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OPERATIONAL ICE FORECAST FOR THE LITTLE RAPIDS CUT

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OPERATIONAL ICE FORECAST FOR THE LITTLE RAPIDS CUT

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An operational 5-day forecast procedure was developed for predicting the initial date of ice-related problems at the Little Rapids Cut and the continuing degree of difficulty the Sugar Island ferry would experience in crossing the St. Marys River at that point. The forecast procedures were developed by use of meteorological and hydrological data, aerial photographs of ice cover, and time lapse films of the motion of jammed ice toward the Sugar Island ferry crossing.

Intense warm and cold spells have many ramifications. For example, it was found that ice problems had generally begun within 10 days after the water temperature in the river had reached 32°F. Once ice problems began, the degree of difficulty in crossing the river, expressed in three probability categories, was forecast daily, based upon air temperatures, upstream ice cover, and shipping activity. Results of the operational-experimental forecast of the onset date of problems during the 1974-75 winter are presented.

Also, shipping activities in January and February were largely responsible for the ice problems, but there are difficulties in applying the shipping factor in the forecast procedure. It was found that, with the continuation of shipping and accumulation of over 850 freezing degree-days, the Sugar Island ferry was often not able to cross the river without icebreaker assistance.

1. INTRODUCTION

As part of the demonstration Program to Extend the Navigation Season on the Great Lakes and St. Lawrence Seaway, procedures were developed to forecast ice-related ferry problems in the St. Marys River at the Sugar Island ferry (SIF) crossing.

Sugar Island lies in the St. Marys River approximately 3 miles downstream of the locks at Sault Ste. Marie, Mich., (fig. 1). To the west of the island, below Frechette Point, lies Lake Nicolet, and the Little Rapids Cut lies west of the island, above Frechette Point. At the northernmost part of the Little Rapids Cut is the ferry crossing between Sugar Island and the mainland at Sault Ste. Marie.

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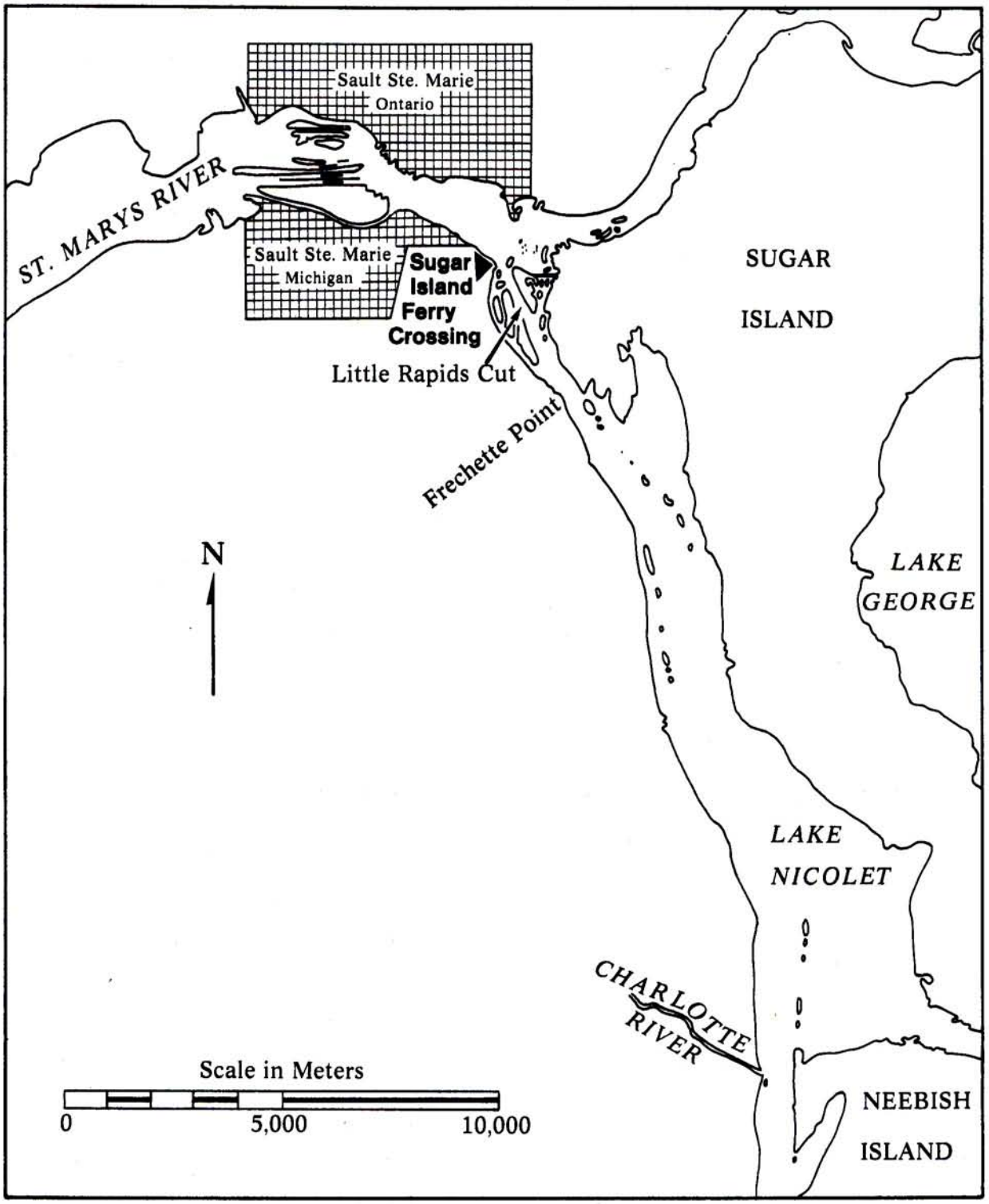

