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THE LAKE ERIE-NIAGARA RIVER ICE BOOM: OPERATIONS AND IMPACTS

Panel on Niagara River Ice Boom
Investigations
Water Science and Technology Board
Commission on Physical Sciences,
Mathematics, and Resources
National Research Council

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This report has been reviewed by a group other than the authors, according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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PREFACE

This report is the result of a request from the International Joint Commission-United States and Canada (IJC) to the National Research Council (NRC) to assist in resolving issues associated with the ice boom located at the entrance to the Niagara River, New York and Ontario.

The Lake Erie-Niagara River Ice Boom has been operated during the past 18 years to prevent the formation of ice jams that would reduce power production at hydroelectric plants using waters of the Niagara River. The boom appears to have reduced substantially the number and severity of ice jams in the river, but some people have contended that an inadvertent result of the boom has been to produce detrimental climatic effects in the Buffalo, New York, and Fort Erie, Ontario, area by retaining ice on Lake Erie later into the spring than would otherwise occur. Past scientific examinations of this issue have concluded the boom's weather impact to be insignificant. Yet, some of the public has rejected this general conclusion and, instead, attributed additional impacts (e.g., negative effects on fisheries, boating, and shoreline stability) to the boom. Thus, despite the great number of studies that have been performed, the IJC's ability to carry out its functions with respect to the ice boom has become complicated. This report represents the IJC's attempt to resolve the issues on well-founded principles of science and technology.

The Panel on Niagara River Ice Boom Investigations of the Water Science and Technology Board was appointed by the Commission on Physical Sciences, Mathematics, and Resources of the NRC. The NRC is the operating and advisory arm of the National Academy of Sciences and the National Academy of Engineering. Panelists were chosen for their special expertise and experience in meteorology, ice mechanics, geography, fisheries biology, and other disciplines necessary to the panel's charge as delineated in the Introduction (Chapter 1). The persons selected to be members of this panel were scientists who not only had expertise relative to the issues involved but also had no real or perceived biases concerning the operation of the ice boom. In addition to the panelists, other experts were consulted. These "resource persons" were able to provide historical facts and information relevant to the issues that could not have been obtained elsewhere, and the panel is grateful for their contributions.

The panel's findings and recommendations are summarized in the first section of the report (pp. 1-3), and supporting discussions are contained throughout the body of the report. Briefly, the panel finds that the negative impacts of the boom are not nearly as great as a large portion of the public perceives them to be, but at the same time, the ice control capabilities of the boom and associated benefits are sometimes overestimated by those persons desiring the boom. Further, the panel recognizes the enormous value to the public of Niagara River hydroelectric resources. Partial or total interruption of generation at these facilities would be extremely costly and has the potential (in the case of a serious mid-winter interruption) of causing a near disaster in New York power generation. There is no feasible alternative to the present structure. However, the IJC and the power entities should give careful consideration to modifying springtime boom removal practices as recommended by the panel.

The chairmanship of this panel has been a gratifying and enriching experience. The panelists and resource persons willingly volunteered much time and counsel and deserve credit for the substance and recommendations found in this report; all devoted expertise and enthusiasm to their tasks. Their reward will be measured by the level of acceptance of the conclusions and recommendations of this report. The panel is grateful to the staffs of the NRC and the IJC for the support that enabled the panel to focus quickly on the assigned task and to complete it on time.

Special mention is made of the outstanding support and assistance provided by Steve Parker, Sheila David, and Jeanne Aquilino, of the Water Science and Technology Board staff, without whose work the panel would not have been able to complete its assigned tasks.

Harry L. Hamilton, Jr., Chairman
Panel on Niagara River Ice Boom Investigations

November 1983

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FINDINGS

The panel considered that its mission basically was to address whether the Lake Erie-Niagara River Ice Boom has a climatic effect in the Buffalo/Fort Erie region, and if so, to determine the magnitude of that effect and what alternative ice control strategy could be implemented that would have less of a climatic effect.

We summarize our findings in relation to our five tasks (underlined). Persons with significant interest in the ice boom are urged to read the full report, which includes extensive background material and is presented in a style that should be comprehensible to the general public. Appendix F defines technical terms used in the context of the report.

1. Review and comment on the scientific basis for the conclusions reached in previous studies relating to possible climatic effects of the ice boom. Previous studies, taken individually, are inconclusive in demonstrating whether the ice boom has a local climatic effect, mostly because of insufficient data. The studies do, however, correctly conclude that a climatic effect, if present, does not extend as far as the Buffalo airport. These studies also show that there has been a general cooling in the Buffalo area since before boom installation, but this is part of a regional cooling trend and is not caused by the ice boom.

The panel sought evidence of a temperature effect beyond the well known significant cooling on Lake Erie shoreside (up to 3 mi or 5 km inland) produced by the lake itself. The additional cooling attributable to the ice retained by the boom, even if kept in place until ice out, is considered minute. Based on previous studies and analyses of additional climatological data, the panel finds that the ice boom will cause no cooling to local climates if it is removed when there is 250 mi^2 (650 km^2) of ice remaining on Lake Erie.

2. Recommend a monitoring program designed to resolve the questions as to the amount and extent of modification to the local climate, if any, by the ice boom. The extent, duration, and magnitude of the climatological effect that might occur is very small in relation to natural weather variability in time and space. The panel finds that a monitoring program is not required, because any

long-term monitoring program would be elaborate and expensive and would be unable to detect any boom-related effects.

3. Utilizing existing data and expert judgment, assess the relative monetary and nonmonetary effects of a flexible versus a fixed date for ice boom removal. All information available leads the panel to conclude that during the colder part of the year, the ice boom has demonstrable, significantly beneficial effects in that it reduces power generation interruptions along the Niagara River and has no apparent negative impacts on other interests.

During early spring, due to the increased solar heating and reduced strength of the ice, the ice-restraining benefits of the boom are reduced while the probability of a local, small-scale cooling effect increases. The panel finds that except in the presence of extensive spring ice cover, net benefits of the boom after the beginning of April have not been demonstrated.

4. Assess the ice boom's impact on local and downstream interests. The ice boom's impacts on local and downstream interests include a significant benefit to both the hydropower producers and the consumers, particularly during ice formation and mature ice stages (December to March). The boom's effectiveness in retaining ice during the ice dissipation stage in April is much smaller, and the resultant benefits are diminished. There is also a flood control benefit to local and downstream interests in that ice-jam-related flooding is reduced somewhat. No negative impacts of the ice boom on navigation, erosion, and fisheries could be demonstrated with the available data.

5. Assess alternative concepts to the current ice boom that would eliminate or reduce potential for local climate modification, should modification in fact exist. The panel concluded that there is no feasible alternative that would produce effectiveness comparable to that of the present ice boom. Alternative concepts considered by the panel and described in Chapter 5 would be either more costly or less effective or would have significantly greater negative impacts than the present ice boom.

RECOMMENDATIONS

The panel makes the following recommendations:

1. The boom should be opened by April 1 and removed for the summer as soon as practical;

2. If on April 1 ice cover surveys show that there is more than 250 mi^2 (650 km^2) of ice east of Long Point, the boom opening may be delayed until the amount of ice remaining in the eastern portion of Lake Erie has diminished to 250 mi^2 (650 km^2).

The panel's recommendations are based on the following considerations:

- After about April 1, the probability of new ice formation in Lake Erie is small because of the amount of solar radiation available during the daytime and the diminished length of the nighttime cooling period.
- After about April 1, the internal strength of Lake Erie ice is considerably less than that of new winter ice and is decreasing rapidly.
- After April 1, the flow of water over Niagara Falls during the daylight hours increases from 50,000 cubic feet per second (1415 cubic meters per second) to 100,000 cfs (2830 cms), thereby increasing the amount of water available for ice transport.
- After the winter lake ice cover has diminished to about 250 mi^2 (650 km^2), the movement of ice into the Niagara River can become of equal significance to in-lake melting in reducing the amount of ice remaining in the lake.

1

INTRODUCTION

Following a treaty between the United States and Canada in 1950 that authorized increased diversions of the Niagara River, the Power Authority of the State of New York (since renamed and hereafter called New York Power Authority or NYPA) and Ontario Hydro (jointly referred to as the power entities) installed over a period of years additional hydroelectric generating capacity that became fully operational by 1961. The Niagara River has always carried ice in the winter and spring, and in the past the power entities used ice breaker boats and built various structures in the river to control the ice. During the winter of 1963-1964, particularly destructive ice jams occurred on the Niagara River, causing severe flooding and very costly power generation disruptions, and demonstrated the need for additional ice control. In the winter of 1964-1965, with approval from the International Joint Commission-United States and Canada (IJC), the power entities began to operate the Lake Erie-Niagara River Ice Boom on a seasonal basis at the head of the Niagara River.

The boom is intended to mitigate downstream ice jams by reducing the flow of lake ice into the river. The functions of the boom are to accelerate the formation of a stable upstream ice cover, reduce movement in the cover while it is being formed, and provide additional stability to the downstream edge of the natural arch, thus minimizing arch erosion caused by the breaking off of ice pieces at the ice/water interface. Figure 1 shows the Niagara River and the location of the ice boom, which extends a distance of about 8800 ft (2680 m) from near the Canadian shore almost to the Buffalo shore. The boom consists of a line of flotation buoys and large timbers attached by chains to a steel cable spanning the outlet and anchored to the bed of Lake Erie. All responsibilities associated with the ice boom are jointly shared by the power entities, and operation of the ice boom is regulated by the IJC.

The ice boom has been effective in lessening (but not totally eliminating) ice runs, and the power entities are satisfied that the boom functions as intended. However, at various hearings and other public forums, questions have been raised about possible negative impacts of the ice boom and the criteria for boom removal in the spring. The most commonly aired concern is that the boom retains ice for significant periods in the spring each year, resulting in reduced

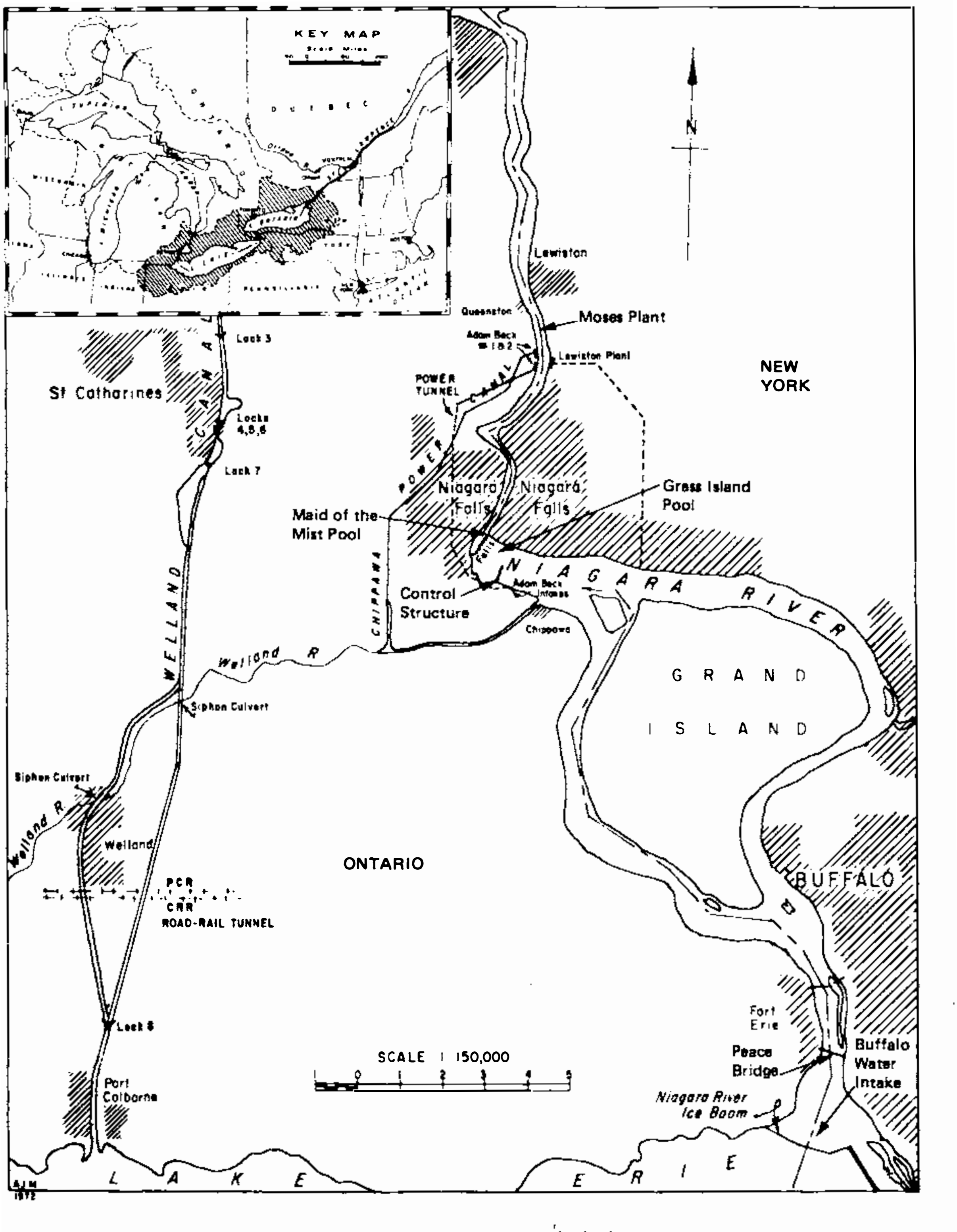

FIGURE 1 Ice boom and vicinity.

temperatures in the Buffalo vicinity. Studies of micrometeorology, climatic statistics, and the operation of the ice boom have been conducted in response to these concerns. These studies concluded that the presence of the boom has caused no significant alteration of the Buffalo area weather.

Nevertheless the issue still persists, and because of the significance of the issue the IJC requested the National Research Council (NRC) to perform the following tasks:

1. Review and comment on the scientific basis for the conclusions reached in previous studies relating to possible climatic effects of the ice boom;
2. Recommend a monitoring program(s) designed to resolve the questions as to the amount and extent of modification to the local climate, if any, by the ice boom;
3. Utilizing existing data and expert judgment, assess the relative monetary and nonmonetary effects of a flexible versus a fixed date for ice boom removal;
4. Assess the ice boom's impact on local and downstream interests; and
5. Assess alternative concepts to the current ice boom that would eliminate or reduce potential for local climate modification, should modification in fact exist.

In response, a Panel on Niagara River Ice Boom Investigations was appointed under the NRC's Water Science and Technology Board. The nine-member panel includes U.S. and Canadian experts in the fields of ice physics and mechanics, meteorology, hydraulic engineering, geography, fisheries biology, and remote sensing applications. The IJC provided the panel with several reports of various types related to the ice boom, and the panel also obtained additional pertinent studies for consideration. This library of material served as the panel's main information base for the study (see Appendix A - Bibliography).

In early May 1983, several members of the panel met in Washington, D.C., with the Water Science and Technology Board staff to sort out assignments and organize the study and to prepare for an intense working meeting of the full panel and other experts with extensive experience and knowledge of the history and operation of the ice boom. The working meeting of the full panel, held in Washington, D.C., on June 27-30, 1983, brought together the panel, other experts, and the IJC and NRC staffs for discussions, reviews, debate, and writing sessions. A draft report was developed from the deliberations of the June working meeting, and the panel refined its findings at a subsequent meeting, held in Hanover, New Hampshire, on September 1-2. Throughout the study process, the panel and staff were acutely aware of the importance of public input and its comprehension of findings. Public input was obtained through the IJC public meeting process and was also invited by the panel through local officials. The panel has attempted to present its findings in a way that is meaningful and convincing to both the public and scientific communities.

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ICE IN LAKE ERIE AND THE NIAGARA RIVER

CHARACTERISTICS OF THE LAKE ERIE REGION

Geography

Lake Erie is the southernmost of the Great Lakes and with an average depth of 62 ft (19 m) is also the shallowest. Its surface area is almost 10,000 mi^2 (25,900 km^2)--fourth among the Great Lakes. The lake bottom slopes generally downward to the east, and the maximum depth is about 212 ft (65 m). Oriented parallel to the prevailing winds and storm motion patterns, its major axis, 240 mi (385 km) in length, lies in a direction about north 70° east. The lake is composed of three basins as depicted on Figure 2. The western basin, lying west of a line from Point Pelee, Ontario, southwesterly through the Lake Erie Islands to Sandusky, Ohio, is the smallest and shallowest basin, being about 30 ft (9 m) deep. Most of the lake volume is in the central basin, whose depth is about 60 ft (18 m) and extends from the western basin to a line from about 20 mi (32 km) west of Long Point to Presque Isle, Pennsylvania. The central basin occupies almost two-thirds of the lake surface area. Excluding the thin peninsula known as Long Point, the effective width of the eastern basin is about 30 mi (48 km). The eastern end of the lake has a funnel shape, the nose of which is squared off for about 8 mi (13 km). The Niagara River discharges from the northernmost corner of Lake Erie into Lake Ontario.

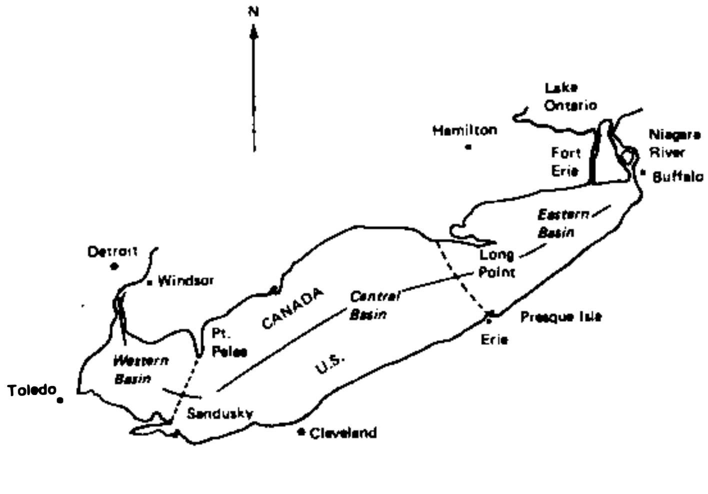


FIGURE 2 The three basins of Lake Erie.

The funnel-shaped entrance to the Niagara River from Lake Erie is obstructed by a series of limestone shoals at shallow depth. The river is 1800 ft (550 m) wide at the Peace Bridge, just downstream from the entrance.

The long-term average level of Lake Erie is 570.4 ft (174 m), International Great Lakes Datum (IGLD 1955). Extreme mean monthly levels are 573.5 ft (174.8 m) IGLD (June 1973) and 567.5 ft (173.9 m) IGLD (January 1964). The mean level of the lake in 1982 was about 2 ft (0.6 m) above the 1900-1982 average level. The level of the lake is largely controlled by natural forces, there being no level control devices at either the entrance or exit to the lake. Strong westerly or easterly winds associated with storms can result in short-term, but pronounced, variations in the lake level. For example, on April 6, 1979, southwest winds caused a rise of 7 ft (2 m) above the calm level at Buffalo--and a corresponding 7 ft (2 m) drop near Toledo, Ohio.

The overall length of the Niagara River from Lake Erie to Lake Ontario is about 35 mi (55 km), and the total fall is 325 ft (99 m). The surrounding topography above Niagara Falls is relatively flat. Downstream from the falls the topography is trough-like with steep banks and few shallow embayments.

Glacial till covers sedimentary rocks which underlie the lake. Shale and limestone exist in the northernmost portion of the lake, but elsewhere these layers are interbedded with standstone. No large faults are in evidence in this lake. Recent alluvial deposits occur in the valley floodplains. Two cross-lake moraines divide Lake Erie naturally into the three basins as described.

Economy

The Niagara River is one of the outstanding recreational and tourist attractions in the world and also one of the most highly developed sources of hydroelectric power. Because of its proximity to this enormous water resource, the area is highly industrialized, resulting in intensive industrial and residential use of the shorelines. The river channels and lake carry a high intensity of shipping and pleasure boating concentrated around the Port of Buffalo on the United States shore and at Port Colborne in Canada.

