NOAA Technical Memorandum ERL GLERL-31

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noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / Environmental Research Laboratories

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CONTENTS

FIGURES

Page

TABLES

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AUGUST 1980

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SUMMARY OF GREAT LAKES WEATHER AND ICE CONDITIONS, WINTER 1978-79*

The winter of 1978-79 was the 16th coldest since 1779 and it was the third consecutive severe winter over the Great Lakes Region. During January and February 1979, the dominate upper air pressure pattern was such that the Great Lakes Region experienced a persistent northerly and northwesterly flow pattern. As a result, record low and near-record low temperatures were recorded over the lakes during January and February. A unique feature of the 1978-79 winter season occurred on February 17 when all of the Great Lakes were nearly 100 percent ice covered. February 17 was also the date when each of the Great Lakes reached their maximum ice cover. Spring breakup of the ice began during March and by the end of April the lakes were mostly ice free except for Lake Superior, where significant ice cover continued into May. The extensive ice cover and its duration during the season again severely hampered shipping on the lakes. The first ice breaker assistance was rendered on December 11 in Saginaw Bay while the last U.S. Coast Guard assistance was provided near Duluth on May 9.

1. INTRODUCTION

F. H. Quinn, R. A. Assel, and B. H. DeWitt

This report on the 1978-79 winter weather and ice conditions is the third coordinated report to combine the activities of the various NOAA components responsible for monitoring Great Lakes ice conditions. The participating units are the National Weather Service (NWS), the Environmental Research Laboratories, and the National Environmental Satellite Service (NESS). DeWitt Associates, Inc., Certified Consulting Meterologists also participated in this joint effort by editing the report and preparing the weekly ice-cover charts, along with the description of the ice cycle on each of the lakes under NOAA Contract NA79 RA C00062.

Most geographic locations referenced in this report are shown in figure 1. The winter of 1978-79 marked the third year of below-normal temperatures and extensive ice cover on the lakes. Ice began to form in the shallow areas of the Great Lakes during late November, and reached its maximum area1 ice extent by February 17, 1979. The simultaneous freeze over all of the Great Lakes on February 17--with nearly 100 percent ice cover--is the first time such an occurrence has been documented with a high degree of scientific certainty.

The harshness of the 1978-79 winter ice conditions severely hampered winter navigation throughout the Great Lakes. However, shipping continued on the upper lakes throughout the winter and a total of 4,359,953 total cargo tonnage was transported. The total value of the cargo shipped was $147,720,000.00.

As in the 1977-78 ice-cover report (Assel et *al.* 1979), supplementary wind data, synoptic surface weather charts, and lake bottom topography charts are given in the appendices of this report so that the reader can better understand the bathymetric and meteorological factors affecting ice cover on the Great Lakes.

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*GLERL Contribution No. 225.

Figure 1.--*Geographic location chart for the Great Lakes.*

2. SUMMARY OF METEOROLOGICAL CONDITIONS

D. F. Kahlbaum and F. A. Keyes

2.1 Synoptic Study of the Winter

For the third consecutive year, most of the United States shivered under a bitterly cold and stormy winter. As with the previous two winters, the Midwest and Great Lakes Region bore the brunt of the foul weather (fig. 3*a*). A check with historical weather records reveals that such a reoccurrence of cold winters has not been observed in the lakes region for nearly 200 years.

Like its two predecessors, the 1978-79 winter season began with a deceptively quiet November (table 1). Figures 2*a*-2*y* are illustrations of the mean monthly and mean weekly 700-mb contours for the winter season. The 700-mb wave pattern for the first half of the month was such that the northern portion of the United States had near zonal flow (figs. 2*b* and 2*c*). This arrangement caused low pressure centers to pass by the Great Lakes every 4 to 5 days and kept temperatures averaging 1°-3° C (2°-6° F) above normal. However, at about mid-month, an upper air low formed over northern Canada and began moving toward Hudson Bay (fig. 2d). This movement triggered an outbreak of arctic air which moved arcoss the Great Lakes on the 19th and caused temperatures to fall below normal. Temperatures remained 1°-4° C (1°-7° F) below normal through the end of the month as the low continued its slow southward movement (fig. 2e).

By early December this low had become stationary over Hudson Bay and was building a trough southwestward toward Baja (fig. 2g). This trough was situated in such a manner that the western and northern lakes received temperatures that averaged 2°-4° C (4°-7° F) above normal.

This upper air pattern remained unchanged until mid-December and then was quickly replaced by zonal flow when the low moved rapidly eastward and dissipated (figs. 2*h* and 2*i*). This zonal flow remained essentially intact during the next 2 weeks and caused low pressure systems to frequently pass over the Great Lakes Region. These passages brought a mixture of warm and cool air masses, and as a result, temperatures averaged only 1°-2° C (1°-4° F) above normal during this period.

Then as December drew to a close, a dramatic shift in the upper air flow occurred. A ridge started to develop along the west coast and another low formed and moved southeastward into Manitoba (fig 2j). Both of these features intensified rapidly and by early January, formed a classic (and now familiar) 700-mb pattern: a well defined ridge located along the west coast and extending up into the Arctic and a deep low center over Hudson Bay (fig. 2*l*). This configuration funneled arctic air into the Midwest regions and caused temperatures to plummet to 7°-10° C (12°- 18" F) below normal over the northern lakes and 4°-7° C (8°-12° F) below normal over the southern half. In addition, because the lakes were now much warmer than the surrounding air, heavy snow squalls soon began to develop to the lee of the lakes.

Because of the positioning of the low, these lake induced snowfalls were soon augmented by the frequent passages of weak low pressure cells. Then during the 13th and 14th, a major storm formed and produced high winds and between 5-41 cm (2-16 in) of snow as it passed over the lakes region. However, the passage of this

Table 1. *-Departures from normal of Great Lakes air temperatures for 1978-79 season*

	November		December		January		February		March		April		Mean	
	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
Lake Superior	-1.3	-2.3	-2.6	-4.6	-3.9	-7.0	-5.1	-9.2	+0.3	+0.6	-0.6	-1.1	-2.2	-3.9
Lake Michigan	[illegible]	+0.2	-1.1	-1.9	-5.1	-9.1	-5.2	-9.3	+0.2	+0.4	-1.9	-3.5	-2.2	-3.9
Lake Huron	-0.2	-0.3	+0.2	+0.4	-2.4	-4.3	-5.7	-10.3	+2.2	+4.0	-0.7	-1.3	-1.1	-2.0
Lake Erie	+0.7	+1.3	+1.4	+2.6	-2.8	-5.1	-5.6	-10.1	+2.9	+5.3	-0.9	-1.7	-0.7	-1.3
Lake Ontario	0.0	0.0	+0.9	+1.7	-1.6	-2.8	-5.7	-10.2	+0.4	+0.7	-1.1	-2.0	-1.2	-2.1

Note: Departure from normal air temperatures are based upon the following stations for each lake

Lake Superior	Lake Michigan	Lake Huron	Lake Erie	Lake Ontario
Duluth, MN	Green Bay, WI	Alpena, MI	Toledo, OH	Toronto, ONT
Marquette, MI	Milwaukee, WI	Wiarton, ONT	Cleveland, OH	Rochester, NY
Sault Ste. Marie, MI	Muskegon, MI	Detroit, MI	Erie, PA	
Lakehead, ONT.	Chicago, IL		Buffalo, NY	
			Detroit, MI	

low also had a disruptive effect on the upper air pattern and eventually caused the 700-mb flow to flatten out (figs. *2m*, *2n*, and *2o*). As a result, temperatures mcd-erated to average 2°-3° C (3°-6° F) above normal by the end of the month. Nevertheless, despite these developments, weak low pressure systems continued to frequently cross near or over the Great Lakes, further adding to the snowfall totals. Thus by the end of the month, some lakeshore stations reported that they had established new January snowfall records (table 2).

Unlike the previous 2 months, the 700-mb flow remained nearly zonal over the United States through most of February (figs. *2q*, *2r*, and *2s*). However, a ridge that formed over the north central Pacific early in the month grew progressively stronger as time passed. As it intensified, this ridge caused increasingly colder high pressure centers to move out of the Arctic and become entrained in the zonal flow, after which they passed south of the Great Lakes Region. Consequently, temperatures plummeted again and averaged 6°-10° C (11°-18° F) below normal during the first 3 weeks of the month. In fact, the period from February 13-17 was the coldest of the 1978-79 season, with temperatures ranging between 8°-11° C (15°-20° F) below normal over the entire lakes region.

Winter's icy grip on the United States finally ended towards the end of February when the north Pacific ridge assumed a more omega shape (fig. *2t*). This change allowed Pacific air to reach the Great Lakes and drove temperatures up to average between 0°-4° C (0°-7° F) above normal. Nevertheless, because of the extreme cold recorded earlier in the month, many stations established new February departure records when the month ended (table 3 and fig. *3d*).

Soon after March began, another shift in the upper air flow occurred. The Pacific ridge moved northwestward and a trough developed off the west coast (figs. *2v* and *2w*). At the same time, a low formed near Hudson Bay and began extending a trough southward toward Texas. These three features caused low pressure systems to pass to the west of the lakes and kept temperatures averaging 2°-3° C (3°-6° F) above normal for the first 3 weeks of the month. However, during the last week of March, the flow degenerated back to a more zonal configuration as the Hudson Bay Low moved northward (figs. *2x* and *2y*). This flow continued into April and caused oet another period of near to below-normal temperatures to prevail over the Great Sakes area.

2.2 Freezing Degree-Days (FDD's)

The concept of degree-day accumulations is useful in forecasting a wide range of phenomena: the use of heating fuel, the maturation of crops, etc. The growth of freshwater ice is closely correlated with accumulation of freezing degree-days (FDD's) (Richards, 1963; Snider, 1974; and Assel, 1976). Calculations of FDD's are sensitive to minor changes in computational procedures, especially in the southern lakes region. The method used in this report is to begin accumulating FDD's on the first day on which one or more FDD's occur (a mean temperature less than 0° C (32° F). For example, on a day with a mean temperature of -3" C, 3 FDD's are accumulated, and on a day with a mean temperature of +2° C, -2 FDD's are accumulated. FDD's continue to accumulate throughout the winter. If at any time the running sum of FDD's becomes negative, the accumulation begins again when the next FDD occurs.

Table Z.--*Near-record temperatures and snowfall for January 1979*

	Temperature		Anomaly		Snow		Remarks
	°C	°F	°C	°F	cm	in	
International Falls, Minn.	-22.6	-8.7	-5.9	-10.6			3rd coldest January
Green Bay, Wis.	-14.5	5.9	-5.3	-9.5			5th coldest January
Houghton Lake, Mich.	-11.4	11.5	-3.3	-5.9			4th coldest January
Muskegon, Mich.	-8.3	17.0	-3.9	-7.0	167.	65.7	2nd coldest January 2nd snowiest January
Rockford, Mich.	-13.5	7.7	-6.9	-12.5			3rd coldest January
Chicago (MDW), Ill.	-10.8	12.5	-6.6	-11.8	103.	40.4	2nd snowiest month
Buffalo, N.Y.					108.	42.6	6th snowiest January

Table 3.--Record and near-record monthly mean temperatures observed during February 1979

Station	Temperature °C	Temperature °F	Anomaly °C	Anomaly °F	Remarks
Fort Wayne, Ind.	-9.6	14.6	-7.1	-12.8	Coldest February and coldest month
Muskegon, Mich.	-9.7	14.5	-5.6	-10.1	Coldest February
Indianapolis, Ind.	-7.3	18.8	-6.6	-11.9	2nd coldest February
Erie, Pa.	-9.9	14.1	-6.2	-11.1	2nd coldest February
South Bend, Ind.	-8.7	16.3	-5.6	-10.0	2nd coldest February
Buffalo, N.Y.	-9.5	14.9	-5.3	-9.5	4th coldest February
Houghton Lake, Mich.	-12.0	10.4	-4.3	-7.8	4th coldest February

Figures 4a-4k show comparisons of long term normal FDD curves (solid lines) versus the winter 1978-79 (dash-dot lines) at 11 Great Lakes cities. Table 4 gives maximum FDD's accumulated for the 1976-77, 1977-78, and 1978-79 winters.

Table 4.--*Maximum accumulated freezing degree-days for tinters of* 1976-77, 1977-78, and 1978-79 compared to *normal*

Station	1976-77		1977-78		1978-79		Normal"	
	°C	°F	°C	°F	°C	°F	°C	°F
Duluth, Minn.	1451	2612	1397	2514	1692	3045	1267	2281
Sault Ste. Marie, Mich.	1246	2243	1142	2056	1227	2209	1008	1814
Green Bay, Wis.	1157	2082	1118	2013	1167	2101	790	1422
Milwaukee, Wis.	852	1534	771	1388	804	1447	500	900
Muskegon, Mich.	673	1211	632	1137	661	1190	370	666
Alpena, Mich.	904	1628	901	1621	884	1591	670	1206
Detroit, Mich.	627	1129	629	1132	526	946	+	+
Toledo, Ohio	732	1317	788	1418	541	974	307	553
Cleveland, Ohio	631	1135	507	913	394	709	246	443
Buffalo, N.Y.	594	1069	610	1098	507	912	361	650
Rochester, N.Y.	527	949	548	987	514	925	364	655

*After Assel (1980)

2.3 Comparison With Previous Winters

In order to be able to compare winters across the Great Lakes, Snider (in Quinn *et al.*, 1978) developed a winter severity index. This index comprises the mean temperatures for November through February for Duluth, Minn.; Sault Ste. Marie and Detroit, Mich.; and Buffalo, N.Y. The mean temperatures are averaged together to obtain a single number.

Table 5 gives a listing of the 22 coldest winters since 1779. Each winter is characterized as early (E), intermediate (I), or late (L), according to the timing of its coldest period. In 15 of the 22 winters, the coldest part of the season occurred in February; in 4 winters, the cold weather was evenly distributed throughout the winter; and in only 3 winters did the major part of the cold weather come in the first part of the season.

Table 5.--*The 22 coldest tinters since 1779*

Rank	Winter	November-February mean temp. °C	°F	November-January mean temp. °C	°F	Character
1	1779-80	-9	15.8	-10	14.0	E
2	1874-75	-9	15.8	-6.5*	20.3	L
3	1783-84	-8	17.6	-6.5*	20.3	L
4	1903-04	-7.9	17.8	-6.2	20.8	L
5	1976-77	-7.7	18.1	-8.2	17.2	E
6	1872-73	-7.5"	18.5	-7.5*	18.5	I
7	1831-32	-7.5*	18.5	-6.5"	20.3	L
8	1855-56	-7.5*	18.5	-6	21.2	L
9	1919-20	-7.4	la.7	-7.0	19.4	L
10	1880-81	-7.3	18.9	-7.2	19.0	I
11	1917-18	-7.2	19.0	-6.8	19.8	L
12	1820-21	-7	19.4	-7	19.4	I
13	1856-57	-7	19.4	-7	19.4	I
14	1822-23	-7	19.4	-4.5*	23.9	L
15	1892-93	-6.8	19.8	-5.8	21.6	L
16	1978-79	-6.8	19.8	-5.1	22.8	L
17	1962-63	-6.5	20.3	-6.3	20.7	L
18	1791-92	-6.5*	20.3	-6	21.2	L
19	1835-36	-6.5*	20.3	-5.5"	22.1	L
20	1817-18	-6.5"	20.3	-5	23.0	L
21	1796-97	-6.0	21.2	-7	19.4	E
22	1977-78	-6.0	21.2	-4.5	23.9	L

Each of the coldest winters was characterized as (E), Early, or (I), Intermediate, or (L), Late, according to the timing of its coldest period.

*Data prior to 1888 were not of sufficient quality to justify means with 0.1° C precision. They have been rounded off to the nearest 0.5" C.

The winter of 1978-79 was the 16th coldest since 1779, with the coldest part of the season occurring during February. Of greater importance to the Great Lakes Region is that this was the third consecutive winter that had temperatures so cold. (The winters of 1977-78 and 1976-77 were ranked 22nd and 5th, respectively.) One has to go back into the 1770s and the 1780s to find any data that might indicate a comparable cold period. In recent times the only consecutive winters that were ranked in the coldest 22 over the last 200 years were the winter of 1855-56 and 1856-57.

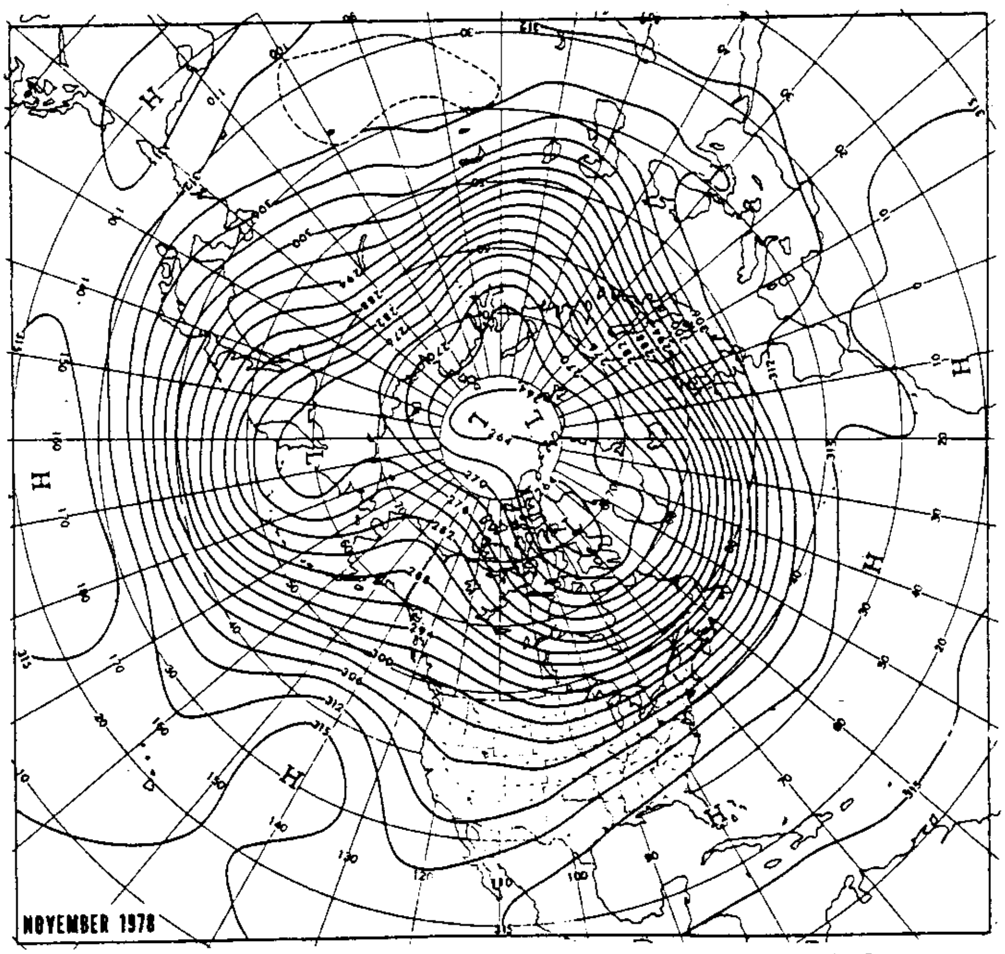


Figure 2a.--*Mean* 700-mb *contours for November 1978.*

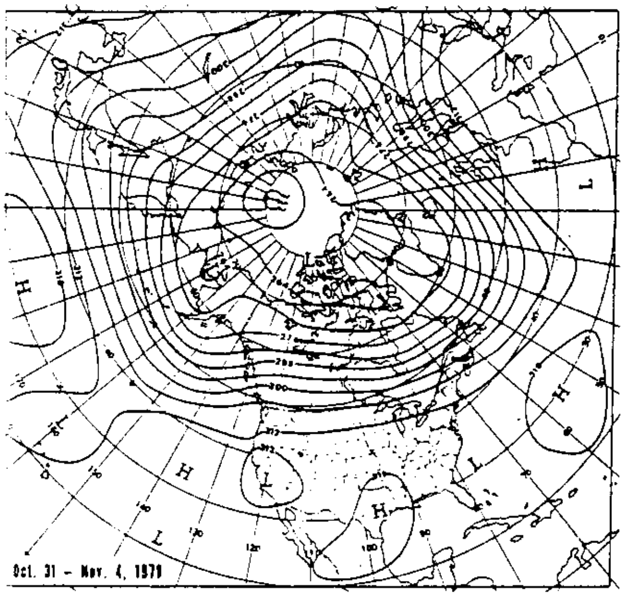


Figure 2b.--Mean 700-mb contours for October 31-November 4, 1978.

