Environment Canada Imaging Cover Page

Report N.: *TEC-795*

SKP Box Number: 672672428

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JAN 2 1974

ATMOSPHERIC ENVIRONMENT SERVICE
DEPARTMENT OF THE ENVIRONMENT – CANADA

Technical Memoranda

AN ASSESSMENT OF THE EFFECTS OF THE NIAGARA ICE BOOM ON ICE CONDITIONS IN EASTERN LAKE ERIE

by

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U.D.C. 551.588.5
CN ISSN 0068-7804

TEC 795
23 AUGUST 1973

ENVIRONMENT CANADA - ATMOSPHERIC ENVIRONMENT SERVICE
4905 Dufferin Street
Downsview, Ontario

AN ASSESSMENT OF THE EFFECT OF THE NIAGARA ICE BOOM ON ICE CONDITIONS IN EASTERN LAKE ERIE

by

M. S. Webb

ABSTRACT

An assessment has been made of the ways in which the Niagara Ice Boom could affect the ice regime of Lake Erie. Although a definitive evaluation was not possible due to a shortage of pertinent data, it would appear that the most significant effect as far as navigation is concerned occurs during the spring break-up. It was estimated that ice retained on Lake Erie by the presence of the boom could extend the ice season by about a day.

UNE ESTIMATION DE L'EFFET DU BARRAGE DE GLACE DE NIAGARA SUR LES CONDITIONS DES GLACES À L'EST DU LAC ÉRIÉ

par

M. S. Webb

RÉSUMÉ

L'on a fact une estimation des façons par lesquelles le barrage de glace de Niagara pourrait affecter le régime glacier du Lac Erié. Bien qu'une évaluation définitive a été impossible vu le manque de données pertinentes, il semblerait que l'effet le plus significatif quant à la navigation se produirait lors de la fonte du printemps. L'on a apprécié que la glace retenue dans le Lac Erié à cause du barrage pouvait allonger d'environ un jour la période de glaces.

AN ASSESSMENT OF THE EFFECT OF THE NIAGARA ICE BOOM ON ICE CONDITIONS IN EASTERN LAKE ERIE

by

M. S. Webb

(Manuscript received August 21, 1973)

1. Introduction

The formation of ice on a lake adversely affects winter shipping and hydro-electric power production in many parts of the world. Nowhere is this fact more apparent than in Lake Erie and the Niagara River. The extensive ice cover which develops on this relatively shallow lake each year prevents winter navigation and frequently interferes with its resumption in the spring. Movement of this ice into the Niagara River can lead to a temporary but serious reduction in hydro-electric power production.

In an attempt to reduce losses, a floating ice-boom has been placed across the entrance to the Niagara River each winter since 1964-65 to restrict the entry of floes of lake ice. For this purpose, the Niagara Ice Boom has proved to be very successful, much to the delight of hydro-electric interests and property owners along the river. On the other hand, shipping interests are of the opinion that the presence of the Boom has increased the quantity of ice on Lake Erie and in particular, has delayed the resumption of navigation in the spring.

Since ice conditions are largely dependent upon recent weather, the St. Lawrence Seaway Authority has requested the Atmospheric Environment Service (A.E.S.) to investigate the possible effects of the Niagara Ice Boom on the ice regime of eastern Lake Erie.

In response to this request, the Lakes and Marine Applications Section of the A.E.S. has undertaken this study. The report which follows presents relevant background information and examines some characteristics of Lake Erie's ice regime. The ways in which the Niagara Ice Boom might affect the ice cover are discussed and a somewhat quantitative assessment is made.

2. Lake Erie's Ice Regime

(i) Characteristics

The Atmospheric Environment Service has made aerial surveys of ice conditions in Lake Erie each winter since 1959-60.

To demonstrate the seasonal changes in coverage, the percentage ice cover from each survey map was estimated and plotted against survey date for eleven winters (Figure 1). Some of the characteristics of Lake Erie's ice regime revealed by this diagram are:

(a) it is remarkably uniform,

(b) freeze-up starts in late December and proceeds rapidly,

(c) usually 90% or more of the lake's area will become ice covered, and

(d) the spring break-up is underway by early March.

Break-up is not as rapid nor as continuous as freeze-up. However by early April, perhaps a quarter of Lake Erie's total area will remain ice covered. Most of this ice will be found in the eastern end of the lake. Further melting occurs at a slower pace and may not be completed until early May. These characteristics are largely climate controlled.

(ii) Climatic Controls

Air Temperature

The formation of an ice cover on a large lake is controlled by the exchange of heat with the atmosphere and by the quantity of heat stored within the water body. While the relationship is complex, a relatively simple method of relating ice conditions to ambient air temperatures is often used.

As the temperature of a lake's surface cools to near 32°F., the rate of heat loss is roughly proportional to the air temperature depression below this value. The term for this temperature depression is the freezing degree-day. (One freezing degree-day is defined as the depression of the mean air temperature by one degree F. below 32°F. for one day.) By determining the number of freezing degree days gained each day and accumulating them, a measure of the severity of the winter can be obtained. The accumulated total at any time can be usefully compared to the existing ice cover. A similar calculation of thawing degree-days can be used to estimate a lake's heat gain acquired during summer heating.

Application of this technique for relating freeze-up and break-up to air temperature should provide the best results for sheltered lakes where atmospheric heat exchange is dominant and the effects of wind and current are minor. Nevertheless this book-keeping approach has been successfully applied to the Great Lakes by Richards (1964).

Table 1 gives the monthly and seasonal totals of accumulated freezing degree-days for the years 1959 through 1970 inclusive as observed at Erie, Pennsylvania on the south shore of the lake. Since the prevailing winds are off-lake all year, its temperature regime should be indicative of over-lake conditions. Thawing degree-day totals for each summer are also included. On the basis of the climatological data contained in this table, it would appear that for Lake Erie:

(a) Freezing degree-days are accumulated between December and March. The average annual total is 698 but the range is large (483 to 1080).

(b) Maximum accumulations occur in January and February but again year-to-year variation can be large.