Climate and Hydrology

The climate of the general region is temperate and humid, with the large water bodies moderating the more extreme conditions characteristic of nearby inland locations. The annual mean temperature at the Greater Buffalo International Airport is about 46^{o}F (8^{o}C); annual precipitation averages about 36 in. (90 cm). Normally, Lake Erie begins to freeze in late December, achieves maximum ice cover in February, and remains partially ice-covered through April; often some ice is present in the eastern basin until mid-May. The orientation of Lake Erie is parallel with the prevailing winds. Winds from the west cause an easterly ice transport, and during spring, last ice leaves slowly from Lake Erie at the eastern end, which is in the shape of a funnel and serves as a natural constriction. Consequently, the local spring climate near the lake shore in Buffalo is made colder naturally by prevailing winds off the cold water and ice in the lake.

The spring season near the lake is cloudier and cooler than at points not affected by the cold lake. Springtime growth of vegetation is retarded and protected from late spring frosts. With heavy winter ice accumulations in the lake, typical spring conditions are delayed naturally until May or early June, but summer comes suddenly by mid-June. The seasonal changes can be inferred from a tabulation of monthly average Niagara River water temperatures at Ft. Niagara:

January-32°F (0°C)	July-71.6°F (22.0°C)
February-32°F (0°C)	August-71.8°F (22.1°C)
March-32°F (0°C)	September-67.5°F (19.7°C)
April-34.3°F (1.3°C)	October-56.8°F (13.8°C)
May-49.6°F (9.8°C)	November-50°F (10.0°C)
June-61°F (16.1°C)	December-33.8°F (1.0°C)

The annual mean water flow rate out of Lake Erie is about 204,000 cubic feet per second (cfs) (5775 cubic meters per second (cms)) into the Niagara River, ranging from a winter monthly average flow of about 160,000 cfs (4530 cms) to a summer monthly average of about 250,000 cfs (7080 cms). Flow across Niagara Falls is covered by the Niagara Treaty of 1950 between the United States and Canada. During the daylight hours of the tourist season (April 1 to October 31), at least 100,000 cfs (2830 cms) must flow over the falls. At all other times a discharge of 50,000 cfs (1415 cms), approximately 30 percent of winter flow, must go over the falls for scenic purposes.

It has recently been found that in 50 percent of the years from 1960 to 1979 at least 85 percent of Lake Erie was ice-covered during February (Assel 1983). Ice break-up begins by early March, but clearing is not as rapid nor as continuous as freeze-up. By early April, it is usually the case that about 15 percent of Lake Erie's total area will remain ice-covered, while about 85 percent of the lake east of Port Colborne (195 mi^2 or 505 km^2) will remain covered. By late April, it is usually the case that only about 5 percent of Lake Erie's total area will remain ice-covered, while about 65 percent (150 mi^2 or 390 km^2) of the lake east of Port Colborne will remain ice-covered (Assel 1983). The eastern end of Lake Erie may not be free of ice until well into May. These characteristics are largely climate-controlled and unrelated to the ice boom.

According to several authorities the Niagara River can pass about 10 mi^2 (26 km^2) of ice per day for extended time periods without jamming. Up to 20 mi^2 (52 km^2) of ice per day can pass through the river for 2 or 3 days.

RIVER ICE FORMATION

Ice conveyed in rivers can cause particularly severe problems because of its tendency to form in jams at a river section where the ice-transport capacity of that particular section is exceeded by the ice discharge to the river. In these cases, the ice comes to rest, and, if the river velocity is sufficiently great, ice floes (slabs) arriving subsequently are forced above and below each other. The result is the formation of an ice jam, which can partially or almost completely block the channel and thereby produce a major increase in the river elevation at that location. This ice may cause localized problems, especially at intakes to water-supply systems and power plants, when the intake becomes wholly or partially blocked by either frazil ice or by the accumulation of submerged ice floes.

The accepted practice for alleviating these intake problems has been to initiate formation of a stable, stationary, relatively thin ice cover at locations where the flow velocity is sufficiently low that the arriving ice is arrested, but not submerged, and the resulting ice cover front is moved upstream by the arrival of new ice. The ice floes are thereby prevented from being transported downstream to sites where they may produce problems. Moreover, the stationary ice cover insulates the underlying water against heat transfer to the air by convection and evaporation. This diminishes the total amount of ice production and essentially stops formation of additional frazil ice, which can be the major cause of intake blockage.

LAKE ICE FORMATION AND DISSIPATION

A lake surface freezes after the near-surface water is cooled to the freezing point and additional heat is transferred to the atmosphere. With an ice cover, the rate of heat loss from the lake is greatly reduced due to the insulating properties of ice, and the rate is further reduced by any snow cover on the ice. Thus, after lake water reaches the freezing point, an initial ice layer forms rather rapidly, but thereafter thickens progressively slower. In addition to a slow growth in thickness of existing ice during cold weather, large amounts of new ice result from the processes of ice cracking, ridging, and rafting through heat loss from the open water areas created by the ice deformation. A stable ice cover protects the lake from additional heat loss during cold weather and minimizes the total volume of ice produced in the lake. Winter ice in the Great Lakes tends to have a high albedo (reflectivity), so that most sunlight falling on the ice during winter is reflected away, and very little melting by the sun can occur.

The freezing of Lake Erie usually begins in late December, after the lake has lost large amounts of heat energy by evaporative and sensible heat flux to the atmosphere. The lake freezes first along the shoreline, since less cooling of the water column is required to lower the surface temperature to the freezing point. In the deeper

Lake Erie eastern basin, more heat must be removed from the water column before ice can form. The mechanical mixing of wind and waves vertically stirs the water column and transfers heat upward from depth. Thus, by the time the surface temperature of any significant portion of Lake Erie reaches 32°F (0°C), the land areas near the shore are already frozen and may well have a snow cover. The formation of ice on the lake begins in the shallower water at the shoreline and spreads out into the lake.

The typical smooth ice thickness on Lake Erie during the 1970's was about 1 ft (30 cm). During the same period, data (Assel 1983) suggest that the average February ice cover on Lake Erie was 86 percent, or 8600 mi^2 (22,275 km^2). From these data, it is estimated that on an average, some 1.6 mi^3 (6.7 km^3) of ice are formed each year. This is a conservative figure (i.e., possibly too small) because it does not take into account the thicker areas of ice where ridging and rafting have occurred. An average ice volume of 2 mi^3 (8 km^3) is likely to be a better estimate.

In general, water temperatures begin rising in a lake after all ice has melted. Because Lake Erie ice is usually transported by wind to the eastern basin during dissipation, however, water temperatures in the western parts of Lake Erie begin rising while the eastern basin water remains at less than 33°F (1°C) as long as significant amounts of ice remain there.

Most ice that is formed on Lake Erie also melts in Lake Erie. From measurements made at Peace Bridge (International Niagara River Working Committees 1975-1977) and from the power entities' data, the amount of ice transported into the Niagara River ranges from nearly zero to somewhat over 300 mi^2 (780 km^2) during the entire ice season (including storm-driven ice in January-March). These discharge rates indicate that 97-100 percent of the ice melts in Lake Erie. During spring, solar heating rapidly warms the lake waters, which supply heat to melt ice. As the ice begins to melt, its surface character changes and more solar energy is absorbed by the ice, hastening the melting process. In advanced stages of melting, the internal structure also changes and the strength of the ice decreases markedly.

ICE MOVEMENTS

The deformation of ice by ridging and rafting and ice transport along the lake surface are largely caused by the force of winds acting on the ice surface, and to a much lesser degree by lake currents. In a storm, high winds over the lake are particularly effective in breaking ice into irregular fragments, which pile up into ridge formations along the shoreline, and in causing layers of ice to submerge or raft over other layers of ice. For example, during a storm on April 2, 1971, the area of ice on the eastern basin of Lake Erie was reduced by about one-half; ice that seemed to disappear was mostly submerged under the remaining ice. The open water quickly froze, forming hundreds of square miles of new ice on the lake.

Temporary rises in water level caused by strong westerly winds are also an effective cause of ice pile-ups. A principal factor causing the greater ice cover usually found on the eastern portion of the lake is the prevailing winds from the west that push the ice eastward, although east winds can drive the ice in the opposite direction. Southwest winds are especially effective in driving ice into the funnel-like configuration at the eastern end of Lake Erie. Consequently, the transport of ice into the Niagara River depends very much on the direction, speed, and duration of the winds near the eastern end of Lake Erie.

When ice is transported from Lake Erie into the Niagara River, the ice cover in the eastern portion of the lake will be reduced only if the ice removed is not replaced either by new ice growth or ice transported from further west. Under freezing conditions and extensive ice cover--for example, more than 1000 mi^2 (2600 km^2)--transport of ice into the river will result in no significant change in the ice cover in the vicinity of Buffalo. This is because the ice removed is soon replaced. On the other hand, during the spring melt period, when the ice cover has been reduced to only a small fraction of the eastern portion of the lake--say, 250 mi^2 (650 km^2)--ice transport into the river is a factor in reducing lake ice cover. In this case, no new ice replaces that discharged to the river. Nevertheless, the process of ice transport is not of equal importance to net radiation in warming up Lake Erie.

The characteristics of the lake ice such as thickness and surface roughness are quite variable and depend on the time of year, the location on the lake, and the particular weather experienced each year. Undeformed ice is relatively smooth and ranges in thickness from an inch or so (a few centimeters) shortly after formation to over 3 ft (about 1 m) after a lengthy frigid period. Deformed ice in ridges can be well over 30 ft (9 m) thick, as demonstrated by past scouring of the lake bottom in deep water and the height of ice ridges above the lake level. A 1982 situation has been documented in which the bottom of Lake Erie was scoured at a depth of 52 ft (16 m) by a massive pile of grounded ice that rose some 32 ft (10 m) above the lake ice surface, for a total ice thickness of over 84 ft (26 m).

THE LAKE ERIE-NIAGARA RIVER ICE BOOM

The development of hydropower on the Niagara River dates back to 1785, when a permit was issued to John Burch to build a hydromechanically powered saw and grist mill. In 1881 an electric generator was installed at the small Schoellkopf plant. Development of hydroelectric power in the vicinity of Niagara Falls proceeded at an accelerating rate through the first half of the Twentieth Century. A desire to harness all available water power in the river culminated in the construction after 1950 of high-head plants at Queenston, 6 mi (10 km) downstream from the falls. The intakes for these high-head plants are located above the falls in the Grass Island Pool. Conduits to carry the water from the intakes to the generating stations consist of an open canal in the case of Sir Adam Beck Plant 1; twin tunnels 45 ft (13.7 m) in diameter under the city of Niagara Falls, Ontario, discharging finally into an open canal for Sir Adam Beck Plant 2; and covered conduits 46 x 66 ft (14 x 20 m) for the Robert Moses Plant development on the U.S. side of the river.

Of the several hydroelectric plants built to utilize the Lake Erie outflow (204,000 cfs (5775 cms) on the average), those listed in Table 1 are currently in service.

As a result of ice runs out of Lake Erie, jams have occurred in the Niagara River, both upstream and downstream from Niagara Falls, damaging both public and private property on the river. Destruction of the Honeymoon Bridge in 1938 is probably the single most spectacular example, and flooding of shore property has occurred at Grand Island, the town of Wheatfield, and Cayuga Island.

Reductions in hydroelectric energy generation at Niagara Falls have been a matter of particular concern. In the years prior to 1950, only a small percentage of the Niagara River's discharge was used for hydropower production because the generating facilities until that time were quite modest in capacity. With the constant increase in demand for electrical energy and the completion of the massive Canadian and U.S. high-head plants in the 1950's and early 1960's, however, the hydraulic generating capacity capable of receiving all of the Niagara River discharge in excess of the required falls flow for scenic purposes became available. Therefore ice jams that could reduce the discharge for power production became of greater concern to the Canadian and U.S. power entities.

An extreme ice jam in the spring of 1955 so alarmed local interests that they prevailed upon the Corps of Engineers to attempt

TABLE 1 Niagara River Hydropower Plants

	Net Head (ft/m)	No. of Units	Installed Capacity (kw)	Flow to Achieve Installed Capacity (cfs/cms)
Ontario	180/55	12	138,000	10,700/303
Canadian-Niagara	135/41	11	80,000	10,600/300
DeCew (two plants)	262/80 286/87	12	154,100	6,400/180
Sir Adam Beck 1	294/90	10	373,000	
Sir Adam Beck 2	292/89	16	1,223,600	82,000/2320
Pump generating	85/26	6	170,000	
Robert Moses	303/92	13	1,950,000	105,000/2970
Lewiston pump-generating	75/23	12	240,000	
TOTAL			4,329,000	214,700/6080

to free the jam by blasting with dynamite. However, the blasting had no effect. Immediately prior to installation of the ice boom, an ice jam in 1964 caused $146,000 worth of shoreline damages (excluding power losses) according to government estimates. In 1962 the Robert Moses Plant was completely shut down by the occurrence of ice jams at its power intakes, and the Sir Adam Beck Plant has similarly suffered serious reductions in its water supply and resultant power production.

A number of ice control measures taken by the power entities prior to 1965 have proved to be worthwhile but have had only limited effects on large runs of lake ice. These measures are now used in coordination with the ice boom. The primary goal of the control measures is to keep ice in the river moving relatively briskly. When ice slows to very low speeds, due to a large quantity of ice entering the river or to some other impediment in the river, a brief stoppage at one point can suddenly form a jam, and huge masses of ice can begin to pile up quickly. As the jam intensifies, it greatly reduces the flow of water past it, thereby decreasing water flow available downstream for both scenic and power generation purposes. Once a jam forms, it is extremely difficult to break, so the power entities are very eager to prevent the formation of any jams. On the Canadian shore an ice-escape channel was constructed 300 ft (91 m) wide and 3800 ft (1160 m) long through the control structure. The New York Power Authority dredged a deeper channel downstream from their intake for the same purpose. Together, the power entities maintain ice breakers in almost continuous service to dislodge and break up incipient ice jams. A large shoal located at the head of the cascades above the falls was also removed to facilitate the discharge of ice from the Grass Island Pool. Also, an Order of the International Joint Commission that is designed to maintain natural levels on the Grass Island Pool may be suspended for short periods to permit the flushing of ice over the falls.

The vast majority of the ice that forms on Lake Erie each winter melts in the lake each spring. Because of prevailing west winds, there is a nearly continuous eastward migration of the lake ice during spring break up. This migration results in a natural accumulation of ice in the eastern end of the lake. Some of this ice finds its way into the Niagara River and is transported downstream. Because the width of the lake where it joins the river is much narrower than the width of the eastern basin, the large-scale ice flow toward the east is pinched off, and an ice arch is formed a short distance upstream from the river entrance. The arch is grounded firmly on one shoreline, arcs slightly westward away from the lake outflow, and is again firmly grounded against the opposite shore. Even though the ice forming the arch is composed of many individual blocks of ice, the arch compacts and consolidates, and cuts off the flow of ice into the river.

The gently curving ice arch forms just upstream from the river reach where the water surface has sufficient slope to accelerate the flow out of Lake Erie (i.e., where flow velocities increase); it thus is located on the boundary of the hydraulic change from lake to river.

As long as this ice arch remains intact, the flow of lake ice into the river is effectively sealed off. However, occasionally heavy storms or wind-driven waves, which are characteristic of the lake, will destroy the arch and permit the entrance of masses of lake ice to the river. After the storm subsides, the arch will again form and again cut off the movement of ice into the river.

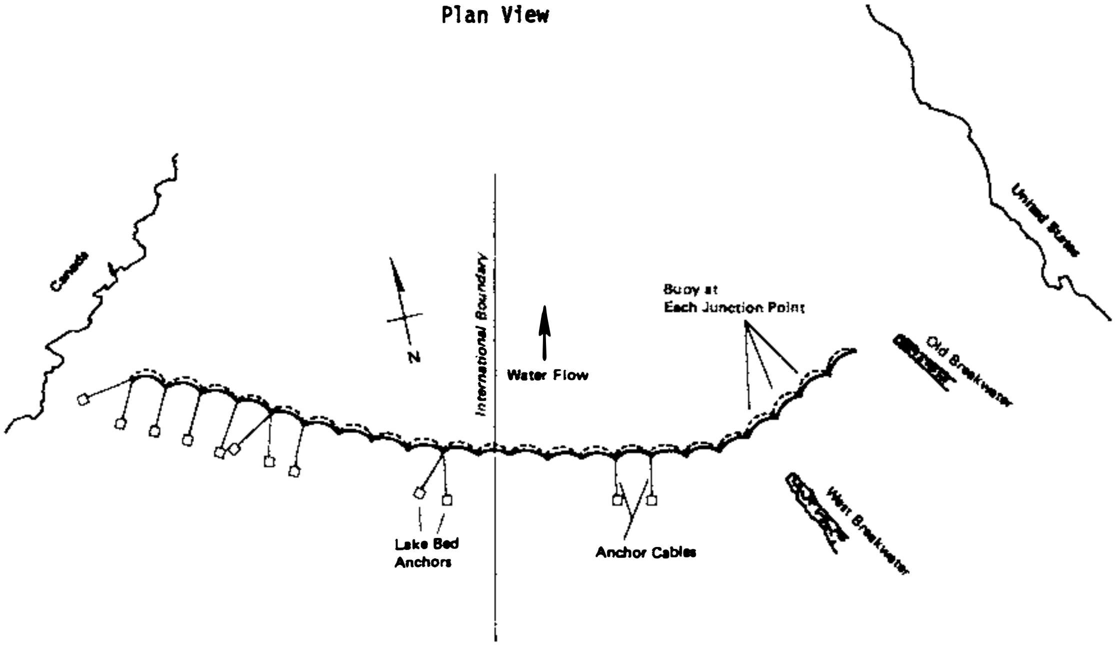
If there is a desire to reduce the transport of ice out of a lake into a river, the usual tactic is to promote the formation and maintenance of a stable ice cover on the lake. Experience on many water bodies around the world has demonstrated that ice booms are the most effective and most practical means of establishing and maintaining such an ice cover on a lake.

The Lake Erie Ice Boom is a typical boom and is shown schematically in Figure 3. The boom is basically composed of a series of wooden timbers held in place by loops of steel cables, which are anchored to the lake bottom. The Lake Erie boom timbers, each 30 ft (9 m) long, 16 in. (41 cm) high, and 22 in. (56 cm) wide, are connected in groups of 13 to strands of 2 in. (5 cm) diameter steel cable. Each timber is attached near each of its ends to the loop of steel cable by a 4-foot (1.2 m) chain. The steel cable is supported in the water by the buoyancy of the timbers themselves, assisted by the flotation buoys at the points where the anchor cables are attached to the boom cables. Each end of the steel cable is connected to the lake bottom by a 500-ft (150 m) anchor cable about 2 1/2 in. (6 cm) in diameter. There are 22 such loops of timbers making up the entire boom, which extends about 8800 ft (2680 m) across the eastern end of Lake Erie, about 1000 ft (305 m) southwest of the water intake crib for the city of Buffalo. The boom does not extend shore-to-shore. The northern end of the boom starts some 500 ft (152 m) from the Canadian shore, and the southern end of the boom starts near the breakwater for the outer harbor, some 2000 ft (610 m) from the U.S. shore. Thus, when there is no ice on the lake, the boom may be passed at either end by boats or ships.

The boom has no rigidity of its own, since the timbers are connected by link-chain to flexible steel cables. In the presence of no wind, the small natural lake current toward the Niagara River will cause the timbers to bow northeastward in each loop, the orientation shown in Figure 3. This will also be the orientation with generally westerly winds. However, with winds out of the east, the timbers will be pushed backwards, and may bob about somewhat aimlessly, occasionally striking an adjacent timber and damaging it, or actually bowing out to the west, forming a mirror image of the orientation in Figure 3.