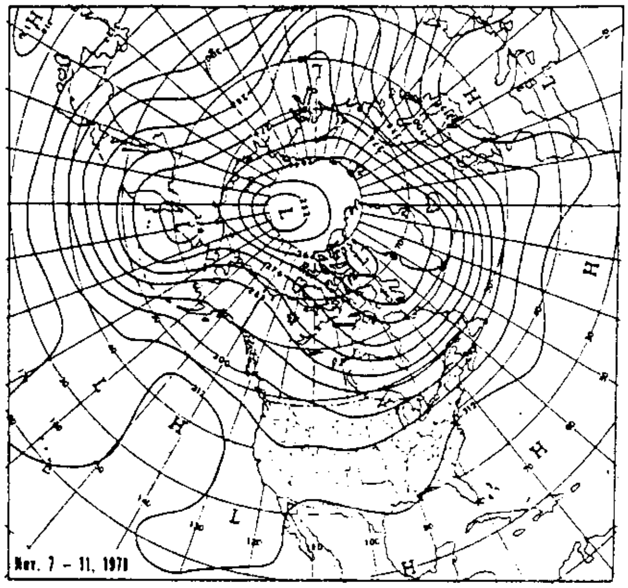
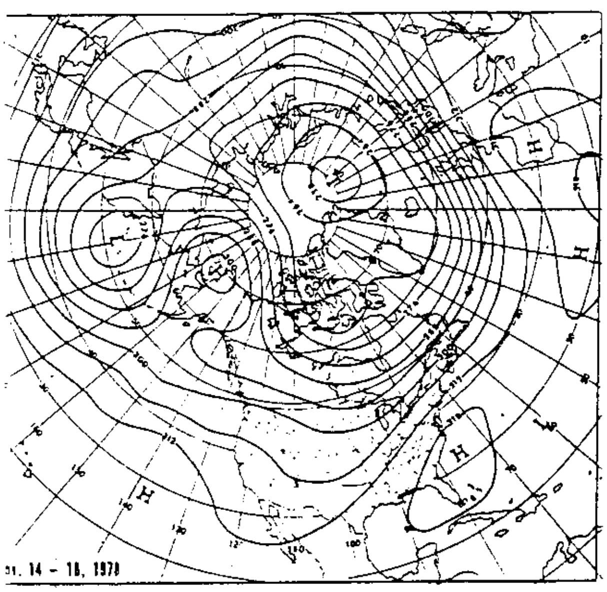


Figure 2c.--Mean 700-mb contours for November 7-11, 1978.



igure 2d.--Mean 700-mb contours for November 14-18, 1978.

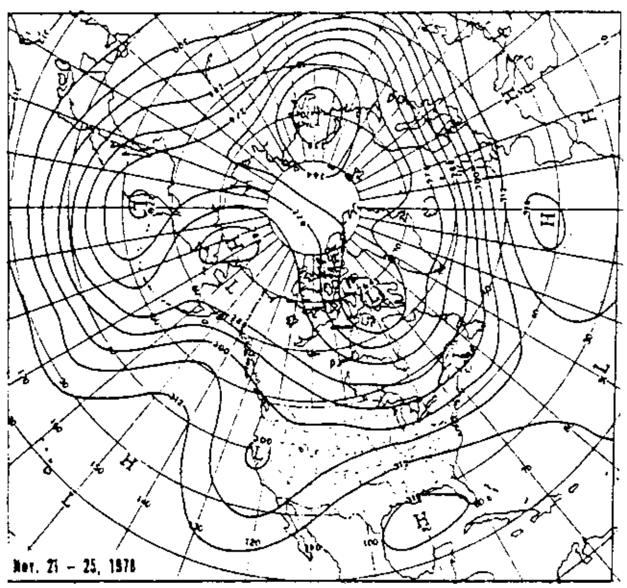


Figure 2e.--Mean 700-mb contours for November 21-25, 1978.

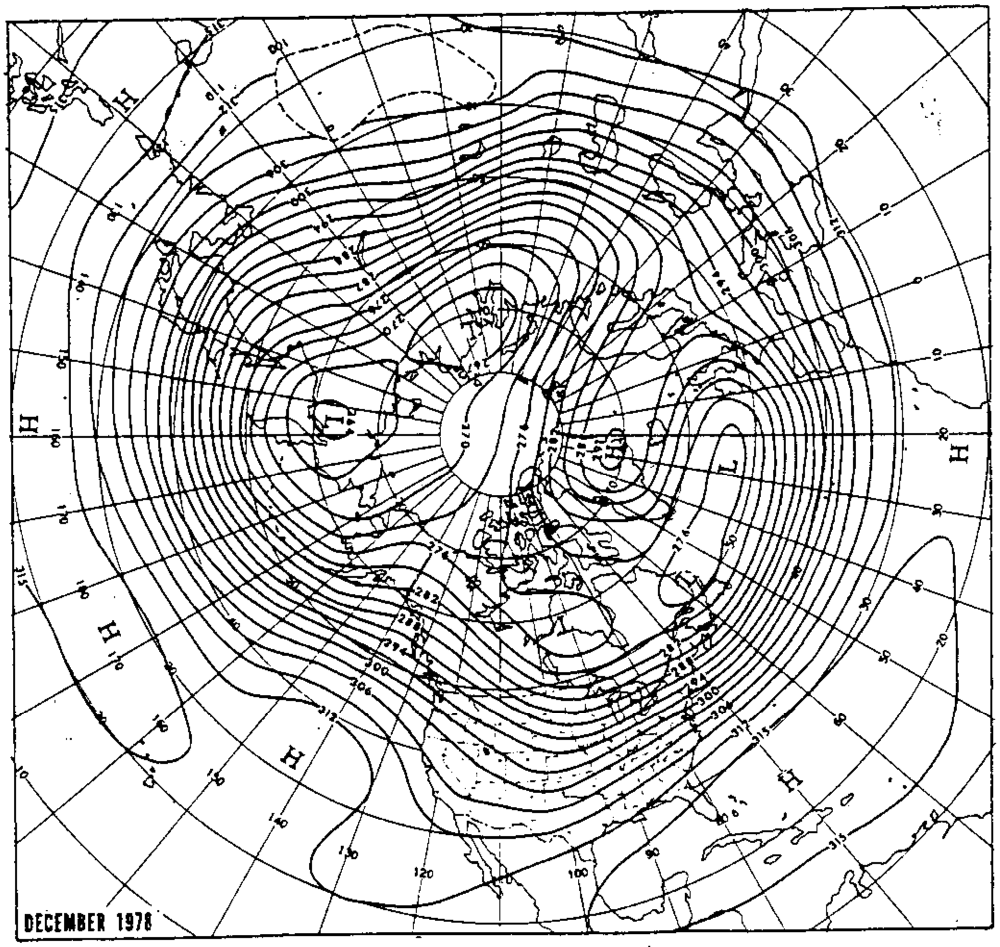


Figure 26.--Mean 700-mb contours for December 1978.

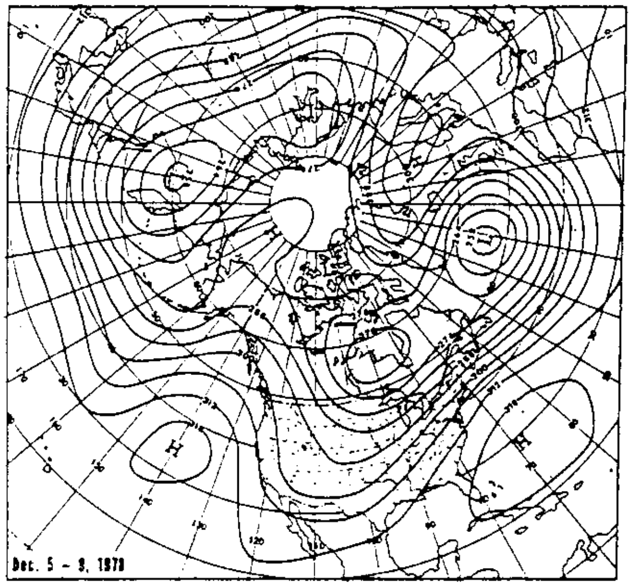


Figure 2g.--Mean 700-mb contours for December 5-9, 1978.

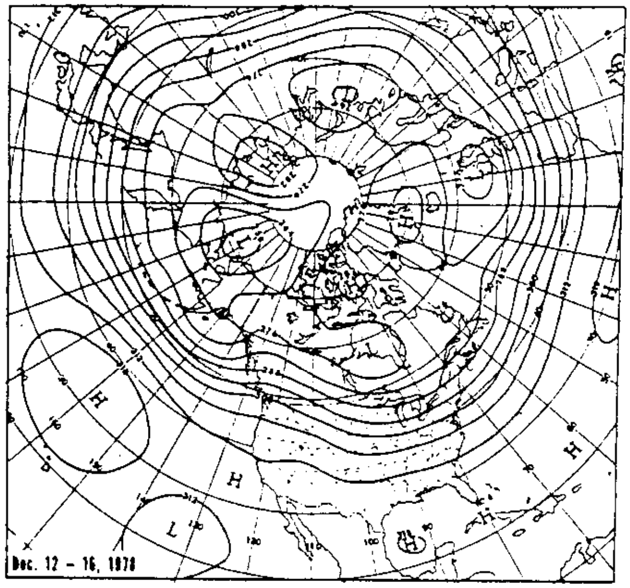


Figure 2h.--Mean 700-mb contours for December 12-16, 1978.

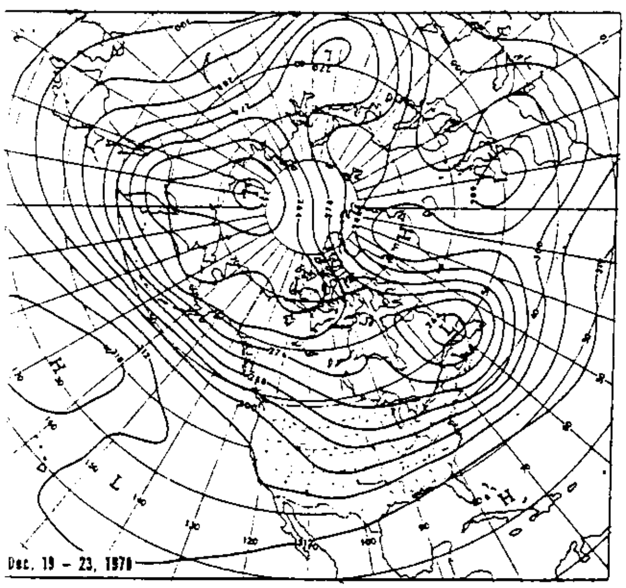


Figure 2i.--Mean 700-mb contours for December 19-23, 1978.

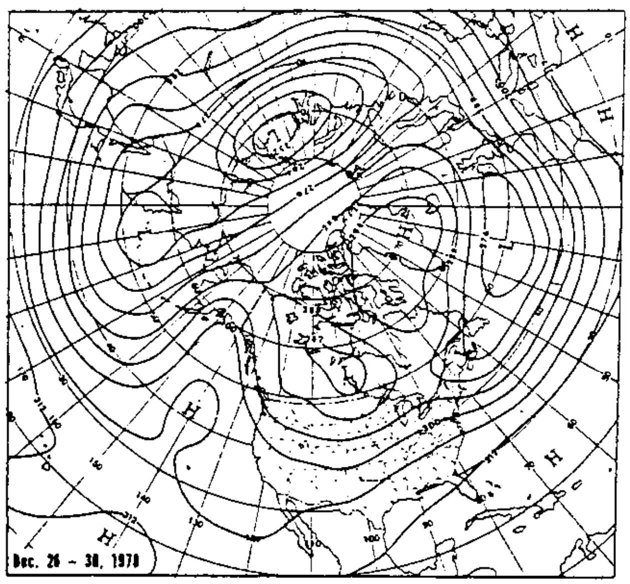


Figure 2j.--Mean 700-mb contours for December 26-30, 1978.

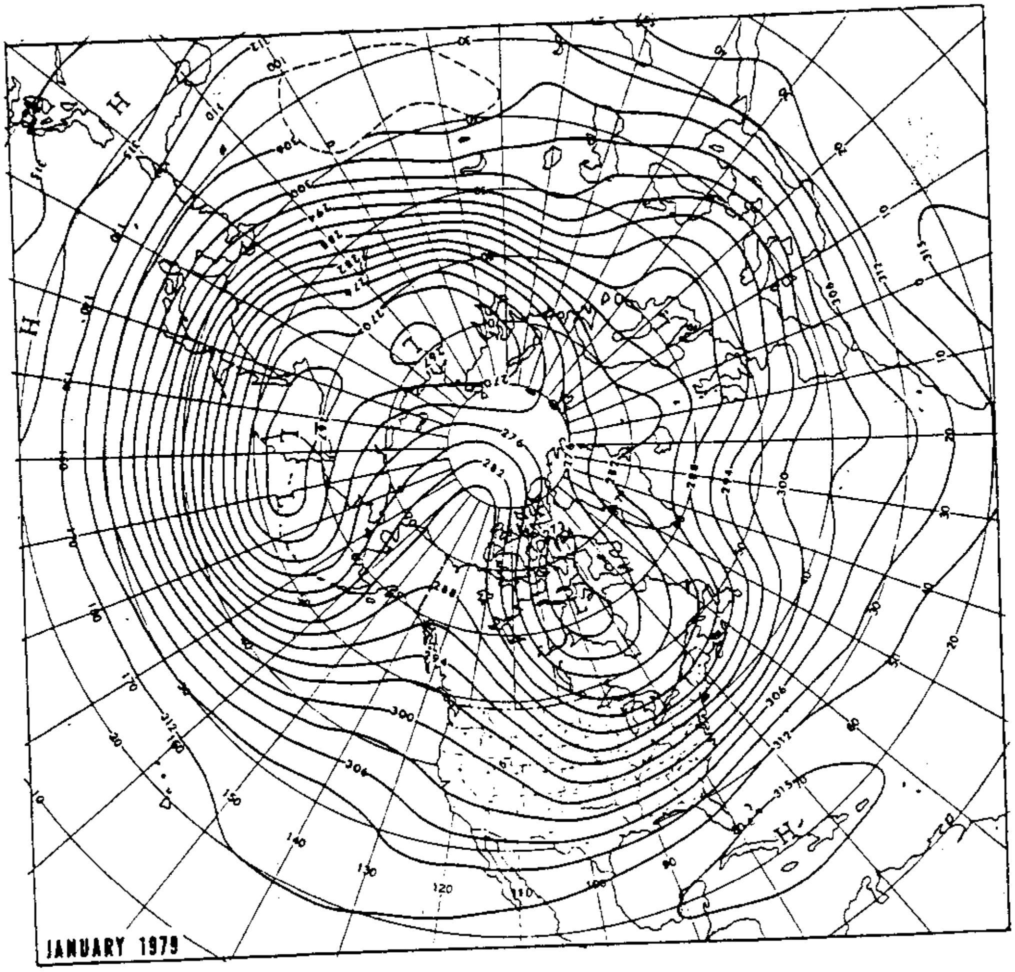


Figure 2k.--Mean 700-mb contours for January 1979.

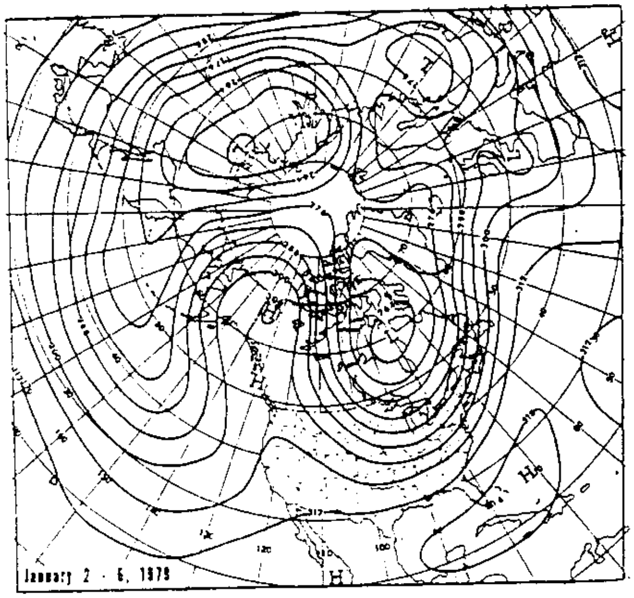


Figure 2l.--Mean 700-mb contours for January 2-6, 1979.

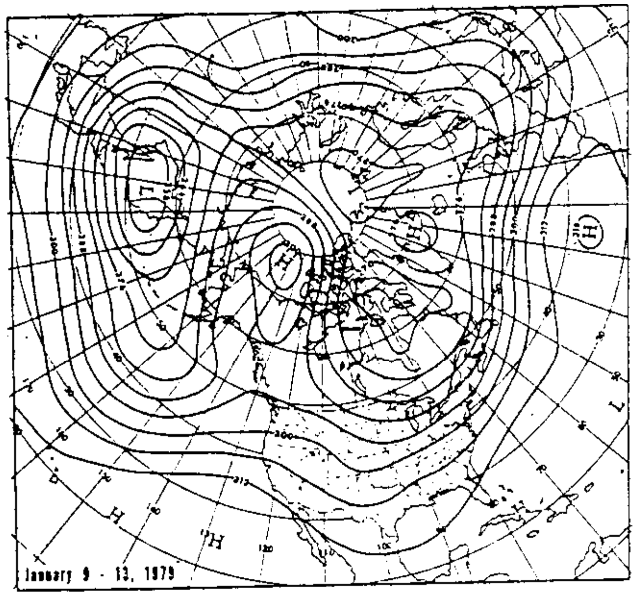


Figure 2m.--Mean 700-mb contours for January 9-13, 1979.