(c) Summer temperatures provide an average of 6680 thawing degree-days, however year-to-year variation is small, 6184 to 7108.

The most important point demonstrated by these data is that almost all of the lake will become ice-covered regardless of the severity of the winter.

(iii) Wind Control

Over-lake winds can have an important control on the amount and on the distribution of ice during the freeze-up and break-up periods. The prevailing winds as revealed by observations taken at Buffalo, N.Y. (Table 2) are from the west to southwest throughout the ice season. Hence any ice which is free to move will be carried eastwards over a period of time.

These winds are important for other reasons. During freeze-up, the new ice is easily broken by wind/wave action. Rafting and hummocking may result as the floes are driven against land or fast ice. On occasion the ice arch which bridges the mouth of the Niagara River may be broken, permitting small ice floes to enter the river. The net result of these actions will be a small reduction in the total ice cover at that stage of winter freeze-up.

During the spring break-up, solar heating can weaken the ice cover so that strong winds can readily break up the rotting cover into small floes, overturning some of them in the process. This mechanical action combined with the effect of wind stress upon the lake surface causes vertical mixing to take place within the lake. Relatively warm water is brought to the surface where it hastens the melting of the remaining ice.

In summary, it is apparent that significant year-to-year variations in Lake Erie's ice cover are largely confined to the periods of freeze-up and break-up. At these times, wind action can have an important influence on the amount and the distribution of lake ice.

3. The Niagara Ice Boom

(i) The Problem

The Hydro-electric power installations on the Niagara River belonging to the Power Authority of the State of New York and the Ontario Hydro-Electric Power Commission constitute one of the largest developments of its kind in the world. Ice is a constant threat to their operation each winter.

There are two sources of ice for this river; frazil and anchor ice which form in the upper reaches of the Niagara River and floes of lake ice which enter the river from Lake Erie (Cork and Chapil, 1966). All this ice must be carried downstream by the river without reducing the flow rate. Because of the importance of maintaining an uninterrupted flow and for the general development of the Niagara River, ice-breakers are used to assist the river in its ice transporting chore (Foulds, 1967a).

According to the requirements of the Niagara Diversion Treaty of 1950, a minimum flow of 50,000 cfs over the Niagara Falls must be maintained during the period from November 1 to March 31. This minimum flow, which is about 30% of the average winter flow, must be increased whenever additional water is required to flush ice above the Falls or through the rapids below the Falls. These occasions are usually the result of floes of lake ice entering the river from Lake Erie.

The edge of Lake Erie's ice cover which forms near the mouth of the Niagara River develops a characteristic arch-shape. This ice arch is very vulnerable to breakage through wind and wave action. When breakage occurs, the small floes are carried into the river. Under critical conditions, the supply of ice can exceed the carrying capacity of the river and jamming may result. A spectacular example occurred in 1938 and resulted in the destruction of the Honeymoon Bridge.

Heavy ice runs are most frequent during the initial development of the arch and later during the spring break-up. These runs are associated with strong southwest winds which serve to:

(a) break the ice cover into pieces which are small enough to enter the river without blocking the entrance,

(b) raise the level of the lake and consequently increase the discharge of water into the Niagara River, and to

(c) drive these small floes into the mouth of the river.

The quantity of ice driven into the river may exceed the carrying capacity of the river. To reduce the chances of an ice jam forming, the amount of upstream water which is usually diverted from the river for power purposes can be reduced. An alternate solution lies in decreasing the size of these ice runs. Hydro interests report that considerable success in this respect has been achieved through use of the "Niagara Ice Boom".

(ii) The Solution

Each winter since 1964-65, the United States and Canadian governments, acting through the International Joint Commission, have granted permission to the Canadian and U.S. power utilities to place a boom across the entrance to the Niagara River (Foulds, 1967a). This boom floats on the surface of the lake in the position usually occupied by the ice arch. As the arch develops, erosion of the edge is reduced and loose pieces of ice are retained on the lake by the presence of the boom. Hence the arch is stabilized. However, when large quantities of ice are thrust towards it by strong southwest winds, the boom will be over-run and ice will enter the river. Later when the wind speed decreases or the direction changes, the pressure of the ice towards the river entrance will weaken. As a result, the natural buoyancy of the boom will cause it to resurface, thus cutting off the stream of loose ice which otherwise would enter the Niagara River. The location of the Niagara Ice Boom is shown in Figure 2.

The boom is constructed of 30 ft. long logs spaced 6 ft. apart, each chained to a submerged cable itself anchored at 23 points along its length (Bryce and Berry, 1967). The entire boom is about

2 miles long and is placed in the location usually taken by the leading edge of Lake Erie's ice cover. Here, the surface water is moving at about 1.5 fps and good convergence of the flow is provided by the Buffalo Harbour breakwaters and Ontario shoreline. The boom does not extend within these breakwaters, leaving the harbour open to the Niagara River.

Hydrointerests have noted the success of the boom in reducing the movement of ice into the Niagara River. In fact after just two years of operation, Foulds (1967b) of the Ontario Hydro-Electric Power Commission wrote that; "the boom has reduced the number of days in which ice used to flow out of Lake Erie to the corresponding number of hours". For this reason, the boom has continued in use. It is installed each winter prior to freeze-up, and opened by the first of May. (Prior to 1969, it had to be opened by the first Monday in April).

As a consequence of the presence of the boom, ice will be retained on Lake Erie which otherwise would have entered the Niagara River. The St. Lawrence Seaway Authority is of the opinion that the amount of ice so retained is significant enough to adversely affect navigation. In a brief presented to the International Joint Commission in July of 1969, the S.L.S.A. made the following statement regarding the Niagara Ice Boom.

> "The Spring date for removal of the ice boom does affect Welland Canal operations, particularly as regards to navigational access at Port Colborne, the Lake Erie entrance to the canal. We believe the existence of the ice boom generally contributes to ice build up in the area and an extended retention of ice cover and conversely, that its removal hastens ice break-up and dispersion down the river".