The key to the successful functioning of a boom is its installation at a site where the flow velocity is sufficiently low so that arriving ice is not submerged. It is also important that the arriving ice floes be sufficiently large and strong that they do not pass through openings between the timbers or that the floes be sufficiently cohesive so as to hold to each other to form an intact ice cover. The forces exerted on the stationary ice by the water flow beneath it and the wind above it are transmitted to the timbers, then

Plan View



Isometric sketch

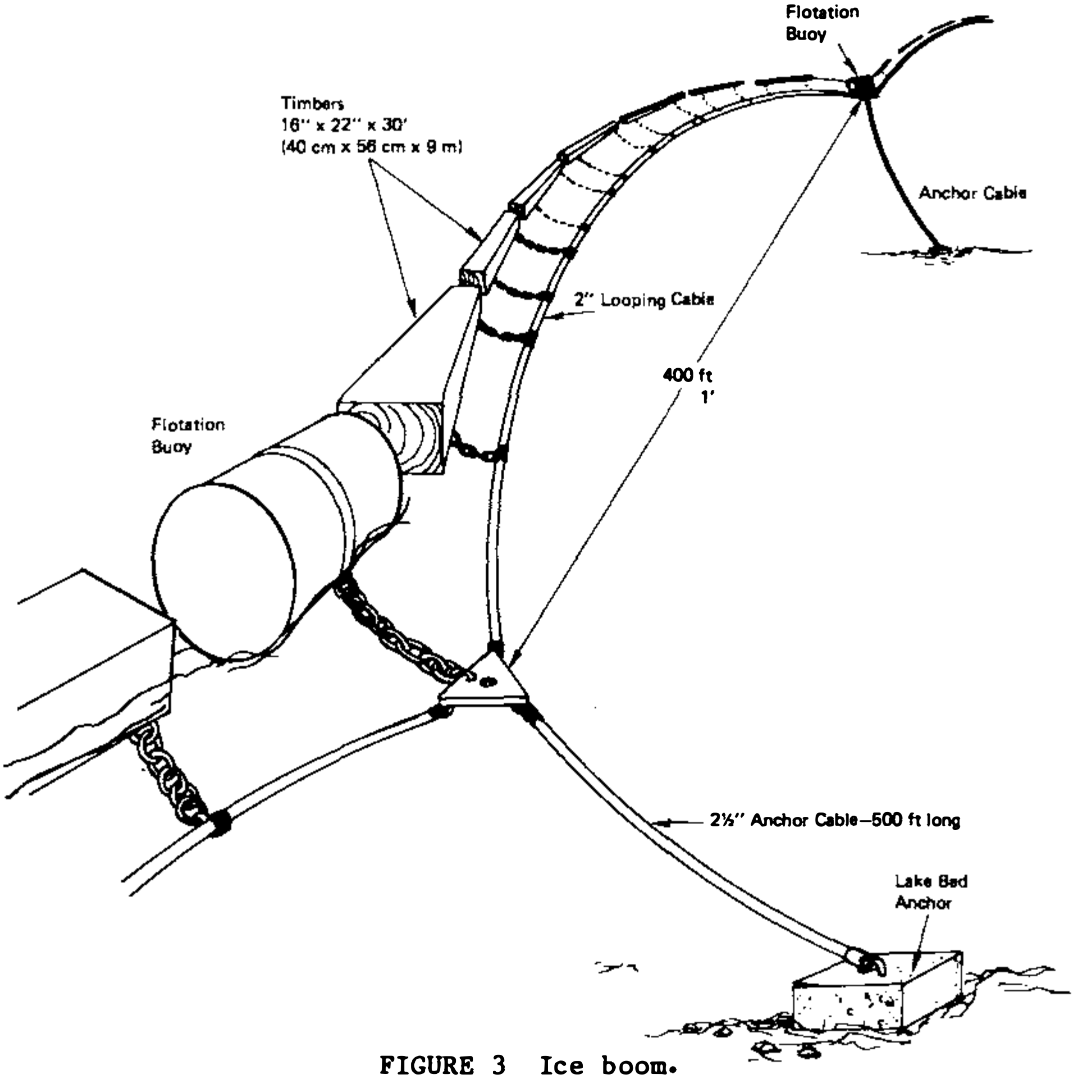


FIGURE 3 Ice boom.

to the anchor cables and eventually to the lake bed anchor. Except during a relatively short period when the stationary ice cover is being initiated, *the boom does not hold the ice in place*. The ice cover is then held by the ice arch that forms when floes in contact with each other freeze together and extend entirely across the end of the lake. The boom only acts to initiate and form this arch when the weather is cold enough; once formed, *the arch holds the ice cover in place*. The ice arch would form when the weather is cold enough--with or without the boom. The boom allows the arch to form more quickly, thus creating a stable ice cover.

Ice booms cannot retain all types of ice. If the ice has relatively low internal strength, as is the case in old or "rotten" ice (such as occurs in late spring), the ice cannot withstand the stresses attendant to the shore-to-shore arching. The wind and current stresses exerted on the ice then are transmitted to the boom timbers, which, because of the way they are tethered, submerge and permit passage of the ice. The discharge rate of ice past the boom section then is determined by the ice-transport capacity of the flow, and the boom plays little or no role in regulating ice movement past it when ice transports are high.

ICE BOOM IMPACT ON ICE FORMATION AND RETENTION

To describe what the Lake Erie Ice Boom accomplishes, it is useful to consider three periods of the annual ice season. During the early winter period, or formation stage, ice starts forming at the shoreline of Lake Erie. If the winds are generally from the west, various sized blocks (or floes) are broken away from the shore by wind and wave action and driven toward the eastern end of the lake where a few floes pass into the Niagara River. Most of these ice floes push into one another as the lake narrows, and an ice arch is formed.

During the mid-winter period, or mature stage, the ice cover is essentially solid across Lake Erie, at least across the eastern basin, and remains intact except when fractured by storms. Some storm-generated ice floes near the entrance to the Niagara River may move into the river. As the storm subsides, however, ice floes in the vicinity of the initial ice arch will refreeze, and again ice will not flow into the river.

During the spring period, or dissipation stage, the ice is deteriorating due to warm weather and increased solar heating. Spring storms produce considerable cracking, rafting, and ridging. Under proper wind conditions, some of the deteriorated ice breaks off from the arch and moves into the river. The arch continually forms and breaks as ice is continuously pushed eastward by the prevailing winds.

The dates for the three periods vary each year, depending on the weather patterns.

The interaction of the boom with the ice is as follows.

1. During the early winter period, usually occurring during December or January, the boom promotes early formation of the ice

arch. Formation of the arch shortly after initial ice formation in the eastern basin promotes the formation of a uniform ice cover west of the boom, thereby reducing the flow of ice into Niagara River. Reduced ice flow into the river reduces power generation interruption but does not add to the ice area in Lake Erie. Any area losing its ice cover to river discharge will quickly form a new cover during prevailing subfreezing temperatures.

2. During the mid-winter period, generally occurring during January, February, and early March, the boom facilitates reestablishment of the ice arch after storms. Under nonstorm conditions the ice remains intact and acts as if the boom were not there, so the boom has no effect on the ice. During storm periods, a west or southwest wind is likely to push ice over the boom, and as much ice would arrive at the river head as would arrive without the boom. Again the boom has no effect. But in the 12 to 24-hr period when winds decrease following a storm, the boom resurfaces, shutting off the supply of ice to the river, preventing the ice transport into the river that would occur without the boom. This is a significant effect that results in benefits to the power entities, because it gives the river and control technicians time to move storm-driven ice through the river without serious interruption of power generation. There is no measurable or calculable negative climatic aspect to the boom's presence following a storm, since the water temperature is about the same as the ice temperature and ice that is transported past the boom will soon be replaced with new ice.

3. During the late winter and early spring period, occurring during late March and April, the ice begins to break up and deteriorate because of solar heating. Substantial amounts of ice are transported to the eastern basin from the central and western basins. With moderate or strong wind blowing toward the inlet of the river, ice flows over the boom, and there is no effect of the boom. With light winds blowing toward the river, the boom will retain ice of sufficient size and strength but will pass rotten ice. Under calm conditions or winds blowing away from the river, ice would not move into the river even if the boom were not there, so there is no effect of the boom. Again, it is in the period following a storm that the boom holds some ice back.

REGULATORY ORDERS

The last severe ice jam in the upper Niagara River during the preboom years occurred in January 1964. It was the effects of this jam that led the power entities to request permission to install the ice boom. Another boom had been installed by Ontario Hydro and the New York Power Authority (NYPA) in the International Rapids section of the St. Lawrence River in 1959 and had proven its value.

In February 1964, the power entities applied to the IJC for permission to construct and install the Lake Erie-Niagara River Ice Boom. After conducting a public hearing in June of 1964, the IJC authorized the construction and placement of the boom on a 1-year trial basis. Authorization was continued on a year-by-year basis until 1967, at which time the period of authorization was extended to 5 years.

The original Order of Approval was amended in May 1965 and again in October 1969. These amendments made only two significant changes. The original orders specified that all sections of the floating boom be opened by the first Monday of April, with disassembly completed by April 15 or earlier if so ordered by the IJC. However, in June 1969, the power entities requested that the IJC consider a later date for boom opening and removal, citing as the basis for their request a number of severe ice runs that had occurred after April 1 (but not during the previous 5 years that the boom had been in place). After conducting a public hearing on this matter in Buffalo, the IJC revised this portion of the original orders. The portion now specifies that "All sections of the floating boom shall be opened on a date to be fixed each year by the Commission, acting on the advice of its International Niagara Board of Control and in the light of weather and other conditions prevailing in that year. Disassembly of the boom shall be completed by 15 May each year." The second significant change made in the 1969 amendment was the inclusion of a requirement that the International Niagara Board of Control, before recommending a boom removal date to the IJC, consult each year with the representatives of the power entities, St. Lawrence Seaway Authority, the Niagara Frontier Port Authority, and such other interests that may be affected by opening of the boom.

3

REGIONAL CLIMATE TRENDS AND LAKE EFFECTS

REGIONAL COOLING TREND

People who pay even casual attention to the weather recognize that temperature and precipitation in most regions of the United States change markedly from day to day and from year to year on the same calendar date. The mean temperature for a day, month, or year is generated from a large number of temperature values, the overwhelming majority of which are above or below that mean value. Indeed, it is very rare to experience a day or month whose temperature behavior is the same as the long-term mean for that time period.

There is also a general recognition that in spite of weather variability, there is a basic pattern of weather events in a given locale that emerges as the climate of the region. Many people feel that the climate or average weather is fixed, meaning that the "average" behavior of the weather is a constant, with values at any given time having a more or less known range of departure from the mean. Departure for several consecutive years of, say, the January average temperature from the climatological mean January temperature is often viewed as "unnatural," and an artificial cause for the departure is sought.

The idea of a fixed climate is, however, generally incorrect. Climate undergoes change, both on a short-term (decades) and on a long-term (thousands or millions of years) basis. Historically, most climate change has occurred irrespective of human presence. However, since the start of the Industrial Revolution, human activities have increasingly had an inadvertent climatic impact on a local and possibly even global basis. With the possibility of both natural and artificial causes of climate change, it becomes important to consider carefully any climate change that appears to have a significant negative impact on the general population to determine if the impact could be mitigated or reversed by changing some human activity.

Turning now to the temperature aspects of the Buffalo region, the evidence is overwhelming, both from official temperature measurements and from peoples' perceptions: spring has been, on the average, somewhat cooler in the past 5-10 years than springs prior to this period. Consider data presented by Quinn et al. (1980) concerning freezing degree days. Figure 4 shows that the number of freezing degree-days in Buffalo was significantly higher in the late 1970's than in the early 1960's. Or consider the heating degree-day (HDD) data of Yee et al. (1981) shown in Table 2. There were on an average 200°F (110°C) more heating degree-days for Buffalo each year in the period 1965-1981 than there were each year in the period 1948-1964. At the hearings held by the IJC on March 3, 1983, in Buffalo, several local residents voiced the opinion that winter now lasts longer than it used to (IJC 1983).

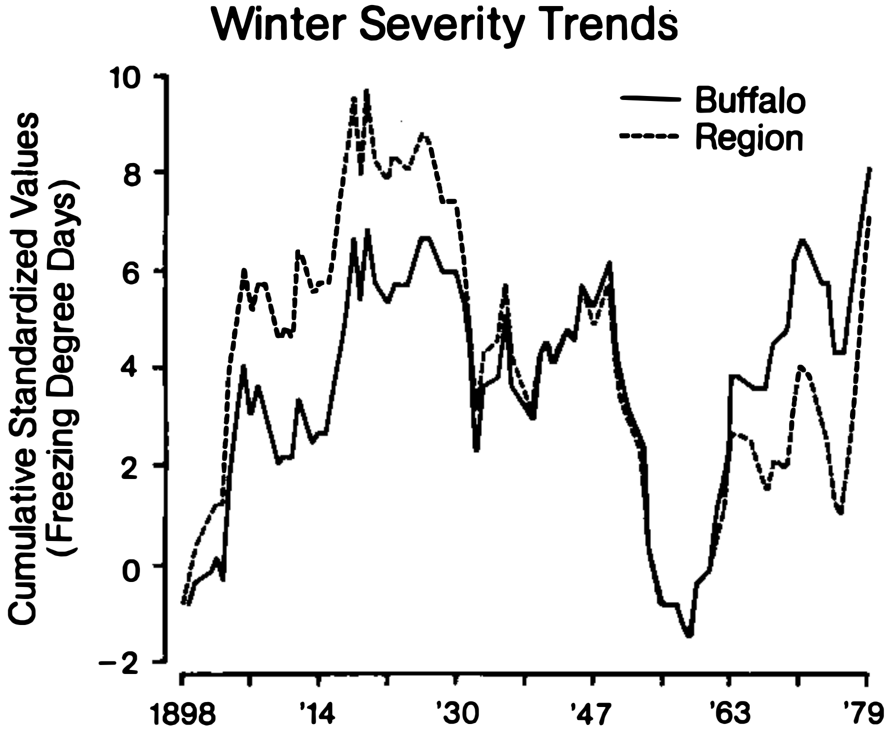


FIGURE 4 Cumulative standardized freezing degree-day values for Buffalo and the region.

SOURCE: Quinn et al. 1980.

TABLE 2 Comparison of Average Annual Heating Degree-Days (°F) for January through May for Preboom and Postboom Years

	16 Preboom Years (1948-64)	16 Postboom Years (1965-81)	Difference
Buffalo, N.Y.	4140	4340	+200
Toledo, Ohio	3880	4140	+260
Cleveland, Ohio	3720	3960	+240
Rochester, N.Y.	4180	4270	+ 90
Syracuse, N.Y.	4160	4340	+180
Hamilton, Ont.	4180	4600	+420
Kingston, Ont.	4630	4920	+290

Source: Yee et al. 1981.

However, the undeniable fact of recent somewhat cooler cold seasons is only part of the story, and it is the rest of the story that is more important: Buffalo air temperature has been dropping since before 1965, and many other locations within 300 mi (about 480 km) of Buffalo have experienced similar temperature declines during the same time period. Figure 4 clearly shows how the annual temperature of Buffalo has oscillated over the 80-year period of 1898 to 1979. From 1898 to about 1920, winters became progressively colder. From 1920 until 1958, winters became warmer. And from 1959 to 1979, winters have gotten cooler again.

Comparison of cold season temperatures at Buffalo with those of other regional cities is most instructive. Table 2 shows that while Buffalo was somewhat cooler (by 200°F or 110°C HDD) in the 1965-1981 period compared to 1949-1964, so were six other cities, up to about 200 mi (320 km) away. At one end of the range, Rochester was 90°F (50°C) HDD cooler, and at the other, Hamilton, Ontario, was 420°F (230°C) HDD cooler. Hassan and Sweeney (1972) show that the mean high and low temperatures for March, April, May, and June for Fredonia, Watertown, and Buffalo (all cities in New York state) show nearly identical behavior for the period 1958 to 1971. From Figure 5, it may be seen that the mean high temperatures for March for these three cities for this period follow very similar annual changes. Interestingly enough, Figure 5 also shows Buffalo March high temperatures to be slightly higher than those at Fredonia and Watertown.

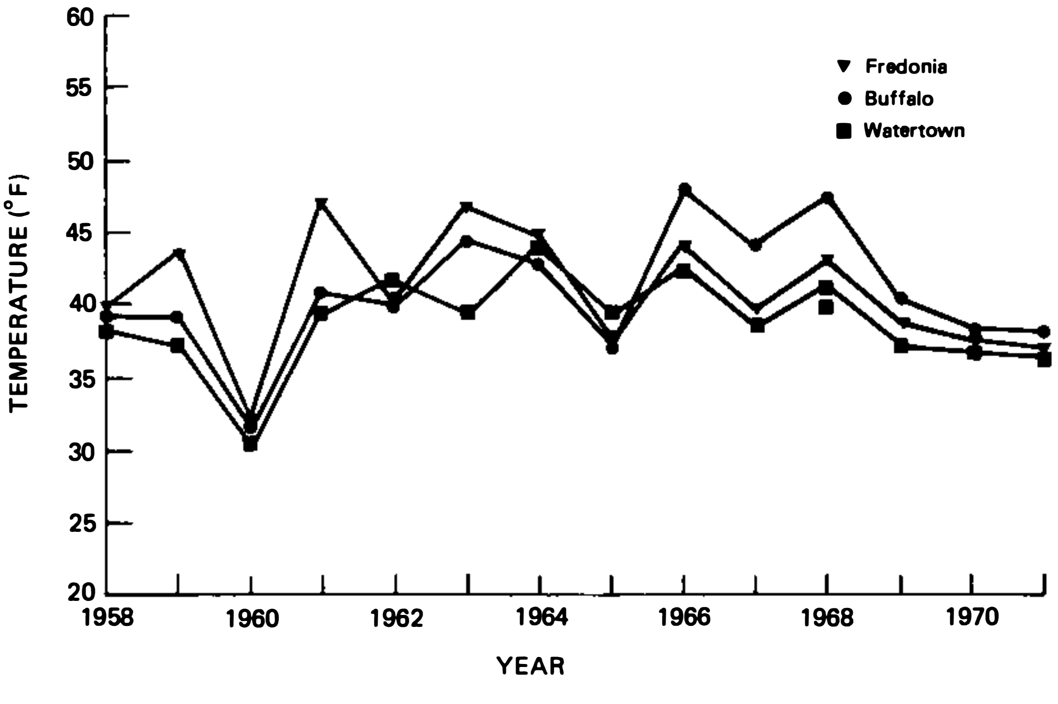


FIGURE 5 Monthly mean high air temperatures--March.

SOURCE: Hassan and Sweeney 1972.

Quinn et al. (1980) calculated combined temperature readings from Erie, Pennsylvania, Rochester, New York, and Toronto, Ontario, to determine the temperature trend for the region surrounding Buffalo. They also averaged temperatures for some 25 stations surrounding the Great Lakes (see Figure 6). From Figures 4 and 6, it may be seen that the winters in Buffalo, as described by freezing degree days, have shown the same general cooling-warming-cooling pattern from 1898 to 1979 as did the region around Buffalo and the entire Great Lakes area.

In 1978, testimony was presented to the Erie County Legislature and Buffalo City Common Council from a study of the January-April average air temperature at five cities. The study showed that this 4-month temperature average decreased slightly for Toledo, Cleveland, Rochester, and Syracuse as well as for Buffalo, for the period 1965-1978 as compared to 1927-1964.

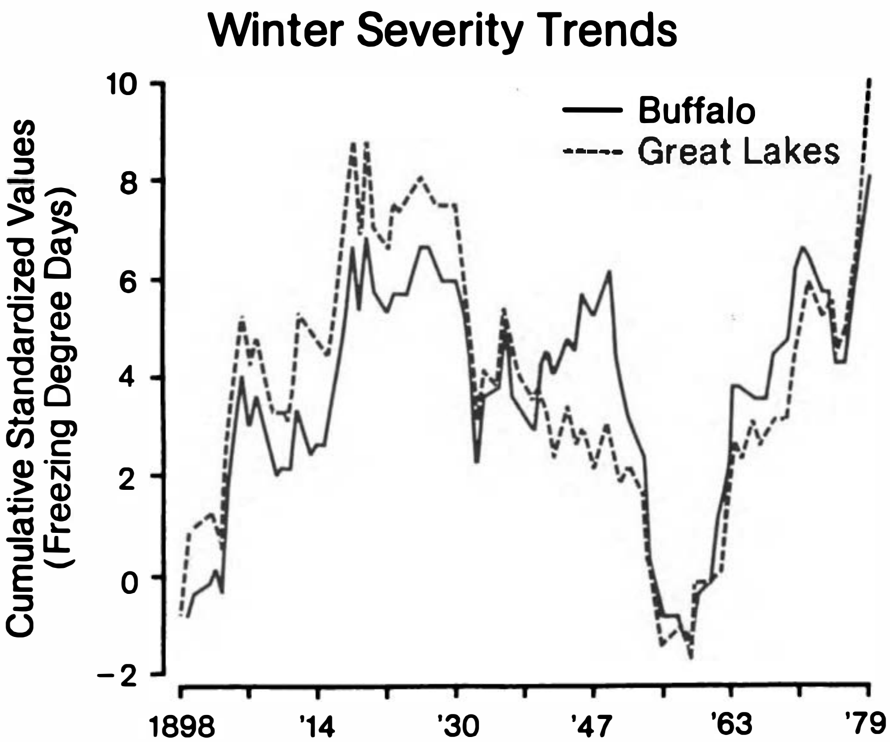


FIGURE 6 Cumulative standardized freezing degree-day values for Buffalo and the Great Lakes.