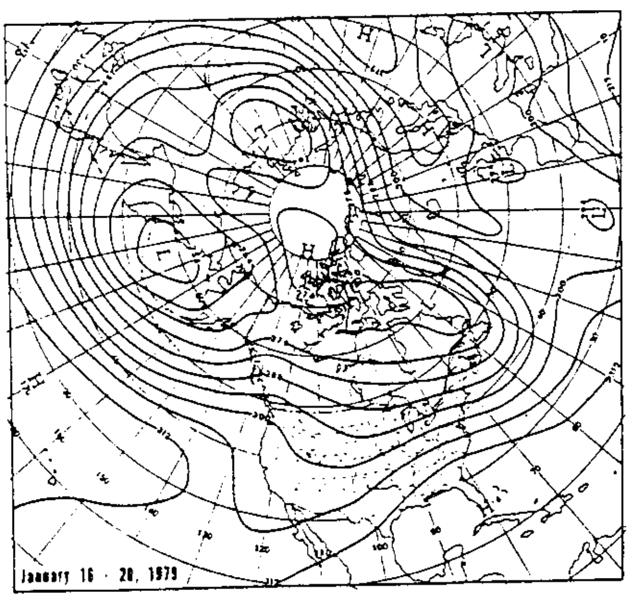


Figure 2n.--Mean 700-mb contours for January 16-20, 1979.

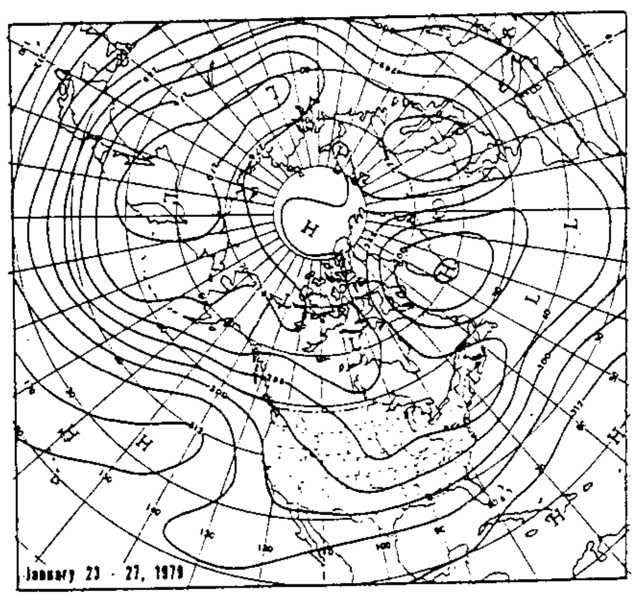


Figure 2o.--Mean 700-mb contours for January 23-27, 1979.

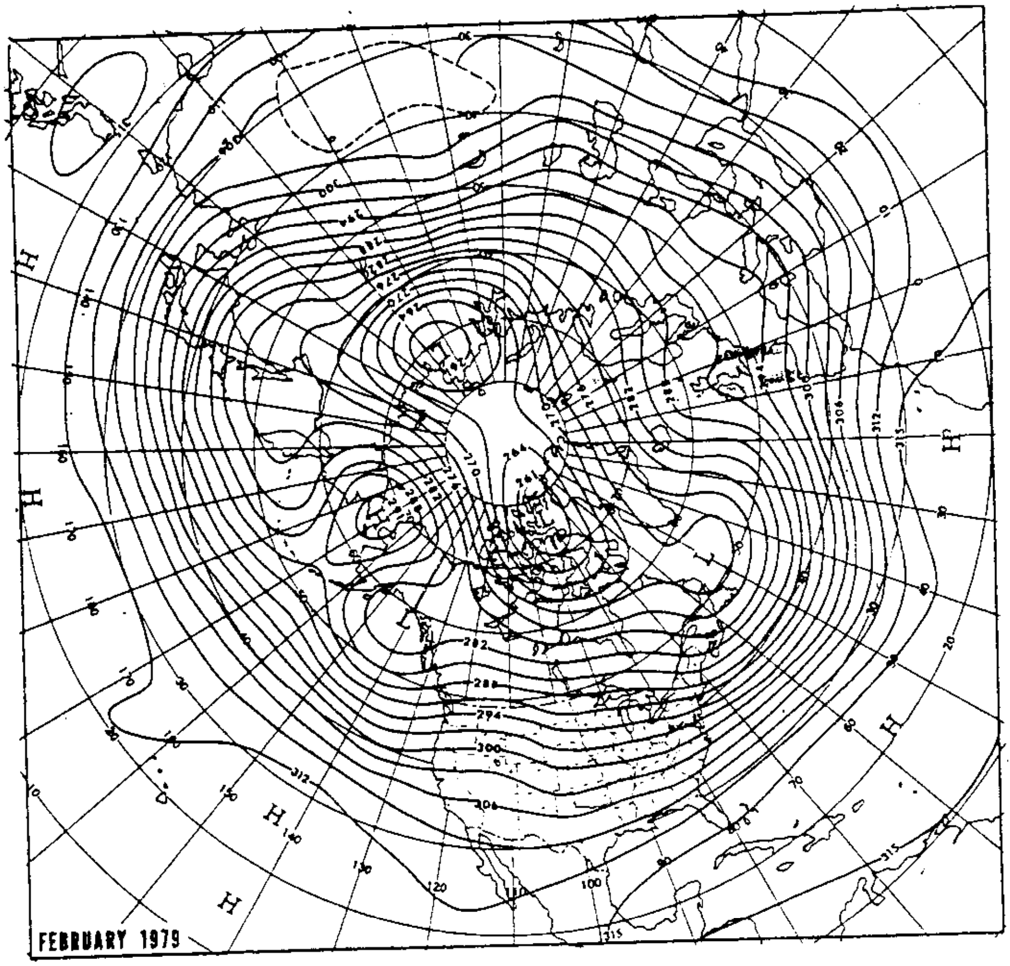


Figure 2p.--*Mean 700-mb contours for February 1979.*

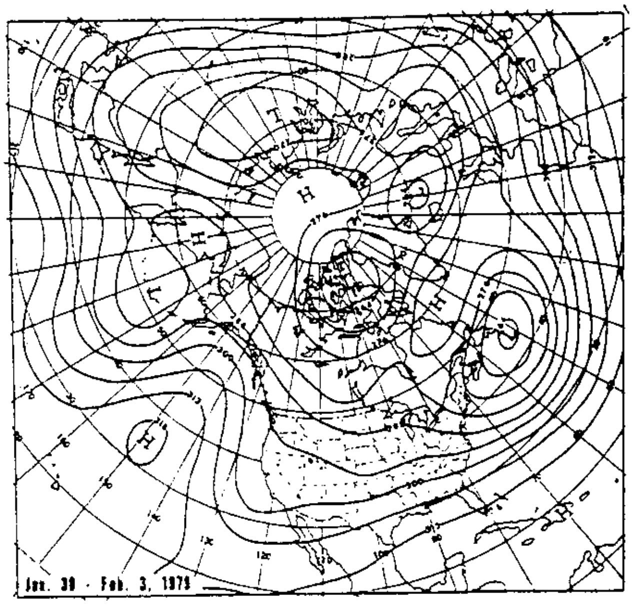


Figure 2q.--Mean 700-mb contours for January 30-February 3, 1979.

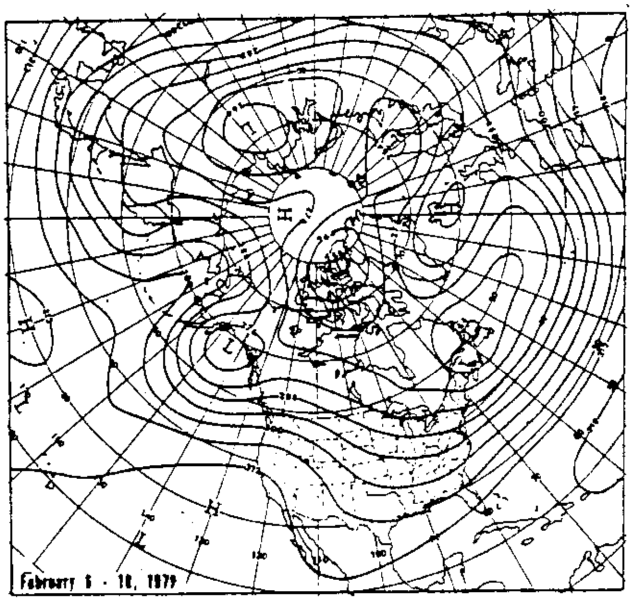


Figure 2r.--Mean 700-mb contours for February 6-10, 1979.

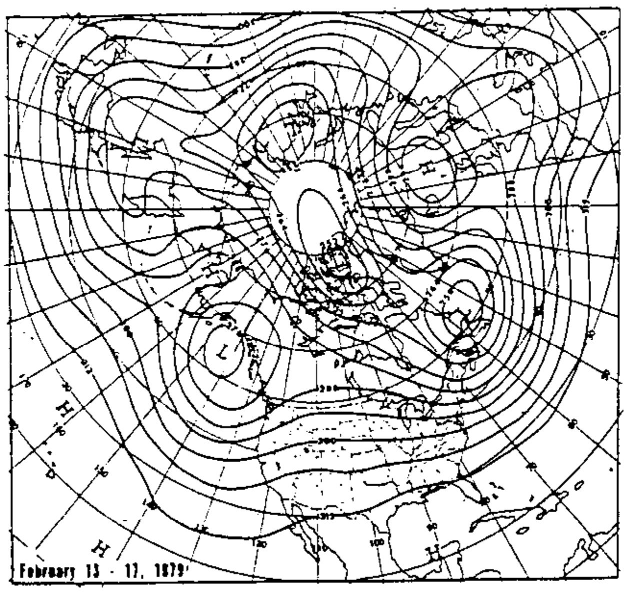


Figure 2s.--Mean 700-mb contours for February 13-17, 1979.

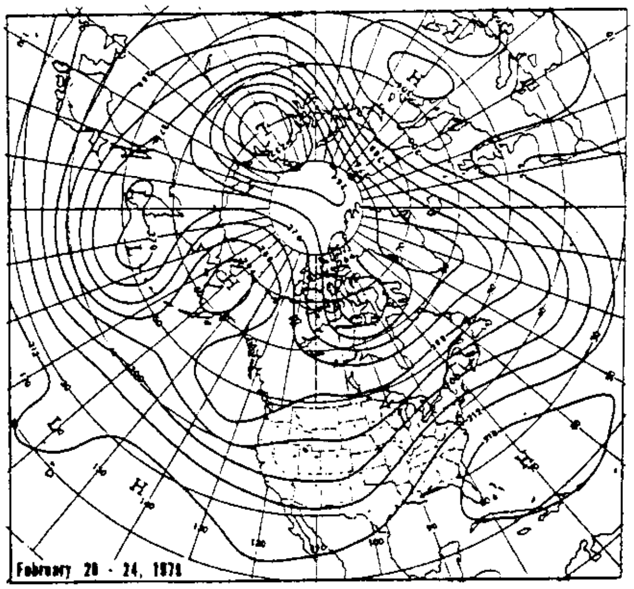


Figure 2t.--Mean 700-mb contours for February 20-24, 1979.

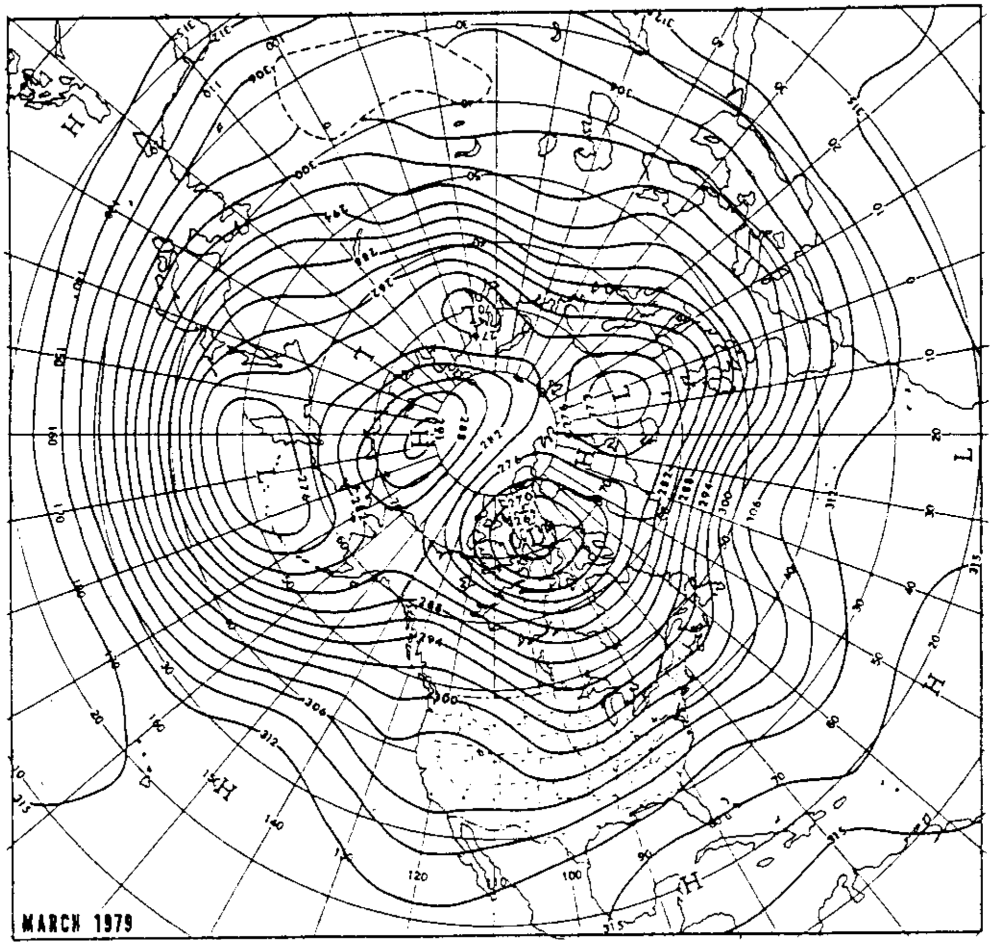


Figure 2u.--Mean 700-mb contours for March 1979.

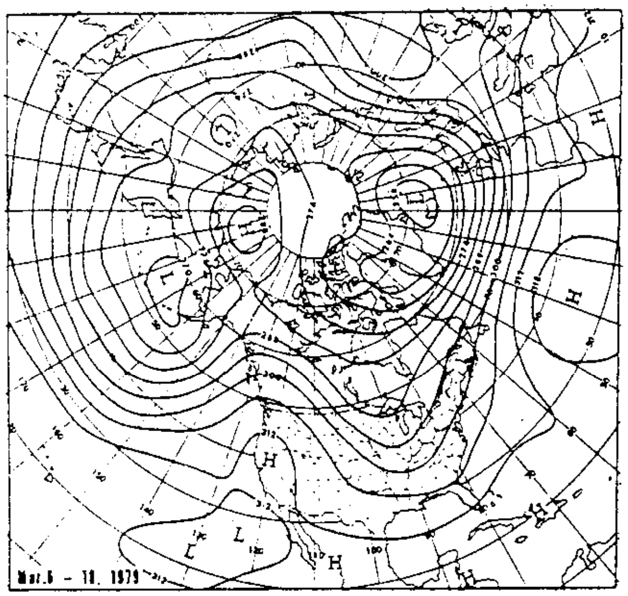


Figure 2v.--Mean 700-mb contours for March 6-10, 1979.

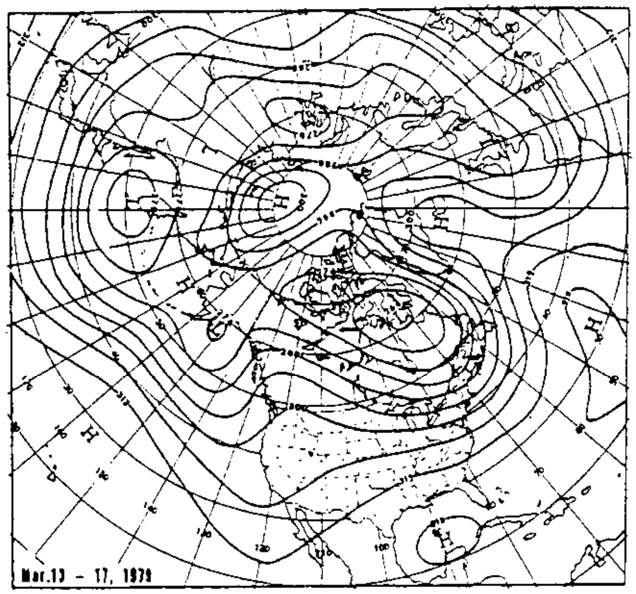


Figure 2w.--Mean 700-mb contours for March 13-17, 1979.

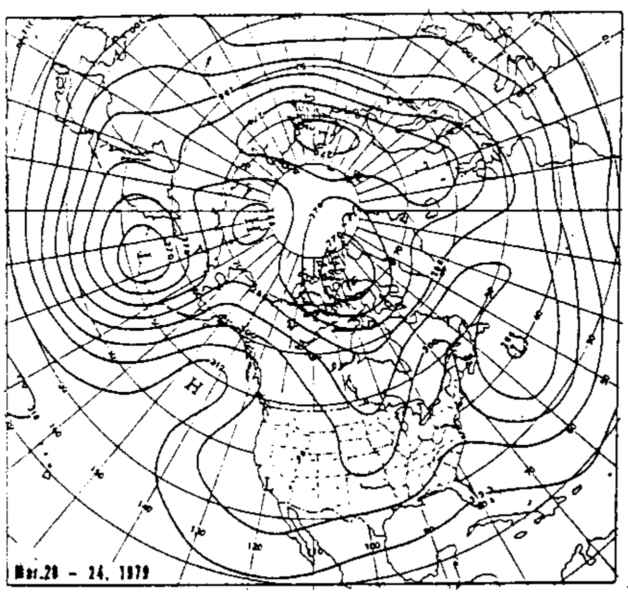


Figure 2x.--Mean 700-mb contours for March 20-24, 1979.