Figure 1. Sugar Island, Lake Nicolet, and the St. Marys River.

The inhabitants of Sugar Island depend upon the regular services of the SIF for transportation to and from the mainland for work and supplies. Normally, even though most of the St. Marys River is ice covered during the winter, the SIF has little trouble making its scheduled runs across the river because the rapidly moving water maintains an open ferry track between the mainland and the island. But sometimes during the last four winters (1970-71, 1971-72, 1972-73, and 1973-74) the time necessary to make a crossing increased and ferry operations were curtailed or sometimes completely halted due to ice problems caused by continued navigation of the river. This is partly because, since 1970, the navigation season on the Great Lakes has extended into January and February, that is, after a solid ice sheet has formed above the open water at the ferry crossing. Loosened ice, broken up by prolonged ship activity, moves downstream past the ferry track, into the Little Rapids Cut, and finally into Lake Nicolet. After a few days the ice begins to accumulate in Lake Nicolet, and then slowly progresses northward. The northernmost front of the ice eventually reaches the ferry crossing marking the onset of crossing difficulty owing to ice. From the time these ice related problems begin until the closing of the navigation season, ferry operations are curtailed and sometimes completely halted.

A technique was developed to forecast the probability that the SIF would experience difficulty crossing the river owing to partial obstruction of the crossing by ice. The indication of the difficulty is the increased time required to make the crossing. This forecast, issued for the following 5 days, allows time to suspend shipping operations on Lake Superior that would aggravate the problem. During the 1974-75 winter, experimental-operational forecasts using this technique were made at the National Weather Service (NWS) Office at Detroit, Mich.

Two forecasts are discussed in the remainder of this report:

1) The 5-day prediction of the onset date of ice problems, and

2) The 5-day prediction of the expected daily degree of difficulty in crossing the river after the onset date.

A 5-day prediction of the complete shutdown of ferry operations due to continuing severe ice problems is also part of the daily degree-of-difficulty forecast. These forecasts include one of the three following probability categories that express the likelihood of ice-related problems:

1) Probability of 0 to 30% that the SIF will be unable to operate because of ice. No icebreaker assistance is required for normal ferry operations.

2) Probability of 31 to 89% that the SIF will be unable to operate because of ice. Icebreaker assistance may be required.

3) Probability of 90 to 100% that the SIF will be unable to operate because of ice conditions.

These probability limits were subjectively determined and did not result from analysis of the 4 years of data.

Ordinarily in the course of a winter, while Lake Nicolet and the Little Rapids Cut are still filling with loose ice, category (1) exists. Category (2) exists when it is expected that jammed ice will reach the SIF crossing on the fifth day henceforth. This represents the onset of ice problems. After the initial date of ice problems, the probability categories are used to express the predicted daily degree of difficulty in crossing the river. Finally, with continuing low temperatures and severe ice conditions the SIF may be unable to cross the river and the complete shutdown forecast is issued using category (3).

Data from only the four winters 1970-71 through 1973-74 were used to develop the forecast procedures as there was no winter navigation during previous winters to break up existing ice. The data sources are listed in Appendix A. Examples of the 1974-75 experimental-operational forecasts are given in Appendix B.

2. FORECASTING THE DATE OF INITIAL ICE PROBLEMS

The dates when ice problems first began for the SIF are given by the Wellington Transportation Company (1973) and from the resume of the SIF daily logs for the 1973-74 season (table 1). Initial analysis indicated that the water temperature at the U.S. hydroelectric plant is a key indicator of impending ice problems. It was noted that in each of the seasons of available data, only a few days before the ice problem began, the water temperature at the U.S. hydroelectric plant at Sault Ste. Marie reached 32°F. The number of days between the date when the water reached 32°F and the date when ice problems began ranged from 4 to 10 days (table 1) with an average of 7 days and a standard deviation of 3 days. The standard deviation indicates there is a 68% probability that ice problems will begin 4 to 10 days after the water reaches 32°F, assuming the data is normally distributed.