SOURCE: Quinn et al. 1980.

The panel believes that the evidence is very clear that, while there has been a slight cooling of winters in Buffalo since the mid-1960's, the cooling did not start then and it was not limited to Buffalo. No known physical laws allow the conclusion that an event unique to the immediate Buffalo area (e.g., the presence of the ice boom) can be responsible for a temperature change in Buffalo that started before the event and is duplicated in many cities at a considerable distance from Buffalo. An overall regional change in climate has occurred.

LAKES AS HEAT RESERVOIRS

In the absorption of energy from the sun and atmosphere and the retransfer of this energy from earth back to the air, lakes behave differently from land surfaces on a daily and seasonal basis. Energy absorbed at the surface of a lake is transferred slowly throughout its volume at rates depending on wave action and currents. By contrast, a land surface transfers heat only within a thin soil layer. At night, the land loses heat more readily to the atmosphere. In winter, when the land is snow-covered and the lake ice-covered, nocturnal heat loss rates are similar--relatively fast. The seasonal effect is that the lake temperature increases more slowly at the surface than the land in spring and decreases more slowly in fall. Lakes usually retain an ice cover longer than snow remains on dry land.

Among the Great Lakes, Lake Erie is the most shallow and has the smallest water volume or heat reservoir. Thus cooling and warming of the lake lags behind the spring and fall temperature changes over land to a lesser extent than, say, Lake Ontario. However, there is a period of several weeks in the spring and fall when the lake is typically cooler during the daytime and warmer during the nighttime than nearby land surfaces. The effect of the warmer or cooler lake on air temperatures is usually evident within the immediate vicinity of the lake, but the affected area varies from hour to hour and day to day, depending on wind and sunshine. This effect is probably slightly larger in magnitude in regions adjacent to the deeper eastern basin of the lake than in regions adjacent to the western two-thirds of the lake. On a day with the wind blowing from a given coastal area out over the lake, the temperature difference effect is minimal over that area, confined to a few meters inland from the shore. When the wind is blowing from the lake toward a coastal area, there is a greater but variable effect depending on the season. In autumn, the lake can be warmer than the land, particularly at night, but this is a "damp" warmth along the shoreline, not bringing any particular comfort to residents. In late fall, cloudiness and reduced visibility become more common, lasting until an extensive area of ice cover forms in December.

In spring, there is a chilling effect from off-lake winds on days when the land would be otherwise considerably warmer than the lake. The distance inland that the cooling extends is related to the wind speed and the contrast in air temperature over the land and water.

When this contrast is marked, i.e., on a sunny day when winds are light, a lake breeze is generated where air flows from the lake onto the land. The inland penetration of this breeze depends on terrain and building structures, at least initially, as the air movement is in the lowest layers of the atmosphere. The lake breeze season lasts through spring and early summer. While it provides natural air-conditioning on hot days to lakeshore people, it can be an uncomfortable situation on cooler days. The same effect as the lake breeze occurs when the regional wind is off-water.

The climate of municipalities such as Buffalo and Fort Erie is moderated by the adjacent lake. They do not experience the same very cold or hot days as localities farther inland. On the other hand, they have higher air humidities, more cloudiness and fog, and greater wind speeds and snowfall during off-lake storms than more inland, continental locations. Here also, spring is retarded for a few weeks, but autumn is likewise prolonged. The growing season is generally longer near the lakeside. Such conditions have promoted extensive horticultural and market garden industries. In terms of winter heating requirements, there is very little difference between lakeshore and inland localities. At Toronto Island, for example, the average seasonal heating degree-day accumulation (1951-1980) is 6980°F (3880°C), which may be compared with Toronto Airport (7460°F or 4145°C HDD) and Toronto itself (6563°F or 3645°C HDD). The airport is at a similar distance inland to that of Buffalo. The heating requirements are less within the city because of the generally elevated air temperature in urban areas.

The contrast in temperatures from lakeshore to inland can be very marked, perhaps more than 18°F (10°C) at the time of ice breakup. Rumer (1980) has observed that the spring average daily temperature difference between the Buffalo shoreline area and the airport is up to 6°F (3°C). Studies of air temperature differences between large lakes and the adjoining land areas indicate a rapid temperature increase on a fine spring day within the first half-mile or kilometer of the lake along a regular shoreline with no particular blocking obstacle. Where shorecliffs or high buildings ring the shoreline, the temperature change occurs closer to the lake. Figure 7 contains a generalized depiction of the natural flow of air from lake to land, and the reverse that occurs when local pressure gradients are established by contrasting air temperatures. Daytime and nighttime, spring and fall cases are illustrated. Local circulations do not form or are not apparent when the regional air circulation is strong or during precipitation.

METEOROLOGICAL OBSERVATIONS AT LAKESIDE CITIES

In addition to air temperature, sunshine (or cloudiness), humidity, and wind conditions at the shoreline may be considerably different from those of some distance inland. What then is a representative site for meteorological measurements at Buffalo and at Fort Erie? It depends on the purpose for which measurements are taken. For many

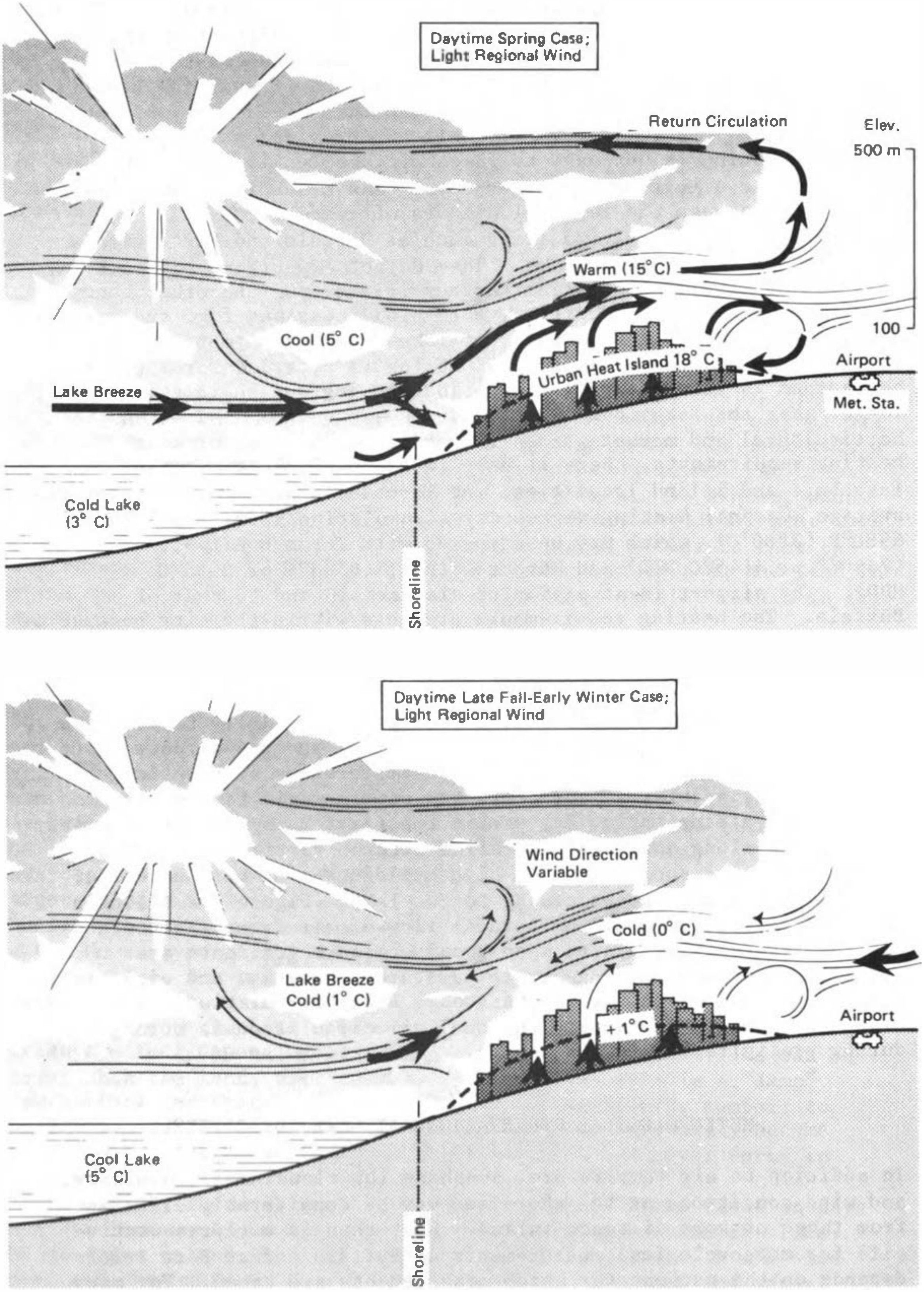
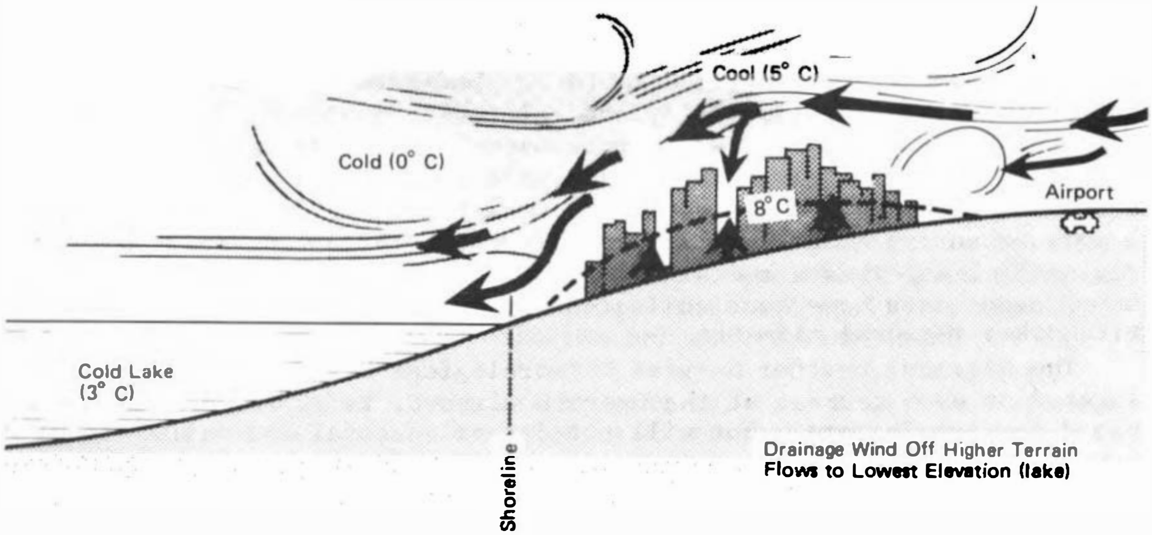
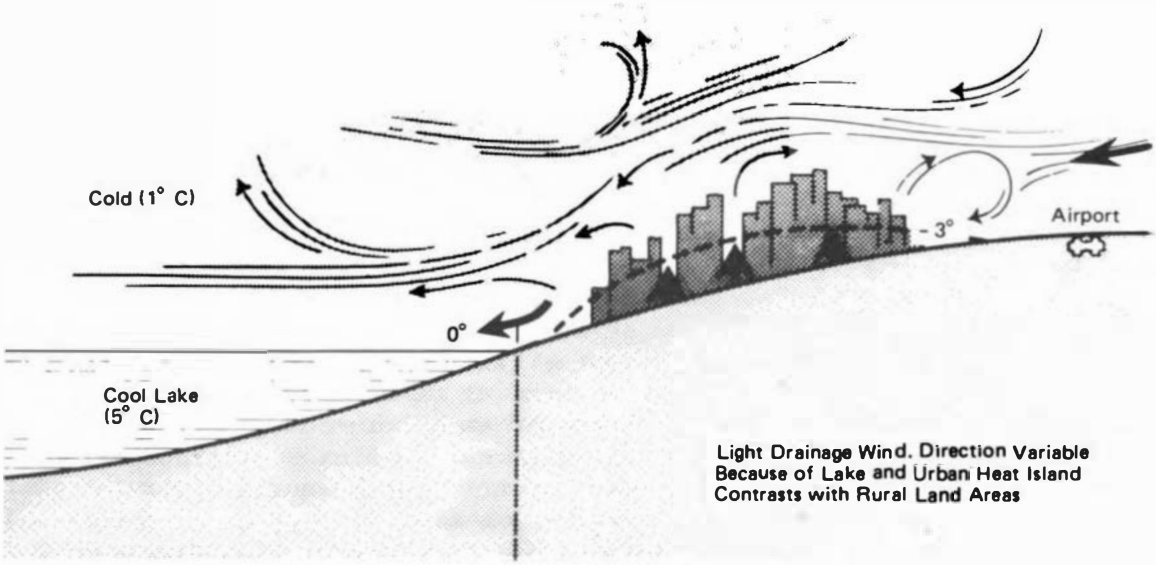


FIGURE 7 Spring and fall cases of local wind and temperature conditions.

**Nighttime Spring Case;
Light Regional Wind**



**Nighttime Late Fall-Early Winter Case;
Light Regional Wind**



days of the year the contrast between lakeside and inland is not great. These are rainy or snowy days, mid- and late-winter days, late summer and early fall days, and days when the wind is off the land. The World Meteorological Organization (WMO) of the United Nations has set standards for the siting of meteorological stations in order to obtain uniform information valid for as extensive an area as possible. The WMO recommends relatively flat sites having a low vegetation where buildings, structures, and abrupt changes in topography and water bodies are well away from the measuring instruments. These recommendations insure that measurements are not influenced by highly localized factors. Temperatures are warmer on sun-facing slopes, for example, and relatively cooler in valleys and depressions at night; winds are more turbulent and variable in direction over hills; the buildings and streets of an urban area absorb more energy and are warmer than the countryside. However, over a more extensive area these effects are counterbalanced, and the regional climate has a certain uniformity, which after sufficient homogeneous data have been collected may be compared and contrasted with other regional climates.

The National Weather Service Meteorological Station at Buffalo, located on even terrain at the Buffalo Airport, is representative of a broad surrounding area, but will not detect seasonal and daily lakeshore climatic characteristics even though it is only about 8 mi (13 km) from the shore. Therefore studies such as Rumer et al. (1983), Quinn et al. (1981), and Hassan and Sweeney (1972) that state that the ice boom does not have an effect on Buffalo's climate are correct in the sense that, for most of Buffalo, as represented by the airport meteorological station, there is no demonstrable effect. However, for local, limited areas near the shoreline, their evidence cannot be used to refute a presumed effect.

ENERGY BUDGET FOR A LAKE

The heat content of Lake Erie has an annual cycle with a maximum in late summer and a minimum in late winter or early spring (Rumer and Yu 1978, Pinsak and Rodgers 1981). In addition, day-to-day variations in heating and cooling of Lake Erie are associated with the passage of storms. During the warming period from late winter to late summer (March through August), the primary process warming Lake Erie is the increased net radiation flux into the lake due to the combined solar and terrestrial radiation. During the cooling period (from late summer to mid-winter), the dominant lake-cooling processes are the evaporation of lake water into the atmosphere and the sensible heating of the cooler atmosphere by the warmer lake. An energy budget model applied to Lake Erie provides understanding of natural mechanisms. The lake (or a portion of it) is treated as a box--changes in average energy in the lake volume are related to energy fluxes or transports through the sides, bottom, and top. A heat budget equation for Lake Erie may be written as follows: $Q = n + v + f + s + e$, where Q is the net heating or cooling of the lake, n is the net radiation flux into the lake, v is the differential heat transport of water flowing into and out of the lake at different temperatures, f is the heat transport by water flowing into the lake replacing ice flowing down the Niagara River, s is the sensible heating of the lake by the atmosphere, and e is the heating effect of evaporation or condensation (latent heating). In the spring period, April or May, the sum of sensible and latent heating over a weekly period is small (Pinsak and Rodgers 1981), so the terms s and e may be dropped from consideration.

It is instructive to apply this heat balance concept in April during final ice dissipation to a volume of Lake Erie of roughly 140 mi^2 (360 km^2) surface area east of a line oriented southeast through Port Colborne (see Figure 8). Let us consider two hypothetical cases in which the eastern half of this area is 100 percent covered by ice 1.6 ft (0.5 m) thick and the western half is ice free (Figure 8). In case A, a weak easterly wind will keep the ice cover in place with no ice transport out of the area. In case B, a westerly wind will result in ice transport down the Niagara River at 10 mi^2 (26 km^2) per day. Typical values (for late April) of the heating processes in units of calories per square centimeter per day ($cal\ cm^{-2}\ day^{-1}$) are n = 350, v = 85, s + e = 0; f would be 0 for case A and 230 for case B; the net heating for case A is 435. If case A conditions persist for 7 days, the water temperature of the ice-free area would increase by 5°F (2.8°C) to a depth of 33 ft (10 m), the ice would melt completely over the initially ice-covered area, and the water temperature would be 32°F (0°C) (see Appendix B for the calculation). If case B conditions persisted for 7 days, 70 mi^2 (180 km^2) of ice would be transported down the Niagara River, the water temperature in the western initially ice-free area would increase by 5°F (2.8°C), the ice would be eliminated from the eastern initially ice-covered area, and the resulting water temperature would vary linearly with distance from 37°F (2.8°C) to 32°F (0°C). The resulting average difference in water temperature between cases A and B would be 2.5°F (1.4°C) over the eastern initially ice-covered area due to ice transported out of the eastern area (and down the Niagara River) being replaced by water and some of the net radiation warming this water rather than melting ice. The examination of cases A and B with this simple energy budget model provides an example of the magnitude of natural variability in the ice dissipation process--lake temperature differences of the order of 2°F (1°C) can result from natural variability in wind velocity. Rumer (1973) has applied similar concepts to an analysis of the ice dissipation process.

The water temperature differences calculated above are well within the natural variability of water temperatures in Lake Erie for different weather conditions in the spring. The impact on air temperature of a small water temperature difference is even smaller, whereas the natural variability of air temperature is large. Thus, small water temperature differences (between ice and no ice conditions) would result in negligible and possibly undetectable air temperature differences on shore. Natural variations in air temperature due to variable wind speed and direction and the depth of

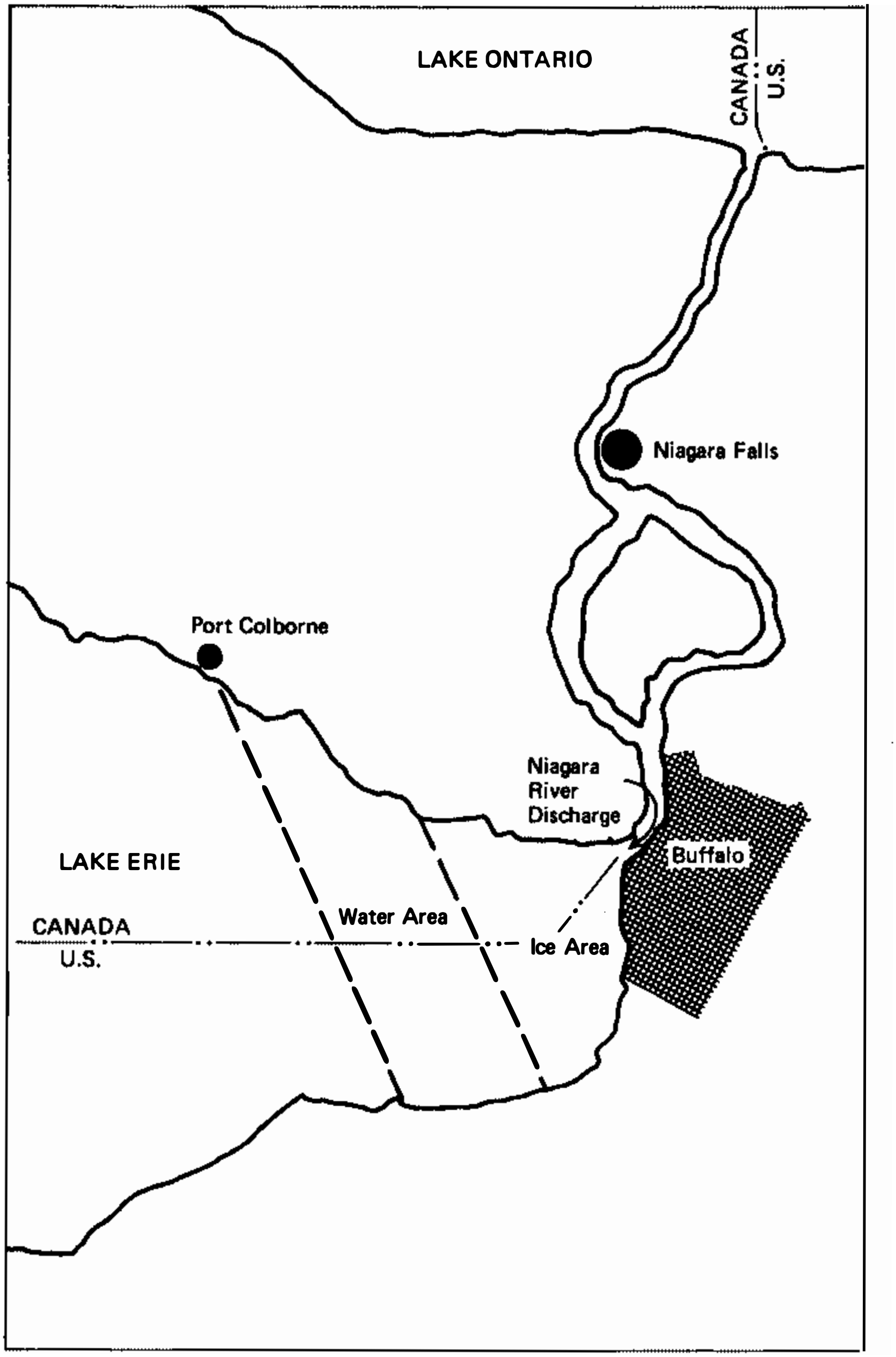


FIGURE 8 Schematic of ice dissipation.

the mixing layer (determined by vertical temperature variation in the air) would eclipse the influence of ice cover.