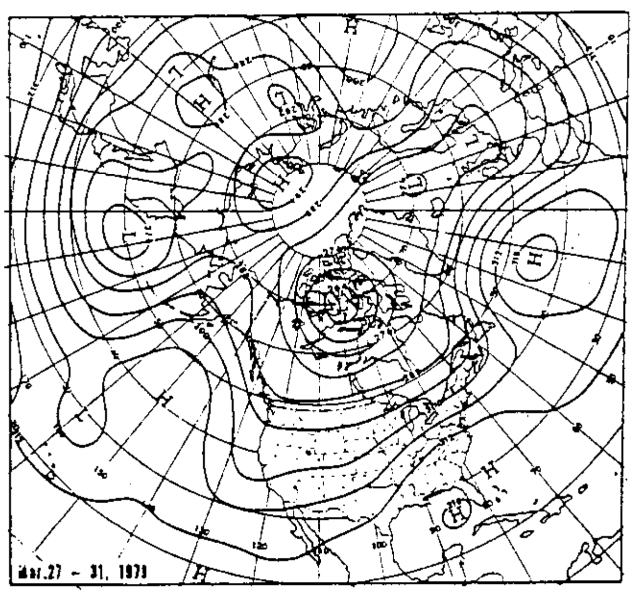


Figure 2y.--Mean 700-mb contours for March 27-31, 1979.

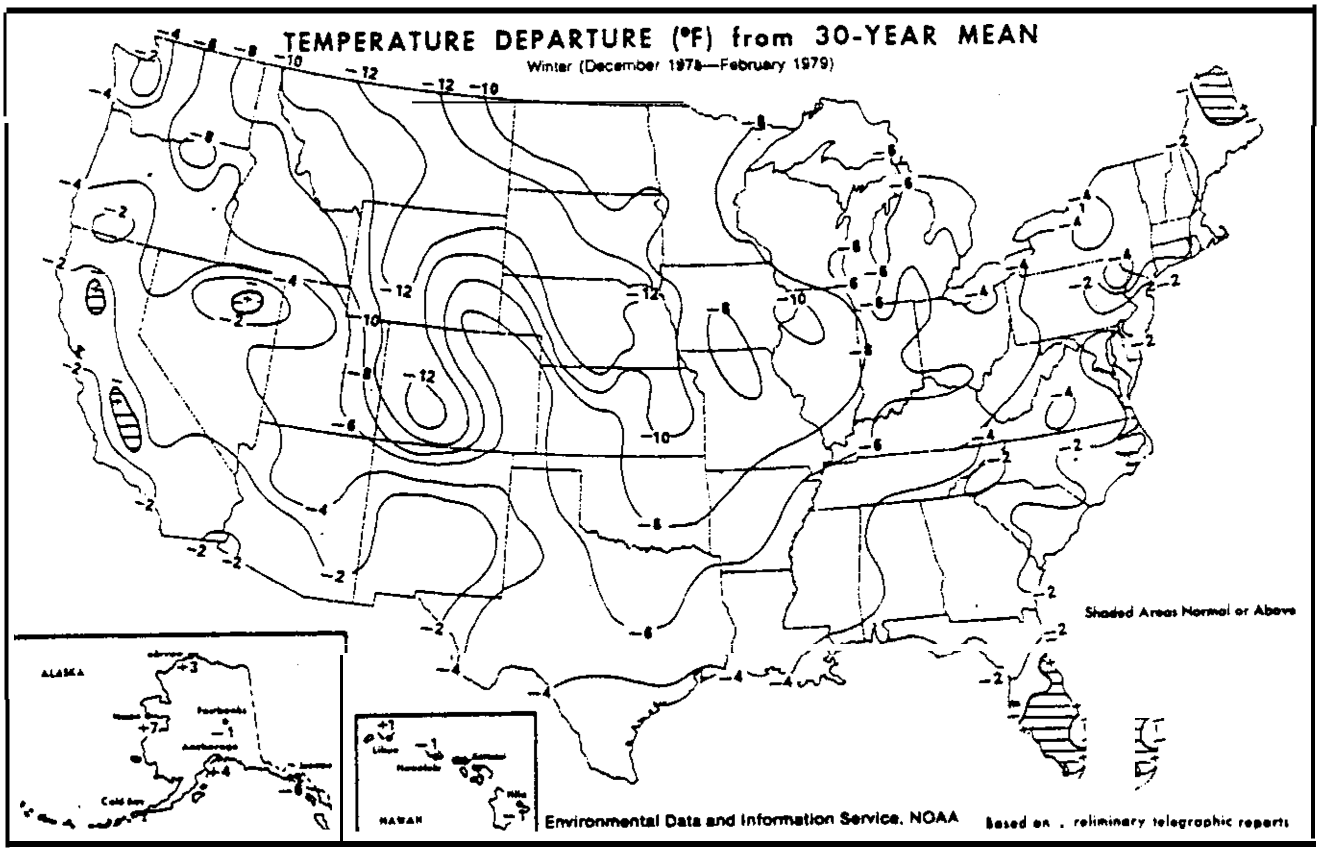


Figure 3a.--*Temperature departure* (°F) *from 30-year mean for winter December 1978-February* 1979.

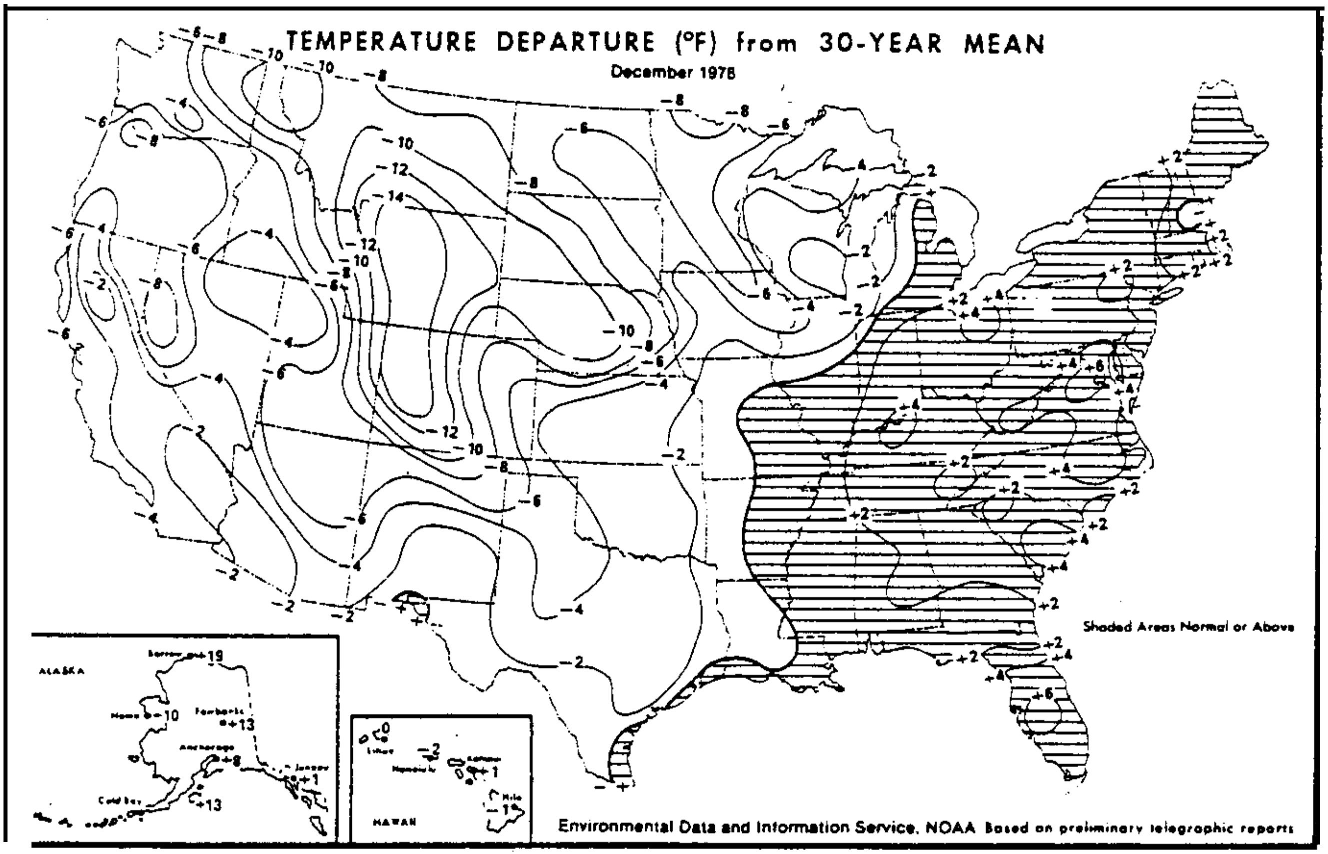
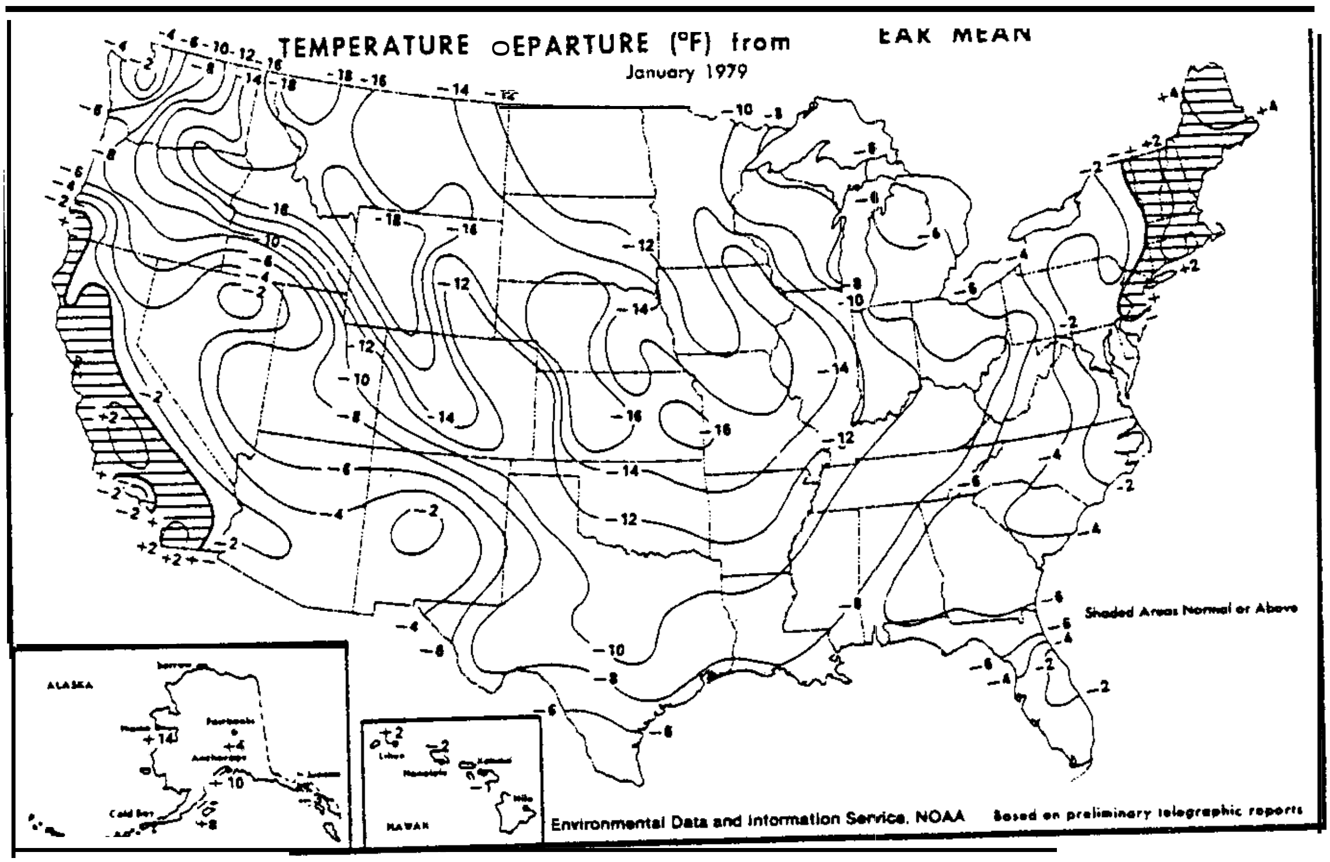


Figure 3b.--*Temperature departure (°F) from 30-year* mean *for December 1978*.



Fi 3c --7 (°F) from 30-year for January 1979.

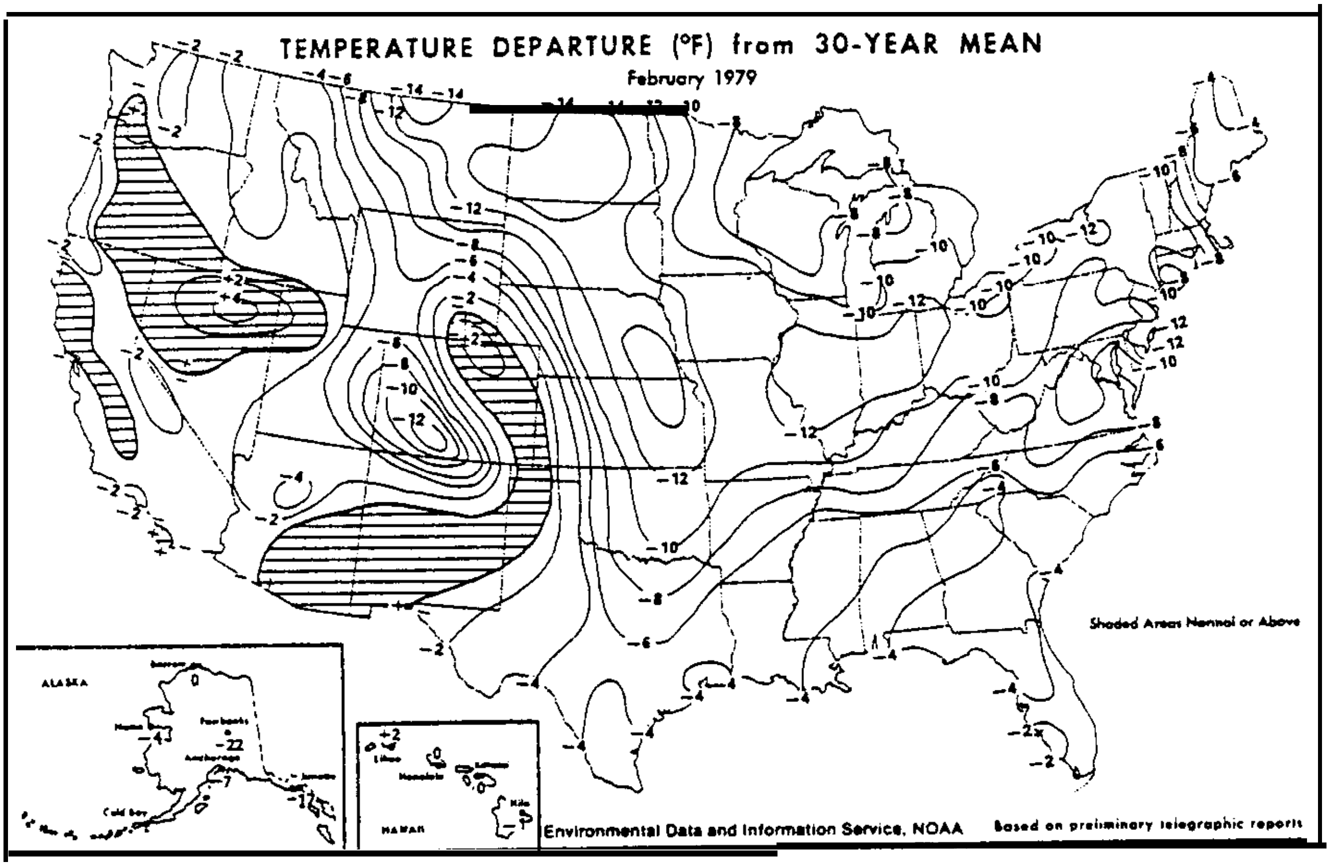


Figure 3d.--Temperature departure (°F) from 30-year mean for February 1979.

