	35	6.7	44	10.6	51
12	6.7	44	3.9	39	1.1	34	2.2	36	6.1	43	11.1	52
13	6.1	43	4.4	40	0.6	33	2.2	36	6.1	43	11.7	53
14	6.1	43	2.8	37	0.6	33	2.8	37	6.1	43	11.7	53
15	6.7	44	1.7	35	1.1	34	2.8	37	6.7	44	11.7	53
16	6.1	43	1.7	35	1.1	34	2.8	37	6.7	44	11.7	53
17	6.1	43	1.7	35	1.1	34	3.3	38	7.8	46	12.2	54
18	6.1	43	1.1	34	1.1	34	3.3	38	7.8	46	12.8	55
19	5.6	42	2.2	36	1.1	34	3.3	38	7.8	46	13.3	56
20	4.4	40	1.7	35	1.1	34	3.9	39	7.8	46	15.0	59
21	5.0	41	1.7	35	1.1	34	3.9	39	8.3	47	15.0	59
22	5.6	42	1.7	35	1.7	35	3.9	39	7.8	46	14.4	58
23	5.6	42	1.7	35	1.1	34	4.4	40	7.8	46	14.4	58
24	5.6	42	1.7	35	1.7	35	5.0	41	7.2	45	15.6	60
25	5.0	41	1.7	35	1.7	35	4.4	40	7.2	45	16.1	61
26	5.0	41	1.7	35	1.7	35	5.0	41	7.8	46	16.7	62
27	5.0	41	1.7	35	1.7	35	4.4	40	7.2	45	17.8	64
28	3.9	39	1.7	35	1.1	34	4.4	40	7.2	45	17.2	63
29	3.9	39	1.7	35	1.7	35	5.0	41	7.2	45	17.8	64
30	3.9	39	1.7	35			5.0	41	7.8	46	18.3	65
31	3.9	39	1.1	34			5.0	41			18.3	65
Avg:	6.2	43	2.7	37	1.6	35	3.3	38	6.6	44	12.7	55
Hi:	8.3	47	4.4	40	2.8	37	5.0	41	8.3	47	18.3	65
Low:	3.9	39	1.1	34	0.6	33	1.1	34	4.4	40	7.8	46

Table 3 Observed Dates of Last Ice, 1905 to Present

Year	Observed Date of Last Ice	Year	Observed Date of Last Ice	Year	Observed Date of Last Ice
1905	7-May	1941	21-Apr	1978	14-May
1906	22-Apr	1942	30-Apr	1979	3-May
1907	30-Apr	1943	20-May	1980	23-Apr
1908	9-May	1944	15-Apr		
1909	26-Apr	1945	9-Apr	1981	30-Apr
1910	30-Apr	1946	No data	1982	20-May
		1947	No data	1983	23-Feb
1911	6-May	1948	No data	1984	25-Apr
1912	29-Apr	1949	No data	1985	1-May
1913	30-Apr	1950	No data	1986	26-Apr
1914	28-Apr			1987	9-Mar
1915	2-May	1951	15-Apr	1988	27-Apr
1916	11-May	1952	27-Mar	1989	9-Apr
1917	30-Apr	1953	Ice-free	1990	10-Apr
1918	20-Apr	1954	27-Mar		
1919	15-Mar	1955	5-Apr	1991	28-Mar
1920	20-May	1956	20-Apr	1992	15-Apr
		1957	11-Mar	1993	16-Apr
1921	14-Mar	1958	10-Apr	1994	1-May
1922	11-Apr	1959	8-May	1995	18-Apr
1923	16-May	1960	5-May	1996	6-May
1924	20-Apr			1997	29-Apr
1925	26-Apr	1961	15-Apr	1998	Ice-free
1926	31-May	1962	30-Apr	1999	2-Apr
1927	9-Apr	1963	11-May	2000	28-Mar
1928	19-May	1964	27-Apr		
1929	2-May	1965*	14-May	2001	27-Apr
1930	7-May	1966	27-Apr	2002	Ice-free
		1967	13-Apr	2003	22-Apr
1931	7-Apr	1968	4-May	2004	30-Apr
1932	21-Apr	1969	26-Apr	2005	11-Apr
1933	23-Apr	1970	30-Apr	2006	5-Apr
1934	23-Apr			2007	29-Apr
1935	13-Apr	1971	31-May	2008	23-Apr
1936	31-May	1972	5-May	2009	16-Apr
1937	14-Apr	1973	15-Mar		
1938	14-Apr	1974	6-Apr	2010	29-Mar
1939	14-May	1975	8-Apr	2011	24-Apr
1940	19-May	1976	19-Apr	2012	Ice-Free
		1977	13-May		

* 1965 First year ice boom was used

Table 4 Dates Water Temperature Reached 4°C (39°F) and Dates of Ice Boom Installation

Date Water Temperature Reached 4°C (39°F)		Installation of the Ice Boom		Date Water Temperature Reached 4°C (39°F)		Installation of the Ice Boom	
7 Dec 1964	1	9 Nov to 15 Dec 1964		27 Dec 1990		27 Dec to 30 Dec 1990	
15 Dec 1965		19 Nov to 8 Dec 1965		19 Dec 1991	1	20 Dec to 27 Dec 1991	
19 Dec 1966	9	8 Nov to 6 Dec 1966		6 Dec 1992		13 Jan to 14 Jan 1993	
29 Nov 1967		17 Nov to 5 Dec 1967		16 Dec 1993	9	17 Dec to 28 Dec 1993	
10 Dec 1968	6	25 Nov to 5 Dec 1968		2 Jan 1995		7 Jan to 10 Jan 1995	
9 Dec 1969	0's	15 Nov to 10 Dec 1969		7 Dec 1995	9	13 Dec to 16 Dec 1995	
<hr/>				<hr/>			
15 Dec 1970		Completed 15 Dec 1970*		4 Dec 1996	0's	8 Dec to 11 Dec 1996	
25 Dec 1971		30 Nov to 10 Dec 1971		13 Jan 1997		17 Dec to 18 Dec 1997	
11 Dec 1972	1	11 Dec to 14 Dec 1972		1 Dec 1999		2 Jan to 9 Jan 1999	
18 Dec 1973		19 Dec 1973 to 9 Jan 1974		27 Nov 1999		19 Dec to 29 Dec 1999	
10 Dec 1974	9	11 Dec to 30 Dec 1974		<hr/>			
20 Dec 1975		24 Dec 1975 to 8 Jan 1976		18 Dec 2000		16 Dec to 28 Dec 2000	
24 Dec 1976	7	30 Nov to 18 Dec 1976		27 Dec 2001	2	17 Dec to 22 Dec 2001	
8 Dec 1977	0's	13 Dec to 31 Dec 1977		3 Dec 2002		11 Dec to 12 Dec 2002	
11 Dec 1978		Completed 19 Dec 1978*		15 Dec 2003	0	16 Dec to 20 Dec 2003	
17 Nov 1979		Completed 22 Dec 1979*		20 Dec 2004		17 Dec to 20 Dec 2004	
<hr/>				<hr/>			
14 Dec 1980		22 Dec to 30 Dec 1980		9 Dec 2005	0	14 Dec to 15 Dec 2005	
11 Dec 1981		19 Dec to 23 Dec 1981		19 Jan 2007	0's	18 Dec to 19 Dec 2006	
4 Dec 1982	1	6 Jan to 8 Jan 1983		9 Dec 2007		13 Dec to 17 Dec 2007	
18 Nov 1983		19 Dec to 21 Dec 1983		5 Dec 2008		10 Dec to 11 Dec 2008	
26 Dec 1984	9	27 Dec to 30 Dec 1984		12 Dec 2009		17 Dec to 19 Dec 2009	
17 Dec 1985		20 Dec to 21 Dec 1985		<hr/>			
15 Dec 1986	8	16 Dec to 17 Dec 1986		8 Dec 2010		12 Dec to 16 Dec 2010	
19 Dec 1987	0's	19 Dec to 26 Dec 1987		28 Dec 2011	2	17 Dec to 18 Dec 2011	
12 Nov 1988		12 Dec to 17 Dec 1988		<hr/>			
6 Dec 1989		7 Dec to 8 Dec 1989			0		
					1		
					0's		