Use of an energy balance model to explain details of ice transport and melt should not be carried too far since significant spatial and temporal variability occurs in the lake, and lake dynamics plays an important role in ice transport and the melting processes. For example, during final stages of ice dissipation east of Port Colborne, the shallower nearshore region of the eastern basin of Lake Erie will warm (due to net radiation) more rapidly than the deeper offshore region. This causes a strong offshore temperature variation and a strong (on the order of 16 mi (26 km) per day) northeastward current along the U.S. nearshore region (see Sayler et al. 1981, pages 283-287, for comparable coastal current phenomena in Lake Ontario). An example of this phenomenon is shown in Figure 9, a map of Lake Erie surface temperature for April 8, 1976. Although the Lake Erie coastal current has had little study, its effect on ice dissipation should be significant. Likewise, the passage of storms influences lake water and ice movements and can pile up large masses of ice along the shoreline for which net radiation is the only melting process.

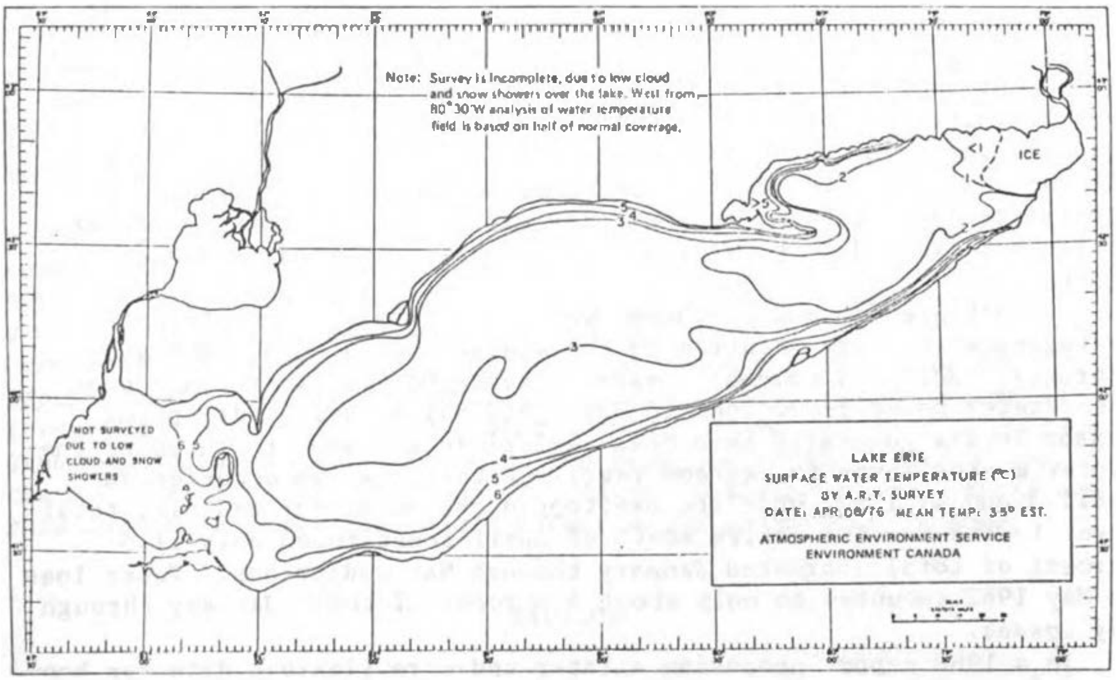


FIGURE 9 Lake Erie surface water temperature, April 8, 1976.

4

IMPACTS OF ICE ON AREA NEAR NIAGARA RIVER

HYDROPOWER

The boom has significantly reduced losses in hydropower benefits caused by ice jams, reduced diversions, elevated tail waters, and damaged equipment. Total installed generating capacity on the Niagara River is over 4000 megawatts (mw), with the Robert Moses and Sir Adam Beck high-head plants constituting over 80 percent of this total capacity. In a 1980 report to the International Joint Commission, the power entities indicated that the boom had effected an average improvement in power generation at these plants of nearly 15 percent in January and about 9 percent in February. These loss reductions represent a savings of nearly 415 million kilowatt-hours annually. In the context of the amount of fossil fuels required to produce the equivalent amount of electrical energy, this amount of energy is equivalent to 170,000 tons of coal or 760,000 barrels of oil. If a very conservative, off-peak value of 2.5 cents per kilowatt hour is assumed, the power generation loss reduction translates to over $10 million annually. The dollar amount of increased power production facilitated by the boom, however, may exceed $30 million or more if losses are assumed to be avoided in the peaking period of winter months.

In both preboom and postboom years, the greatest reductions in hydrogeneration have occurred in the winter months of January and February, and, to a somewhat lesser extent, March. There have been ice-related power reductions in April and May as well, but spring season losses generally have been negligible compared to those of the winter months, even in extreme years. Although a jam occurred on April 3 and 4, 1982, when ice overtopped the boom, for example, total power losses for the entire month of April constituted only 11.5 percent of total estimated January through May reductions. Power loss in May 1982 amounted to only about 4 percent of total January through May losses.

In a 1968 report proposing a later and more flexible date for boom removal, the Niagara River Board of Control estimated that energy losses after April 1 averaged approximately $5,200 per year for the 4 years that the boom had been in operation and were "relatively minor." Most of the post-April 1 losses were attributed to decreased diversions to insure an adequate flow to carry ice over the falls. Although the Board of Control cited cases of large runs of lake ice in late April and early May--specifically in 1909, 1938, and 1947--and argued that similar conditions could create excessive losses after the first week of April, spring losses of record have been orders of magnitude less than reductions experienced in winter months. The relatively minor nature of post-April 1 hydropower losses is further confirmed in a 1980 statement by the power entities, which reports that differences in preboom and postboom power generation for the months of April and May have been "insignificant."

A recent (NYPA and Ontario Hydro 1983) report estimates two sets of April power generation figures for 1965 through 1982, one set assuming that the boom was in place for the month and the other assuming no boom. Comparisons of these estimates are then employed to quantify the dollar value of the boom in reducing April power losses. While admitting that such calculations are based on numerous assumptions, the power entities estimate that the boom can save several thousands of dollars in April--particularly during the first 10 days of the month--and hundreds of thousands of dollars in extreme years such as 1976 and 1982. The power entities express concern that particularly severe ice runs in April, such as those that occurred prior to the construction of the high-head plants, could inflict so much damage to some of the generating facilities themselves that they could not be repaired economically. At the same time, the power entities acknowledge that April energy savings attributable to the boom are typically quite small in relation to those accruing earlier in the ice season.

In addition to there being negligible average spring power reductions, monitoring of ice discharged from the lake over a period of three years indicates that spring ice usually has little or no internal strength, and as a result, the boom has very limited restraining effect (International Niagara Working Committee 1975, 1976, 1977).

In summary, all available information indicates that the ice boom substantially reduces losses in power generation in all but very severe storms. Depending on specific time of occurrence, reduction in yearly losses may realistically exceed $30 million, but even by conservative estimates, the ice boom precludes energy losses of approximately $10 million annually. Historically, most substantial losses have occurred in the winter months; consequently, it is during January, February, and March that the presence of the boom has been the most critical and the most effective. Damaging runs in April are rare but in extreme cases could effect major reductions in power.

EROSION

The Niagara River shoreline includes 69 mi (110 km) of mainland and 37 mi (60 km) of island. Erosion of the shoreline results principally from rapidly moving river water. Erosion is greatest when water flows are abnormally high. When flows are near normal, the erosional process is usually slow since most of the easily erodible material has already been removed and transported downstream. The established channel provides a good water transportation route.

Erosion increases when water levels/flows go up and/or when material such as ice is transported by the water. Erosion is highest when water levels are in the upper normal range, especially if large quantities of hard ice are also being transported. High water flows expose the river banks to the force of the water. River banks or shorelines in the Buffalo area are frequently composed of soft, easily erodible sediments such as weak shale beds, and unconsolidated materials of glacial origin. The increased erosion continues until either all broken material is removed or the water levels/flows return to "normal" and the riverbed stabilizes.

Transportation of ice can increase the erosional process, particularly hard pieces of blue or black ice, which will scour and gouge the riverbed and shoreline. If combined with high water levels, the destructive force of the ice and water can greatly modify river banks, channels, and shorelines and destroy even strongly built structures. A recent survey indicated 2174 boat slips and 225 moorings in existence on the U.S. side of the Niagara River alone (ILERSB 1981) could be damaged.

Water levels/flows in the Niagara River are directly related to Lake Erie's water levels. Lake Erie's levels in turn are a natural function of meteorological and hydrological conditions of the upper Great Lakes region. Therefore the conceivable impact of the ice boom on water levels/flows is limited to the ability of the boom to keep the ice from forming ice dams and allowing the water to flow unrestricted under the ice field.

The impact of the ice boom on downstream erosion and ice damage has not been completely quantified. However, the boom appears to decrease the chances of local flooding caused by ice jams by decreasing the abundance of hard ice entering the river. Ice runs in 1964, just prior to the boom installation, caused $146,000 in damages to marinas.

FLOODING

Flooding has been a recurring problem on the Niagara River. The most vulnerable areas have been Cayuga Island and Grand Island. Cayuga Island, for example, has experienced 10 floods since the advent of residential development in the early 1940's. Unlike most riverine floods, which are caused by excessive seasonal runoff, floods on the Niagara have resulted from a backwater effect caused by ice jams, strong southwesterly winds that raise the water level at the eastern end of the lake, or a combination of both.

Reduction of flooding on the Niagara River has been a frequently emphasized secondary benefit of the ice boom. While there does appear to have been a decrease in flood severity and frequency in postboom years, two points merit attention: (1) the ice boom has little effect on ice jam floods of extreme magnitude; and (2) the decrease in flooding is not attributable solely to the ice boom but also has been affected by regulatory changes governing diversions from Grass Island Pool.

As evident from ice-jam-induced floods of 1975 and 1982, the boom neither completely eliminates floods nor reduces the magnitude of extreme events. As more thoroughly described in Chapter 2, the boom is designed to facilitate the formation of an ice arch. While the boom has successfully done this, it will submerge in large storms and allow wind-driven ice to move downstream across the submerged structure. Ice passing over the boom in such events may become jammed downstream in the river and cause flooding. Although arguments in support of the boom's effectiveness often cite the March 1955 flood (the greatest flood of record) as a particularly damaging event that would have been mitigated by the boom, there is no reason to believe that a comparable event would be eliminated or appreciably altered if it occurred with the boom in place (U.S. Army Corps of Engineers 1979).

During periods of free flow down the Niagara River, water diverted for power can reduce Grass Island Pool levels. Such diversions can be significant in reducing floods caused by storm-induced increases in lake level. When the boom is overtopped by large ice runs, however, the stage of Grass Island Pool must be maintained at a level that facilitates the movement of ice and reduces the amount of ice grounding.

While the ability of the boom and diversions from Grass Island Pool to mitigate ice jam floods of extreme magnitude is doubtful, there is ample reason to believe that more frequent, moderate floods are alleviated in severity or eliminated entirely. A 1966 Corps of Engineers feasibility study for flood control on Cayuga Island prior to installation of the ice boom established a stage height of the 25-year flood as 567.5 ft (173 m) IGLD. A similar Corps study released after several years of boom operation and regulatory changes affecting Grass Island Pool indicated that the 25-year flood stage was reduced by 0.6 ft (18 cm). Seemingly small, this decrease considerably lessens the area of inundation in a 25-year flood. Similarly, there have been fewer ice jam floods on Cayuga Island since the installation of the boom than occurred in the slightly shorter period of record prior to 1965. As a result, the 1979 Corps study concluded that reductions in flooding obviated the need for structural controls that had previously been recommended as technically and economically feasible.

The inability to segregate completely the effects of the boom from the effects of the Grass Island Control Structure and the difficulties of isolating events that have been reduced or eliminated by these structures confound any effort to draw specific conclusions about the effectiveness of the boom in mitigating flood losses. However, it can be safely and fairly generalized that, while diversions from Grass Island Pool reduce the magnitude of free-flow floods, *the ice boom reduces the frequency of ice jam flooding, although the boom has little effect on high-magnitude floods*.

BIOLOGICAL NATURAL RESOURCES

The Niagara River, with approximately 106 mi (170 km) of shoreline (mainland and island combined), is a very productive fish and wildlife area. Approximately 721 acres (2.92 km^2) of wetlands exist on the U.S. side of the river (ILERSB 1981). A recent fish survey in the boom area identified 27 fish species. Relative abundances are given in Appendix Table C-1. Other studies have identified 91 species of fish from the Niagara River and tributaries (Appendix Table C-2). A large sports fishery exists on the extreme eastern end of Lake Erie and the upper Niagara River. This fishery is mainly populated by smallmouth bass, yellow perch, walleye, northern pike, muskellunge, and various species of introduced trout and salmon.

The impact of the ice boom on these fish resources is considered negligible during the early and mid-winter time periods. The greatest potential for a boom impact occurs during the spring spawning season by (1) altering the spring rise in water temperature and (2) altering the degree of ice scouring on the Lake Erie shores and upper Niagara River.

Water temperature is an important factor in the reproduction, growth, and behavior of fishes. In particular, the timing and success of reproduction of species that spawn in the spring are often related to the rate and regularity of water warming during the spawning and incubation periods. Yellow perch, walleye, northern pike, muskellunge, smallmouth bass, common sucker, and burbot spawn in the early spring in eastern Lake Erie and the upper Niagara River (O'Mara 1977, Harrison et al. 1978, Spotila et al. 1979, ILERSB 1981).

No studies have been undertaken to assess directly the impact of the ice boom on reproductive success of fishes in this area, and insufficient data exist to effectively evaluate the direction and magnitude of such an effect, should it exist.

A review of the available fisheries literature provides some very general guidelines as to the level of boom-related physical changes necessary to affect fishes. If the delay in spawning is of a few days and the change in temperature is less than 1.0^{o}F (0.5^{o}C) or the rate of change in temperature is compensated for within 2 days, any affect on fishes would be negligible under normal circumstances. *It is concluded from estimates of the effect of the ice boom on water temperatures that the boom does not significantly affect fisheries in the area.* Should the effect of the ice boom (ice holding) on the water temperature be underestimated, impacts on fisheries resources might occur (see Appendix C for discussion).

Ice scouring of the bottom occurs within Lake Erie and the Niagara River. The effects of the boom on ice scouring either in the lake or the river is not known. Ice scours could destroy habitat or even fish eggs of early spawners in the case of late ice floes. Ice scours could also have beneficial impacts by creating habitat diversity in a region, thereby increasing the production of benthic invertebrates, or by providing good spawning sites or larval refugia for fishes.

A list of other types of wildlife in the Great Lakes area including the Niagara River and eastern Lake Erie and western Lake

Ontario is given in Appendix F of Environmental Effects of the Lake Erie Water Level Study (ILERSB 1981). Information concerning the potential impact of the ice boom on these resources is not available. Colonial nesting birds such as the Common Tern, Ring-Billed Gull, and Herring Gull occupy nesting sites located on the Buffalo Breakwater, on the southeast portion of Buckhorn Island, and in the Niagara Gorge areas (Scharf 1979). These birds may find feeding a little more difficult during an extension of the length of ice cover, but a few days would be insignificant.

RECREATIONAL FISHING

Eastern Lake Erie and the Niagara River are used extensively by sports fishers. A statewide angler survey conducted by the New York Department of Environmental Conservation in 1976-1977 showed a total of 613,100 angler days spent annually on the New York waters of Lake Erie. Total expenditures at the destination are estimated at $1.8 million or approximately $3 spent per angler day (Brown 1980). Approximately 98 percent of these angler days originated in the Buffalo area. A further total of 510,700 angler days was estimated for the Niagara River with an average expenditure at destination of $2 per angler day. About 99 percent of these angler days originated from the Buffalo area.

Eastern Lake Erie anglers fish for a variety of species. Approximately one-third of the anglers preferred to fish for walleye. Other major target species are coho salmon, various species of trout, bass, yellow perch, northern pike, muskellunge, and bullheads.

It has been contended that the ice boom significantly delays the beginning of the spring recreational boating and fishing due to the presence of ice and that this in turn affects the local economy. To assess adequately the maximum effect of the boom on this recreational fishing we need to know (1) the extent that the boom delays ice removal in the lake, (2) the extent to which fishing in Lake Erie is delayed by the presence of the ice, and (3) the factors that initiate the beginning of spring fishing and recreational boating (e.g., air temperature may be important). Extending the duration of ice on the lake for a few days should have a negligible effect on the local economy. Fishing effort and recreational boating vary seasonally and do not peak in early spring. For example, the fishing seasons for muskellunge and bass in New York State waters of Lake Erie do not begin until the third Saturday in June, and the fishing seasons for walleye and northern pike do not open until the first Saturday in May (they are closed from March 15).

As an upper-limit estimate of the potential economic impact of a delayed start of recreational fishing due to ice cover, it can be assumed that fishing effort is negligible during ice cover and spread equally throughout the rest of the year, say, April 1 to December 31. The results show a loss of 2229 angler days on Lake Erie for each day that the start of the spring fishing season might be delayed. This amounts to over $6700 per day. This simple analysis assumes a lack of a seasonal variation in fishing effort; it also assumes that any delay in the initiation of spring fishing will not be compensated for by an increase in fishing effort later in the season and thus tends to grossly overestimate the impact. It also assumes that fishing and recreational boating lost on Lake Erie will not be compensated for by transferring activities to nearby areas such as the Niagara River downstream from the boom. *If the boom is removed while ice is still in the lake as recommended, there is no expected delay of the start of the spring fishing season and consequently no impact on recreational fishing.*

COMMERCIAL SHIPPING

The ice boom itself poses no structural barrier to navigation, since it does not cross the navigation channel for ships and is open at both ends to permit the passage of small boats. However, the opening of the navigation season in the eastern end of Lake Erie depends in large part on the timing of ice dissipation. Navigation on the Niagara River itself does not commence until nearly all lake ice has dissipated. Ice influences the opening of Buffalo Harbor and the entrance to the Welland Canal at Port Colborne. Based on the contention that the boom can retard the dissipation of lake ice, some commercial shipping interests have argued that the boom delays the opening of the navigation season by a number of days or even weeks.