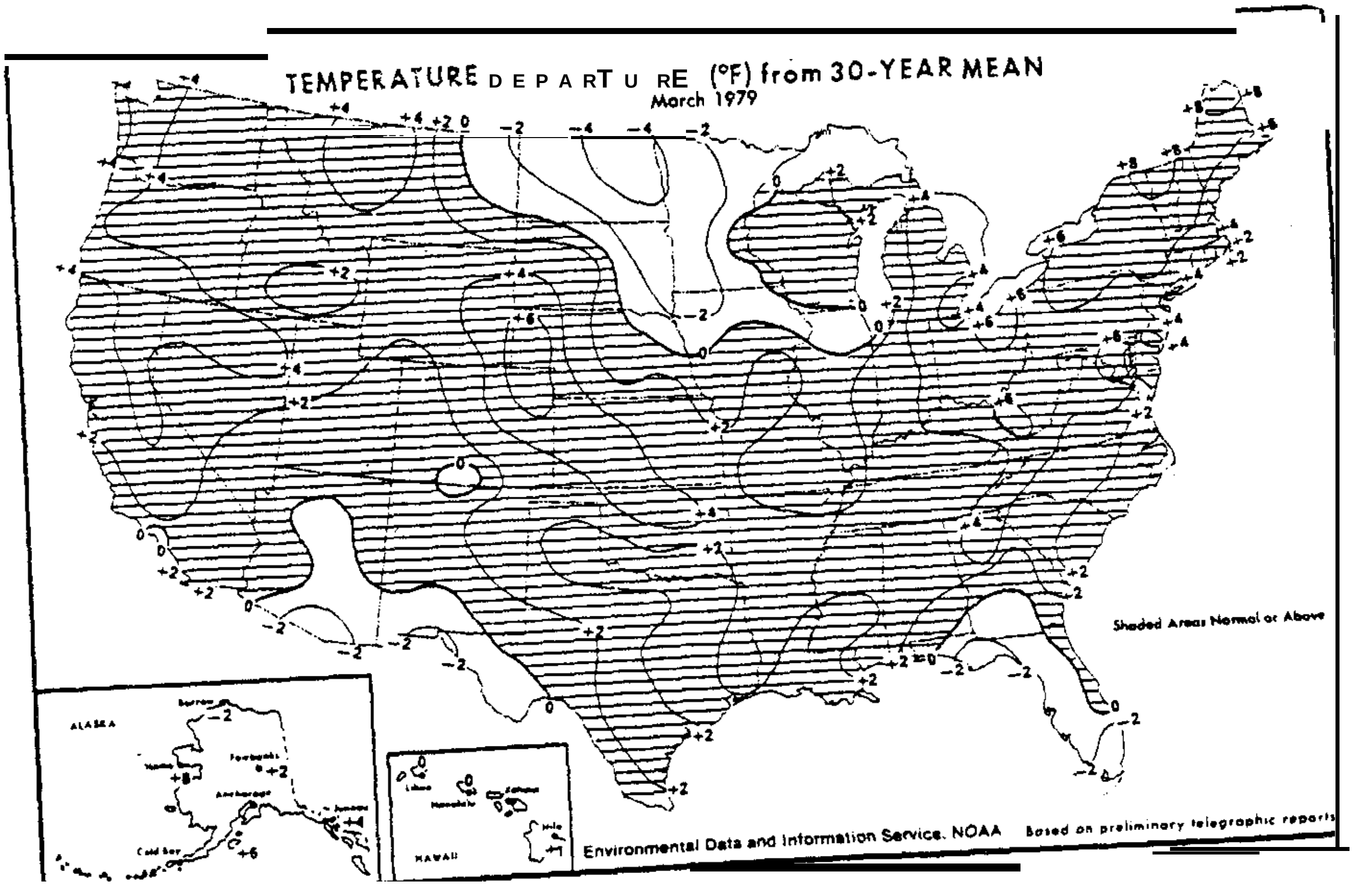


Figure 3e.--*Temperature departure* (° F) *from 30-year mean for March 1979.*

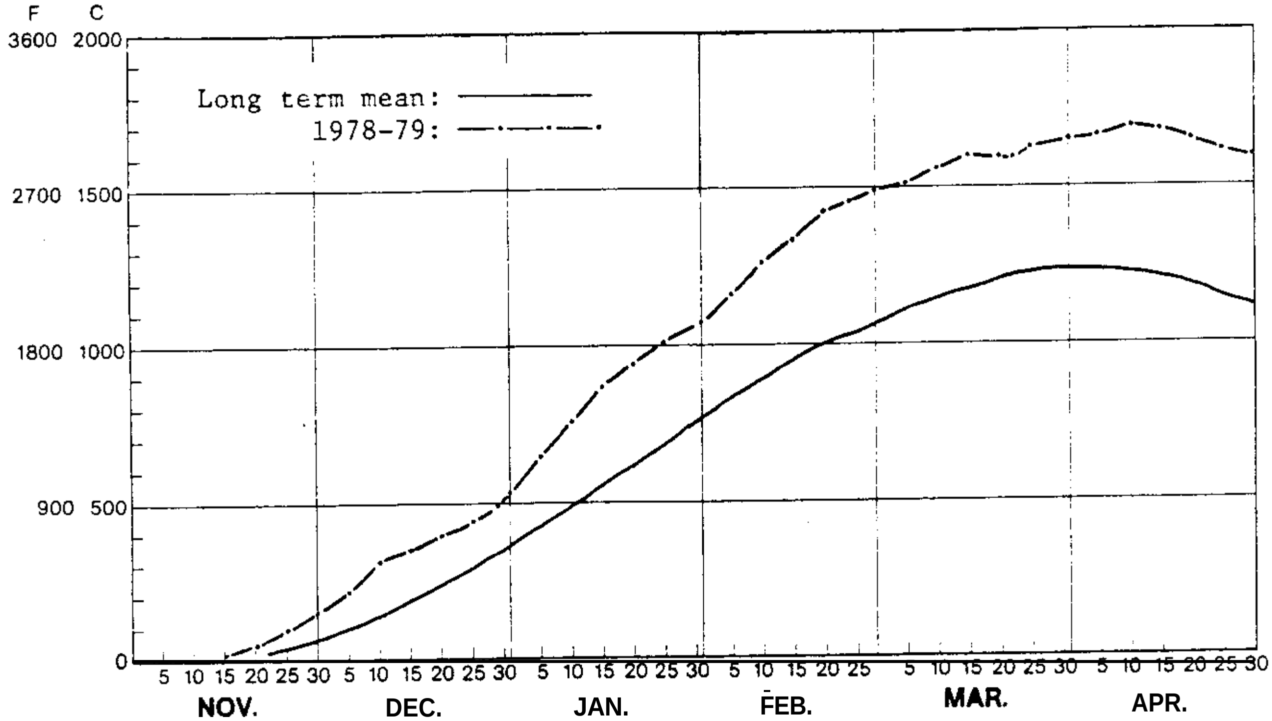


Figure 4a.--Freezing degree-day accumulations, Duluth, Minn.

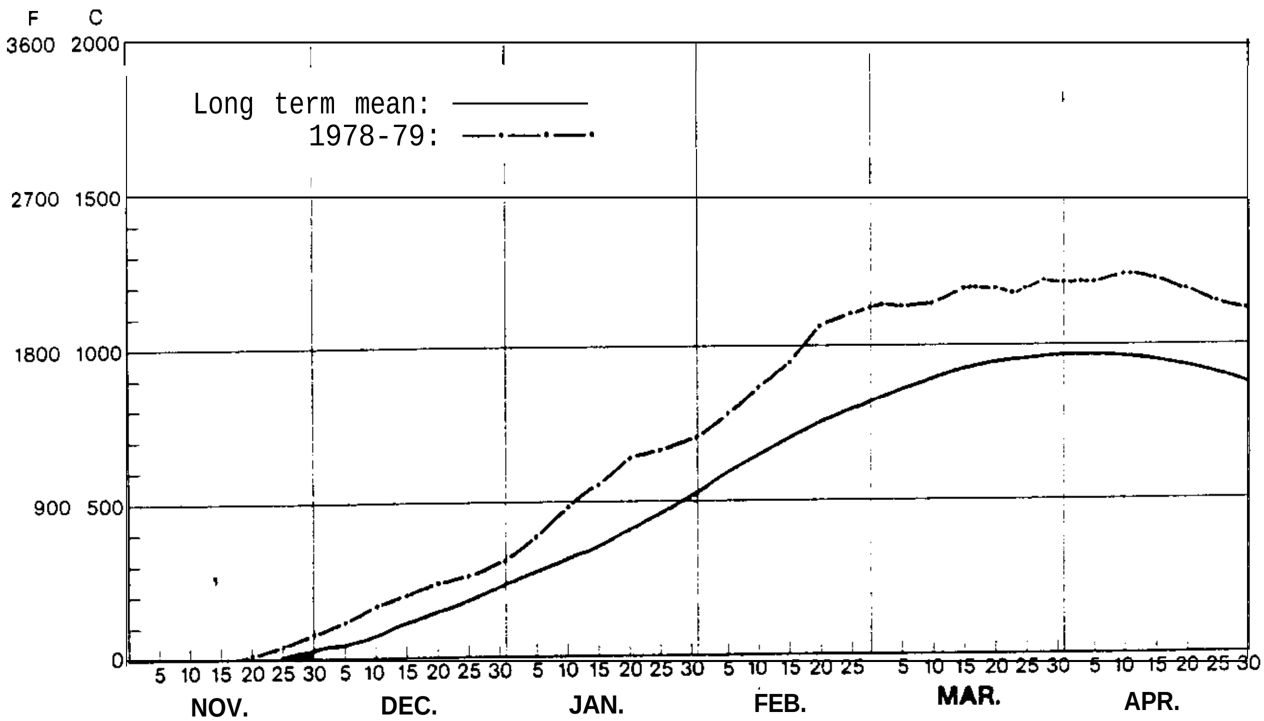


Figure 4b.--Freezing degree-day accumulations, Sault Ste. M & e , Mich.

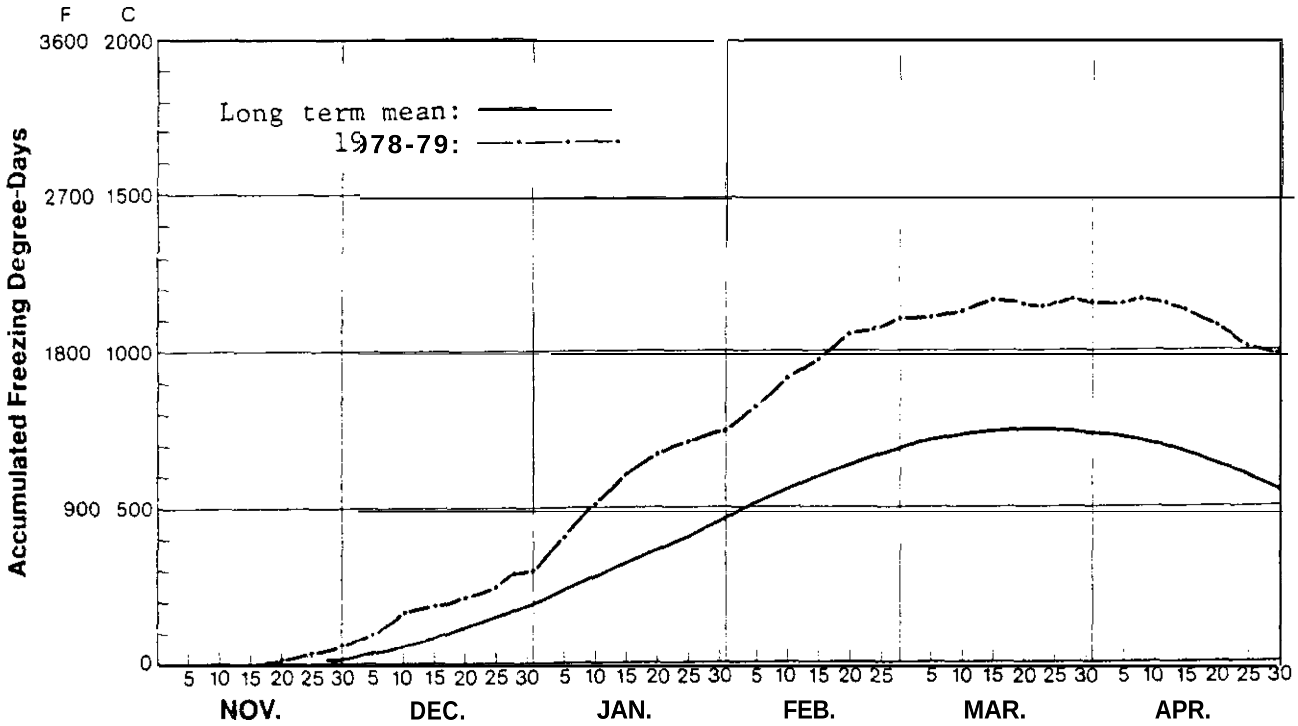


Figure 4c.--*Freezing degree-day accumulations, Green Bay, Wis.*

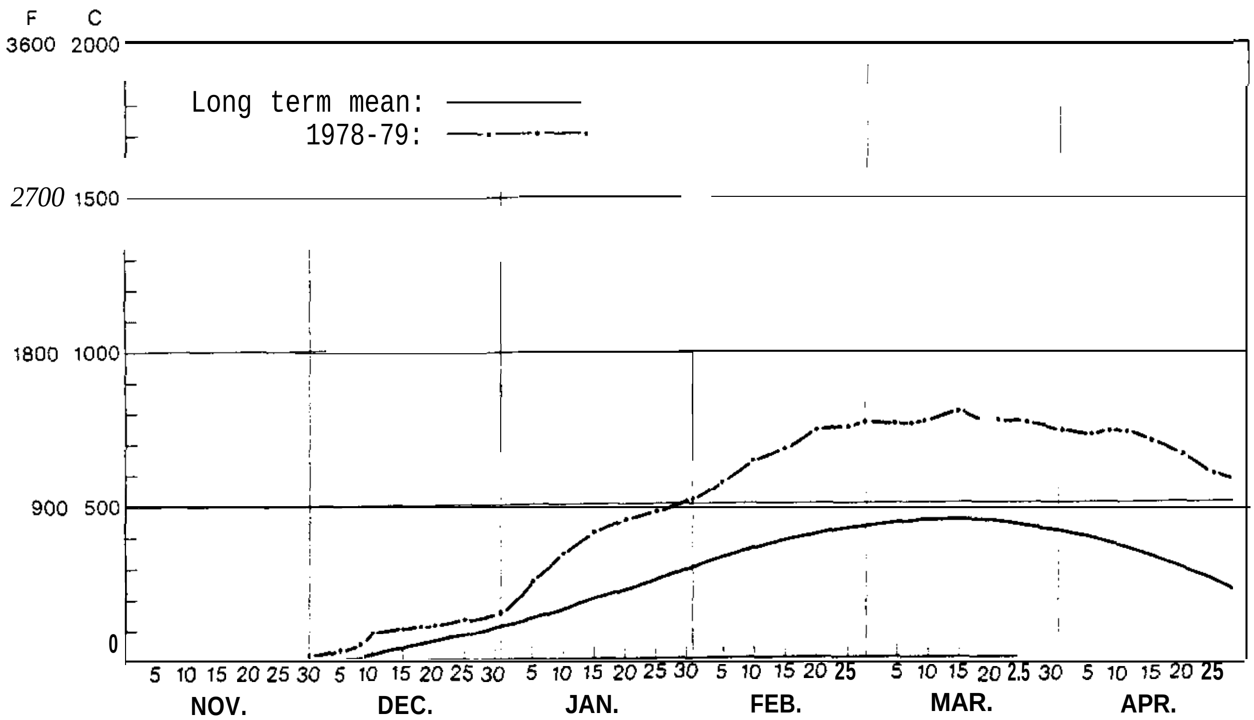


Figure 4d.--*Freezing degree-day accumulations, Milwaukee, Wis.*

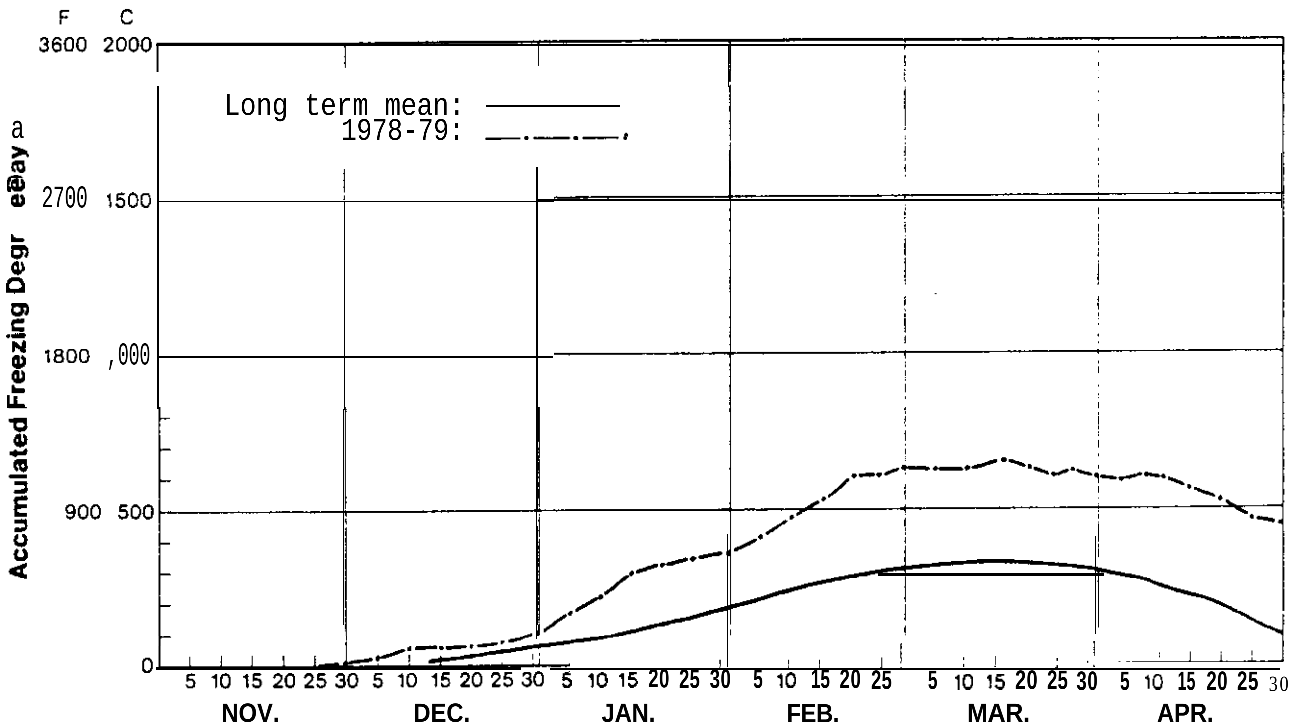


Figure 4e.--Freezing degree-day accumulations, Muskegon, Mich.

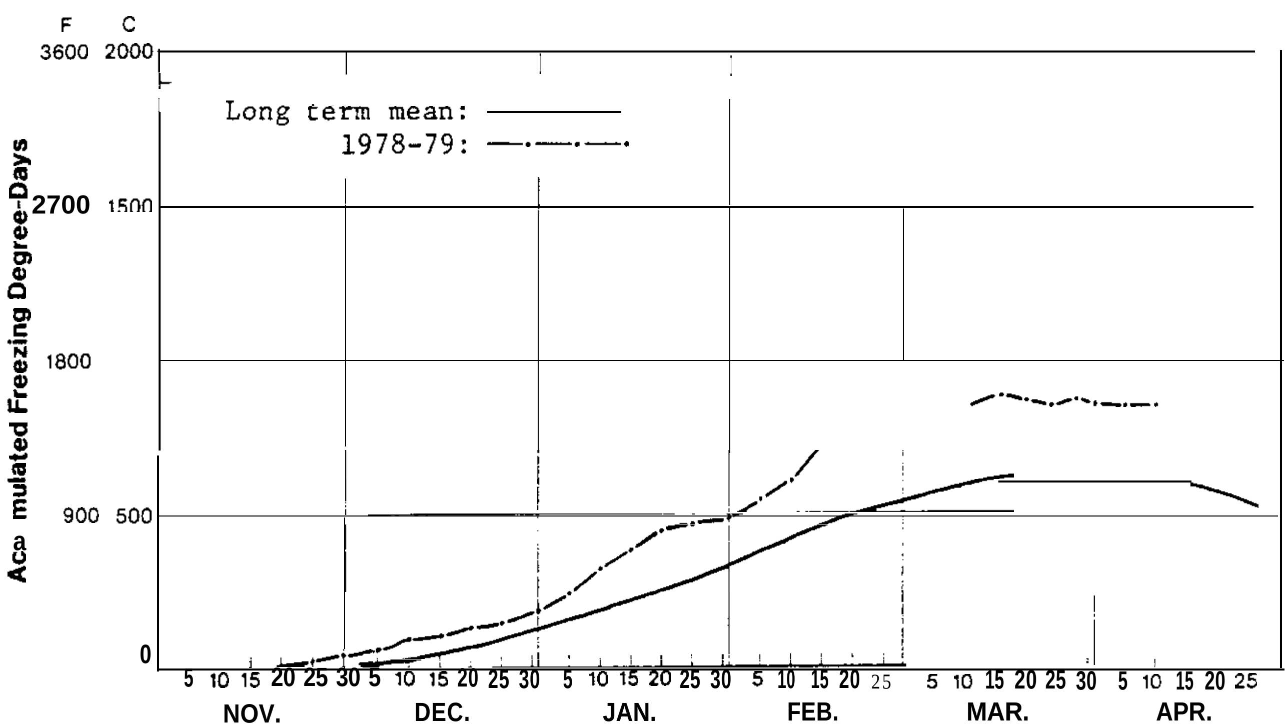


Figure 4f.--Freezing degree-day accumulations, Alpena, Mich.