Table 1. Dates of Ice Problems in the SIF Crossing

Season	Date When the Water Reaches 32°F (A)	Date When Ice Problems Begin (B)	Days Between (A) and (B)
1970-71	1/14	1/24	10
1971-72	1/14	1/19	5
1972-73	12/30	1/6	7
1973-74	1/3	1/7	4
Mean (Days)			7
St. dev. (Days)			3

However, it is not feasible to base the SIF ice problem forecast solely on water temperature. This is because there is a 32% probability that ice problems may begin in less than 4 or more than 10 days from the time the water reaches 32°F and, if that were to occur, the 5-day ice problem forecast would not be accurate. A more versatile forecast, capable of daily revision, would be based on meteorological and ice conditions in the vicinity of the Little Rapids Cut below the SIF crossing. Nonetheless, the date when the water reaches 32°F serves as a significant warning that the probability of ice problems will increase from the 0 to 30% range to the 31 to 89% range in a few days.

2.1 Procedural Development of the Initial Ice Problem Forecast

Two parameters found to be most useful in establishing the 5-day forecast of initial ice problems are:

1) Air temperature at the Sault Ste. Marie NWS station after the water reaches 32°F.

2) The rate at which jammed ice begins moving up the channel and cut west of Sugar Island because the position of the jammed broken ice affects the SIF. These parameters are represented in the forecast methodology by the 5-day air temperature forecast and the position of the jammed ice front.

A study of the available data for the four winters of the forecast revealed that the two parameters described above are closely interrelated. For example, after the water has reached 32°F a sudden cold spell with temperatures 10 to 20°F below normal for the date can lead to rapid formation of broken ice if ship traffic continues. Under these conditions the ice may move downstream, jam, and then proceed northward and jam the cut, all in less than 2 days. This occurred during the 1972-73 winter. Similarly, an unexpected warm spell (defined as a period of above normal temperatures despite the fact that they may still be below freezing) could slow or stop formation of broken ice and the northward progression of the jammed ice front, regardless of the position of the front and ship traffic. Once the ice front is close to the SIF crossing, however, the ferry operations could be interrupted by the chance loosening and intrusion of one very large ice floe from upstream.

Although the exact rate at which the jammed ice proceeds northward in the channel or cut under varying temperature conditions is not yet known, it was approximated with available data from the four winters 1970-71 through 1973-74. This information was then combined with the air temperature relationships cited in the previous examples (i.e., air temperatures 10 to 20°F below normal) to formulate standard 5-day forecast "conditions." Condition A is an arctic outbreak with temperatures 10 to 20°F below normal, high-pressure, and generally clear skies in the area. Condition B is a warmer than normal period. Conditions C and D are the results of considering two different ice front positions. The former occurs when the position of the jammed ice front is somewhere in the Little Rapids Cut

below the SIF crossing. Condition D occurs when the position of the jammed ice front is in Lake Nicolet, below both the SIF crossing and the cut. The forecast conditions are then combined to form forecast combinations A with C (A/C), A with D (A/D), B with C (B/C), and B with D (B/D).

Once the water temperature approaches 32°F, the forecast is issued. The forecaster must decide which combination exists and issue the forecast conditions described for that combination.

2.1.1 Combination A/C

This is the combination of ice somewhere in the cut near the SIF and an arctic outbreak expected for all or part of the upcoming 5-day period. These conditions are ideal for ice formation; therefore the cut could fill with ice in less than 2 days as occurred in 1972-73. Since the forecast must be issued 5 days in advance, it is of prime importance that the forecaster be able to detect arctic outbreaks in advance of their onset at Sugar Island and be prepared to change upcoming forecasts accordingly. The rapid northward progression of the jammed ice front under these conditions requires accurate 5-day meteorological forecasts as well as daily or twice daily ice position observations by trained observers. The forecaster must continually be looking for the onset of arctic outbreak conditions.

2.1.2 Combination A/D

This is the combination of an arctic outbreak with a jammed ice front in Lake Nicolet. With this combination, ice is jammed further downstream than it was for combination A/C. During this extended period of below normal temperatures, the jammed ice will rapidly progress northward until it reaches the Little Rapids Cut. At that time the combination is changed from A/D to A/C. Changes must consequently be made in all forecasts to accomodate the changing conditions.

2.1.3 Combination B/C

This is the combination of warmer than normal temperatures and ice in the Little Rapids Cut. Even if ice is in the cut and perhaps very close to the SIF crossing, a warmer than normal period is often sufficient to slow or stop the northward progression of the jammed ice front, provided there are no large ice floes upstream which may potentially break loose. Once again, the forecaster must be cautious as an arctic outbreak may occur and suddenly change conditions to combination A/C.