The task of identifying the effect of the Niagara Ice Boom on Lake Erie's ice regime and of estimating its magnitude is very difficult. Remember that the purpose of the boom is to reduce erosion of the ice arch which forms near the entrance to the Niagara River and thus to accelerate the formation of a permanent ice cover on the lake. It is not intended nor designed to withstand the pressure from lake ice which might be thrust towards it by strong winds.

A potentially useful method of evaluating the boom would have been to compare navigational records for the years before and after introduction of the boom in order to see if difficulties due to ice conditions had increased. These difficulties could then have been evaluated in terms of meteorological conditions and conclusions might have followed regarding the influence of the Niagara Ice Boom on Lake Erie's ice cover.

Unfortunately, the necessary navigational records have not been maintained. Therefore a definitive assessment of the boom's effect on Lake Erie's ice regime cannot be made. This fact also precludes an exhaustive evaluation of the boom/nagivation question. As a result the remainder of this report has been limited to a discussion of the ways in which the boom might influence Lake Erie's ice cover. A quantitative estimate of the boom's influence is included.

4. The Effect of Niagara Ice Boom on Lake Erie's Ice Regime

(i) General

There are two ways in which the Niagara ice boom might affect the ice cover on Lake Erie. It could interfere with the free movement of ice about the lake and over a period of time, it could influence the amount of ice on the lake, particularly near the entrance to the Niagara River. These possibilities are discussed below:

(ii) Effect on Ice Movement

Movement of a lake's ice cover is the result of winds and currents. Since lake currents are characteristically very slow, day-to-day changes in the distribution of the ice are almost exclusively the work of wind. During freeze-up, movement often results in rafting and hummocking. The leads which develop usually refreeze so that the end effect on the total ice area is negligible. Later during break-up when the ice is disappearing, large pieces may become detached and move more freely with the wind. By spring most of the remaining ice will be found at the eastern end of the lake.

Now consider the effect of wind upon the movement of this ice and consequently the interference which the boom might offer. If the winds are from the north or east, the ice will be pushed away from the Niagara Ice Boom towards the centre of the lake. Clearly, the boom has no control. (Incidentally, these winds favour the rapid melting of the ice during the spring break-up by bringing warm sub-surface water to the lake surface. They also tend to position the ice in mid-lake where it can readily interfere with ships using the Welland Canal).

When the winds are from the south, the ice will move north towards the Ontario shoreline and the harbour at Port Colborne may become plugged with ice. On the other hand, westerly winds will force the ice towards the eastern end of the lake. Some ice may even be driven over the breakwaters at Buffalo and become trapped in the harbour. It appears therefore, that movement of the ice by either south or west winds will be restrained, not by the boom, but by the shoreline. Nevertheless, if the edge of the ice field were close to the river entrance, some would likely break free and enter. This amount would probably be small enough to be easily carried by the river.

It is only when the winds are southwesterly that the ice cover will be directed at the Niagara River entrance. If the wind is sufficiently strong, the ice will be broken into small pieces and a massive discharge into the river can result. Light winds would only serve to plug the entrance with large floes. In the latter case, little ice will be able to enter the river.

In summary, the Niagara Ice Boom directly opposes the movement of lake ice only when the wind is from a generally southwest direction. If these winds are strong enough, large quantities of ice can be driven over the boom and into the river.

(iii) Effects of Boom on the Area of Ice on Lake Erie

(a) Effect of Boom During Freeze-up and Break-up

In an earlier section is was noted that over an 11-year period, ice encompassed 90% or more of the area of Lake Erie regardless of the severity of the winter. Complete coverage is probably rare since there will usually be some movement of the ice pack in response to winds and the open areas could be expected to refreeze. Consequently the effect of the boom upon the maximum ice area must be minimal.

However during freeze-up the discharge of ice into the Niagara River represents only a temporary delay in the development of the lake's maximum ice cover. However during break-up, retention of ice on the lake by the action of the boom might noticeably delay the eventual clearing. To assess the length of this delay it is necessary to know the quantity of lake ice which could be discharged into the Niagara River.

(b) Ability of Niagara River to Transport Lake Ice

The loss of ice from Lake Erie to the Niagara River is limited by the ability of the river to transport the supply without restricting the flow. Estimating the quantity which does enter the Niagara River is very difficult and is one reason why records have not been kept. However, an estimate of the peak daily discharge rate was included by the power interests in their 1969 submission to the International Joint Commission. Their report reads as follows:

> "The power entities believe that from considerations of river velocity and surface area, and assuming no impedance from the ice boom, 40 square miles of ice is the maximum amount that can pass out of Lake Erie in any 24-hour period. If such a run occurred, there would probably be major ice jams in the Maid of the Mist Pool and in the lower river between Lake Ontario and the high head plants.
>
> It is also believed that the river can accept up to 20 square miles of lake ice in a single 24-hour period without severe ice problems. Similar runs on successive days would, however, cause serious difficulties."

Since these figures are based upon experience and would appear reasonable considering the 24-square-mile area of the Niagara River, they provide a basis for estimating the maximum discharge of lake ice into the river.

(c) Effect of Boom on Rate of Clearing During Spring Break-up

A reduction in the area of Lake Erie's ice cover during the spring break-up can occur in two ways; viz, either the ice melts on the lake or it leaves via the Niagara River. Together these processes must account for the disappearance of over 9,000 square miles of lake ice during a period of about 70 days. In the extreme case therefore, either all of this ice melts on the lake or all of it discharges into the Niagara River. For the latter to happen, discharge would have to average about 145 square miles per day. However, a heavy run of ice could only account for perhaps 40 square miles in a day, while the daily average would be considerably less. Therefore it is apparent that the bulk of Lake Erie's ice cover must melt on the lake.

(d) Quantitative Assessment of Effect of the Boom

Since most of the winter's ice cover must remain on the lake to be melted, it is possible to make a quantitative assessment of the boom's control.

It was noted in an earlier section that Lake Erie's ice cover disappears from west to east. Also as much as 80% may be lost over perhaps a 40-day period. During this period, the ice cover at the east end of the lake will remain largely intact, thus limiting the loss to the Niagara River. Hence, the total loss through discharge at this time would be negligible in comparison to the melt loss.