* Starting date unknown

Note: Prior to the 1980-81 Ice Season, the International Joint Commission Orders required that complete closure of the ice boom shall not be accomplished before the first Monday in December.

Table 5 Comparison of Ice Areas Near Time of Ice Boom Opening

		Areas of Ice in Eastern Lake Erie		Opening of Ice Boom				Areas of Ice in Eastern Lake Erie		Opening of Ice Boom	
Year	Date of Observation	Square KMs	Square Miles	Start	Completed	Year	Date of Observation	Square KMs	Square Miles	Start	Completed
1965	No Data Collected			21-Mar	27-Mar	2000	21-Mar	410	160	23-Mar	24-Mar
1966				20-Mar	1-Apr	2001	14-Apr	390	150	17-Apr	20-Apr
1967				22-Mar	29-Mar	2002	Ice-free			7-Mar	7-Mar
1968				8-Mar	20-Mar	2003	10-Apr	490	190	10-Apr	11-Apr
1969				26-Mar	3-Apr	2004	5-Apr	1110	430	6-Apr	7-Apr
1970	16-Apr	2590	1000	23-Apr	30-Apr	2005	4-Apr	210	80	5-Apr	6-Apr
1971	27-Apr	2850	1100	3-May	14-May	2006	20-Mar	80	30	20-Mar	21-Mar
1972	18-Apr	1300	500	20-Apr	25-Apr	2007	7-Apr	620	240	10-Apr	18-Apr
1973	14-Mar	260	100	16-Mar	21-Mar	2008	14-Apr	310	120	15-Apr	19-Apr
1974	18-Mar	320	125	26-Mar	1-Apr	2009	6-Apr	100	40	6-Apr	13-Apr
1975	21-Mar	80	30	25-Mar	28-Mar	2010	18-Mar	570	220	22-Mar	24-Mar
1976	15-Apr	130	50	19-Apr	21-Apr	2011	11-Apr	230	90	12-Apr	22-Apr
1977	14-Apr	520	200	18-Apr	20-Apr	2012	Ice-free			28-Feb	2-Mar
1978	27-Apr	710	275	1-May	8-May						
1979	10-Apr	390	150	13-Apr	17-Apr						
1980	1-Apr	700	270	2-Apr	7-Apr						
1981	15-Apr	1220	470	18-Apr	22-Apr						
1982	26-Apr	1090	420	27-Apr	2-May						
1983	2-Mar	Trace	Trace	7-Mar	8-Mar						
1984	5-Apr	780	300	7-Apr	10-Apr						
1985	12-Apr	780	300	13-Apr	15-Apr						
1986	7-Apr	1010	390	12-Apr	14-Apr						
1987	5-Mar	130	50	6-Mar	6-Mar						
1988	8-Apr	700	270	9-Apr	10-Apr						
1989	27-Mar	340	130	30-Mar	6-Apr						
1990	26-Mar	230	90	26-Mar	30-Mar						
1991	25-Mar	50	20	27-Mar	30-Mar						
1992	31-Mar	160	60	30-Mar	2-Apr						
1993	3-Apr	540	210	5-Apr	6-Apr						
1994	19-Apr	620	240	21-Apr	28-Apr						
1995	28-Mar	410	160	30-Mar	17-Apr						
1996	17-Apr	730	280	19-Apr	3-May						
1997	24-Apr	60	25	25-Apr	28-Apr						
1998	Ice-free			5-Mar	5-Mar						
1999	30-Mar	Trace	Trace	30-Mar	30-Mar						

Table 6 Estimated Power Losses Due to Ice for Period of Record 1975 to Present

Winter Season of:	December	January	February	March 2012	April	May	Totals
1974-75	*	*	150,000	15,100	*	*	165,100
1975-76	*	78,700	36,500	45,800	32,000	*	193,000
1976-77	*	54,000	23,500	0	0	0	77,500
1977-78	*	88,000	600	600	0	0	89,200
1978-79	*	30,000	3,700	0	1,600	0	35,300
1979-80	*	6,000	30,000	13,000	10,500	0	59,500
1980-81	14,000	9,000	3,900	1,100	4,100	0	32,100
1981-82	*	58,000	27,000	10,000	13,000	5,000	113,000
1982-83	0	0	0	0	0	0	0
1983-84	53,000	57,000	4,000	25,000	0	0	139,000
1984-85	0	65,000	25,000	11,000	29,000	0	130,000
1985-86	10,000	65,000	8,000	5,000	6,000	0	94,000
1986-87	0	28,000	32,000	4,000	0	0	64,000
1987-88	0	13,000	24,000	0	4,000	0	41,000
1988-89	0	0	30,000	1,000	2,000	0	33,000
1989-90	6,000	7,000	5,000	5,000	0	0	23,000
1990-91	0	14,000	11,000	6,000	0	0	31,000
1991-92	0	21,000	3,000	14,000	0	0	38,000
1992-93	0	0	2,000	2,000	0	0	4,000
1993-94	0	11,000	12,000	0	1,000	0	24,000
1994-95	0	0	11,000	2,000	7,000	0	20,000
1995-96	0	45,000	4,000	13,000	0	0	62,000
1996-97	0	80,000	4,000	3,000	16,000	0	103,000
1997-98	0	0	0	0	0	0	0
1998-99	0	17,000	700	0	0	0	17,700
1999-2000	0	0	1,200	0	0	0	1,200
2000-01	700	3,600	500	100	0	0	4,900
2001-02	0	0	0	0	0	0	0
2002-03	0	35,000	11,500	1,500	0	0	48,000
2003-04	0	26,000	5,800	0	0	0	32,000
2004-05	0	7,000	13,100	8,500	0	0	28,600
2005-06	0	0	14,300	18,600	0	0	32,900
2006-07	0	2,500	37,600	3,800	7,800	0	51,700
2007-08	0	15,000	153,900	1,300	500	0	171,200
2008-09	0	4,700	17,600	0	2,400	0	24,700
2009-10	0	36,700	3,000	0	0	0	39,700
2010-11	0	8,400	5,800	0	15,300	0	29,500
2011-12	0	0	0	0	0	0	0