In the fall of 1968, the Niagara River Board of Control queried concerned parties about the prospect of making the date for boom removal more flexible as necessitated by the particular seasonal characteristics. Three of 10 commercial shipping interests that responded expressed the view that the dissipation of lake ice was functionally related to the boom and opposed any extension of the period of boom operation. The director of the St. Lawrence Seaway Authority voiced similar objections, and the Niagara Port Authority was reluctant to endorse a flexible date of boom removal without a thorough study of the possible impact on the ice season. At a public hearing convened by the International Joint Commission in 1973, the U.S. Lake Carriers' Association also contended that the beginning of the navigation season was related to the date of boom removal, particularly during severe winters.

The St. Lawrence Seaway Authority prevailed on the Atmospheric Environment Service (Canada) to conduct an investigation of boom impacts on navigation, particularly the opening at Port Colborne. In the resulting study, Webb (1973) found that detailed navigational records necessary for a meaningful preboom versus postboom comparison were not available. As a consequence, Webb carried out a theoretical examination of ice dissipation. That examination concluded that the effects of the boom were "almost nil" and that any delay in ice dissipation would involve only a matter of hours.

Information on annual dates of opening for Buffalo Harbor does exist. For the preboom years 1927 through 1964, the average date of harbor opening was April 7. The average opening in postboom years with flexible removal date (1970-1982) was also April 7, and the average opening date for all postboom years (1965-1982) was April 8. Corresponding data for Port Colborne show an average March 30 opening date, but neither the Buffalo Harbor nor the Port Colborne data provide a sound basis on which to evaluate possible boom impacts on commercial shipping. Specifically, opening dates reflect many factors in addition to ice dissipation: advances in ice-breaking technology, occurrence of holidays, and variable economic conditions, for example. For this reason, most people analyzing boom impacts have been reluctant to consider harbor and port opening dates as meaningful indices of navigation conditions and commercial shipping activity.

In the absence of adequate and appropriate data on navigation in eastern Lake Erie and the Upper Niagara River, the boom's possible effect on commercial shipping must be evaluated in the context of ice dissipation information and climatological data. Since the boom has had, at most, small and very short-term effects on local air and water temperatures that cannot be discerned with existing data (and are perhaps indiscernible), the panel concurs with Webb's conclusion that *the effect of the boom on commercial shipping activities has been negligible and that any boom-induced delays in the opening of the navigation season are indeed on the order of hours rather than days or weeks as has sometimes been contended.*

OTHER PUBLIC CONCERNS

During public meetings held in March 1983 in Fort Erie and Buffalo, a number of additional concerns were voiced about the boom and its possible impacts on local activities and environments. While several of these issues are implicitly addressed elsewhere in this report, the panel wishes to respond to all concerns as specifically and completely as available information permits.

The objections to the boom most frequently expressed at the public meetings were based on the belief that by causing a protracted period of cool temperatures, the boom effects shorter growing seasons and contributes to higher residential heating bills. Although data needed to evaluate these concerns directly are not available, it is indeed quite likely that the growing season has been somewhat shorter in recent years and that space heating costs have risen faster than increases in fuel prices. These circumstances, however, are attributed to climatic cooling experienced throughout much of the Great Lakes region (see Chapter 3) rather than the presence of the ice boom.

Several residents of Buffalo and the eastern Lake Erie area also noted that the lake level has risen markedly in recent years. This is true; the level of Lake Erie as well as several of the other Great Lakes has been rising. Higher lake levels, however, reflect natural processes that are unrelated to the presence of the ice boom. Because of how the boom operates, the amount of water held back by the boom at any time is negligible. In fact, the volume of water discharged in recent years from the lake into the Niagara River during winter and early spring months has been well above the long-term average.

An alternative explanation volunteered at the Buffalo meeting to account for the rise in the surface elevation of Lake Erie suggests that the boom has inhibited normal ice scouring of the Niagara River, thereby increasing the riverbed elevation and correspondingly the outlet from Lake Erie at the head of the river. This explanation is untenable for two reasons. First, as noted elsewhere, the boom does not prevent large ice runs, and scouring still occurs. Second, water entering the river at the lake outlet would normally contain little sediment since the lake itself acts as a sediment trap. As a result, relatively little sediment is available for deposition, and the river has sufficient energy to transport it downstream. In addition, the riverbed is probably scoured seasonally by anchor ice that forms in the river independently of Lake Erie. Even if sedimentation were occurring, it is highly improbable that net aggradation of the bed during the period of the boom's existence could occur at a rate rapid enough to account for the claimed 2-ft (0.6 m) rise in lake level.

The observation also was made that water at the Wanakah Water Company, which supplies the town of Hamburg, becomes foul tasting and malodorous each spring. The data necessary for a preboom versus postboom comparison of water quality at the Wanakah intake are not available. Such a situation, however, would not be unusual. Surface water supplies typically have less desirable taste and odor characteristics in spring months in part due to increased surface runoff and in part due to additional treatment procedures (greater chlorination, for example) commonly employed to neutralize the increased runoff. The claim was made, however, that quality degradation at the Wanakah intake results from a damming effect of the boom, which in turn results in the retention of more surface runoff. However, it has already been noted that the boom does not dam the waters of Lake Erie.

Finally, at the 1980 public hearing to consider extension of the boom operation agreement, there was concern that the boom presented a navigational hazard, particularly to small craft. Warning markers attached to the boom were suggested as a means of making boaters aware of the boom. Although the amount of time that boating can occur when the boom is in place is normally quite limited, a 1980 report issued by the power entities expressed their willingness to install safety devices pending advice from navigation authorities on current regulations. By the 1983 public meetings, however, safety markers had not yet been installed, and the issue was again raised. If there continue to be periods when the boom is in place that boating can and does occur, the panel concurs that it would be advisable for the power entities to install safety markers.

5

ALTERNATIVE METHODS OF ICE CONTROL

A number of alternatives to the present ice boom were considered by the panel; however, *the panel concludes that there is no feasible alternative that would be comparably effective to the present ice boom*. Alternatives considered range from ice retention structures to changes in the operational use of the present boom.

FIXED STRUCTURES

A variety of concepts for ice retention structures other than ice booms exist in the field of ice engineering. Most of these consist of anchor points such as small islands or large piers that would be spaced across the Lake Erie outlet to the Niagara River. In comparison with the present boom, these have large disadvantages, most notably large costs and the inability to be operated so as to allow, at appropriate times, free passage of ice and water into the Niagara River. Permanent structures also would present a permanent aesthetic change in the appearance of the lake at the entrance to the Niagara River. For the purpose of ice retention to prevent large ice runs of extended duration, the present ice boom is considered superior to other structural alternatives.

ICE MANAGEMENT

Considerable efforts over the years by the power entities have already resulted in intake details, configurations, and operating procedures to avoid or minimize interruptions to power production caused by ice. In general, except for very large ice runs that result in ice jamming in the river and consequent flow blockage, these measures have been successful. The large, extended-duration ice runs that the presence of the ice boom has alleviated are not able to be accommodated by any known improvement in ice management techniques at the intake locations.

ALTERNATE ICE BOOMS

Alternate configurations of the present boom were considered. Another boom, either in addition to the present boom or as a replacement, located farther out in the lake, was considered to be much more expensive while not offering any measurable advantage to the present boom that is located in coincidence with the location of the natural ice arch locations that occurred prior to the installation of the present boom. The boom also would not function if located closer to the Niagara River entrance or farther downstream, since water velocities there exceed the maximum velocities at which ice booms are effective.

Similarly, use of ice booms that only partially extend across the exit of the lake were considered, but no particular advantages were found. Presumably, openings in the booms would be for the purpose of passing some ice. This is advantageous only at the very end of the ice season, and opening and removal of the boom occurs prior to this time.

OTHER ALTERNATIVES

A number of other alternatives aimed at reducing the quantity of ice in the lake near the end of the ice season were examined but judged to be not feasible. Dusting of the ice cover with sand or coal dust would increase the absorption of solar radiation and increase melting rates somewhat, but the costs would be greater than the benefits, and there are some objections to dusting on aesthetic and ecological grounds. Waste heat (e.g., from steam-electric power plants) of a magnitude necessary to cause significant reduction in ice volumes is not available. Significant increase through channel improvements in the ability of the Niagara River to carry larger amounts of ice without jamming would require immense changes in the river's geometry that clearly are inappropriate.

Water intakes often have grates, called trash racks, across their openings to prevent large objects from entering. These trash racks often become clogged with ice, particularly frazil ice that sticks to the bars of the trash racks. To alleviate this type of clogging, the bars of the racks are sometimes heated to prevent the ice from sticking to the bars. Trash rack heating will not alleviate the problems of the large ice runs that the ice boom seeks to limit, since the problem is caused by clogging of the river with ice rather than local ice blockage at the intakes.

Air bubbler systems are often used to aid in managing ice problems. There are two general types of air bubbler systems. In the first, the rising air bubbles act to move warm water from below against the ice cover, and over time result in melting a local area of ice cover. In the second, large flows of air are used to create a surface current to flush ice away from intake areas. Neither kind of bubbling system is considered applicable in the present case to mitigate the difficulties of the large ice runs that the ice boom seeks to limit. The first system has no warm water to draw upon, and the second "flushing" system is only useful locally and cannot solve the major problem of the large ice runs, i.e., the clogging of large stretches of the river with ice. Both types of systems may be useful, however, in mitigating less severe ice problems in very small areas.

It has sometimes been proposed that ice breakers could be used in Lake Erie to keep the ice cover broken up. However, this would be a massive task and is considered impractical for that reason. Further, the continual breaking of ice would both result in more ice production and be redundant with the natural processes that result in periodic breaking of the ice cover.

6

MODIFICATION OF CURRENT PROCEDURES

In examining the experience of operation of the present boom together with the experience of power interruptions prior to installation of the boom in 1964, the panel found that the most severe ice problems associated with power production occurred during the initial formation stages and mid-winter periods when the lake ice cover was of great extent. Not only were the power interruptions due to ice small during the thawing period but it was also found that the boom did not significantly restrain ice movement into the Niagara River during these thawing periods. *It appears that when the ice has deteriorated in quality as a result of partial thawing, the ice boom is ineffective in preventing ice movement into the Niagara River due to lake storms. At these same times, should a troublesome run of ice occur, the poor quality of the ice makes it more manageable at the intakes. Even if power interruption should occur, the potential for extended interruption is much less than during early winter or mid-winter. These considerations strongly suggest that there is only marginal benefit from the boom during the thawing period.*

The panel recommends that the boom be opened by April 1 and removed as soon as practical unless the ice cover is larger than 250 mi^2 (650 km^2) of ice, east of Long Point. Under these conditions the boom opening may be delayed until the ice remaining reduces to 250 mi^2 (650 km^2) in area.

The panel considers an ice quantity of 250 mi^2 (650 km^2) after April 1 as the turning point representing the final stage of winter conditions. This quantity is also near the maximum that could be handled by the river during a long and intense outrun with only a small chance of a major blockage. The 250 mi^2 (650 km^2) criteria is indicative of significant ice melting and usually coincides with reduced ice strength.

The April 1 date is chosen because there is a low probability of ice reformation at this time, ice is likely to be in a deteriorated condition due to increased solar radiation, and, by regulation, the water that must pass over the falls during the day time increases from 50,000 to 100,000 cfs (1415 to 2830 cubic meters per second) on this date. This change in water flow significantly increases the ice-carrying capacity of the river over the falls without incurring power loss.

It is emphasized that air and water temperatures in the Buffalo region with an ice boom will be similar to those that would exist without an ice boom, and the preponderance of any cooling effect is caused by natural conditions. However, after the ice area at the eastern end of Lake Erie has been reduced to a relatively small amount (less than 250 mi^2 (650 km^2)), the portion of that ice that can be attributed to the ice-retaining capacity of the boom, at most perhaps 100 mi^2 (260 km^2), can cause a slight chilling of the water and microclimate that would not otherwise exist during the early spring warming period. Removing the boom removes this possibility.

The ice boom is from all available information operating as intended: it is expediting the formation of an arch in the beginning of the ice season, expediting the re-formation of an ice arch after storms in mid-winter, and reducing to some degree the passage of ice into the river following storms. During the coldest portion of the year it accomplishes these purposes with no significant negative impacts on any other feature of the environment. During this period the boom does not by itself restrain significant amounts of ice in the lake.

In early spring the situation is different. Lake ice is relatively weak; once broken the ice arch is unlikely to reform because temperatures are not low enough; and the amount of ice remaining on the lake is but a small fraction of the area of the lake. Under these conditions, there are situations in which the boom could retain measurable amounts of ice that would not normally remain in the lake. As an example, if in April 100 mi^2 (260 km^2) of ice remain and a period of gentle west winds sets in, without the boom in place, it is probable that perhaps 10 mi^2 (26 km^2) of ice per day would leave the lake and move into the river. With the boom in place, essentially no ice will move into the river. During the time ice remains in the lake it is melting, but without a doubt there is more ice in the lake than would be present without the boom.

The weather impact of this retained ice is small but not zero. Due to the energy available (from sun and air) the 100 mi^2 (260 km^2) of ice would melt in the lake in about 10 days with the boom in place. The water temperature would be almost 32°F (0°C) at the end of this time. If the boom were not present, 10 mi^2 (26 km^2) per day would move out of the lake into the river at the same time melting would be occurring. The melt rate and discharge rate are about the same; the melt rate decreases the ice thickness, and the discharge rate decreases the ice area. Under the assumption of a wind effect that keeps the ice at the same thickness, the ice would be gone from the lake in 5 days. Then the water temperature would begin rising at about 1/2°F (1/4°C) per day. See Appendix E for the actual calculations. Rumer et al. (1974) performed a similar analysis.

The differences in the two conditions are then as follows:

1. With the boom in place, after 5 days about 50 mi^2 (130 km^2) of ice remain in the lake with water and ice temperature at 32°F (0°C); after 10 days no ice is present and water temperature is 32°F (0°C).

2. Without the boom, after 5 days there is no ice, and water temperature is 32°F (0°C), and after 10 days the water temperature has increased about 2°F (slightly over 1°C).

Air moving over the region of the lake and going inland would for 5 days be affected similarly in the two cases. During the next 5 days, without the boom the average surface temperature over this region of the lake is 1°F (0.5°C) warmer than it would be with the boom. This small surface temperature difference would produce at most a 1°F (0.5°C) air temperature difference, clearly a very small amount.

It must be emphasized that this example is designed to show a maximum impact and is based on several assumptions that do not occur very often. Under more typical conditions, the difference between boom and no-boom results is smaller in both amount and duration. The assumptions are that the winds are steady toward the entrance to the river for 10 days; that the ice is relatively uniform in thickness; that the melting process operates exclusively to reduce the area of the ice rather than to reduce ice thickness as well as area; and that the energy input throughout the period is the average amount for that time of year.

7

MONITORING PROGRAM

As previously discussed, distinctive climatic zones exist between the near-water localities of Buffalo and Fort Erie and sites farther inland such as Buffalo Airport. In order to specify more precisely the differences occurring, it would be necessary to establish meteorological observing stations in the lakeshore environment and to study more thoroughly the older records on file from these. The observational period for new stations should be about 10 years at least.

However, the problem at hand is not particularly to contrast the nearshore and inland climates; it is, rather, whether the ice boom has had any effect on the lakeshore climate. Lakeshore meteorological stations are required to address this question. Before embarking on such a monitoring program, it is worth considering the likelihood of success in resolving the problem.

The ice boom controversy has centered on the breakup period in spring when in the postboom period there has been an alleged longer lake ice season at the inlet to the Niagara River. The freeze-up period has not gotten the same attention. During the breakup season, March to May, the temperature of the ice or water surface is close to 32°F (0°C). Therefore air moving over this surface (an on-shore wind at the river inlet) will be modified to about the same temperature whether there is ice and water present or an ice sheet. The normal range of variation of lake surface temperature is less than 2°F (1°C) and, hence, the effect on air moving over it would be a very slight temperature deficit of something on the order of a fraction of a degree F and not likely to be measurable within the natural variability due to changing wind speed and vertical mixing of the air.

The panel's best estimate is that during final stages of ice dissipation from Lake Erie the amount of ice retained by the boom is small. While it is theoretically feasible to measure small effects, it would be very difficult, require many years of measurement (on the order of 100 or more) and require a randomized experimental design. The cost would run in the tens of millions of dollars. It is not clear that the perceived small effect could be defined with acceptable precision, considering the large year-to-year variability in ice regimes. It is clear, however, that such large experimental costs are not justified.

The panel does not consider a monitoring program to be economically viable, as there is no firm assurance that the small values will be clearly distinguishable from normal instrument measurement error.

APPENDIX A

BIBLIOGRAPHY

Acres, Limited, H. G. (1972) Water Survey of Canada - Study of Lake Erie Ice Boom.

Arden, R. S., and Wigle, T. E. (1972) Dynamics of Ice Formation in the Upper Niagara River. International Symposia on the Role of Snow and Ice in Hydrology. Banff, Alberta, Canada.

Assel, R. A. (1983) Lake Erie Ice Cover Exceedance Study - Preliminary Results, report of Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan.

Bellaire, F. R. (1965) The Modification of Warm Air Moving Over Cold Water. Great Lakes Research Division, Ann Arbor, Michigan.

Brown, T. L. (1980) A Market Segmentation of New York's Great Lakes Anglers. N.Y. Sea Grant Research Report, 46 pp.

Bryce, J. B., and Berry, G. T. (1967) Lake Erie-Niagara River Ice Boom. Congress of Canadian Engineers. Montreal, Canada.

Busch, W.-D., Scholl, R. L., and Hartmann, W. L. (1975) Environmental Factors Affecting the Strength of Walleye (*Stizostedion v. vitreum*) Year-Classes in Western Lake Erie, 1960-70. J. Fish Res. Board Can. 32(10):1733-1743.

Chase, P.E., Parker, J. L., and Lewis, E. W. (1970) Ice Data Collection and Usage: Emphasis on Prediction Techniques. Proceedings 13th Conference Great Lakes Research, pp. 790-797.

Ecology and Environment, Inc. (1978) The Influence of the Niagara River Ice Boom on Gas Energy Demand (unpublished).

Erie County (1983) Affidavits filed in U.S. District Court, Western District of New York by Edward J. Rutkowski against International Joint Commission, Federal Energy Regulatory Commission, New York Power Authority, and Ontario Hydro.

Federal Power Commission (1966) Eastern Great Lakes Tributaries Planning Status Report. Water Resource Appraisals for Hydroelectric Licensing.

Ferguson, H. L. and Cork, H. F. (1972) Relationship Between Meteorological Variables and Ice Flow in the Upper Niagara River. Canadian Met. Res. Reports, Atmospheric Environment Service, Department of the Environment.

Foulds, D. M. (1964). Niagara Power Versus the Ice Machine. Montreal, Quebec.

Foulds, D. M. (1972). Method of Calculating Ice Outflow from Lake Erie With No Ice Boom in Place.

Harrison, E. J. and Hadley, W. F. (1978) Ecologic Separation of Sympatric Muskellunge and Northern Pike. Am. Fish. Soc. Spec. Publ. 11: 129-34.

Hartman, W. L. (1972) Lake Erie: Effects of Exploitation, Environmental Changes, and New Species on the Fishery Resources. J. Fish. Res. Bd. Can. 29: 899-912.

Hassan, J. and Sweeney, R. (1972) Influence of the Upper Niagara River Ice Boom on the Climate of Buffalo, New York. Special Report #13, prepared for The International Niagara Board of Control, International Joint Commission, reprinted 1978.

International Joint Commission, Public Meeting on Proposed Ice Boom Study (1983) Proceedings held March 3, 1983 at the Buffalo and Erie County Public Library Auditorium, Lafayette Square, Buffalo, New York.

International Joint Commission, Public Meeting on Proposed Ice Boom Study (1983) Proceedings taken March 4, 1983 at the Garrison Inn, Fort Erie, Ontario.

International Joint Commission, United States and Canada (1965) Rules of Procedure and Text of Treaty. Ottawa, Canada-Washington, D.C.

International Lake Erie Regulation Study Board (1981) Lake Erie Water Level Study - Main Report and Appendix F. Environmental Effects. IJC.

International Niagara Working Committee (1964) Report on the Proposed Ice Boom in Lake Erie at Entrance to Niagara River to the International Niagara Board of Control. Washington, D.C.

International Niagara Working Committee (1968) Report on Proposal to Consider a Later Date for Opening of Lake Erie-Niagara River Ice Boom. Report to the Niagara Board of Control.

International Niagara Working Committee (1975) Evaluation of 1974-75 Data Collection Program in Connection with the Lake Erie-Niagara River Ice Boom Study. Report to The International Niagara Board of Control.