In contrast, disappearance of the final 20% or so will be at a noticeably slower pace because of the relatively slow warming of the deep water in eastern Lake Erie. Furthermore, this ice is often very thick due to rafting and ridging earlier in the winter.

To estimate the magnitude of the boom's control during this final stage, suppose that the ice cover had been reduced in area to 2000 square miles. Now by assuming various mean daily discharge rates into the Niagara River, it is possible to calculate the total amount of ice which could be lost over various periods of time (Table 3).

TABLE 3

Area of Ice Entering Niagara River
Mean Exit Rate in Square Miles Per Day

		30	20	10	5	2.5	1
Number of Days to	40	1200	800	400	200	100	40
Zero Ice Cover	30	900	600	300	150	75	30
	20	600	400	200	100	50	20
	10	300	200	100	50	25	10

As an example, Table 3 reveals that the loss of 10 square miles of ice each day for 30 days would result eventually in a total loss of 300 square miles, leaving 1700 to melt on the lake. Now consider the consequences, assuming a constant daily rate of melt and discharge.

This example indicates that with the boom in position and 100% effective, 2000 square miles of ice melt on the lake. Without the boom however, 300 square miles would be lost to the Niagara River leaving 1700 to melt. These areas accumulated over the 30 day period are illustrated in Figure 3.

The proportion of open water versus ice on each day during the 30 day period is shown in Figure 4. This diagram reveals the day-to-day effect of Niagara Ice Boom upon Lake Erie's dwindling ice cover. With the boom in position, the ice/water division follows the heavy line whereas without the boom, ice would be discharged into the Niagara River and the division would fall along the light line. The area between these lines represents the quantity of ice which has entered the river. In this particular example, the presence of the boom would have delayed the final clearing of the lake by about four days.

How realistic is this assessment of the Niagara Ice Boom? The most questionable assumption made concerns the uniform discharge and melt rates. At this time of year, melting can be a nearly continuous process although the rate will vary depending upon weather conditions. In general, the fraction of ice melting on any day would be almost independent of the amount present and consequently of the presence of the boom.

In regards the discharge rate, movement of ice into the Niagara River can only occur (even without the boom) when the wind direction is favourable. Even then, a large discharge into the river is only possible when the winds are strong. Under these conditions, much of the ice would be forced into the river despite the presence of the boom. If the winds are light, yet favourable in direction, the large ice floes will jam into the river entrance and prevent entry into the river. Under these latter conditions, the boom could be expected to reduce erosion from the edge of the ice cover.

It is clear that any significant entry of ice into the Niagara River is dependent upon favourable wind conditions. Now consider the winds observed at Buffalo, New York between 1951 and 1960 (Table 2). These records should be indicative on the average of conditions near the Niagara River entrance. During March and April when the ice area is rapidly disappearing, 37% of the hourly winds were from the direction WSW through SWW. However only 12% exceeded 18 m.p.h. while less than 2% were over 30 m.p.h. If those percentages are applied to the 30-day period along with "maximum" discharge rates, a "maximum discharge" into the river can be calculated (Table 4).

TABLE 4

Potential Ice Discharge into Niagara River

Wind (mph) Speed	Frequency	No. of Days out of 30	Discharge Rate (sq. miles a day)	Total Ice Discharged
$0 < \text{Wind} \leq 18$	25%	8	1	8
$19 \leq \text{Wind} \leq 31$	10%	3	5	15
$\text{Wind} > 31$	2%	1	40	40
				63 sq. miles

The amount of ice lost comes to 63 square miles for an average of about two square miles of ice per day. This rate is only a fifth of that used earlier in the example. Therefore it would appear that on the average, the quantity of ice entering the Niagara River is almost negligible relative to that lost on Lake Erie through melting. As the total of 63 square miles is about equal to the average daily melt rate, over the last 30 days the effect of the boom in extending the ice season comes to about a day. When you further consider that this quantity would also be subject to melting and that some of it might have been driven into the river despite the presence of the boom, it is clear that any extension to the ice season is best measured in hours, not in days.

5. Summary

At the request of the St. Lawrence Seaway Authority, an investigation has been made into the influence of the Niagara Ice Boom on ice conditions in Lake Erie. Unfortunately the lack of pertinent shipping records both before and after introduction of the boom for the 1964-65 winter has precluded an evaluation of the effects of the boom on navigation. For this reason, discussion has been restricted to the ways in which the boom might affect Lake Erie's ice cover.

The present study indicates that the net effect of the Niagara Ice boom on Lake Erie's ice cover is almost nil. The only time when the effect could prove significant occurs during the spring break-up. It was estimated that ice retained on Lake Erie by the presence of the boom might extend the ice season by a day or so, at the most. If this assessment was grossly in error, then the introduction of the boom would have had a noticeable effect on the climate of the Buffalo area and on local lake temperatures. A study by Hassan and Sweeney (1972) based on fourteen years of data showed no statistically significant changes in either.

APPROVED,

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TABLE 1

Climatological Data for Erie, Penna 1959-70

Season	Antecedent Heating		Start	0	N	D	J	F	M	A	End	Total
				Monthly Totals of Freezing Degree-Days								
1969-70	6184	With Boom	Nov 29	0	2	193	476	274	135	0	Mar 16	1080
1968-69	6775	With Boom	Dec 6	0	0	131	241	187	85	0	Mar 16	644
1967-68	6316	With Boom	Dec 23	0	0	74	293	340	83	0	Mar 14	790
1966-67	6844	With Boom	Dec 19	0	0	51	105	246	88	0	Mar 19	490
1965-66	6470	With Boom	Jan 8	0	0	0	313	202	0	0	Feb 28	515
1964-65	6721	With Boom	Nov 30	0	7	96	247	226	105	11	Apr 4	692
1963-64	6681	No Boom	Dec 1	0	0	217	165	217	0	0	Feb 29	599
1962-63	6734	No Boom	Dec 8	0	0	227	386	405	20	0	Mar 2	1038
1961-62	6859	No Boom	Dec 13	0	0	129	277	239	84	0	Mar 7	729
1960-61	6793	No Boom	Dec 8	0	0	249	318	161	0	0	Feb 16	728
1959-60	7108	No Boom	Dec 19	0	0	58	99	142	283	0	Mar 24	483
Mean	6680			0	1	121	265	240	80	1		698

TABLE 2

SUMMARY OF HOURLY WIND OBSERVATIONS FOR BUFFALO, N.Y., 1951–60

OCTOBER
7440 Obs.