* No Data Published

Note: No data available for period 1964-74

Table 7 Comparative Data for Years Ice Boom Has Been in Place

Opening of Ice Boom				Opening of Ice Boom			
Year	Start*	Completed	Welland**	Year	Start*	Completed	Welland**
1965	21-Mar	27-Mar	1-Apr	2000	23-Mar	24-Mar	28-Mar
1966	20-Mar	1-Apr	4-Apr	2001	17-Apr	20-Apr	30-Mar
1967	22-Mar	29-Mar	1-Apr	2002	7-Mar	7-Mar	26-Mar
1968	18-Mar	20-Mar	1-Apr	2003	10-Apr	11-Apr	26-Mar
1969	26-Mar	3-Apr	1-Apr	2004	6-Apr	7-Apr	23-Mar
1970	23-Apr	30-Apr	1-Apr	2005	5-Apr	6-Apr	23-Mar
1971	3-May	14-May	29-Mar	2006	20-Mar	21-Mar	21-Mar
1972	20-Apr	25-Apr	29-Mar	2007	10-Apr	18-Apr	20-Mar
1973	16-Mar	21-Mar	28-Mar	2008	15-Apr	19-Apr	20-Mar
1974	26-Mar	1-Apr	29-Mar	2009	6-Apr	13-Apr	31-Mar
1975	25-Mar	28-Mar	25-Mar	2010	22-Mar	24-Mar	25-Mar
1976	19-Apr	19-Apr	1-Apr	2011	12-Apr	22-Apr	22-Mar
1977	18-Apr	20-Apr	4-Apr	2012	2-Feb	2-Mar	22-Mar
1978	1-May	8-May	28-Mar				
1979	13-Apr	17-Apr	28-Mar				
1980	2-Apr	7-Apr	24-Mar				
1981	18-Apr	22-Apr	25-Mar				
1982	27-Apr	2-May	5-Apr				
1983	7-Mar	8-Mar	5-Apr				
1984	7-Apr	10-Apr	28-Mar				
1985	13-Apr	15-Apr	1-Apr				
1986	12-Apr	14-Apr	3-Apr				
1987	6-Mar	6-Mar	1-Apr				
1988	9-Apr	10-Apr	31-Mar				
1989	30-Mar	6-Apr	31-Mar				
1990	26-Mar	30-Mar	28-Mar				
1991	27-Mar	30-Mar	26-Mar				
1992	30-Mar	2-Apr	30-Mar				
1993	5-Apr	6-Apr	30-Mar				
1994	21-Apr	28-Apr	5-Apr				
1995	30-Mar	17-Apr	24-Mar				
1996	19-Apr	3-May	29-Mar				
1997	25-Apr	28-Apr	2-Apr				
1998	5-Mar	5-Mar	24-Mar				
1999	30-Mar	30-Mar	31-Mar				
1965-2011	4-Apr	8-Apr	29-Mar	Average for post-ice boom period			
1970-2011	6-Apr	10-Apr	29-Mar	Average for the flexible boom opening period.			

1970 Commencement of flexible date for boom opening.

* Denotes opening of first boom span. Mobilization time precedes this date.

** Opening date is usually established in advance and may relate to Welland Canal repair schedule.

Appendix A – Description of the Lake Erie-Niagara River Area

A.1 Hydraulics and Hydrology

The Niagara River, about 58 kilometres (36 miles) in length, is the natural outlet from Lake Erie to Lake Ontario (Figures 2). The elevation difference between the two lakes is about 99 metres (326 feet); and about half of this occurs at Niagara Falls. Over the period 1860-2010, the average Niagara River flow at Queenston, Ontario has been 5,859 cubic metres per second (m³/s) (206,910 cubic feet per second (cfs)). The Welland Canal carries a small portion of the Lake Erie outflow. The total upper Great Lakes drainage basin upstream of the Niagara River is approximately 684,000 square kilometres (264,000 square miles). Figures 1 and 2.

The Niagara River, as described in the following paragraphs, consists of three major reaches: the upper Niagara River, the Niagara Cascades and Falls, and the lower Niagara River.

(a) Upper Niagara River

Upper Niagara River extends about 35 kilometres (22 miles) from Lake Erie to the Cascade Rapids which begin 1 kilometre (0.6 mile) upstream from the Horseshoe Falls. From Lake Erie to Strawberry Island, a distance of approximately 8 kilometres (5 miles), the channel width varies from 2,740 metres (9,000 feet) at its funnel-shaped entrance to 460 metres (1,500 feet)

at Squaw Island below the Peace Bridge. The fall over this reach is around 1.8 metres (6 feet). In the upper 3.2 kilometres (2 miles) of the river, the maximum depth is approximately 6 metres (20 feet), with velocities as high as 3.7 metres per second (m/s) (12 feet per second (ft/s)) in the vicinity of the Peace Bridge. Below Squaw Island, the river widens to approximately 610 metres (2,000 feet) with velocities ranging from 1.2 to 1.5 m/s (4 to 5 ft/s).