2.1.4 Combination B/D

This is the combination of a warm spell with jammed ice in Lake Nicolet. When ice is being produced slowly and the jammed ice is still a great distance from the SIF crossing, the forecaster may be reasonably sure that ice problems will not begin in the next 5 days. Although one must be cautious of changes to arctic outbreak conditions, crossing problems are not likely because combinations must first change from B/D to A/D before they can change to combination A/C, the condition that produces ice rapidly.

The four combination forecasts provide a basis for predicting the initial date of the onset of ice-related problems at the SIF crossing. Under operating conditions, the forecaster may make changes in these forecasts based upon his experience and the pre-existing conditions near the SIF crossing. The operating procedure for the onset of problems forecast is given in Appendix C. The actual forecast will include one of the three probability categories (described in the introduction) which indicate the probability of the onset of ice conditions.

3. FORECASTING THE DAILY DEGREE OF DIFFICULTY

Once the jammed ice front has reached the northernmost end of the Little Rapids Cut and the SIF begins experiencing difficulty in crossing the St. Marys River, a different forecasting methodology is needed. Now the three probability categories will express the degree of difficulty the SIF is expected to have in crossing the river rather than the probability of the onset of ice problems. When ice problems begin, the ice cover downstream of the ferry crossing in the cut and in Lake Nicolet is virtually 100%. As a result, the degree-of-difficulty forecast will not be able to incorporate the ice position parameter used in the forecast of the onset of problems. The remaining usable parameter from the previous procedure is air temperature.

The degree of difficulty the SIF has in crossing the river depends on the amount of ice cover at the crossing. This is shown in figure 2, based on 66 days of data (January 7 to March 13) in the 1973-74 season, which indicates that there is a direct relationship between the amount of ice cover at the SIF crossing and the percentage of time associated with difficulties in crossing the river. The equation line $Y = -1.804 + 0.9532X$ is valid within the range of $10\% < X \leq 100\%$.

While air temperature will be the most important parameter in determining the ice cover at the crossing, and therefore the potential degree-of-difficulty, several other parameters may be considered in the methodology. The upstream ice cover which may break loose and obstruct the crossing and ship passages are closely related to each other and to air temperature.

3.1 Upstream Ice Cover and Air Temperature

Sharp decreases in air temperature (especially daily minimum temperatures below 0°F) are ordinarily associated with significantly increased ice coverage upstream. Similarly, physical reasoning indicates that sharp rises in maximum temperatures, especially above 32°F, would in many cases be associated with decreased coverage upstream. Unfortunately, this expected physical relationship does not always apply; during cold weather more ice is generated upstream, but much of it is flushed downstream as it is broken up by ships in the area. Thus, the expected thick ice cover upstream is frequently never seen. Nonetheless, the broken ice moves downstream and blocks the SIF crossing.

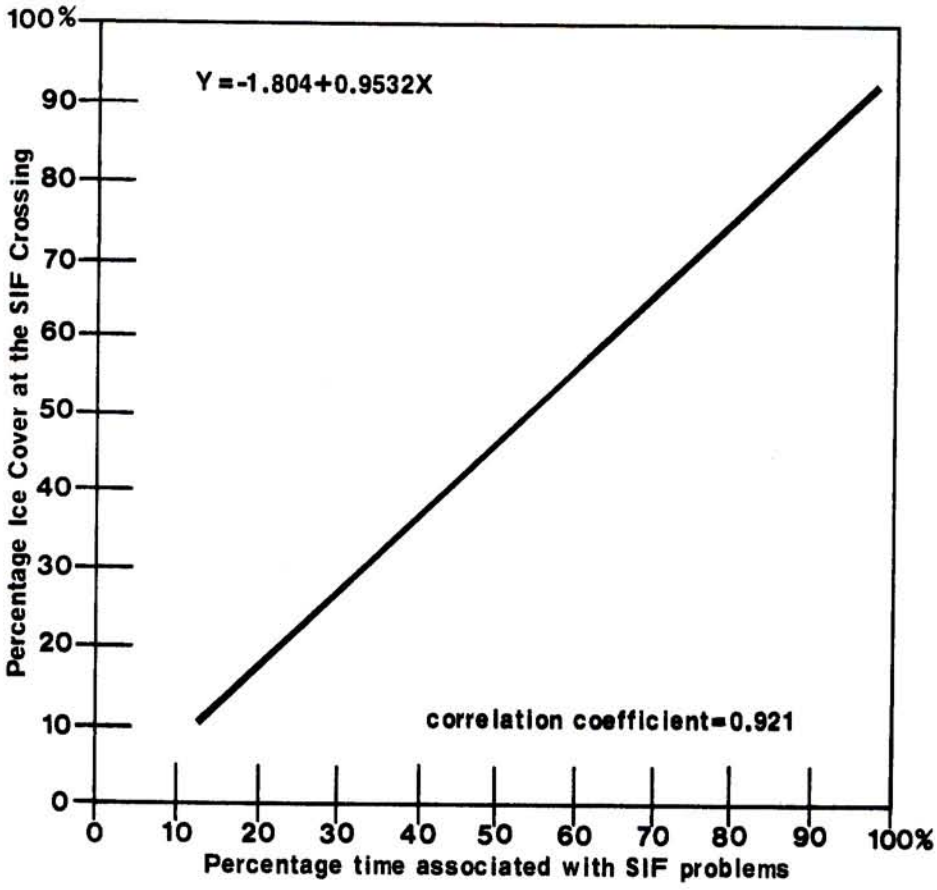

Figure 2. Relationship between percentage of time with SIF crossing problems and percentage of ice cover during the 1973-74 winter.