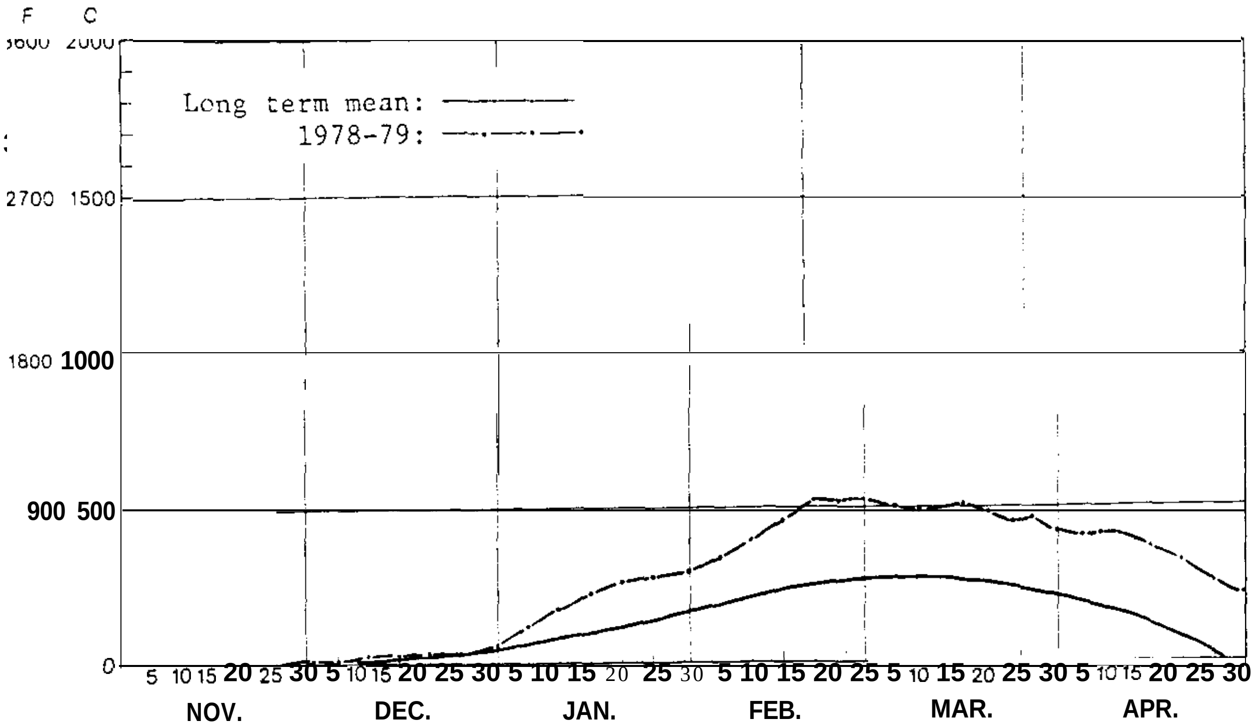


Figure 4g.--Freezing degree-day accumulations, Detroit, Mich.

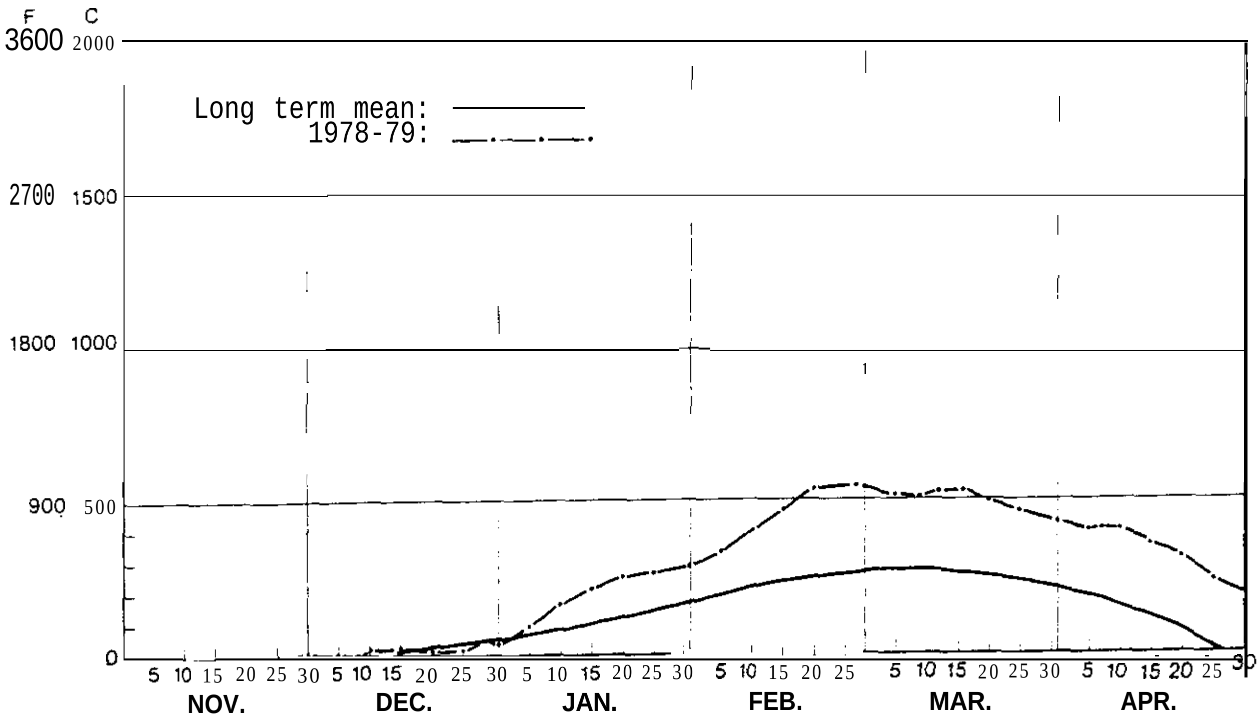


Figure 4h.--Freezing degree-day accumulations, Toledo, Ohio.

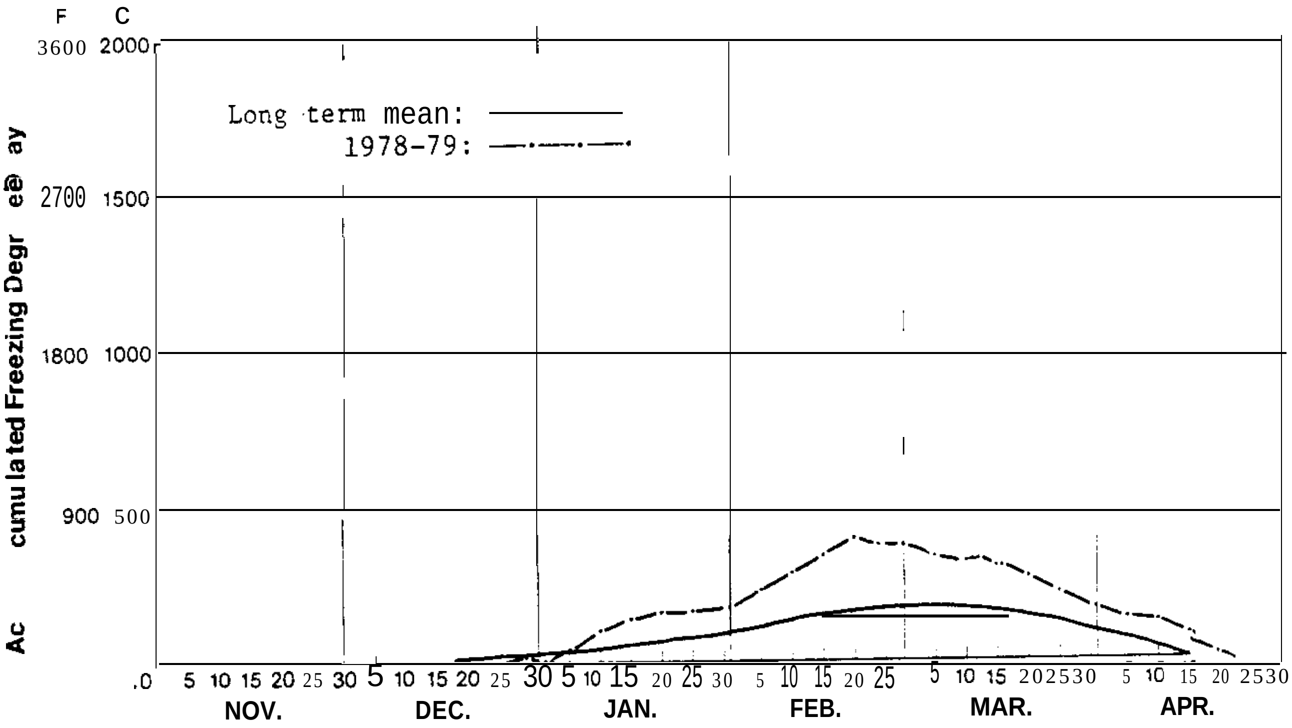


Figure 4i.--*Freezing degree-day accumulations, Cleveland, Ohio.*

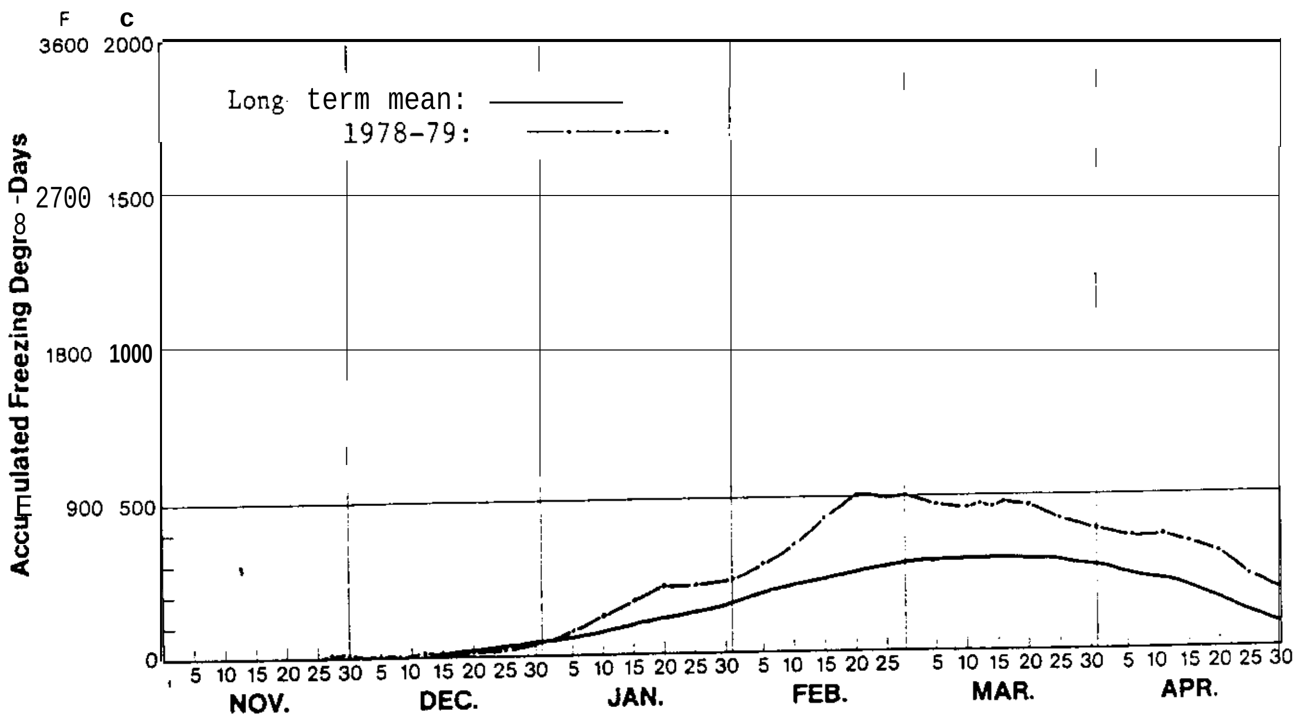


Figure 4j.--*Freezing degree-day accumulations, Buffalo, N.Y.*

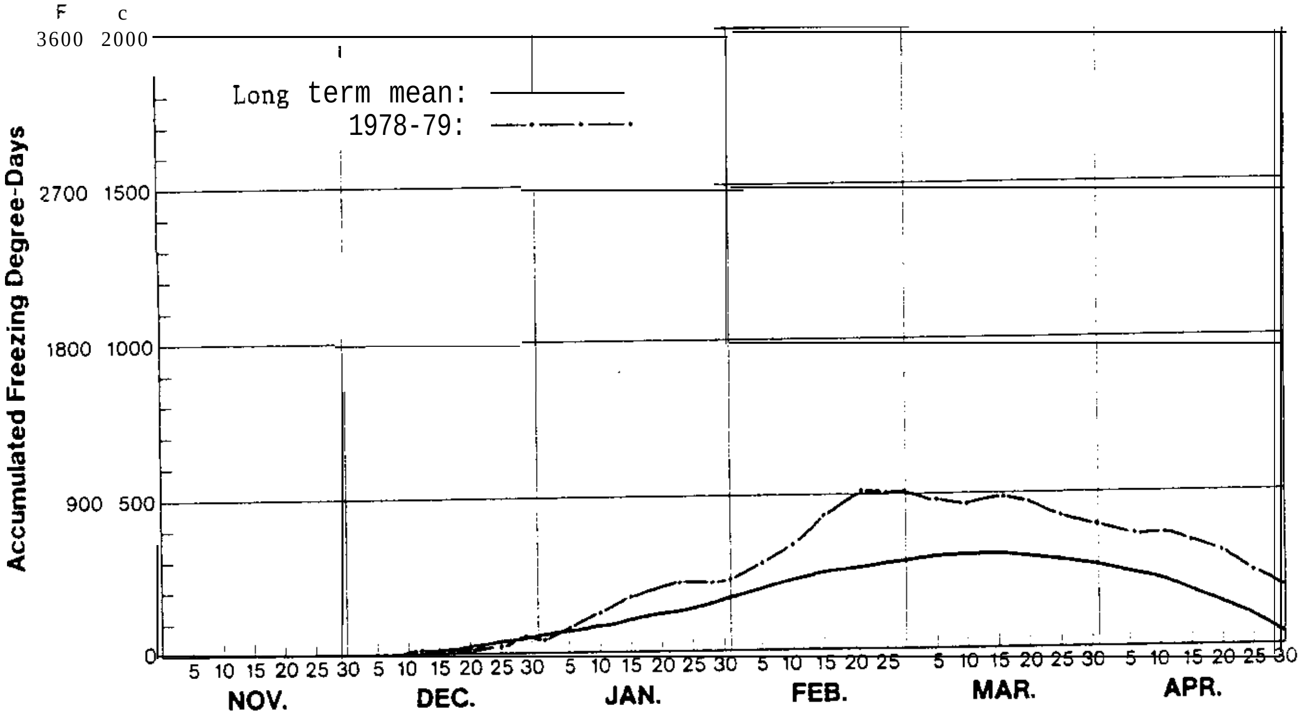


Figure 4k.--Freezing degree-day accumulations, Rochester, N.Y.

3. SUMMARY OF ICE CONDITIONS

D. F. Kahlbaum, J. Wartha, D. G. Baker, and B. H. DeWitt

3.1 Data Collection Platforms and Processes

Primary sources of ice-cover information used to document the 1978-79 Great Lakes ice cover include: visual aerial ice reconnaissance, side looking airborne radar (SLAR), and satellite imagery. Ice charts are the end result of interpretation of these data. Ice charts depicting ice distribution and concentration, as well as size and age of floes, were received at the Great Lakes Environmental Research Laboratory (GLERL) throughout the winter from the Ice Navigation Center, Cleveland, and Ice Forecasting Central, Ottawa, Ontario. Interpretations of ice conditions made from TIROS-N, and Geostationary Operational Environmental Satellite (GOES) imagery were received from NESS in Washington, D.C. SLAR imagery and ice charts based on it were received from the Ice Navigation Center, Cleveland. In addition to these primary data, weekly and daily surface reports of ice conditions and thickness were received from observers for GLERL and the U.S. Coast Guard.

3.1.1 Visual Aerial Ice Reconnaissance

Trained ice observers for the United States Coast Guard and the Canadian Department of the Environment record visually observed ice conditions on the Great Lakes periodically during winter.

U.S. Coast Guard aircraft used for visual ice reconnaissance include the Grumman HU-16 Albatross and smaller fixed wing craft and rotary (helicopter) aircraft. Flights are made from Chicago, Ill.; Detroit, and Traverse City, Mich. Canadian aircraft used to support visual aerial ice reconnaissance include a Douglas DC-3 and a Lockheed Electra L188C.

3.1.2 Side Looking Airborne Radar

The National Aeronautics and Space Administration Lewis Research Center, in cooperation with the U.S. Coast Guard and NOAA, has developed an HC 130B SLAR system for ice surveillance on the Great Lakes. The system, mounted aboard an HC-130B aircraft operating out of Cleveland, operates in the X-band at a frequency of 9.245 GHz (3.245 cm wave length). Flight altitude for SLAR missions is 3.35 km (11,000 ft) with an average ground speed of 280 kn. Flights are made regularly over all of the Great Lakes with the exception of Lake Ontario. The advantage of SLAR over visual reconnaissance and satellite imagery is its all-weather capability and ability to "See" through clouds. Schertler et *al.* (1975) give a history of the development of the current system.

3.1.3 Satellite Imagery

TIROS-N and GOES satellite imagery were used in ice-cover documentation. The TIROS-N satellite represents the third generation of operational satellites in the National Environmental Satellite Service. The orbit is near polar and Sun synchronous so the satellite always crosses the Equator at the same local solar time, in this case 0730 and 1500. This type of orbital coverage permits detection of dynamic snow and ice events twice daily. Cloudiness commonly reduces these observations, but in most of the United States it is possible to secure at least one cloudless view per week.

The GOES images ware prepared from Visible Spin Scan Radiometer (VISSR) negatives stored at NOAA's Environmental Data and Information Service. Tapes were not archived for GOES/VISSR images. Most of the GOES images presented here have not been enhanced or rectified. North-south foreshortening is noticeable in images taken in higher latitudes, such as those of the Great Lakes.

3.2 General Description

The ice cycle that occurs on the Great Lakes each winter can be divided into three phases (Rondy, 1976): a cooling phase, an ice formation phase, and a breakup or fragmentation phase. In brief, the cooling phase starts in fall as air temperatures drop below water temperatures and the water begins to lose heat. Ice formation starts after fall overturn is completed and a stable water density gradient enables rapid cooling to take place in the surface layer. During the ice formation phase, both stable and dynamic ice is formed. Even though the net energy balance of the lake is negative during this time, i.e., the water mass is losing heat, rapid and extensive changes in ice extent and thickness can occur owing to wind- and current-induced ice movement, upwelling of warmer waters, and even midwinter thaws on some portions of the Great Lakes. The breakup period begins when the energy balance of the ice cover becomes positive and may be well defined and short if a warming trend starts and is persistent, or it may drag on as cold and warm periods alternate in frequency and intensity in spring.