At Grand Island, the river divides into the West Channel known as the Canadian or Chippawa Channel and the East Channel known as the American or Tonawanda Channel. The Chippawa Channel is approximately 17.7 kilometres (11 miles) in length and varies from 610 to 1,220 metres (2,000 to 4,000 feet) in width. Velocities range from 0.6 to 0.9 m/s (2 to 3 ft/s). The Chippawa Channel carries approximately 60% of the total river flow. The Tonawanda Channel is 24 kilometres (15 miles) long and varies from 460 to 610 metres (1,500 to 2,000 feet) in width above Tonawanda Island. Downstream thereof, the channel varies from 460 to 1,220 metres (1,500 to 4,000 feet) in width. Velocities range from 0.6 to 0.9 m/s (2 to 3 ft/s). North of Grand Island, the channels unite to form the 4.8 kilometre (3 mile) long Chippawa-Grass Island Pool. At the downstream end of the Pool is the International Niagara Control Works. This gated control structure extends from the Canadian shoreline about halfway across the width of the river. The Niagara Falls are located about 1,370 metres (4,500 feet) downstream of the structure. The average fall from Lake Erie to the Pool is 2.7 metres (9 feet).

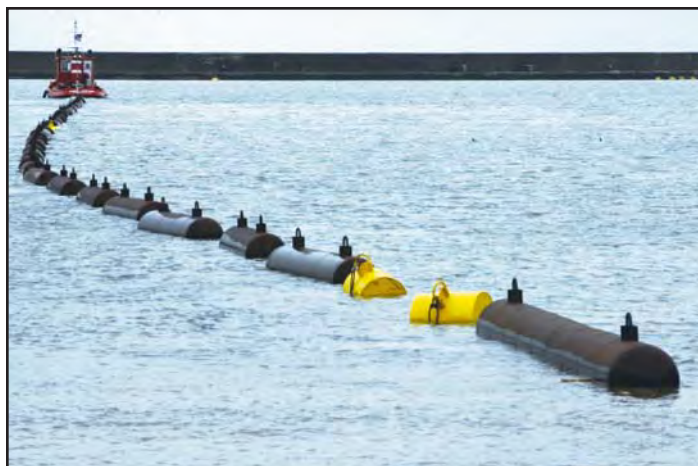


(b) Niagara Cascades and Falls

Below the gate control structure, the river falls 15 metres (50 feet) through the Cascade area and is divided into two channels by Goat Island. These channels convey the flow to the brink of the Canadian and American Falls (Figure 3). The Canadian or Horseshoe Falls is so named because the crest is horseshoe shaped. During the non-tourist hours, the minimum Falls flow is 1,416 m³/s (50,000 cfs). This produces a fall of about 57 metres (188 feet). Minimum Falls flow for tourist hours is 2,832 m³/s (100,000 cfs) which results in a fall of about 54 metres (177 feet). These minimum flow values are combined Horseshoe and American Falls flows. There are small accumulations of talus (rock debris) at the flanks. At the American Falls, water plunges vertically ranging from 21 to 34 metres (70 to 100 feet) to a talus slope at its base.

(c) Lower Niagara River

The Niagara Gorge extends from the Falls for 11 kilometres (7 miles) downstream to the foot of the escarpment at Queenston, Ontario. The upper portion of this reach is known as the Maid-of-the-Mist Pool, with an average fall of approximately 1.5 metres (5 feet). This reach is navigable for practically its entire length. The Maid-of-the-Mist Pool is bounded downstream by the Whirlpool Rapids, which extends a further 1.6 kilometres (1 mile). The water surface profile drops 15 metres (50 feet) in the Whirlpool Rapids, where velocities can reach as high as 9 m/s (30 ft/s). The Whirlpool, a basin 518 metres (1,700 feet) long, 365 metres (1,200 feet) wide and depths up to 38 metres (125 feet), is where the river makes a near right-angled turn. Below the Whirlpool there is another set of rapids which drop approximately 12 metres (40 feet). The river emerges from the gorge at Queenston, Ontario and subsequently drops 1.5 metres (5 feet) to Lake Ontario. At Queenston, the river widens to 610 metres (2,000 feet) and is navigable to Lake Ontario.



A.2 Hydro-Electric Installations and Remedial Works

A major portion of Lake Erie outflow is utilized for power production and is diverted to hydroelectric plants by intake structures located above the Falls (Figure 3). A lesser portion is diverted for power via the Welland Canal. The high head plants, Sir Adam Beck Nos. 1 and 2 in Canada and the Robert Moses Niagara Power Project in the United States, withdraw water from the Chippawa-Grass Island Pool and return it to the lower Niagara River at Queenston, Ontario and Lewiston, New York, respectively. Figure 3 shows the location of these diversion structures and hydro-electric power plants.



The amount of water that can be diverted for power generation is determined by a 1950 Treaty between the Governments of Canada and the United States concerning "The Diversion of the Niagara River", generally referred to as the "1950 Niagara Treaty." The Treaty requires the flow over Niagara Falls to be no less than 2,832 m³/s (100,000 cfs) during the daylight hours of the tourist season. The tourist season is from 0800 to 2200 hours local time from 1 April to 15 September and then from 16 September to 31 October the hours are 0800 to 2000 local time. At all other times, the flow must be not less than 1,416 m³/s (50,000 cfs). The Treaty also specifies that all water in excess of that required for domestic and sanitary purposes, navigation, and the Falls flow requirements, may be diverted for power generation. River levels are monitored using water level gauges located throughout the Niagara River. Gauge locations are referenced on the map in Figure 2.

Remedial works were constructed by the Power Entities in the 1950's, with the approval of the International Joint Commission to maintain the Falls flows required by the treaty and to facilitate power diversions. The remedial works consist of excavation and fill on both flanks of the Horseshoe Falls and the International Niagara Control Works structure extending about 0.8 kilometre (0.5 mile) into the river from the Canadian shore at the downstream end of the Chippawa-Grass Island Pool. The Chippawa-Grass Island Pool control structure has 13 gates completed in 1957 and 5 additional gates completed in 1963. The control structure is operated jointly by the Power Entities and regulates the water level in the Chippawa-Grass Island Pool within limits set by the International Joint Commission. It also functions to adjust Falls flow promptly from 2,832 m³/s (100,000 cfs) to 1,416 m³/s (50,000 cfs)

and vice-versa during the tourist season. The operation of the control structure is under the supervision of the International Joint Commission's International Niagara Board of Control. In 1964, with the International Joint Commission's approval, the Power Entities installed a floating ice boom in Lake Erie, near the head of the Niagara River. The boom has been installed early each winter and removed in the spring every year since then. Its main purpose is to reduce the frequency and duration of heavy ice runs into the Niagara River which may lead to ice jams that could seriously hamper power diversions and damage shoreline installations. A more detailed description of the boom is contained in Section B.3.