International Niagara Working Committee (1976) Evaluation of the 1975-76 Data Collection Program in Connection with the Lake Erie-Niagara River Ice Boom Study. Report to The International Niagara Board of Control.

International Niagara Working Committee (1977) Operation of the Lake Erie-Niagara River Ice Boom and Related Studies. Report to The International Niagara Board of Control.

International Niagara Working Committee (1982) 1981-1982 Operation of the Lake Erie-Niagara River Ice Boom. Report to The International Niagara Board of Control.

Ludwig, Colonel D. D. (1978) Lake Erie-Niagara River Ice Boom Presentation to Erie Co. Legislature and Buffalo Common Council Buffalo, New York.

Marshall, E. W. (1968) Great Lakes Ice Cover. Limnos 1(4).

Munn, R. E., Hirt, M. S., and Findlay, B. F. (1969) A Climatological Study of the Urban Temperature Anomaly in the Lakeshore Environment at Toronto. Journal Applied Meteorology, Volume 8, pp. 411-422.

O'Mara, T. B. (1977) Population Statistics and Movement Patterns of Smallmouth Bass (Micropterus dolomieui) in the Upper Niagara and Adjacent Lake Erie (1975-1976). M.A. Thesis. State University of New York, Buffalo.

Pariset, E. and Hausser, R. (1966) Formation of Ice Covers and Ice Jams in Rivers. Proceedings, ASCE. Vol. 92, No. HY 6, pp. 1-24.

Perham, R. E. (1976). Some Economic Benefits of Ice Booms. Proceedings of the Second International Symposium on Cold Regions Engineering.

Pinsak, A. P. and Rodgers, G. K. (1981) Energy Balance. In IFYGL The International Field Year for the Great Lakes, E.J. Aubert and T.L. Richards, editors. Ann Arbor, Michigan, pp. 169-197, Ann Arbor: Great Lakes Environmental Research Laboratory.

Poddubny, A. G. (1971) Ecological Topography of Fish Populations in Reservoirs. Academy of Sciences of the USSR. Leningrad. Translated 1976.

Power Authority of the State of New York and The Hydro-Electric Power Commission of Ontario (1969) Statement to The International Joint Commission on Dates for Installation and Removal of the Lake Erie-Niagara Ice Boom.

Power Authority of the State of New York and Ontario Hydro (1983) The Value of the Lake Erie-Niagara River Ice Boom in April.

Quinn, F. H., Assel, R. A., and Gaskill, D. W. (1981) An Evaluation of the Impact of the Niagara River Ice Boom on the Air Temperature Regime at Buffalo, New York. Great Lakes Environmental Research Laboratory Contribution No. 257. Reprinted from Journal of Applied Meteorology, Vol. 21, No. 3, March 1982.

Quinn, F. H., Assel, R. A., and Gaskill, D. W. (1980) An Evaluation of Climatic Impact of the Niagara Ice Boom Relative to Air and Water Temperature and Winter Severity.

Richards, T. L. (1963) Meteorological Factors Affecting Ice Cover on the Great Lakes. Great Lakes Research Division, Ann Arbor, Michigan.

Rumer, R. R. (1973) Mathematical Model for Ice Dissipation Process. Appendix report to The International Niagara Working Committee, Contract No. DACW49-73-C-0086.

Rumer, R. R. and Acres Consulting Services Limited (1974) Lake Erie-Niagara River Ice Boom Study.

Rumer, R. R. (1980) Lake Erie-Niagara River Ice Boom Effects on Environment. Prepared for the Power Authority of the State of New York.

Rumer, R. R. (1980) An analysis of the document prepared by Ecology and Environment, Inc., entitled The Influence of the Niagara River Ice Boom on Gas Energy Demand.

Rumer, R., Atkinson, C., and Lavender, S. T. (1975) Effects of Lake Erie-Niagara River Ice Boom on the Ice Regime of Lake Erie. Proceedings, 3rd International Symposium on Ice Problems, IAHR, pp. 289-300. Hanover, New Hampshire.

Rumer, R. R., and Yu, P. M. (1978) Modelling Ice Dissipation in Eastern Lake Erie, J. Great Lakes Res. pp. 194-200.

Rumer, R. R., Bialas, W. F., Quinn, F. H., Assel, A., and Gaskill, D. W. (1983) Niagara River Ice Boom: Effects on Environment. Revised version for publication in Journal of Technical Topics.

Russell, B. E. (1972) Ice Formation in Lake Erie and the Niagara River, Its Effects and Control. Guelph, Ontario.

Sayler, J. H., Bennett, J. R., Boyce, F. M., Liu, P. C., Murthy, C. R. Pickett, R. L., and Simmons, T. J. (1981) Water Movements. In IFYGL--The International Field Year for the Great Lakes, E.J. Aubert and T.L. Richards, editors, pp. 247-324, Ann Arbor: Great Lakes Environmental Research Laboratory.

Scharf, W. C. (1979) Nesting and Migration Areas of Birds of the U.S. Great Lakes (30 April to 25 August 1976). U.S. Fish and Wildlife Service, Office of Biological Service. FWS/OBS-77/2. 113 pp.

Schumann, G. (1964) Die Wirkung abnormaler Temperaturen auf das Laichen and die Entwicklungsfahigkeit der Eir nordamerikanisher Zanden. Osterr. Fisch. 5:85-87. Translated 1970.

Shaykewich, J. E. (1980). Report presented to The International Joint Commission at the IJC Public Hearing on the Lake Erie-Niagara River Ice Boom.

Spotila, J. R., Terpin, K. M., Koons, R. R., and Bonati, R. L. (1979) Temperature Requirements of Fishes from Eastern Lake Erie and the Upper Niagara River: A Review of the Literature. Env. Biol. Fish. 4(3): 281-307.

Stewart, K. M. (1973) Winter Conditions in Lake Erie with Reference to Ice and Thermal Structure and Comparison to Lakes Winnebago (Wisconsin) and Mille Lacs (Minnesota). Proceedings, 16th Conference on Great Lakes Research.

U.S. Army Corps of Engineers, Buffalo District (1955) Report on Ice Jams Niagara River. Buffalo, New York.

U.S. Army Corps of Engineers, Buffalo District (1964) High Water and Ice Conditions--January - April 1964--Upper Niagara River. Buffalo, New York.

U.S. Corps of Engineers, Buffalo District, Department of the Army (1966) Detail Project Report for Flood Control on Little River and Cayuga Creek at and in the Vicinity of Cayuga Island, Niagara County, New York.

U.S. Army Corps of Engineers, Buffalo District (1979) Detailed Project Report for Flood Damage Reduction on Little River and Cayuga Creek at and in the Vicinity of Cayuga Island, Niagara County, New York. Draft.

Wake, A., and Rumer, R. (1979) Modelling the Ice Regime of Lake Erie. Journal of the Hydraulics Division, ASCE, Vol. 105, No. HY 7, pp. 827-844.

Wake, A., and Rumer, R. (1983) Great Lakes Ice Dynamics Simulation. Journal of Waterway, Port, Coastal and Ocean Engineering. ASCE, Vol. 109, No. 1, pp. 86-102.

Webb, M. S. (1973) An Assessment of the Effects of the Niagara Ice Boom on Ice Conditions in Eastern Lake Erie, Atmospheric Environment Service, Technical Memoranda 795, 21 p.

Williams, G. P. (1965) Correlating Freeze-up and Break-up With Weather Conditions. Canadian Geotechnical Journal, Vol. II, No. 4, pp. 313-326.

Yee, P., Wigle, T. E., Hollmer, A. (1981) The Lake Erie-Niagara River Ice Boom - An Operational Experience.

APPENDIX B

CALCULATIONS SHOWING THE POTENTIAL IMPACT OF THE BOOM

The energy balance equation is applied to two scenarios of final ice dissipation in the eastern end of Lake Erie in order to give some understanding of the importances of the various processes involved. The energy balance equation is $Q = n + v + f + s + e$, where Q is the net rate of heating or cooling of the lake volume, n is the net radiation flux into the lake through its surface, v is the differential heat transport of water flowing into and out of the lake at different temperatures, f is the differential heat transport of water flowing into the lake replacing ice flowing down the Niagara River, s is the sensible heating of the lake by a warmer atmosphere, and e is the heating effect of condensation (evaporation will cool the lake); see Pinsak and Rodgers (1981) for a more complete discussion of the energy balance equation.

We apply the energy balance concept during the final stages of ice dissipation to a volume of eastern Lake Erie of 140 mi^2 (360 km^2) surface area, east of a north-south line through Port Colborne. Let us consider a hypothetical case in which the eastern half (70 mi^2 or 180 km^2) of the area is 100 percent covered with ice 1.6 ft (0.5 m) thick at an ice and water temperature of $0^{o}C$ and the western half is ice free at a water temperature of $0.1^{o}C$. We postulate two scenarios: case A--a weak easterly wind will keep the ice cover in place with no transport; and case B--all available ice is transported down the river at the rate of 10 mi^2 per day (26 km^2 per day). Typical values of the heating processes (for late April) are assumed to be constant over a week; i.e., $n = 350$ cal cm^{-2} day^{-1}, $v = 85$, $\dot{s} + e = 0$; $f = 0$ for case A and $f = 230$ for case B.

The energy budget concept applies to a constant lake volume in terms of the change in internal energy that results from energy transports or fluxes through the boundary surfaces of the volume, but it gives no clues to the nature of variability or dynamics within the volume. While we recognize that we are in some respects stretching the energy budget concept, we will proceed to consider the two cases.

Case A

$$Q = n + v = 435 \text{ cal cm}^{-2} \text{ day}^{-1}$$

Ice-Free Area

- We assume that Q is applied evenly to the top of the water surface and that it heats the water evenly to a depth of 10 m. The resulting temperature change is

$$\Delta T = \frac{Q}{\rho c_w \Delta Z} = \frac{435}{1 X 1 X 10^3} \simeq 0.4^{o}C \ day^{-1}$$

- Over 7 days, the water temperature would increase by 2.8°.

Ice Area

- We assume that the heating will be applied evenly over the area to melt ice, and we assume ice density (ρ_i) is 0.8 g cm^{-3}. The resulting change in ice thickness is

$$\Delta Z = \frac{Q}{L_f \rho_i} = \frac{435}{80 X 0.8} \simeq 7 \ cm \ day^{-1}$$

(L_f, is the latent heat of fusion, equals 80 cal g^{-1}).

- Over 7 days, the ice thickness would decrease by 49 cm ($\simeq$ 0.5 m).

Summary

- In the ice-free area the water temperature from the surface to a depth of 10 m would increase from 0.1°C to 2.9°C over 7 days.
- In the ice-covered area, 0.5 m of ice--the total ice cover--would melt in 7 days; the resulting water temperature would be 0°C.

Case B

Ice-Free Area--same as case A.

Ice Area

- Of the initial 70 mi^2 of ice we assume that all available ice is transported down the river at the rate of 10 mi^2 day^{-1}. Since the heating processes (n + v) are continually melting the ice, however, the thickness of the ice (and the resulting ice volume transport) will decrease with time over a 7-day period. (There is no clue from the energy budget approach on what assumptions on internal ice dynamics are feasible and reasonable.) We assume that open water will develop from the western side at the rate of 10 mi^2 day^{-1}.

- The ice slab (initially of 70 mi^2) will decrease by 10 mi^2 day^{-1} due to ice transport.
- The thickness of the moving ice slab will decrease by 7 cm day^{-1} due to heating by processes n + v as in case A.
- The open water will increase by 10 mi^2 day^{-1}.
- The temperature of the open water will increase at the rate of 0.4°C day^{-1} (as in case A).

<u>Summary</u>

- In the ice-free area the water temperature from the surface to a depth of 10 m would increase from 0.1°C to 2.9°C over 7 days.
- In the ice-covered area, no ice would remain. The water temperature, surface to 10-m depth, in the open water area vacated by ice, would be heated as a function of the time it was ice free, at the rate of 0.4°C day^{-1}. Over a 7-day period the water temperature (surface to 10-m depth) would vary linearly toward the east from 2.9° to 0°C. The average water temperature would be 1.4°C.

APPENDIX C

BIOLOGICAL NATURAL RESOURCES

The public's concerns about the effects of the ice boom on fisheries and other natural resources were well recognized by the panel. After considerable deliberations the panel concluded that the ice boom does not significantly affect fisheries or natural resources in the area. This appendix summarizes some of the major questions addressed by the panel.

What are the fisheries resources of eastern Lake Erie and the Upper Niagara River?

The Niagara River, with approximately 106 mi (170 km) of shoreline (mainland and island combined), is a very productive fish and wildlife area. Approximately 721 acres (3 km^2) of wetlands are found on the U.S. side of the river (ILERSB 1981). A recent fish survey in the boom area identified 27 fish species. Relative abundances are given in Table C-1. Other studies have identified 93 species of fish from the Niagara River and tributaries (Table C-2). A large sports fishery exists on the extreme eastern end of Lake Erie and the Upper Niagara River. This fishery is mainly targeted on smallmouth bass, yellow perch, walleye, northern pike, muskellunge, and various species of introduced trout and salmon.

Have there been any studies directed toward assessing the impact of the ice boom on these fish resources?

No studies have been undertaken to directly assess the impact of the ice boom on fishes in this area, and insufficient data exist to evaluate effectively the direction and magnitude of such an effect, should it exist.

TABLE C-1 List of Fish Species Collected in the Buffalo Area of the Niagara River Through the Use of a Variety[1] of Collection Gear, May 16-19, 1983

Common Name	Scientific Name	Abundance[2]
Gizzard Shad	Dorosoma cepedianum	A
Rainbow Trout	Salmo gairdneri	O
Brown Trout	Salmo trutta	O
Rainbow Smelt	Osmerus mordax	R
Northern Pike	Esox lucius	O
Muskellunge	Esox masquinougy	O
Carp	Cypinus carpio	C
Goldfish	Carassius auratus	C
Carp X Goldfish		C
Goldenshiner	Notemigonus crysoleucas	O
Emerald Shiner	Notropis antherinoides	A
Common Shiner	Notropis cornutus	A
Spottail Shiner	Notropis hudsonius	A
Bluntnose Minnow	Pimephales notatus	
Common Sucker	Catostomus commersonnii	C
Brown Bullhead	Ictalurus nebulosus	C
Black Bullhead	Ictalurus melas	O
White Bass	Morone chrysops	C
Black Crappie	Pomoxis nigromaculatus	C
Rock Bass	Ambloplites rupestris	C
Smallmouth Bass	Micropterus dolomieui	C
Largemouth Bass	Micropterus salmoides	C
Pumpkinseed Sunfish	Lepomis gibbosus	C
Walleye	Stizostedion vitreum	O
Yellow Perch	Perca flavescens	A
Johnny Darter	Etheostoma nigrum	O
Freshwater Drum	Aplodinotus grunniens	R

[1]Gear types--small trawl, electro fishing, gill net, trap net, beach seine.

[2]A - abundant, C - common, O - occasional, R - rare.

Source: U.S. Fish and Wildlife Service, Cortland, NY.

TABLE C-2 Species Historically Recorded in Niagara River Not Listed in Table C-1

Common Name	Scientific Name	Source
Silver Lamprey	Ichthyomyzon unicuspis	(2)
Brook Lamprey	Lampetra lamottei	(2)
Sea Lamprey	Petromyzon marinus	(2)
Lake Sturgeon	Acipenses fulvescens	(2) (4)
Spotted Gar	Lepisosteus oculatus	(2)
Longnose Gar	Lepisosteus osseus	(2) (4)
Bowfin	Amia calva	(2)
Alewife	Alosa pseudoharengus	(1) (2) (4)
American Shad	Alosa sapidissima	(2)
Coho Salmon	Oncorhynchus kisutch	(1)
Brook Trout	Salvelinus fontinalis	(2)
Lake Trout	Salvelinus namaycush	(2)
Lake Herring	Coregonus artedii	(2)
Lake Whitefish	Coregonus clupeaformis	(2)
Round Whitefish	Prosopium cylindraceum	(2)
Mooneye	Hiodon tergisus	(2)
Central Mudminnow	Umbra limi	(1) (2) (4)
Grass Pickerel	Esox americanus	(1) (2) (4)
Stoneroller	Campostoma anomalum???	(2) (4)
Redbelly Dace	Chrosomus eos	(1) (2)
Lake Chub	Couesius plumbeus	(2)
Silver Chub	Hybopsis storeriana	(4)
Hornyhead Chub	Nocomis biguttatus	(1) (4)
River Chub	Nocomis micropogon	(1) (2) (4)
Bigmouth Shiner	Notropis dorsalis???	(4)
Blackchin Shiner	Notropis heterodon	(4)
Blacknose Shiner	Notropis heterolepis	(1) (2) (3) (4)
Rosyface Shiner	Notropis rebellus	(4)
Spotfin Shiner	Notropis spilopterus	(1) (2) (4)
Sand Shiner	Notropis stramineus	(2) (4)
Mimic Shiner	Notropis volucellus	(1)
Fathead Minnow	Pimephales promelas	(1) (2) (3) (4)
Blacknose Dace	Rhinichthys atratulus	(1) (3) (4)
Longnose Dace	Rhinichthys cataractae	(2) (4)
Creek Chub	Semotilus atromaculatus	(1) (2) (3) (4)
Pearl Dace	Semotilus margarita	(2)
Quillback Carpsucker	Carpiodes cyprinus	(2)
Longnose Sucker	Catostomus catostomus	(2) (3)
Lake Chubsucker	Erimyzon sucetta	(1) (2)
Hog Sucker	Hypentelium nigricans	(1) (2) (4)
Redhorse Species	Moxostoma sp.	(1)
Silver Redhorse	Moxostoma anisurum	(4)
Northern Redhorse	Moxostoma macrolepidotum	(2) (4)
Channel Catfish	Ictalurus punctatus	(2) (4)
Stonecat	Noturus flavus	(4)

Tadpole Madtom	Noturus syrinus	(1) (2) (4)
Brindled Madtom	Noturus miurus	(2)
American Eel	Anguilla rostrata	(2) (4)
Banded Killifish	Fundulus diaphanus	(1) (2) (4)
Burbot	Lota lota	(2)
Brook Silversides	Labidesthes sicculus	(2)
Brook Stickleback	Culaea inconstans	(1) (2) (4)
Threespine Stickleback	Gasterosteus aculeatus	(1) (2) (4)
Trout-Perch	Percopsis omiscomaycus	(1) (2) (4)
White Perch	Morone americana	(3)
Longear Sunfish	Lepomis megalotis	(2)
White Crappie	Pomoxis annularis	(1) (2)
Sauger	Stizostedion canadense	(2)
Greenside Darter	Etheostoma blennioides	(2) (4)
Rainbow Darter	Etheostoma caeruleum	(2) (4)
Iowa Darter	Etheostoma exile	(1) (2) (4)
Fantail Darter	Etheostoma flabellare	(4)
Logperch	Percina caprodes	(1) (2) (3) (4)
Blackside Darter	Percina maculata	(4)
Mottled Sculpin	Cottus bairdi	(2) (4)
Spoonhead Sculpin	Cottus ricei	(2)

(1) Species taken by Ontario Ministry of Natural Resources 1957-1974.
(2) Species collected by A. R. Mumma, Conservation Officer, Ontario 1958.
(3) Older ROM records--card catalogue prior to 1957.
(4) Species recorded on American side as given in the New York State biological survey before 1928.

Source: ILERSB 1981, Appendix F.

When is the greatest potential for an ice boom effect on fishes?

The impact of the ice boom on these fish resources is considered negligible during the early winter and mid-winter time periods. The greatest potential for a boom impact is during the spring spawning season. These effects are (1) altering the spring rise in water temperature and (2) altering the degree of ice scouring on the Lake Erie shores and upper Niagara River.

How important is water temperature to the spawning success of fishes?

Water temperature is an important factor in the reproduction, growth, and behavior of fishes. In particular, the timing and success of reproduction of species that spawn in spring have often been directly related to the rate and regularity of water warming during the spawning and incubation periods although other physical factors such as weather, lake level, flow rate, water turbidity, the frequency of storm events, oxygen concentration, and siltation and biological factors such as predation, food availability, and the number of spawning adults can also significantly affect reproductive success during any one year. Fishes are commonly characterized by very large natural fluctuations in the number of young produced from year to year, particularly in Lake Erie (Hartman 1972).

What factors are important in assessing the potential impact of the ice boom on the fish resources during spawning?