A set of 21 composite ice charts and 23 satellite images illustrate the distribution and concentration of ice cover during the 1978-79 winter. (See figs. 5a-5u and 6a-6w). The composite ice charts were prepared at weekly intervals; each chart provides an estimate of the synoptic ice conditions for Wednesday of that week. In the preparation of each chart, it was necessary to critically evaluate available source data described in section 3.1. During this evaluation process, it was interesting to note a considerable day-to-day change in the ice cover during a single weekly period. However, a study of synoptic weather charts and wind data verified that the changes in ice cover logically responded to the strong winds associated with storm passage. Consequently the weekly ice charts, which it will be recalled represent synoptic ice conditions for a given date during the week and not average ice conditions for the week, do not always reflect progressive continuity during the winter season.

FDD's, which progressively accumulate during the winter season, are plotted on each ice chart for eight representative locations. FDD's are useful to define winter severity (Assel and Quinn, 1979, and Rondy, 1971) and they have also been correlated with ice thickness and extent (Assel, 1976, and Rogers, 1976). However, it should be noted that numerous other variables are involved in the formation, extent, and decay of ice on the Great Lakes and the FDD's provide only one index for gaging the potential for ice formation and winter severity. Other factors, such as water depth, storm passage, and lake bottom topography, are discussed later in this re-. port and documented in the appendices. The FDD's given on the composite ice charts were calculated from daily National Weather Service weather observations, and they provide a summary of (1) the current FDD total in the week ending on the date of each chart, (2) the total accumulation of FDD's for the season, and (3) the climatological normal accumulation up to and including the date of each chart. Because of the conversion of the original data from degrees Fahrenheit to degrees Celsius, the summary FDD's on the ice charts in some instances are inconsistent owing to rounding off.

3.2.1 Fall Cooling Phase

Each lake goes through an isothermal stage twice each year, usually in April or early May, and again in December. At these times the lake is isothermal at 4° C (39.2' F). The heat content associated with this temperature can be taken as the base heat content of the lake.

Any excess or deficiency above or below this base heat content has been absorbed from or lost to the atmosphere since the last isothermal stage. Average air temperatures, integrated over periods of several months, have been found to give useful indications of the water's heat content.

Several different methods of integrating air temperature have been used. The most useful attempt so far, incorporating a "decay factor" to give greater weight to more recent data, is calculated as follows:

$$S_m = \frac{\Delta T_m + S_{m-1}}{2},$$

where

S_m is the heat storage factor at the end of a month,

ΔT_m is the departure from normal of the average air temperature for the month, and

S_{m-1} is the heat storage factor at the end of the previous month.

The physical meaning of the heat storage factor cannot be precisely defined. It approximates the excess heat, sensible and latent, of a unit water mass within the epilimnion.

By the end of August 1978, the heat storage factor was positive for Lake Ontario and negative elsewhere. The trend was reversed at the end of September except at Sault Ste. Marie. The predominately cooler than normal temperatures over the lakes region during October, November, and December of 1978 were reflected in the negative heat storage factor for all of the lakes except Ontario and Duluth during October. The heat storage factors for the fall of 1978 compare favorably with the fall of 1977. However, both the fall of 1977 and 1978 were not as cold as the fall of 1976 over the lakes region. The heat storage factors for the fall of 1976, 1977. and 1978 are summarized in table 6.

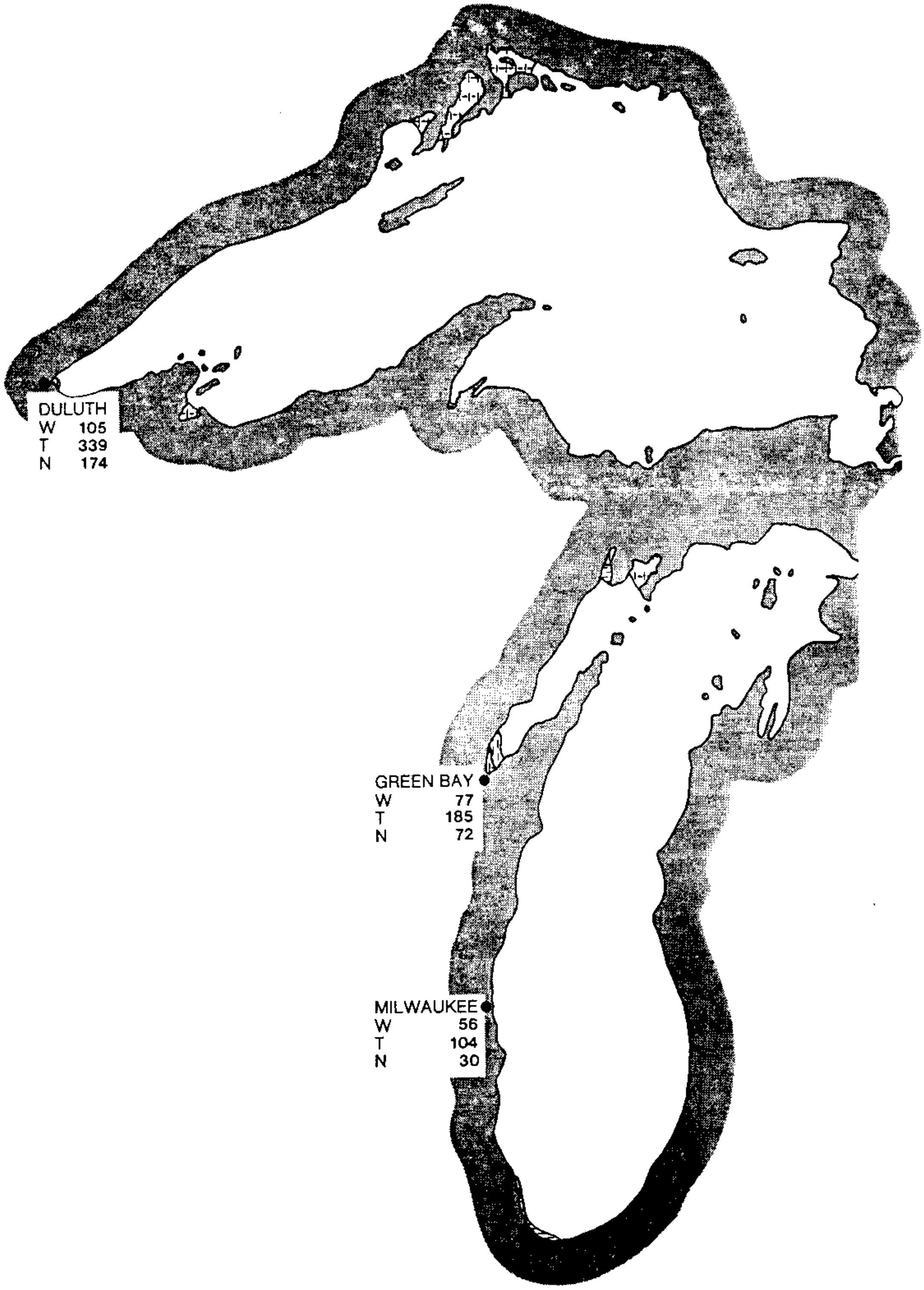


Figure 5a.--Composite ice chart for December 13, 1978.

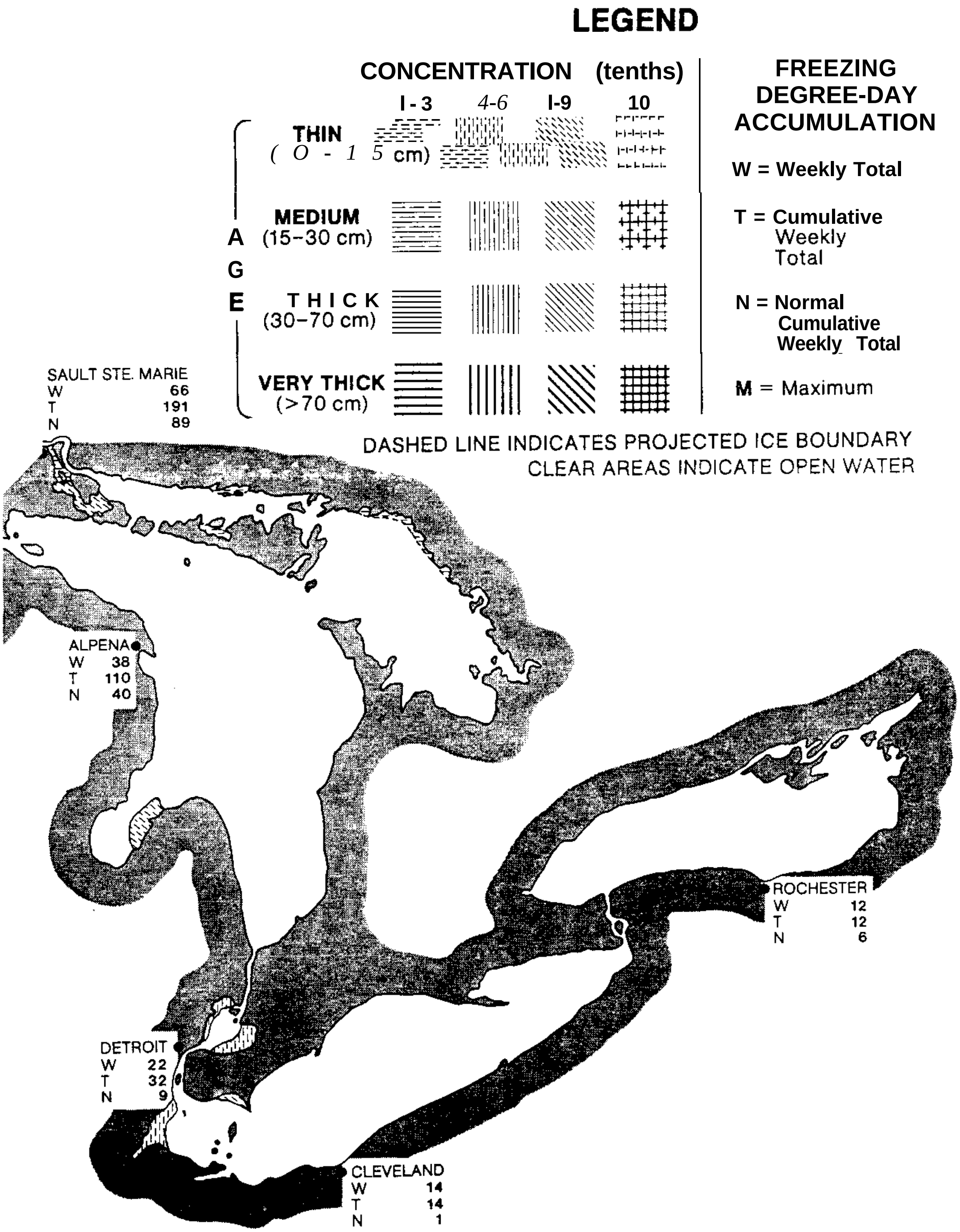


Figure 5a.--Composite ice chart for December 13, 1978 (con.).

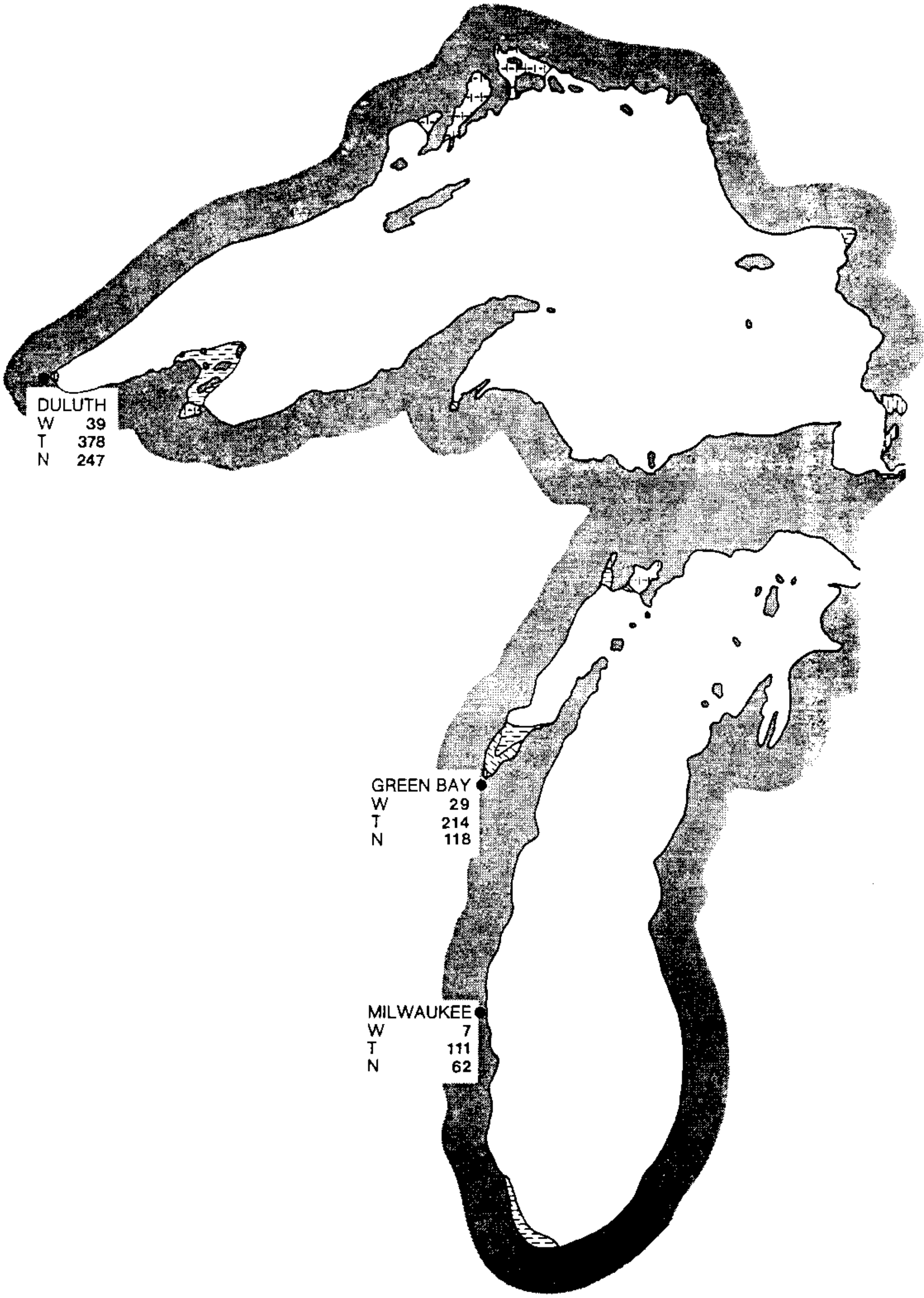


Figure 5b.--Composite ice chart for December '20, 1978.

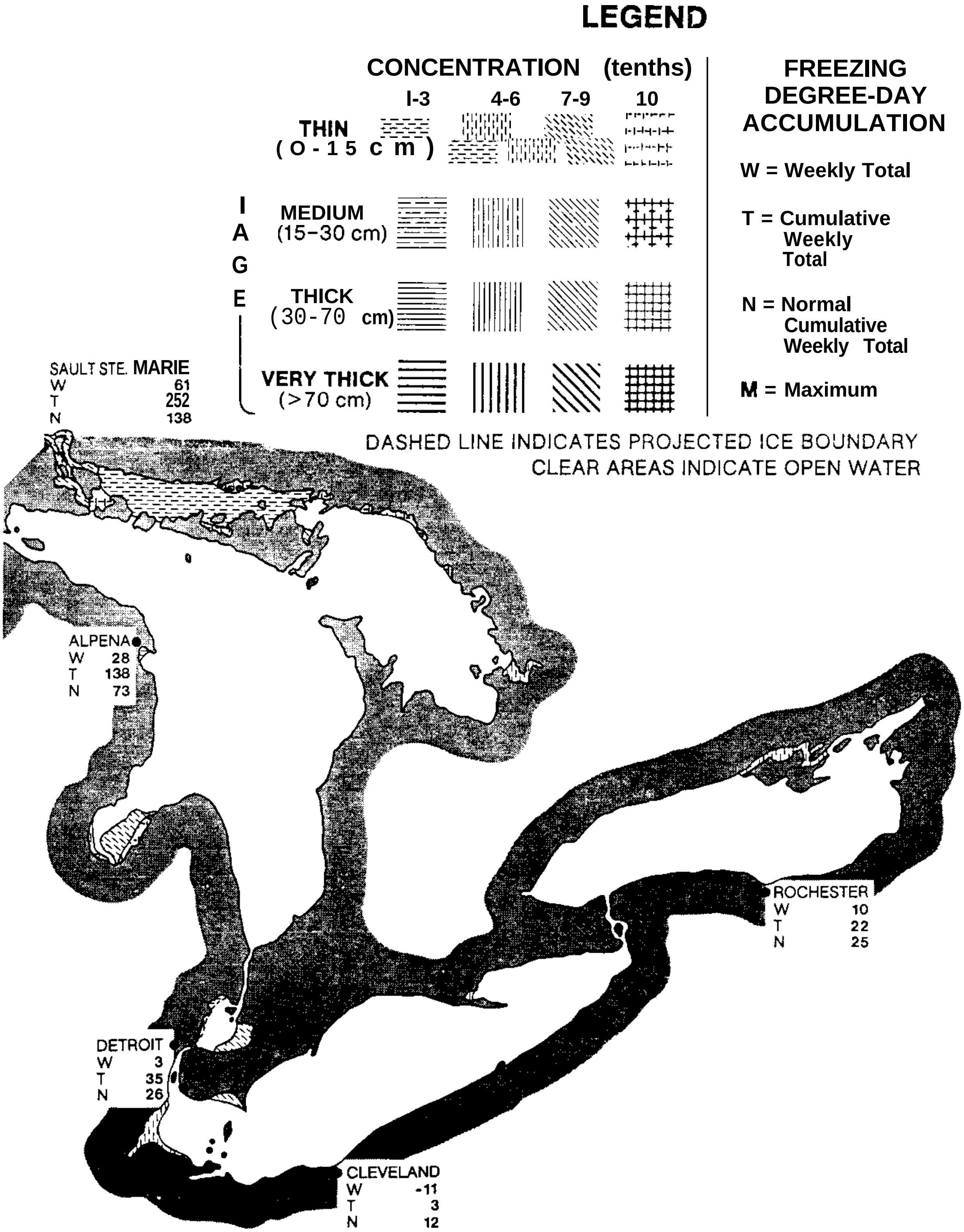


Figure 5b.--Composite ice chart for December 20, 1978 (con.).