A.3. Other Shore Installations

The Black Rock Canal parallels the upper reach of the Niagara River from Buffalo Harbor to the downstream end of Squaw Island. The canal provides an alternate route around the constricted shallow and high velocity Peace Bridge reach of the upper Niagara River. Extending from Buffalo Harbor to above Strawberry Island, the canal is separated from the river at the upstream end by the Bird Island Pier, a stone and concrete wall, and by Squaw Island at the downstream end. The Black Rock Lock, which has a lift of 1.5 metres (5 feet), is located near the lower end of the canal. A navigation channel extends from Squaw Island via the Tonawanda Channel to Niagara Falls, New York. The channel and canal are maintained to a depth of 6.4 metres (21 feet) below low water datum to North Tonawanda and then to a depth of 3.7 metres (12 feet) below low water datum to the city of Niagara Falls, New York.

The U.S. Government rehabilitated a portion of the Bird Island Pier in 1985 and 1986. Prior to rebuilding, most of the pier was overtopped by water passing from the Canal into the Niagara River at times of storm and/or high outflow from Lake Erie. Although the rebuilding raised the level of the pier slightly, culverts were incorporated into the structure to ensure unimpeded pre-project flow conditions that occurred over and through the pier.

Two bridges linking the Province of Ontario and State of New York span the upper Niagara River. The Peace Bridge (highway) crosses the head of the river and the Black Rock Canal close to Lake Erie. The International Railway Bridge crosses the river and the canal 2.4 kilometres (1.5 miles) downstream from the Peace Bridge. The South and North Grand Island highway bridges traverse the Tonawanda Channel at Tonawanda and Niagara Falls, New York, respectively. Docks for recreational craft are located at many points along the Niagara River, with a high concentration along the Tonawanda Channel. There are a few commercial docks for bulk commodities along the United States shoreline between the lower end of the Black Rock Canal and North Tonawanda, New York. Several municipal and industrial water intakes and waste outfalls are located in the upper river. Some of these have structures extending above the water surface.

A.4 Ice Problems

Flow retardation due to ice in the Niagara River is a common winter event. During periods of high southwest winds, ice from Lake Erie sometimes enters the Niagara River and becomes grounded in shallow areas such as the shoals near the head of the river and in the Chippawa-Grass Island Pool. During severe winter weather, ice originating in the river often adds to the problems caused by ice runs from the lake. These ice conditions can retard the flow in the Niagara River and occasionally lead to shore property damage and flooding. Accumulations of ice at the hydroelectric power intakes above Niagara Falls or ice jams upstream can reduce the amount of water diverted into these intakes. At times, a combination of reduced diversions, manipulated water elevations in the Chippawa-Grass Island Pool and ice breaker activity is necessary to facilitate ice passage. Ice accumulations in the Maid-of-the-Mist Pool may pose potential hazards to the Maid-of-the-Mist Steamboat Company facilities located downstream of the Falls. Heavy ice runs in the upper river, if added to a large volume of ice already in the Maid-of-the-Mist Pool, have severely damaged this installation on occasion.



Appendix B – Background Information on the Ice Boom

B.1 Authorization for Placement of the Ice Boom

The International Joint Commission authorized the Power Entities to install the ice boom on a test basis under an Order of Approval dated 9 June 1964. This Order has subsequently been modified by Supplementary Orders. The operation of the ice boom is reviewed by the International Joint Commission when circumstances require, but no less than once every five years. The most recent review was completed in 2009. A 1999 review resulted in the Commission issuing a Supplementary Order which modified condition (d). A 1984 Order of Approval established the current conditions for ice boom opening modifying condition (e). A Supplementary Order was issued in 1997 to remove any reference to the material required for the ice boom's pontoons.

Condition (d) regarding installation and Condition (e) regarding boom removal state, respectively:

- (d) "Installation of the floating sections of the boom shall not commence prior to December 16 or prior to the water temperature at the Buffalo Water intake reaching 4° C (39° F), whichever occurs first, unless otherwise directed by the Commission."
- (e) "All floating sections of the ice boom shall be opened by April 1, unless ice cover surveys on or about that date show there is more than 250 square miles (650 square kilometres) of ice east of Long Point. The ice boom opening may be delayed until the amount of ice east of Long Point has diminished to 250 square miles (650 square kilometres). Complete disassembly and removal of all remaining flotation equipment shall be completed within two weeks thereafter. Notwithstanding any other provision of this Order, the Commission retains the right to require retention, opening or removal of all or any part of the boom at any time because of the existence of an emergency situation."

B.2 Purpose of the Ice Boom

The ice boom accelerates the formation of the natural ice arch that forms most winters near the head of the Niagara River and also stabilizes the arch once it has formed. A map of eastern Lake Erie indicating the location of the ice boom is shown in Figure 5. The boom reduces the severity and duration of ice runs from Lake Erie into the Niagara River, thereby lessening the probability of large-scale ice blockage in the river. Such blockages could lead to both hydropower generation reductions and shoreline property flooding. In addition, it reduces the probability of ice damage to docks and other shore structures.

Once the ice arch is formed, the arch bears the pressure of upstream ice. Seasonal storms may overcome the stability of the arch and force large masses of ice against the boom. The boom was designed to then submerge and allow the ice to override it until the pressure is relieved. After storm conditions subside, the boom resurfaces and again restrains

the ice. Throughout the winter season, the ice boom facilitates stabilization of the broken ice cover during the refreezing process. In the spring, it minimizes the severity of ice runs by reducing the quantity of loose ice floes which enter the river.

B.3 Description of the Ice Boom

When in position, the 2,700 metre (8,800 feet) ice boom spans the outlet of Lake Erie and is located approximately 300 metres (1,000 feet) southwest of the water intake crib for the city of Buffalo. The boom is made up of 22 spans. Spans are anchored to the lake bed at 122 metre (400 foot) intervals by 6.4 centimetre (2.5 inch) diameter steel cables. Figure 4 illustrates structural details and a plan view of the ice boom. As a result of studies conducted by the Power Entities, all of the timber pontoons were replaced with 76 centimetre (30 inch) diameter, 9 metre (30 foot) long steel pontoons. This replacement was done to improve the ice-overlapping resistance of the ice boom and reduce its maintenance costs. The replacement of timbers with steel pontoons was completed in the fall of 1997 and the first all-steel-pontoon ice boom was used in the 1997-1998 ice season.

Based on experience gained during the 1997-1998 ice season, it was recommended that to reduce the potential for damage to the ends of the pontoons, from collisions due to storm-induced wave action during open water periods, one steel pontoon from each of the spans A through J be removed. Therefore, beginning with the 1998-1999 ice season, spans A through J contain 10 instead of 11 steel pontoons. This modification greatly reduced damage to the pontoons in this reach.