PERCENTAGE FREQUENCIES
OF WIND DIRECTION AND SPEED:

DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED (IN MILES PER HOUR)										AV. SPEED
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 OVER	TOTAL	
N	+	1	2	1	+	+				5	9.8
NNE	+	1	1	1	+	+				3	9.7
NE	1	1	2	1	+	+				6	9.8
ENE	+	1	2	1	+	+				4	10.1
E	+	1	2	+						3	7.9
ESE	+	1	2	+						3	7.9
SE	1	2	4	1	+					7	8.8
SSE	+	2	4	1	+					8	9.5
S	1	3	5	3	1	+				13	10.5
SSW	+	1	3	3	1	+	+	+	+	9	13.6
SW	+	1	3	3	2	1	+	+		11	15.4
WSW	+	1	2	2	2	1		+		8	14.6
W	+	1	2	1	1	+				5	13.3
WNW	+	1	2	2	1	+	+			6	11.8
NW	+	1	2	2	+	+	+			5	11.9
NNW	+	1	2	1	+	+				4	11.0
CALM	+									+	
TOTAL	5	20	39	23	10	3	+	+	+	100	11.5

NOVEMBER
7200 Obs.

PERCENTAGE FREQUENCIES
OF WIND DIRECTION AND SPEED:

DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED (IN MILES PER HOUR)										AV. SPEED
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 OVER	TOTAL	
N	+	1	1	+	+					2	9.6
NNE	+	1	1	1	+	+	+			2	10.5
NE	+	1	1	1	+	+	+			4	10.0
ENE	+	1	1	1	+	+				3	10.9
E	+	1	1	+	+					2	8.5
ESE	+	1	1	+						2	7.9
SE	+	2	4	1	+	+				7	9.4
SSE	+	1	3	2	+	+	+			7	11.4
S	1	2	5	4	2	+	+			14	12.9
SSW	+	1	2	4	2	1	+	+		10	15.3
SW	+	1	2	2	2	1	+	+	+	9	17.0
WSW	+	1	3	4	4	1	+	+	+	13	17.2
W	+	1	3	4	2	+	+			10	14.8
WNW	+	1	2	2	1	+				7	13.0
NW	+	1	2	1	+	+	+			4	11.2
NNW	+	1	1	1	+	+				3	10.6
CALM	+									+	
TOTAL	4	15	32	27	15	4	1	+	+	100	13.3

DECEMBER
7440 Obs.

PERCENTAGE FREQUENCIES
OF WIND DIRECTION AND SPEED:

DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED (IN MILES PER HOUR)										AV. SPEED
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 OVER	TOTAL	
N	+	1	1	1	+	+				2	9.8
NNE	+	1	1	1	+	+				2	9.9
NE	+	1	2	1	+					6	10.7
ENE	+	1	2	1	+	+				4	11.0
E	+	1	1	+						2	7.8
ESE	+	1	1	+	+					2	7.3
SE	+	2	2	1	+					5	8.8
SSE	+	1	2	1	1	+	+			6	11.2
S	+	2	3	3	2	+	+			11	11.6
SSW	+	1	3	4	3	1	+	+		12	14.8
SW	+	1	1	3	3	1	1	+	+	9	18.6
WSW	+	1	2	4	4	1	+			13	17.3
W	+	1	2	4	3	1	+			10	16.0
WNW	+	+	2	3	1	+	+			7	14.5
NW	+	1	2	2	+	+				4	12.6
NNW	+	+	1	1	+		+			3	11.0
CALM	+									+	
TOTAL	4	15	28	29	17	5	1	+	+	100	13.5

JANUARY
7440 Obs.

PERCENTAGE FREQUENCIES
OF WIND DIRECTION AND SPEED:

DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED (IN MILES PER HOUR)										AV. SPEED
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 OVER	TOTAL	
N	+	1	2	1	+	+	+			4	11.4
NNE	+	1	2	1	+	+				4	10.5
NE	+	1	3	2	+	+				6	11.7
ENE	+	1	2	1	+					4	11.4
E	+	1	1	+	+					3	9.0
ESE	+	1	1	+						2	8.6
SE	+	1	2	1	+	+				4	8.9
SSE	+	1	2	1	+	+				4	11.0
S	1	2	2	3	2	1	+			10	13.3
SSW	+	1	1	3	2	1	+			8	14.4
SW	+	1	1	3	2	1	+	+		8	15.5
WSW	+	1	3	4	4	1	+	+	+	14	17.3
W	+	1	3	5	3	+	+	+		12	15.3
WNW	+	1	2	3	1	+	+			7	14.6
NW	+	1	2	2	1	+				6	13.1
NNW	+	1	1	1	+	+				4	12.0
CALM	+									+	
TOTAL	4	13	30	30	17	5	1	+	+	100	13.5

TABLE 2 (Cont'd)

FEBRUARY
6792 Obs.

PERCENTAGE FREQUENCIES OF WIND DIRECTION AND SPEED:

DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED (IN MILES PER HOUR)										AV. SPEED
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 OVER	TOTAL	
N	+	1	1	1	+					4	12.0
NNE	+	+	1	1	+					3	11.4
NE	+	1	2	2	+	+	+			5	11.9
ENE	+	1	2	2	1	+				4	12.9
E	+	1	1	+	+	+				3	9.5
ESE	+	1	1	+	+					2	9.2
SE	+	1	3	1	+	+				6	9.8
SSE	+	1	2	1	1	+	+	+		5	13.1
S	+	1	3	2	1	+	+			8	12.1
SSW	+	1	2	2	2	+	+			8	14.0
SW	+	1	3	4	3	2	+	+		14	17.4
WSW	+	1	2	4	3	1	+	+		12	16.9
W	+	+	2	4	3	1	+			11	15.0
WNW	+	1	2	3	2	+	+			8	15.0
NW	+	+	2	2	1	+				5	12.9
NNW	+	+	1	1	+	+				3	12.7
CALM	+									+	
TOTAL	3	12	30	32	17	5	1	+		100	13.9

MARCH
7440 Obs.