The relationship between temperature and upstream ice cover is more stable during warm spells. Frequently during the ice season there occur several days warmer than normal or even above freezing (e.g., the January thaw) which help melt the ice cover. Several examples of warm spells and their influence on the ice were noted in the four winters from 1970-71 through 1973-74. During 1971-72 a warmer than normal period occurred before the St. Marys River water temperature reached 32°F and delayed the onset of ice problems. A 1972-73 warm spell, starting less than 1 week after the onset of ice problems, prevented the ice cover from thickening and stabilizing near the SIF crossing. As a result, ice problems ended temporarily in mid-January until the 29th of that month. In 1973-74 a less intense warm spell began 2 weeks after the onset of ice problems. This warm spell had little influence on the ice cover because its onset occurred after jammed ice had stabilized to several feet in thickness at the SIF crossing. That warm spell did not open the river to SIF traffic.

A closer study of air temperatures, in the form of freezing degree-days, led to the conclusion that a warm period will destroy upstream ice

and ice at the SIF crossing if the following conditions are met:

1) The warm spell occurs very shortly, most likely within 1 week, after ice problems begin.

2) Daily maximum temperatures are in the upper thirties or lower forties for several days, and the daily average temperature is sufficiently high for those days so that 15 to 20 total freezing degree-days are lost. A freezing degree-day is defined as the negative departure of one Fahrenheit degree from 32°F averaged over one day ($32°F - \overline{T}_{day}$).

If the warm period occurs more than 1 or 2 weeks after the onset of problems, a considerably warmer and longer spell will be needed. It is unlikely that such a warm spell would occur.

3.2 The Influence of Ship Passages

Ship traffic is largely responsible for the ice problems at the SIF crossing. Once the SIF encounters problems in crossing the river caused by ice, only a suspension of shipping activities, frequent warm spells, or intense icebreaker activity (or some combination of the preceding) will permit continued ferry crossings through the remainder of the ice season. If shipping continues, without warmer weather or icebreaker activity, ice will continually be broken and move downstream jamming the crossing, or below it, until ice thickness reaches a point where even ship traffic on the river is impossible. Analysis of the Corps of Engineers time lapse motion pictures for ice seasons 1971-72 through 1973-74 revealed that, once shiping has stopped for a period of 24 to 36 hours, the degree-of-difficulty the SIF has in crossing the river will decrease. This is due to the rapidly moving water which clears out the previously shifting broken ice in the vicinity of the crossing.

Both ship passages and the amount of broken ice generated by ships are difficult to predict. One cannot make a 5-day forecast of the time of ship passages at the crossing. However, general tendencies are apparent which may be of use in establishing the forecast procedure, including the continuous decline in the number of ships on the lakes during January, February, and March as well as the generality that during colder weather more potential broken ice is available upstream for clogging the crossing. Nor can one make an advance determination of the amount of broken ice eventually generated. The corps of Engineers' films reveal that fewer than half the ships passing the crossing produced broken ice which later jammed the crossing site. Although this may be due to one ship loosening most of the potential broken ice, leaving more for following ships, the parameters involved cannot be forecast accurately.

The degree-of-difficulty forecast is based on 5-day-in-advance air temperature forecasts combined with a knowledge of the ice problems associated with ship traffic and upstream ice cover. These factors are then applied to determine expected ice coverage at the crossing site and the degree-of-difficulty the SIF will have in traversing the river.

3.3 The Methodology of the Degree-of-Difficulty Forecast

Based upon the parameters described above (air temperature, upstream ice cover, and ship passages), a standard operating procedure for forecasting the ice cover at the SIF crossing and the degree of difficulty is presented in Appendix D.

4. FORECASTING OF DATE OF COMPLETE SHUTDOWN OF FERRY OPERATIONS DUE TO ICE

The continuation of shipping and low temperatures during the winter, without the benefit of icebreaker assistance or warm spells, will result in jammed ice which prevents the SIF from crossing the river. The dates of the first SIF shutdown for the winters from 1970-71 to 1973-74 because of severe ice conditions are shown in table 2. Along with these dates for the four winters 1970-71 through 1973-74 is information concerning the length of the period of shutdown and data on accumulated freezing degree-days.