Great Lakes - St. Lawrence Drainage Basin



Figure 1

Map of Niagara River Showing Water Level Gauge Locations

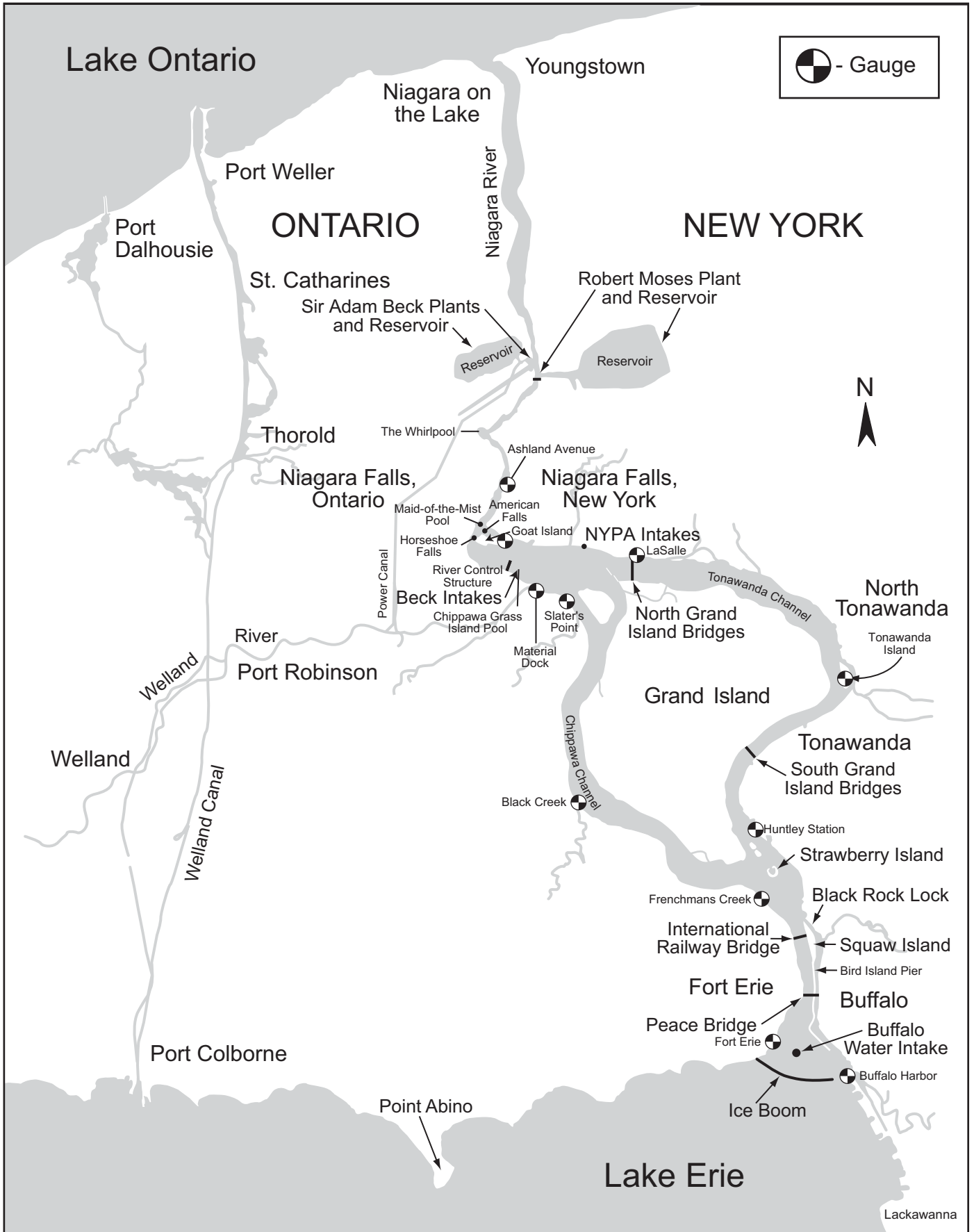


Figure 2