It has been argued that the ice boom significantly delays the spring warming by holding back ice in the eastern basin. Unfortunately, from an ecological point of view, the monthly mean water temperatures used in some of the meteorological reports are too coarse a measurement to evaluate cooling effects that may be only days in length.

Three factors are important in assessing the effect of artificial changes in the rate of spring warming: (1) change in the time of initiation of spring warming; (2) change in the rate of spring warming once initiated (i.e., ^{o}C/time); and (3) temperature at the end of the spring spawning period. All three processes can affect a fish's reproductive success.

What are some potential negative impacts of the ice boom on fish resources?

If there is a significant delay in the rise of spring water temperature in the Niagara River, wetland spawning fishes could experience a negative impact. Approximately 551 of the 721 U.S. acres of Niagara River wetlands are of a protected type. The shallow water in these wetlands would normally warm at a faster rate than the river water. The differences in the water warming could be even greater if the river water were chilled by an ice field. Most fishes do not move into their spawning area until they have reached ripeness (ready to spawn). Fishes waiting to reach ripeness in the cold river may not be ready to spawn until water temperature and other wetland conditions have passed "optimum" in the wetlands due to the lack of synchrony in the water warming regimes of the wetlands and the artificially chilled river.

The delay in spring warming could also reduce the overall growing season for fishes, but a few days either way would not be detectable or would be compensated for later in the season.

What are some potential positive impacts of the ice boom on fish resources?

Fishes may benefit from an ice-boom-induced delayed warming since the ripening of fishes, spawning, and incubation would take place with very little chance of major water temperature reversals. Delays in spawning, once the fish is ready to spawn, can be very harmful (Poddubny 1971, Schumann 1964). Delays are usually caused by an early or false spring following a mild winter. Under these conditions the water warms to the mid and high 30's (°F), and the early spawning fish become ripe and may start moving to the spawning areas. The weather then changes back to winter conditions, and water temperatures cool. The ripe fish will not spawn until the water warms again. If the warming is delayed by a week or more, the fish may not spawn at all. If it does spawn, the egg development may not go beyond cleavage (Schumann 1964).

Fish reproduction could also benefit by the compression of time for the spawning activity and faster egg incubation. For example, the number of young walleye and yellow perch produced in Lake Erie were synchronous in the 1960's, and reproductive success for these species was positively correlated with the rates and regularity of spring warming (Hartman 1972, Busch et al. 1975). However, the compression of the warming period in time may also cause the various spawning/incubation periods of different species of fish to overlap. This would have negative effects since predation (on eggs and larvae) and competition (loss of food availability) could be increased.

In your judgment, does the ice boom significantly affect fish resources in eastern Lake Erie or upper Niagara River by altering the spring water temperatures?

A review of the available fisheries literature provides some very general guidelines as to the level of boom-related physical changes necessary to affect fishes. If the delay in spawning is of a few days and the change in temperature is less than 1.0°F (0.5°C) or the rate of change in temperature is compensated for within 2 days, any affect on fishes would be negligible under normal circumstances. With delays of 7 days or more and 2°F (1°C) or more, effects could be very significant. Slight impacts could occur at intermediate conditions. The impact may be positive or negative and will likely vary from species to species and year to year. We conclude from estimates on the effect of the ice boom on water temperatures that the ice boom does not significantly affect fisheries in the area. Should the calculation underestimate the effect of the ice boom (ice holding) on the water temperature, impacts on fisheries resources would occur.

What are the potential impacts of ice scouring on fishes?

Ice scouring of the bottom occurs within Lake Erie and the Niagara River. The effects of the boom on ice scouring either in the lake or the river is not known. Ice scours could destroy habitat or even fish eggs of early spawners in the case of late ice flows. Ice scours could also have beneficial impacts by creating habitat diversity in a region, thereby likely increasing the production of benthic invertebrates, or by providing good spawning sites or larval refugia for fishes.

Could the ice boom affect other biological resources, such as birdlife, in the area?

A list of other types of wildlife in the Great Lakes area including the Niagara River and eastern Lake Erie and western Lake Ontario is given in Appendix F of Environmental Effects of the Lake Erie Water Level (ILERSB 1981). Information concerning the potential impact of the ice boom on these resources is not available. Colonial nesting birds such as the Common Tern, Ring-Billed Gull, and Herring Gull occupy nesting sites located on the Buffalo Breakwater, on the southeast portion of Buckhorn Island and in the Niagara Gorge areas (Scharf 1979). These birds may find feeding a little more difficult during an extension of the length of ice cover, but a few days would be insignificant.

APPENDIX D

PANEL REVIEW OF PUBLIC CONCERNS

The panel studied comments made at public hearings conducted by the IJC in Buffalo, New York on March 3, 1983, and in Fort Erie, Ontario, on March 4, 1983. It also studied affidavits prepared by Erie County for a court suit designed to force the permanent removal of the boom. Many statements were made in these forums attributing various climatic effects to the presence of the ice boom. Based on all evidence available to it, the panel concludes that while many of the observations of cool weather and attendent side effects made in these statements are correct, they are not at all due to the presence of the ice boom, and would be present were the boom not in place. There were many suggestions made as to alternative ice control methods. These have been considered and are discussed in Chapter 5. Following is a digest of the stated concerns, along with the panel's responses.

1. The presence of the boom has caused springs in the Buffalo-Fort Erie area to start later. Response: Data from a number of sources and studies clearly document that temperatures in March, April, and May have been decreasing in the Buffalo area and in a wide region around Lake Erie. However, the cooling started before the boom was first installed in 1964. The lake-ice effects do not extend even to the Buffalo Airport, yet temperatures at the Buffalo Airport are decreasing, as are those several hundred miles away. The very real springtime cooling in the Buffalo area is due to natural climate variability, not the ice boom.

The Buffalo region has and always will continue to have a day-to-day temperature pattern that is highly variable. Some years will have early springs and some will have late springs, regardless of the ice boom. In years with late springs, there will be many consequences, such as delayed tree budding, later access to recreational boating and swimming pools, and delayed pollination. However, these effects will occur over thousands of square miles and will be much more pronounced than the minute effect that may be caused by the ice boom. The possible boom effect would be so small that it is safe to say that any weather effect directly noticed by people could not have been caused by the ice boom.

2. The ice boom causes ice to form earlier than normal. Response: The ice boom cannot directly cause the formation of more than a trivial amount of ice on the timbers. In the early winter, the boom holds near it ice that has already formed at the shoreline and has broken off and floated eastward. The presence of the boom speeds the formation of the natural ice arch by holding ice floes in the proper location while the low temperatures freeze them into a solid ice cover.

3. The presence of the boom has caused heating bills to increase. Response: Heating costs are closely related to air temperature. With a cooling trend, one would expect a general increase in heating costs.

4. Diversion of water for power generation lowers the river level, thereby causing ice blockage problems that then require installation of an ice boom. Response: Diversion of water does not lower river levels due to the presence of the International Niagara Control Structure (the control dam), which is specifically operated to maintain the same levels as would occur without diversions.

5. Ice retained on Lake Erie by the ice boom causes increased shore erosion. Response: Shore erosion is caused by ice pushing along the shore or ice scouring the shore due to wave action. In actuality, the presence of the ice boom reduces shore erosion. By facilitating the formation of the ice arch, it reduces to some extent the movement of ice toward Niagara River, and it speeds the formation of a solid ice cover, which reduces wave action.

6. Retention of ice by the boom reduces scouring of the lake bottom, thereby reducing lake water outflow and increasing the level of Lake Erie. Response: Scouring is mainly caused by large masses of ice, not by small floes. In storm conditions, large ice floes are pushed past the boom, so scouring can occur downstream from the boom. However, the lake bottom near the entrance to Niagara River is largely bare rock, with no silt build-up. Lake level is not maintained by lake bottom conditions, but rather by precipitation and evaporation rates. The ice boom could have no impact on lake level or scouring amounts.

APPENDIX E

CALCULATION OF ICE DISSIPATION

During the mid-March to May period, the average energy input to the earth's surface in the Buffalo area is about 260 cal cm^{-2} day^{-1} (Rumer 1974). This energy is the difference between the solar heating by day and radiational cooling at night. The relatively small amount of energy available from warm air passing over a cool surface has not been included.

Using a value of 80 cal cm^{-3} as the energy needed to melt ice, for each square centimeter of exposed ice, the available energy could melt

$$\frac{260 \text{ cal cm}^{-2} \text{ day}^{-1}}{80 \text{ cal cm}^{-3}} = 3.25 \text{ cm day}^{-1} \text{ of ice.}$$

The ice cover on Lake Erie is assumed to be 1 ft (30 cm) thick, so the ice would melt in

$$\frac{30 \text{ cm}}{3.25 \text{ cm day}^{-1}} = 9.25 \text{ days (say 10 days).}$$

The total energy input to the 100 mi^2 (260 km^2) region of the lake is 260 cal cm^{-2} day^{-1} X 260 km^2 = 6.8 X 10^{14} cal day^{-1}. The volume of ice that this energy could melt is

$$\frac{6.8 \text{ X } 10^{14} \text{ cal day}^{-1}}{80 \text{ cal cm}^{-3}} = 8.5 \text{ X } 10^{6} \text{ m}^3 \text{ day}^{-1}.$$

The total volume of ice in the 260 km^2 region is 260 km^2 X 32 cm = 8.3 X 10^7 m^3. In a 5-day period of ice discharge of 26 km^2 per day from the lake, half of this amount would depart the lake, and that would leave 4.2 X 10^7 m^3 of ice the lake. The time for this amount of ice to melt is

$$\frac{4.2 \text{ X } 10^{7} \text{ m}^3}{8.5 \text{ x } 10^{6} \text{ m}^3 \text{ day}^{-1}} = 5 \text{ days.}$$

Thus, in 5 days half of the ice melts and half of the ice moves into the Niagara River.

For the next 5 days all energy input to this region of the lake will cause the water to warm. The water in the eastern basin is well mixed in the spring, so the energy will be mixed through a depth of water of at least 10 m. The temperature rise would be

$$\frac{260 \text{ cal cm}^{-2}\text{day}^{-1}}{1 \text{ cal cm}^{-3} \text{ deg}^{-1} \times 10 \text{ m}} = 0.25 \text{ deg day}^{-1} = 1/4^{\circ}\text{C day}^{-1}.$$

Then in 5 days the water temperature would rise $5 \times 1/4^{\circ} \text{ day}^{-1} = 1\text{-}1/4^{\circ}\text{C}$.

This hypothetical example is based on several simplifying assumptions, any one of which may be debated. However, it is believed that the group of assumptions yields a scientifically sound result that is consistent with observations.

APPENDIX F

GLOSSARY

This appendix defines many terms as used in this report. The definitions are generally simplified, and applicability may be limited to understanding of usage in the context of this report.

AGGRADATION--The buildup or elevation of a stream or river bed by the deposition of sediment.

AIR TEMPERATURE GRADIENT--The change of temperature over distance.

ALBEDO--The reflectivity of a surface, e.g., ice, expressed as the ratio of reflected to incoming solar radiation.

BACKWATER EFFECT--The rise in water surface elevation caused by a downstream obstruction (e.g., a bridge or ice jam) or channel roughness.

BANK TO BANK BRIDGING--See "Ice Bridge."

BENTHIC INVERTEBRATES--Small animals (without bones) that live in or on the bottom of a lake.

"CONTINENTAL" LOCATIONS--Inland locations remote from lakes or ocean influence.

DEFORMED ICE--A general term for ice that has been pushed together and forced upward and downward in places. Subdivisions are rafted ice, ridged ice, hummocked ice, and other similar deformations.

DEGREE-DAYS--The departure of the daily average air temperature from an established threshold summed over a period of days.

FREEZING DEGREE-DAYS (THAWING DEGREE-DAYS)--The threshold is 32°F (0°C). Consecutive days with average daily temperatures of 31°F, 30°F, 29°F, and 28°F would accumulate 10°F degree days.

HEATING DEGREE-DAYS--The threshold is typically 65°F (18°C).

FRAZIL ICE--Small ice crystals suspended in water.

GROUNDED ICE--Ice that has run aground.

HEAD--Approximately, the difference in water surface elevations between two points, for example above and below a waterfall.

HEAT BUDGET EQUATION--Mathematical description of heat gains and losses in a given region.

HEAT CONTENT--Amount of thermal energy stored in a material.

HIGH-HEAD--Refers to the elevation difference between the upstream energy gradient and the water level downstream from a power plant. A high-head plant generally has a drop of 100 ft (30 m) or more.

IGLD (International Great Lakes Datum)--A set of reference elevations used to measure water depths.

ICE ARCH--A crescent-shaped bridging of ice formed between shores.

ICE BOOM--A floating structure designed to stabilize an ice cover.

ICE BRIDGE--A continuous ice cover of limited size extending from shore to shore across a river like a bridge.

ICE-CONVEYANCE CAPACITY--The maximum rate of ice flow that a channel is capable of passing.

ICE DEFORMATION--Squeezing together and forcing upward and downward of ice.

ICE FLOE--Piece of ice, greater than approximately 3 ft (1 m) in extent.

ICE JAM--An accumulation of ice at a given location, which, in a river, restricts the flow of water.

LAKE BREEZE--A cool breeze blowing inland from a lake.

LATENT HEATING--The heat exchange that is associated with evaporation/condensation or freezing/thawing.

NET HEATING--The heating that results from adding all the gains and losses.

NON-POINT DISCHARGE--Liquid effluent coming from an area rather than a single, concentrated source. Storm runoff flowing over cultivated fields is a non-point discharge.

POINT DISCHARGE--Liquid effluent released from a single source such as a pipe or conduit.

PREDATION--The act of an animal killing and eating another for food.

RAFTED ICE--Type of deformed ice formed by one sheet of ice overriding another.

RAFTING--Processes whereby one piece of ice overrides another. Most common in new ice.

REFUGIA--A place of shelter or protection from danger or stress.

RIDGED ICE--Ice piled haphazardly one piece over another in the form of ridges or walls.

RIDGING--The process by which ice is forced into ridges.

RIPARIAN--Referring or pertaining to the banks or shores of a natural water body, usually a river.

"ROTTEN" ICE--Ice in an advanced stage of disintegration. Very weak ice.

RUNOFF--The water contained in a river or lake that is contributed by storm waters or snowmelt from adjacent land areas.

SCOUR--The erosive action of running water and/or ice upon the land in contact with a water body.

SENSIBLE HEATING--The heat flow that results from contact of air with water or ice that is a different temperature.

TAIL WATERS--The water flowing just below or downstream from hydropower-generating facilities.

TRASH RACK--A grid or screen across a hydraulic structure for the purpose of catching debris.

TWENTY-FIVE YEAR FLOOD--A flood having a magnitude that is equaled or exceeded once every 25 years on the average. The 25-year flood can also be defined as an event that has a 4 percent chance of being exceeded in any given year.

WATER COLUMN--The water contained in a volume with a one square unit surface area and a height equal to the depth of the water body.

WIND SET-UP--The rise in water level due to wind blowing across a water body.

APPENDIX G

BIOGRAPHICAL SKETCHES OF PANEL MEMBERS AND RESOURCE PERSONS

PANELISTS

HARRY L. HAMILTON, JR. holds a B.A. degree in physics from Beloit College and M.S. and Ph.D. degrees from the University of Wisconsin in meteorology. He is Dean of Undergraduate Studies at the State University of New York at Albany. He has extensive and diverse academic, consulting, research, and administrative experience and, until recently, had been chairman of the Department of Atmospheric Science at SUNY-Albany. His particular expertise is in micrometeorology.

GEORGE D. ASHTON received B.S. (University of Iowa), M.S. (University of Arizona), and Ph.D. (University of Iowa) degrees in civil engineering, mechanics, and hydraulics, respectively. Prior to joining the Cold Regions Research Engineering Laboratory (CRREL) of the U.S. Army Corps of Engineers in 1971, Dr. Ashton did hydraulic and ice engineering research and worked with the Bechtel Corporation as a structural engineer. He was chief of the Snow and Ice Branch at CRREL from 1975 to 1981 and is now chief of the Geophysical Sciences Branch. Dr. Ashton is active in many technical and advisory committees and has published widely in the areas of hydraulics, hydrology, and ice mechanics and control.

EUGENE J. AUBERT holds B.S. and M.S. degrees from New York University and a Ph.D. from MIT in meteorology. Dr. Aubert has held technical and management positions in the field of meteorology for 40 years; he is director of the Great Lakes Environmental Research Laboratory of the National Oceanic and Atmospheric Administration (1974 to present); he has been the U.S. director of the International Field Year for the Great Lakes (IFYGL) (1971-1981); vice president of the Travelers Research Center, Hartford, Connecticut, and director of the Atmospheric and Oceanographic Sciences Department (1960-1969). He has published numerous professional papers on atmospheric and oceanographic subjects, primarily in numerical prediction.

STEPHEN B. BRANDT received B.A., M.S., and Ph.D. degrees from the University of Wisconsin at Madison. Dr. Brandt's doctorate was in oceanography and limnology, and his research emphasized fisheries and fish ecology in Lake Michigan. Until recently, he had worked for 4 years as a senior research scientist in the Division of Fisheries Research, CSIRO, Sydney, Australia. Currently, he holds an associate professorship at the State University of New York at Oswego and at the SUNY--ESF, Syracuse. In the latter position, he is conducting research on Lake Ontario fisheries. Dr. Brandt's publications address both Great Lakes and marine questions.

ROBERT R. CHURCHILL holds B.S. and M.S. degrees from Northern Illinois University in earth science and a Ph.D. in geography from the University of Iowa. He has done diverse research and published in such areas as topoclimatology and natural hazards. He is currently a professor and chairman of the Department of Geography at Middlebury College.

BRUCE F. FINDLAY holds a M.Sc. in geography from McGill University. He has served the Canadian government for about 15 years as a micro- and physical-climatologist and is head of the Climate Assessment and Impacts section of Environment Canada.

JOHN F. KENNEDY is a member of the National Academy of Engineering and the Water Science and Technology Board and has served on numerous NRC study committees. He received engineering degrees from Notre Dame (B.S.) and Caltech (M.S. and Ph.D.). Dr. Kennedy has held various academic and research positions related to hydraulic design and is currently director of the Institute of Hydraulic Research at the University of Iowa.

DAVID MUDRY holds a B.Sc. in geology and geophysics from the University of British Columbia. He has 16 years professional experience in the field of meteorology and is currently chief of the Ice Climatology and Applications Division of Environment Canada.

H. JAY ZWALLY received a B.S. degree in engineering from Drexel University and a Ph.D. in physics from the University of Maryland. Dr. Zwally has worked in the areas of glaciology, oceanography, and ice physics; he is currently head of the Ice Section at the NASA Goddard Space Flight Center. His expertise includes remote sensing applications for ice studies.

RESOURCE PEOPLE

W.-DIETER N. BUSCH holds a B.S. from Ohio State University and has completed M.S. course work at Bowling Green State University. He has been with the U.S. Fish and Wildlife Service for 16 years in capacities such as fishery research biologist working on Lake Erie and Ontario, fish and wildlife biologist working on the Gulf of Mexico, and, for the past 4 years, the Boston Regional Great Lakes Coordinator providing guidance concerning Great Lakes habitat resource problems. He has published more than a dozen research articles concerning the Great Lakes.

DEREK M. FOULDS received his B.A.Sc. in engineering from the University of Toronto. He has much experience in managing the water resources of Ontario Hydro, particularly under adverse weather conditions of flood and drought, wind, cold, snow, and ice. He initiated the International Hydrologic Decade Project on the causes and effects of frazil, anchor, and other forms of ice. Mr. Foulds is an expert on ice problems affecting rivers and water intakes of all kinds. He also had 12 years of applied research experience on design of water controlling and conveying structures for a number of hydroelectric stations in Ontario.

RALPH R. RUMER, JR. is a professor of civil engineering at the State University of New York at Buffalo. He received degrees from Duke University (BSCE), Rutgers University (MSCE), and the Massachusetts Institute of Technology (Sc.D.) and has served on the faculties at Rutgers University, MIT, SUNY at Buffalo, and the University of Delaware. Dr. Rumer has co-authored or authored some 60 papers, reports, and book chapters on topics in hydraulics, water resources, and environmental engineering. His research has dealt with groundwater hydrology, hydraulic modeling, lake circulation and mixing, pollutant transport and water quality modeling, phosphorus dynamics in Lake Erie, and ice dynamics in Lake Erie.