Table 2. Data Regarding the Complete Shutdown of Ferry Operations

Season	Initial Date Complete Shutdown (A)	Length of Shutdown (B)	Accumulated Freezing Degree-Days °F, (A)	Accumulated Freezing Degree-Days, °F at the End of (B)
1970-71	1/25/71	6	995	1150
1971-72	1/6/72	6	798	932
1972-73	none	0	741*	841*
1973-74	1/28/74	5	905	949

*Accumulated freezing degree-days as of 1/25/73 and 1/31/73 for comparative purposes.

Table 2 provides information for determining the expected date of complete shutdown of ferry operations owing to ice. For example, if the 1972-73 season data were ignored, an average date of complete shutdown might be established for sometime around January 26 of each year. However, using freezing degree-days as well as data from the 1972-73 season is a better methodology. During 1972-73 fewer freezing degree-days had occurred by January 25 and 31 than by the initial dates of complete shutdown in the other three winters. During 1971-72, when the number of freezing degree-days were nearly as low (798) on January 26 as during the 1972-73 season, very cold

weather (932 - 798 = 134 freezing degree-days in 6 days) caused complete shutdown for 6 days despite the previously warm weather.

A complete procedure for predicting the date of complete shutdown of the SIF will not be detailed here; however, it is likely that, if icebreakers do not clear the river occasionally, ferry operations may be completely curtailed after 850 to 900 freezing degree-days accumulate during a winter season. During the 1970-71, 1971-72, and 1973-74 winters, the SIF was able to continue after the complete shutdown period only because either the navigation season ended or there was continual icebreaker assistance.

5. HINDCASTS OF ICE PROBLEM ONSET DATES AND THE 1974-75 EXPERIMENTAL-OPERATIONAL FORECAST

An attempt was made to determine the accuracy of the forecast technique in predicting the onset date of ice problems at the SIF crossing. Air temperature data at Sault Ste. Marie for the four seasons of data (1970-71 through 1973-74) were used to make hindcasts of the onset date. The hindcast procedure, therefore, assumed a perfect 5-day temperature forecast and it also assumed that jammed ice was collecting in the Little Rapids Cut (Condition C). Hindcasts began on the dates when the water reached 32°F (table 1). The hindcast onset date was either the third consecutive day during which combination A/C existed or it was the fifth day of a 5-day period in which combination A/C existed for at least 2 days (table 3). These constraints may not be applied under future conditions.

Table 3. Hindcast Dates of the Onset of Ice Problems

Season	Date Hindcasts Began	Onset Date Hindcast	Actual Date of Onset (Climatology)	Hindcast Error (days)
1970-71	Jan. 14	Jan. 19	Jan. 24	-5
1971-72	Jan. 14	Jan. 19	Jan. 19	0
1972-73	Dec. 30	Jan. 6	Jan. 6	0
1973-74	Jan. 3	Jan. 8	Jan. 7	+1
Average (days)			Jan. 14	-1.0
Standard error of estimate (days)			8.9	2.9

In three of the four seasons the hindcast date was within 1 day of the actual onset date. The large hindcast error and standard error of estimate

(SE) are due to the poor results of the 1970-71 season, but the SE is still better than for methods using climatology.

During the 1974-75 winter, forecasts of the onset date of ice problems and the ongoing degree of difficulty were initiated on an experimental-operational basis. Using real-time data supplied by the U.S. Coast Guard, the Corps of Engineers at Sault Ste. Marie, Mich., and the NWS at Detroit, Mich., the daily ice problem forecasts were made for the NWS by Bernard DeWitt and Associates. The forecasts were sent from the Detroit NWS to the Coast Guard at Sault Ste. Marie, Mich., to the Ice Navigation Center in Cleveland, Ohio, and the Detroit Corps of Engineers via telecopier. The forecasts were first issued on December 16, 1974. For 1 month, the air and water temperature data and the monitored ice growth indicated a 0 to 30% probability of ice problems developing.

The forecast message of January 17, 1975, (shown in Appendix B) predicted the onset of ice problems on January 20. While this message was only 3 days in advance of the ice problems, the forecast date was accurate. Late on January 20 the icebreaker *Naugatuck* was needed to make cuts in the ferry slip to disperse a brash ice jam so that the SIF could complete its scheduled runs.

The forecasted daily degree of difficulty from January 21 to April 11 (date of the final forecast) fluctuated between the (1) and (2) forecast categories depending upon the expected temperatures. A (3) probability forecast would have been appropriate for February 9, 1975, since the SIF was shutdown by heavy snow and ice cover on that day and the icebreaker *Naugatuck* was needed to transport passengers. By February 9, 973 freezing degree-days had been accumulated at Sault Ste. Marie. Generally the 1974-75 winter was mild and the intensive Coast Guard icebreaking effort kept the Little Rapids Cut open for a considerable distance below the crossing.