Niagara River Diversion Structures and Power Plants

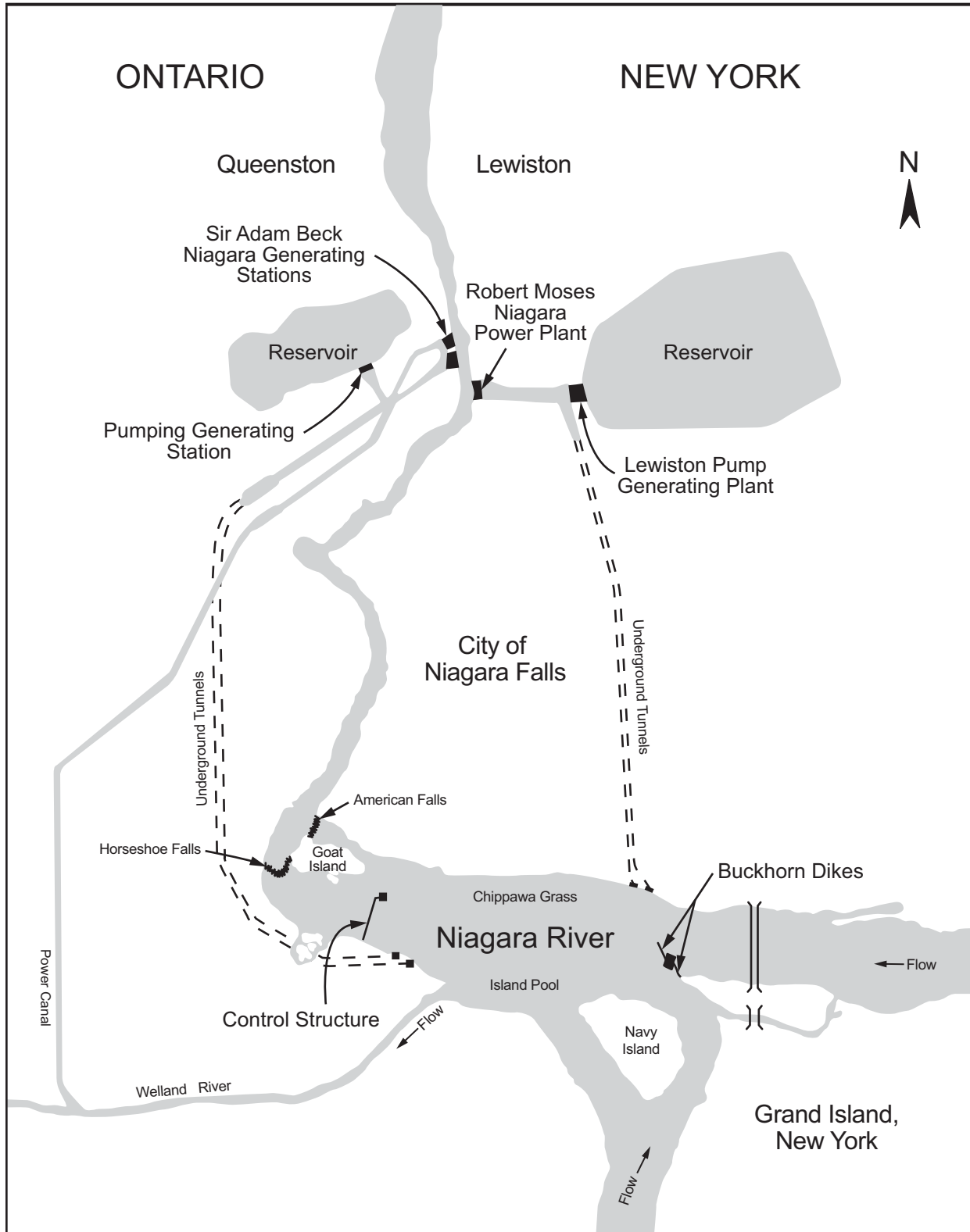


Figure 3

Structural Details of the Ice Boom

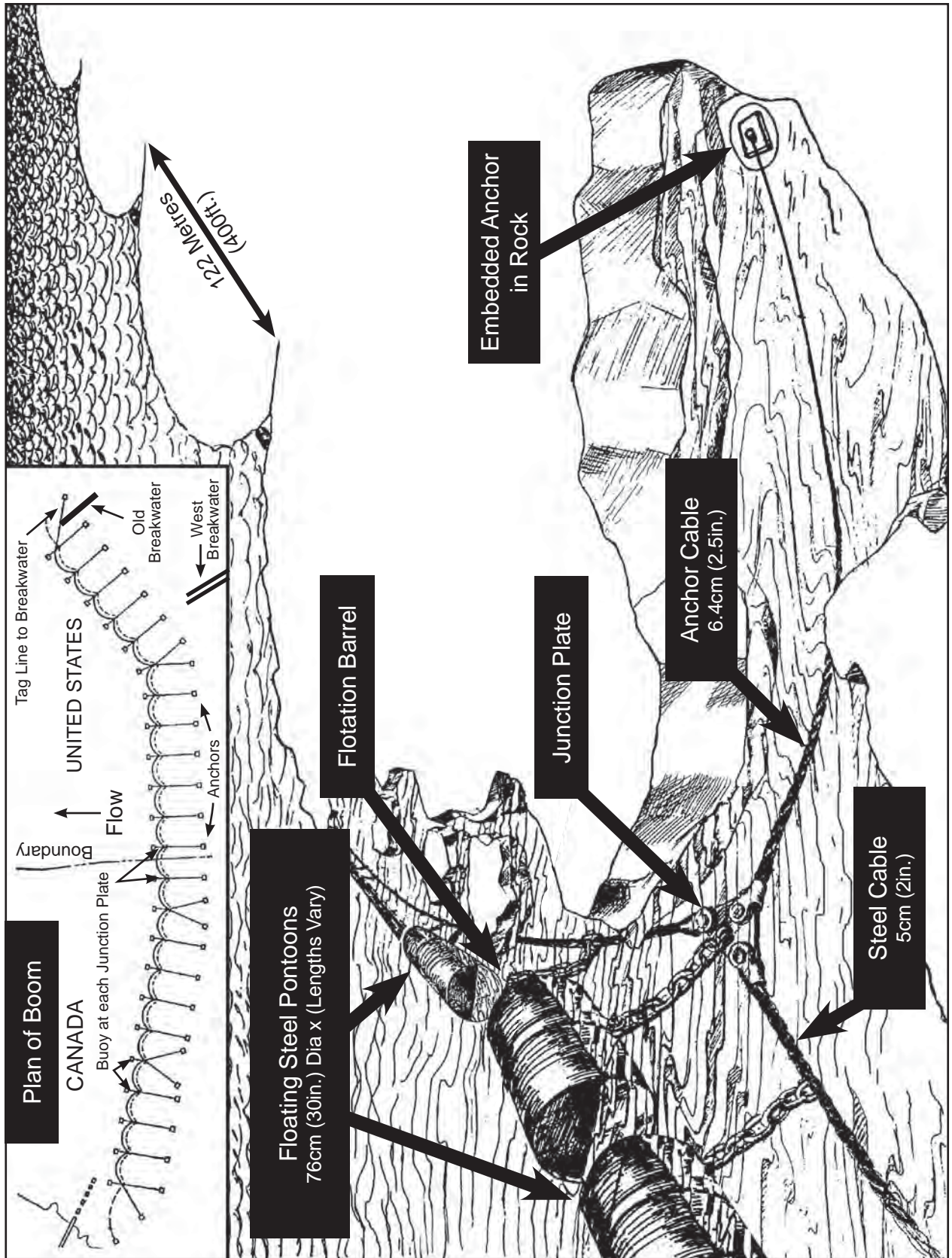


Figure 4