PERCENTAGE FREQUENCIES OF WIND DIRECTION AND SPEED:

DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED (IN MILES PER HOUR)										AV. SPEED
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 OVER	TOTAL	
N	+	1	1	1	+	+				3	10.5
NNE	+	1	1	1	+	+				3	10.7
NE	+	1	3	3	1	+				9	12.7
ENE	+	1	2	2	1	+				6	13.5
E	+	1	2	1	+					3	10.6
ESE	+	1	1	+	+					2	9.2
SE	+	1	2	1	+	+	+	+		4	10.8
SSE	+	1	2	1	1	+	+	+		5	12.8
S	+	2	2	1	1	+	+	+		6	11.5
SSW	+	1	2	2	1	1	+	+		7	14.8
SW	+	1	3	4	4	2	1	+	+	17	18.0
WSW	+	1	2	3	3	1	1	+		11	17.9
W	+	+	2	2	1	+	+	+		7	15.5
WNW	+	1	2	2	1	+	+			7	14.2
NW	+	1	2	2	1	+				7	12.2
NNW	+	+	1	1	+	+				3	11.8
CALM	1									1	
TOTAL	4	13	30	28	16	6	2	1	+	100	14.1

APRIL
7200 Obs.

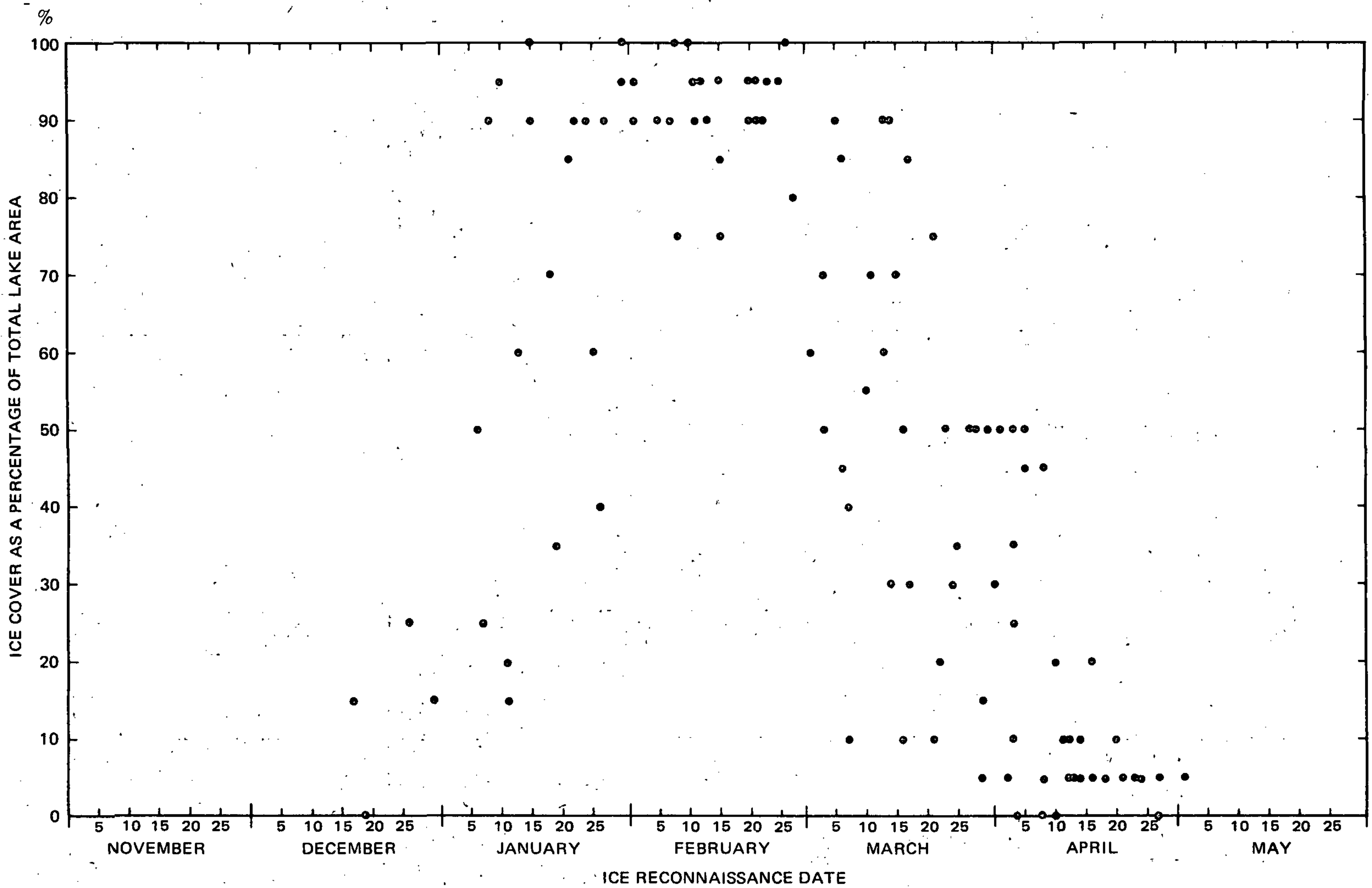
PERCENTAGE FREQUENCIES OF WIND DIRECTION AND SPEED:

DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED (IN MILES PER HOUR)										AV. SPEED
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 OVER	TOTAL	
N	1	1	1	1	+	+				4	10.3
NNE	+	1	1	2	+	+				4	12.1
NE	1	1	3	2	1	+				7	11.3
ENE	+	1	2	2	1	+				7	12.4
E	+	1	2	1	+	+				4	9.6
ESE	+	1	1	+	+					2	9.4
SE	+	1	2	1	+	+				4	9.7
SSE	+	1	2	1	+	+				5	11.5
S	1	2	2	2	1	+				7	11.6
SSW	+	2	3	3	2	+	+	+		10	13.4
SW	+	2	4	5	5	3	1	+		21	17.3
WSW	+	1	3	3	2	1	+			10	15.2
W	+	1	1	1	1	+	+			4	13.1
WNW	+	1	1	1	1	+			+	5	13.1
NW	+	+	1	1	+	+				3	12.4
NNW	+	1	1	1	+	+				3	9.9
CALM	+									+	
TOTAL	6	16	29	28	15	5	1	+	+	100	13.2

MAY
7440 Obs.