Another factor which significantly influenced the 1974-75 experimental-operational forecast was the rapid drop in water temperatures in the St. Marys River. After a storm passage, water temperatures dropped from 36°F on January 12 to 33°F on January 13. On January 17, the day of the initial ice problem forecast, the water reached 32°F. As a result, water temperatures could not provide a warning of impending ice problems as they would have in previous years.

6. CONCLUSION

An operational forecast procedure has been developed for predicting the initial date of ice problems and the continuing daily degree of difficulty 5 days in advance at the SIF crossing. Using three probability categories, the forecaster is able to indicate when ice-related problems will begin and the probability that the SIF will need aid in crossing the St. Marys River.

The procedure to forecast the onset of ice problems is based on a knowledge of the rate of motion of jammed ice up the St. Mary's River. There is no precise knowledge of this rate of motion because forecasters have only 4 years of intermittent data. Estimates were made and the actual standard

operating procedure, shown in Appendix C, is based on the two parameters needed to estimate rates of motion, a 5-day temperature forecast and the current position of the jammed ice front. Forecasting the daily degree of difficulty is a procedure based on knowledge of expected air temperatures, upstream ice cover, and ship passages. This procedure, detailed in Appendix D, may be hampered by the inability to predict the ship passage and upstream ice parameters. Despite problems in procedural development and unusually warm weather conditions during the 1974-75 winter, the experimental forecast of the onset of ice problems issued for that season correctly predicted January 20 as the day difficulties would begin for the SIF in crossing the river.

The essential procedures needed for forecasting ice in the Little Rapids Cut near the SIF crossing are unique in some respects. The forecaster is not forecasting the date of ice formation, but rather when jammed ice will reach the SIF crossing in the St. Marys River after being broken loose by wintertime ship traffic or by natural processes. Modification of forecasting procecedures contained here will depend upon the individual forecaster's experiences with the procedures and the accumulation of more data from the study area. It has been shown that available data has led to a forecast procedure which can be highly accurate and suitable for present needs.

7. ACKNOWLEDGMENTS

The authors gratefully acknowledge the advice and guidance of Dr. F. H. Quinn, Head of the Lake Hydrology Group, Great Lakes Environmental Research Laboratory, and R. A. Assel of the Lake Hydrology Group, Great Lakes Environmental Research Laboratory.

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APPENDIX A

DATA BASES FOR THE SIF ICE PROBLEM FORECASTS

Data used to develop the ice problem forecast for the Sugar Island Ferry came from the previous four winters, 1970-71, 1971-72, 1972-73, and 1973-74. The data consisted of the following elements:

(A) Daily water temperatures for the St. Marys River at the U.S. hydroelectric plant at Sault Ste. Marie, Mich.

(B) Daily air temperatures from the NWS station at Sault Ste. Marie, Mich.

(C) U.S. Army Corps of Engineers' time lapse ice-cover films for the 1971-72, 1972-73, and 1973-74 seasons.

(D) U.S. Army Corps of Engineers aerial photographs of ice conditions on the St. Marys River.

(E) The "Sugar Island Ferry Study for the U.S. Army Corps of Engineers" by the Wellington Transportation Company, hereafter referred to as Wellington (1973).

(F) The daily ice reports kept by the pilot of the *MV Sugar Islander* between December 15, 1973, and April 8, 1974.

(G) A resume of the Poirier Marine, Inc., ferry operations during January and February 1974.

(H) Records of ship passages at the Locks at Sault Ste. Marie, Mich., during the extended navigation seasons 1971-72, 1972-73, and 1973-74.

(I) U.S. Coast Guard ice reports, ice charts, and teletype messages (Great Lakes Marine Circuit).

(J) Detroit NWS analysis charts.

(K) U.S. Army Corps of Engineers ice thickness reports for the vicinity of the Little Rapids Cut.

APPENDIX B

1974-75 OPERATIONAL FORECAST MESSAGES

The following is the 1974-75 operational ice forecast of the onset of ice problems at the SIF crossing:

Ice Forecast - Little Rapids Cut

NWS, Detroit, Mich.

11 a.m. EST Friday, January 17, 1975

Temperatures in the vicinity of Sault Ste. Marie today through Tuesday will average 4°F below normal. Normal daytime high near 22°F, normal low 6°F. Not as cold tonight and moderating into the twenties on Saturday, then turning colder again Sunday.

Moderate to rapid ice growth in the next 5 days gradually increasing early next week. Ice will build out from along the shore upstream from the Soo and from the Soo to the Sugar Island ferry crossing. 100% ice cover is expected from below the ferry crossing downstream to the vicinity of De Tour by Monday. The probability of Sugar Island ferry difficulty due to ice conditions is 0 to 30% through Sunday changing to 31 to 89% on Monday (January 20, 1975) and Tuesday.