Map of Eastern Lake Erie

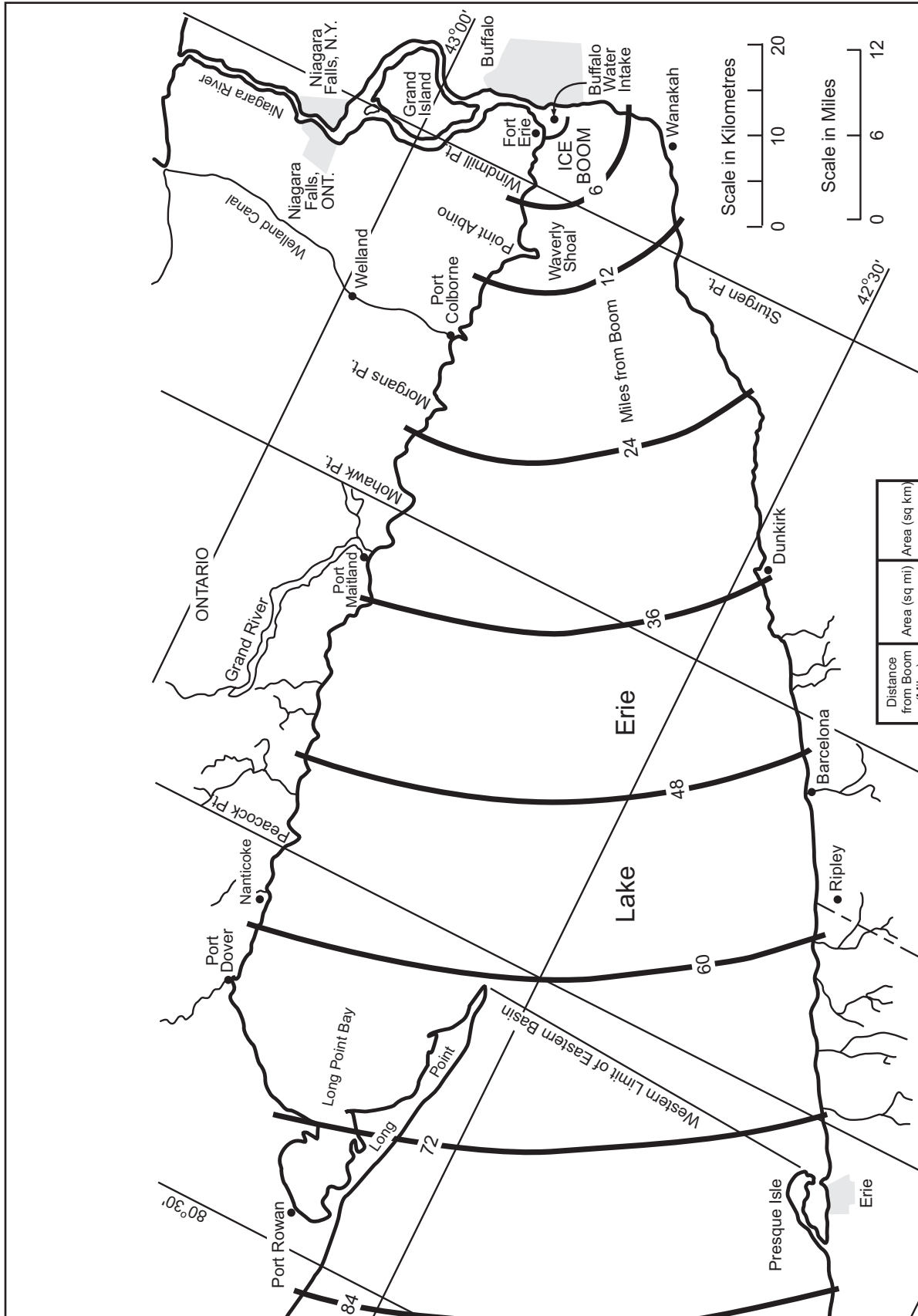


Figure 5

Plan View of Ice Boom and Sequence of Removal

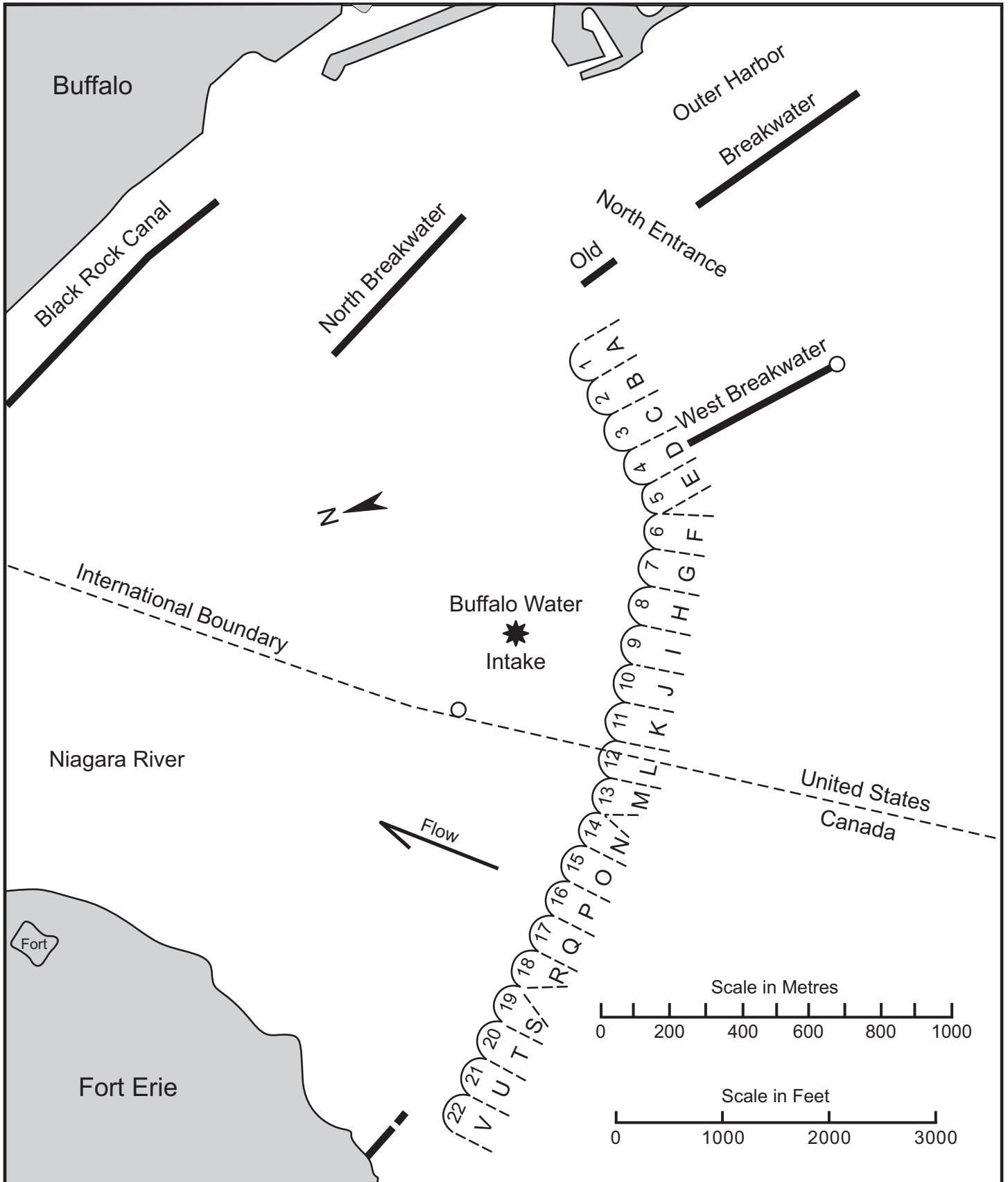


Figure 6