PERCENTAGE FREQUENCIES OF WIND DIRECTION AND SPEED:

DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED (IN MILES PER HOUR)										AV. SPEED
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 OVER	TOTAL	
N	+	1	2	1	+					4	10.6
NNE	+	1	1	1	+					4	10.5
NE	+	1	3	2	1					7	11.1
ENE	+	1	2	1	1	+				5	11.5
E	+	1	1	1	+					3	9.6
ESE	+	1	1	+	+					2	8.7
SE	+	1	2	1	+					5	8.9
SSE	+	1	2	1	+	+				5	9.3
S	1	3	5	2	1	+				10	10.1
SSW	+	2	5	3	1	+				11	12.0
SW	+	2	5	6	5	1	+	+		19	15.0
WSW	+	1	3	3	1	1	+			9	13.9
W	+	1	1	1	+	+				3	11.0
WNW	+	+	1	1	1	+	+			4	13.0
NW	+	1	2	1	+	+	+			4	11.7
NNW	+	+	1	1	+					3	12.4
CALM	+									+	
TOTAL	5	18	36	27	11	2	+	+		100	11.9



PERCENT ICE COVER ON LAKE ERIE BY DATE FOR WINTERS 1959–60 THROUGH 1969–70

Figure 1.

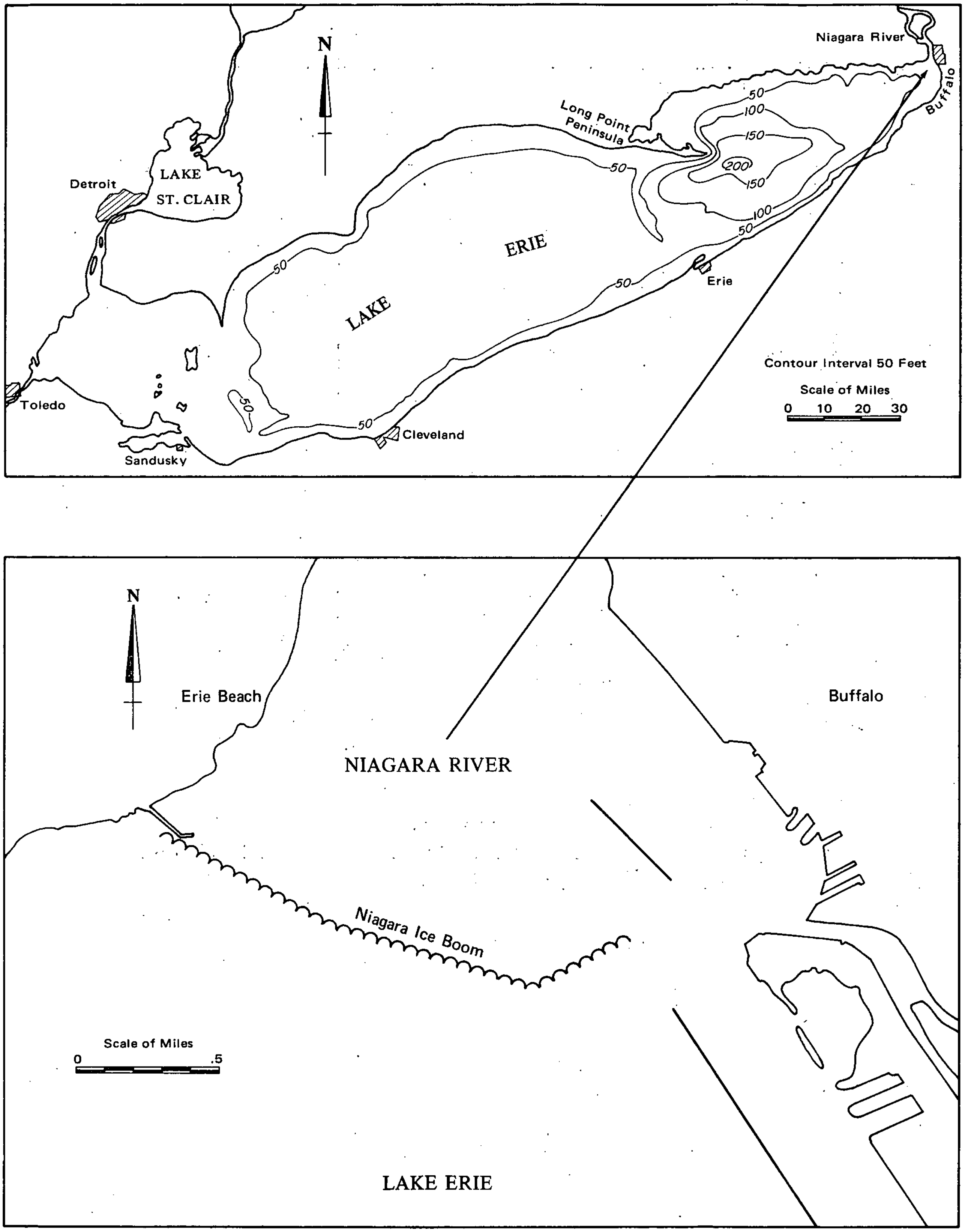


Figure 2.
Lake Erie
Water Depth and Location of Niagara Ice Boom

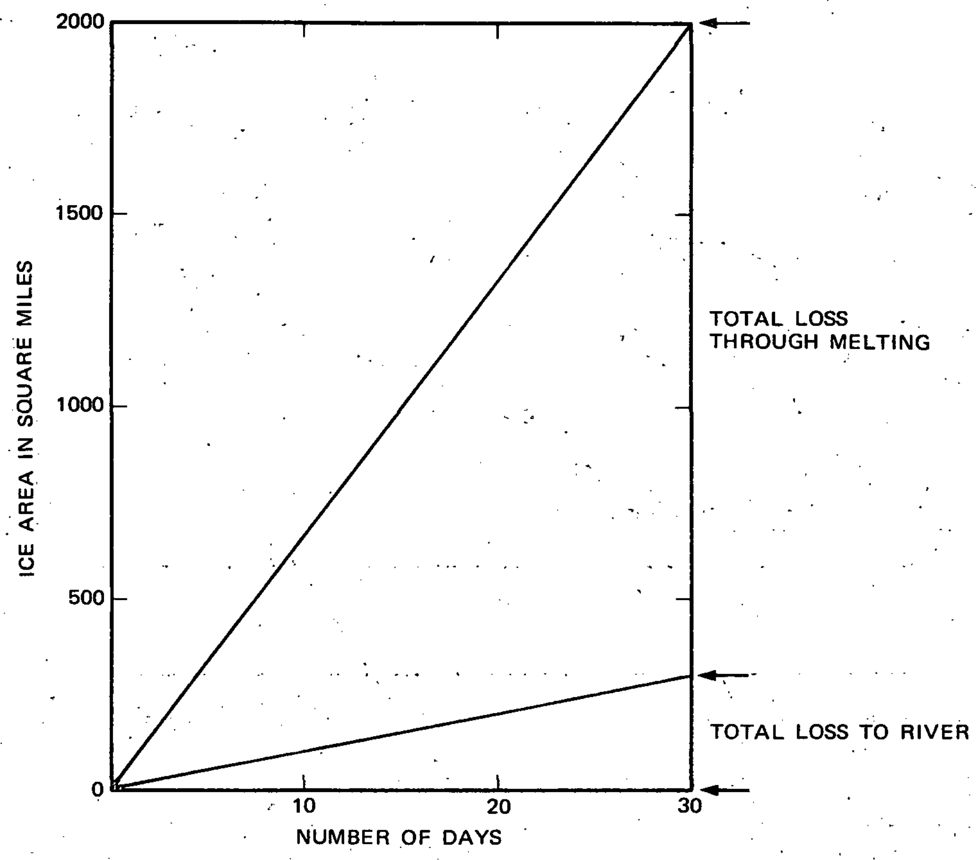


Figure 3.
Accumulated Losses of Ice From Lake Erie by Cause

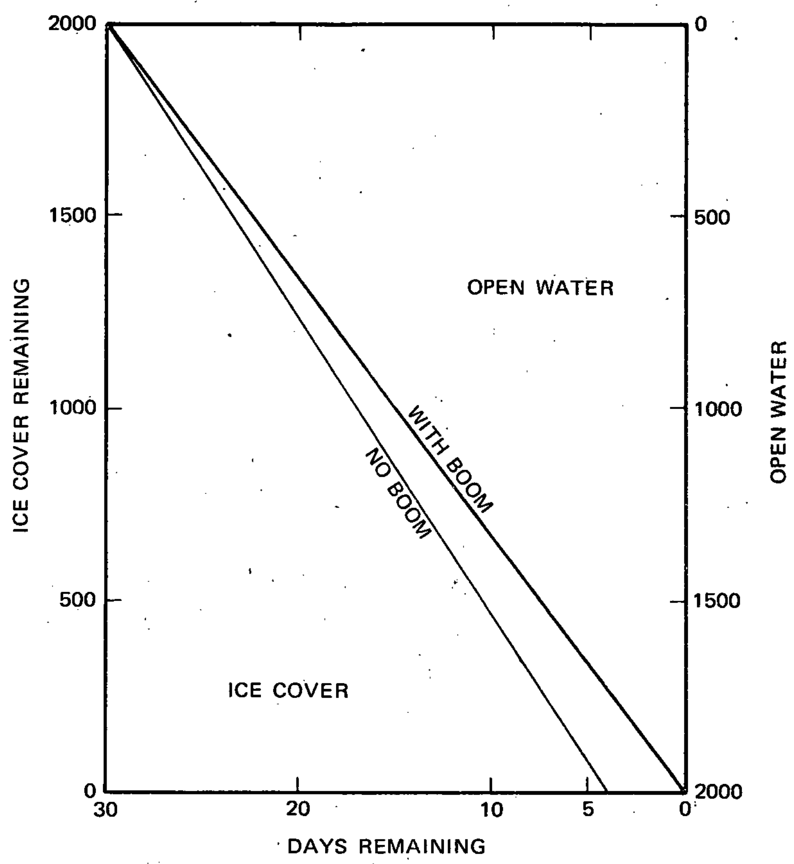


Figure 4
Proportion of Ice and Open Water Over 2000 Square Mile Area of Eastern Lake Erie During Melt Period

TEC-795 UDC: 551.588.5
23 August 1973

CANADA
Environment - Atmospheric Environment Service
4905 Dufferin Street, Downsview, Ontario

An Assessment of the Effect of the Niagara Ice Boom on Ice Conditions in Eastern Lake Erie
by M.S. Webb

14 pps. 4 figs. 6 refs. 4 tbls.

Subject Reference 1. Ice Boom
2. Niagara River

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2. Niagara River

ABSTRACT: An assessment has been made of the ways in which the Niagara Ice Boom could affect the ice regime of Lake Erie. Although a definitive evaluation was not possible due to a shortage of pertinent data, it would appear that the most significant effect as far as navigation is concerned occurs during the spring break-up. It was estimated that ice retained on Lake Erie by the presence of the boom could extend the ice season by about a day.

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