The following is an example of the daily degree-of-difficulty forecast issued during the 1974-75 season:

ICE Forecast - Little Rapids Cut

NWS, Detroit, Mich.

11 a.m. EST Tuesday, January 21, 1975

Temperatures for the next 5 days will continue low in the vicinity of the St. Marys River. A cold front passing through the area will result in much lower temperatures. Tonight's low is expected to be 5 to 10° below zero, with highs Wednesday of 10 to 15°F. Thursday through Saturday highs will range from the mid-teens to the low twenties. Lows will be from zero to 10°F above zero. Normal highs and lows are 21 and 6°F, respectively.

Winds shifting to strong northwest to northerly behind the cold front will combine with expected subzero temperatures tonight and result in some jamming of ice in the vicinity of the Sugar Island ferry crossing. Ice breaker assistance to ferry operations will be required tonight and Wednesday. Probability of ferry difficulties due to ice conditions will be 31 to 89% through Saturday. Weather conditions for the next several days are expected to continue without much change. Steady growth and consolidation of ice cover is expected on the entire river with increasing ice formation occurring between the Soo Locks and the ferry crossing.

APPENDIX C

STANDARD OPERATING PROCEDURE FOR FORECASTING THE INITIAL DATE OF ICE PROBLEMS FOR THE SIF

(1) Check water temperature on a daily basis. When it reaches 32°F, problems may begin within 4 to 10 days in many seasons.

(2) Check, or make, a 5-day temperature forecast for Sault Ste. Marie, Mich.

(A) If the expected average temperatures will be more than 10°F below normal temperatures for that period, or if the minimum temperatures are to be near or below zero, then condition A exists.

(B) If the expected temperatures are to be above normal, condition B exists.

(3) Check the position of the jammed ice front in the St. Marys River system.

(A) If the jammed ice front is in the Little Rapids Cut, which extends from the SIF crossing to Frechette Point, then condition C exists.

(B) If the jammed ice front is somewhere in Lake Nicolet to Neebish Island and the Charlotte River, then condition D exists. If the jammed ice is near the cut, however, take into account that condition D may rapidly change to condition C.

(4) Decide which combination exists based on (2) and (3). Is it A/C, A/D, B/C, or B/D?

(A) Combination A/C indicates ice problems will begin within 2 or 3 days.

(B) Combination A/D indicates ice problems will begin in 5 days.

(C) Combination B/C indicates ice problems will begin in 5 days.

(D) Combination B/D indicates ice problems will not begin in the upcoming 5 days.

Combination changes must be anticipated and the forecasts must allow for daily revision in the conditions and combinations. Consult this report for further details.

(5) The forecast message will need to contain a probability that ice problems will begin in 5 days. Based on the information gathered through step (4), that probability will be: (1) 0 to 30%, (3) to 89%, (3) 90 to 100%. Choose the correct category and include it in the forecast message.

APPENDIX D

STANDARD OPERATING PROCEDURE FOR FORECASTING THE DAILY DEGREE OF DIFFICULTY FOR THE SIF

(1) Check if there is ice cover along the SIF crossing or upstream at the present time.

(A) If there is no ice upstream or at the crossing, return to Appendix C and continue using the initial ice problem forecast steps (2) through (5). Although ice problems may have started previously, the initial ice problem forecast must be re-used every time the jammed ice moves south of the crossing.

(B) If there is ice at the crossing and ice upstream, go to step (2) below. A 31 to 89% probability for the need of icebreaker assistance exists.

(2) Check ship passages for the next 5 days.

(A) If no ships are expected to pass the SIF crossing for 24-48 hours during the forecast period, or if the navigation season is expected to end, the SIF crossing will clear of ice toward the end of the same 24-48 hour period. The degree of difficulty will drop to 0 to 30%.

(B) If ship passages are expected to continue, so will SIF difficulty in crossing the river. Go to step (3).

(3) Make or check the 5-day temperature forecast for Sault Ste. Marie, Mich.

(A) If temperatures for the next 5 days, especially including the fifth day, are expected to average over 10°F below normal, or if the overnight minimum temperatures will be near or below 0°F, then ice will generate at a sufficient rate for continuance of a 31 to 89% probability for ice problems. If ship traffic is discontinued, return to step (2) (A) above. Also see step (4) below.

(B) If the average temperatures for the next 5 days, especially including the fifth day, are forecast to be above normal or if the maximum temperatures will be above 32°F, then ice may either deteriorate or move downstream of the crossing. If there is a good chance of the ice moving from the SIF crossing, then the expected degree of difficulty becomes 0 to 30% and the next daily forecast should be started from Appendix C, step (2).

(4) How many freezing degree-days (using °F) have accumulated for the winter? If the total is approaching 850 or 900, look for ice conditions to become extremely severe at any time, especially if temperatures will remain near 0°. The probability of the need for icebreaker assistance will become 90 to 100%. If ship traffic is discontinued, refer to step (2)(A).