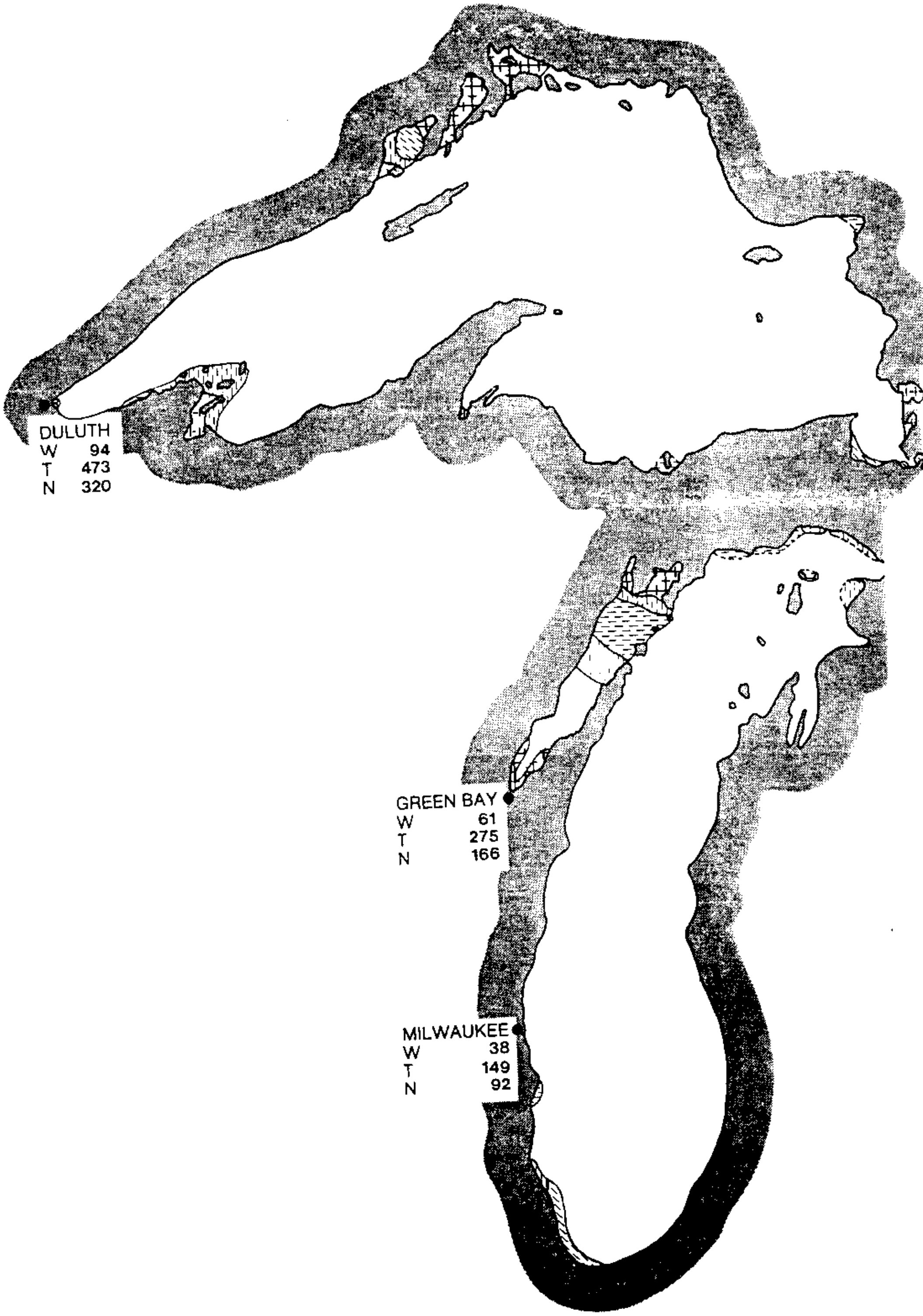


Figure 5c.--*Composite ice chart for December 27, 1978.*

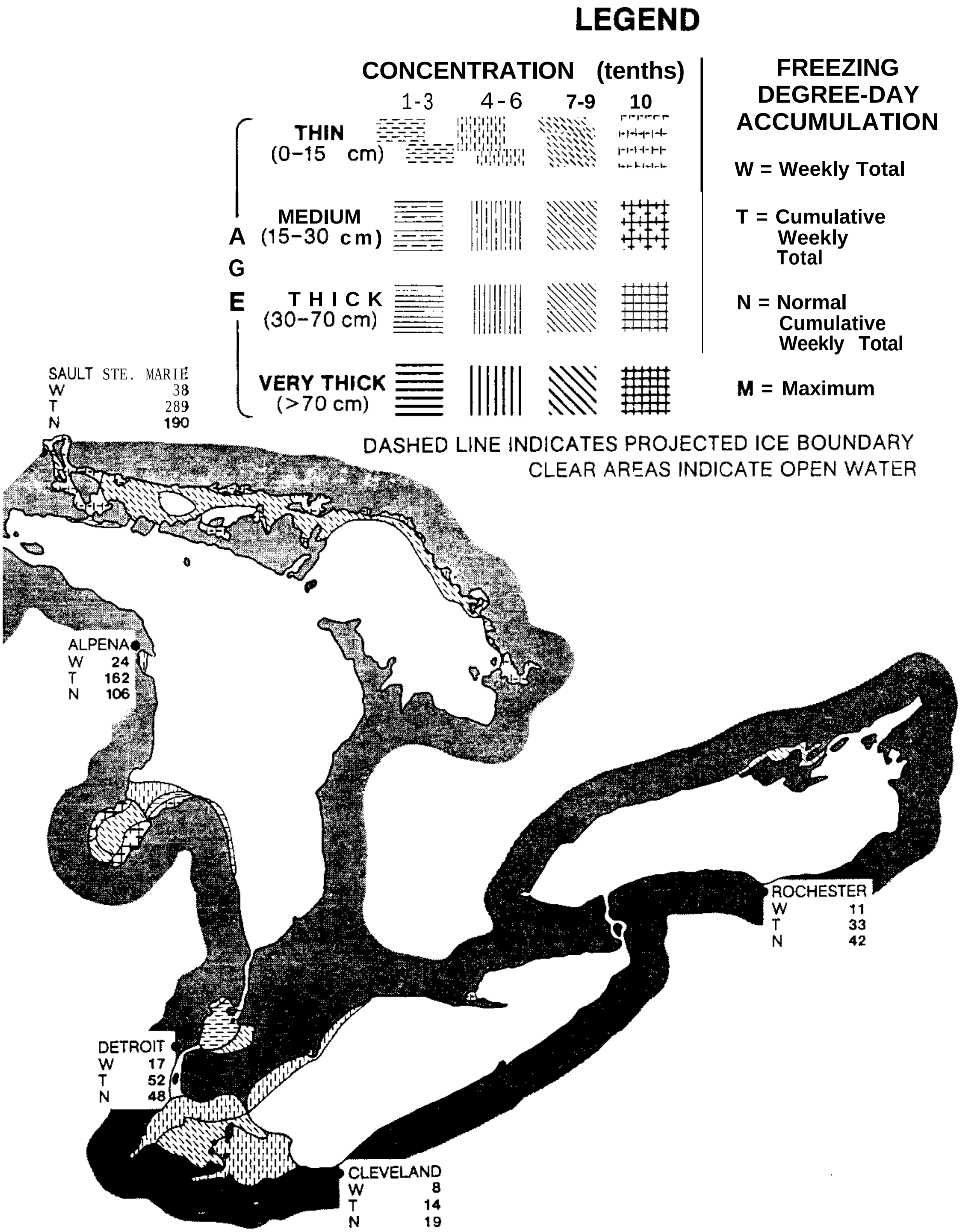


Figure 5c--Composite ice chart for December 27, 1978 (con.).

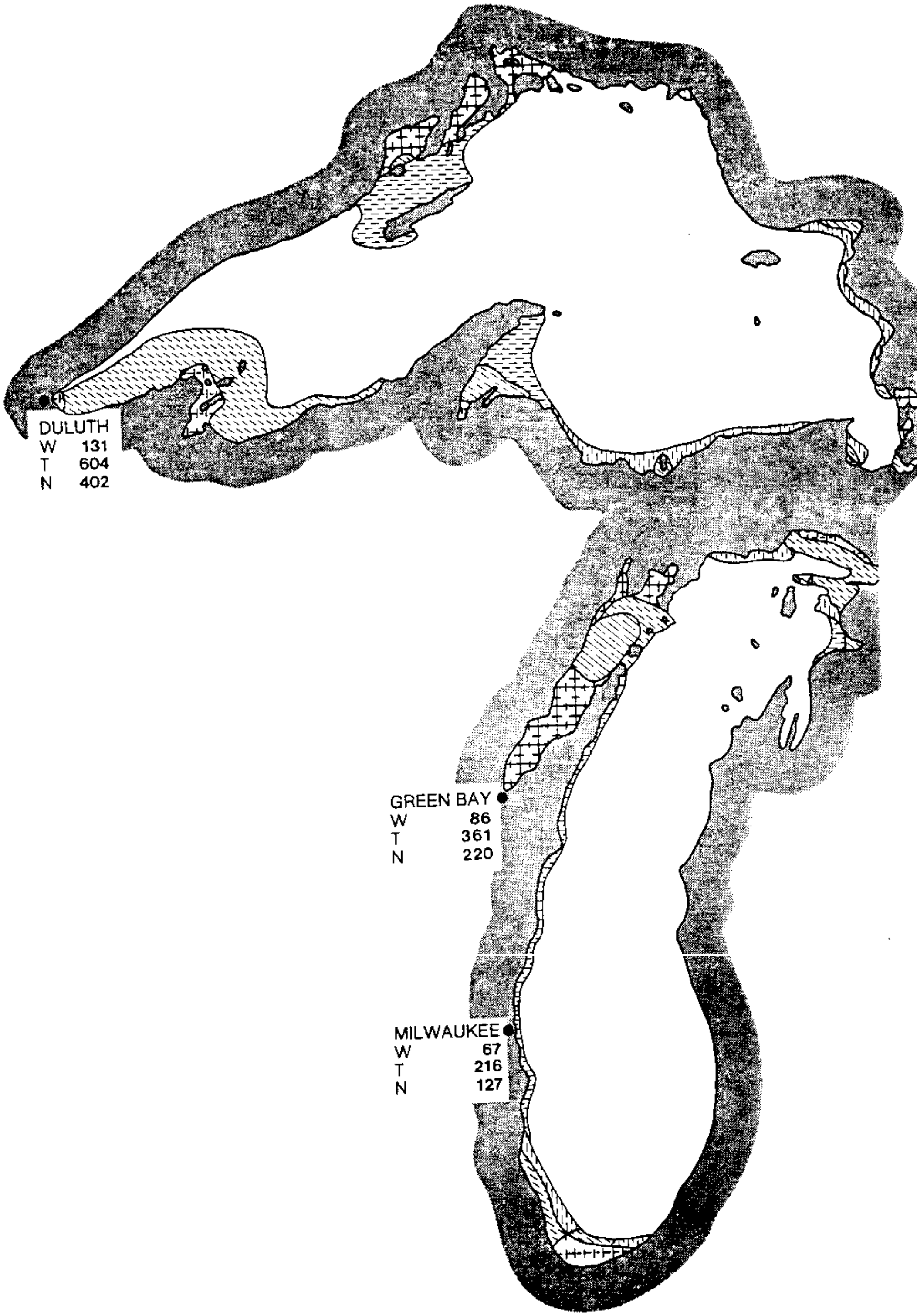


Figure 5d.--Composite ice chart for January 3, 1979.

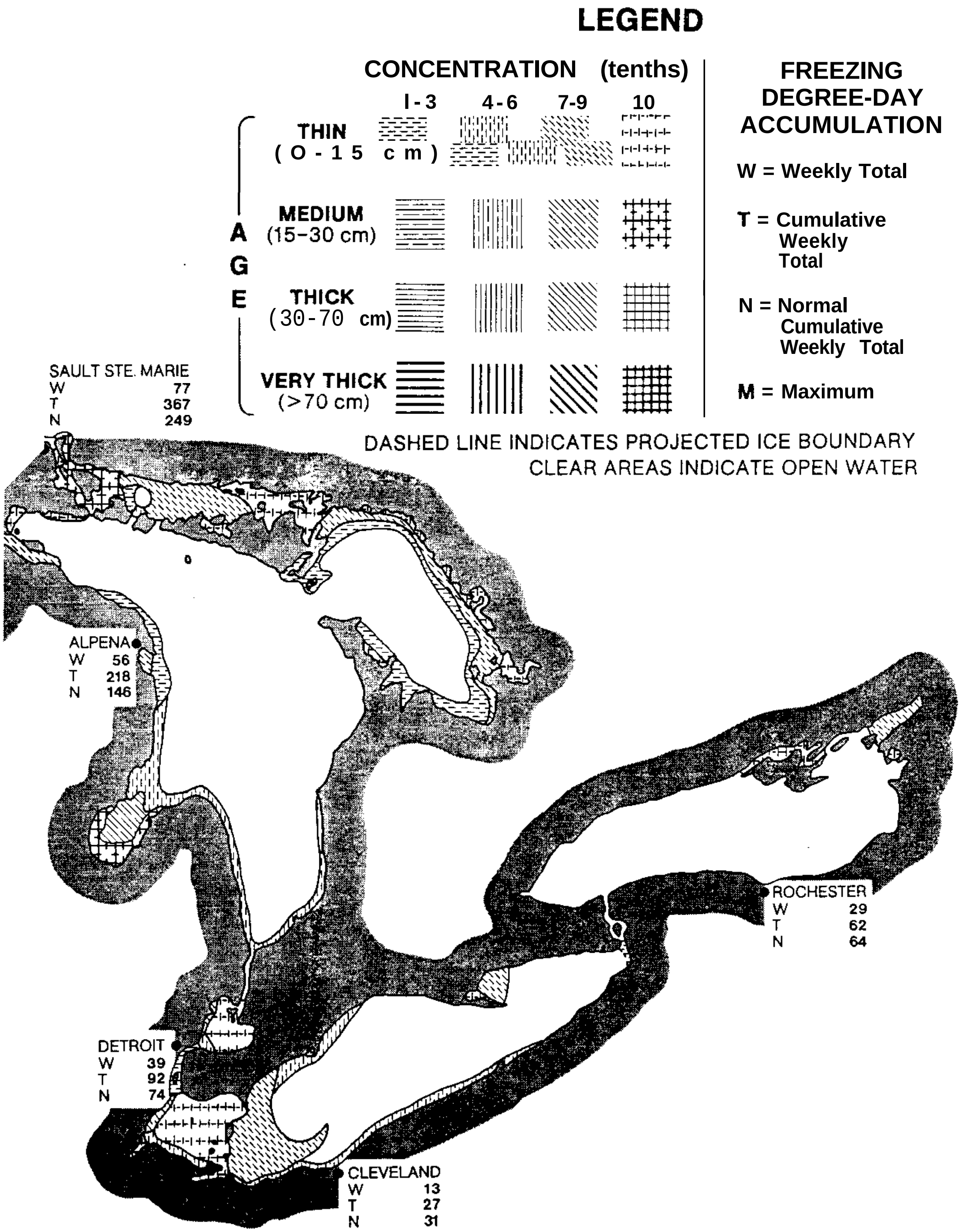


Figure 5d.--*Composite ice chart for January 3, 1979 (con.).*

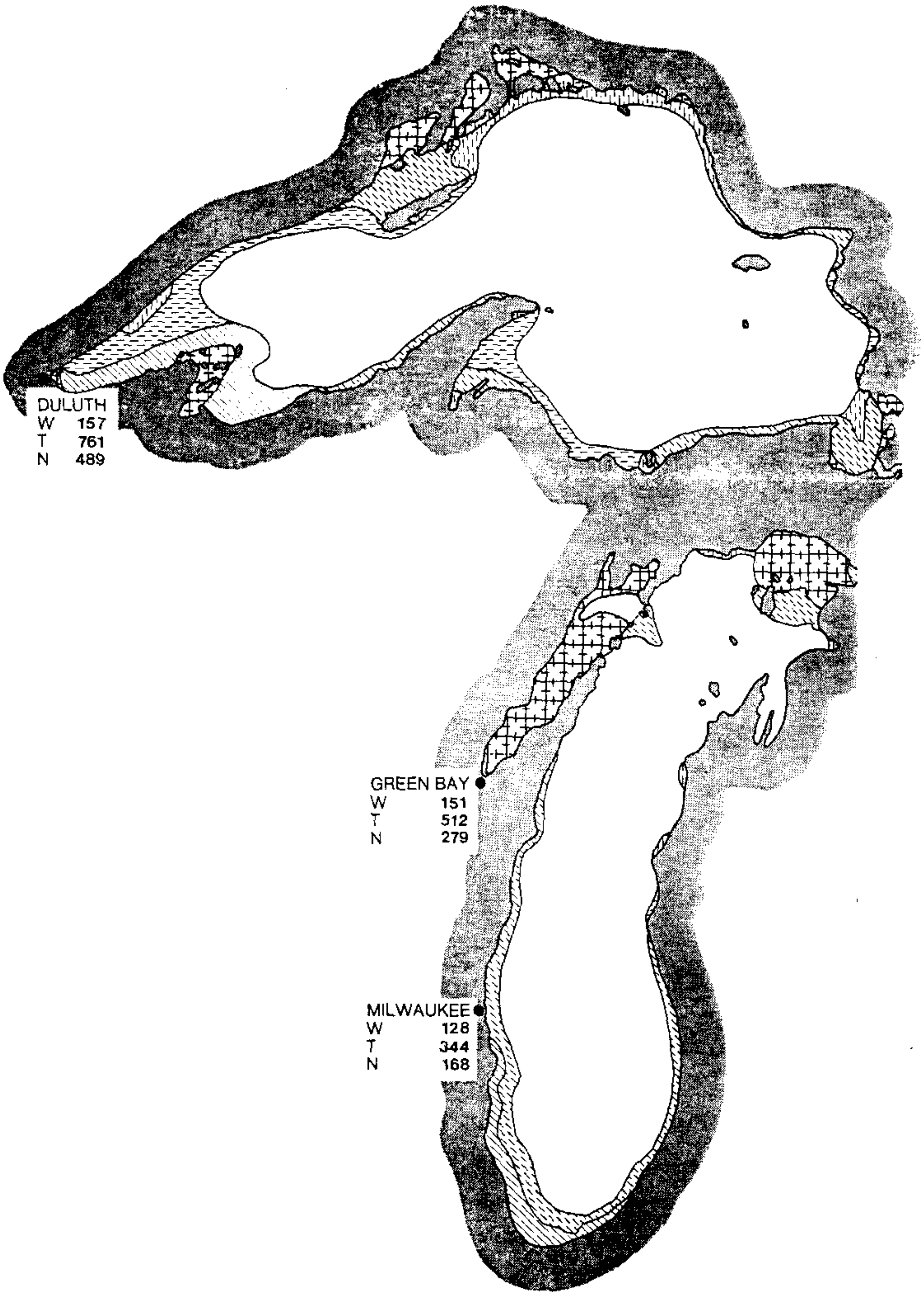


Figure 5e.--*Composite ice chart for January* 10, 7979.

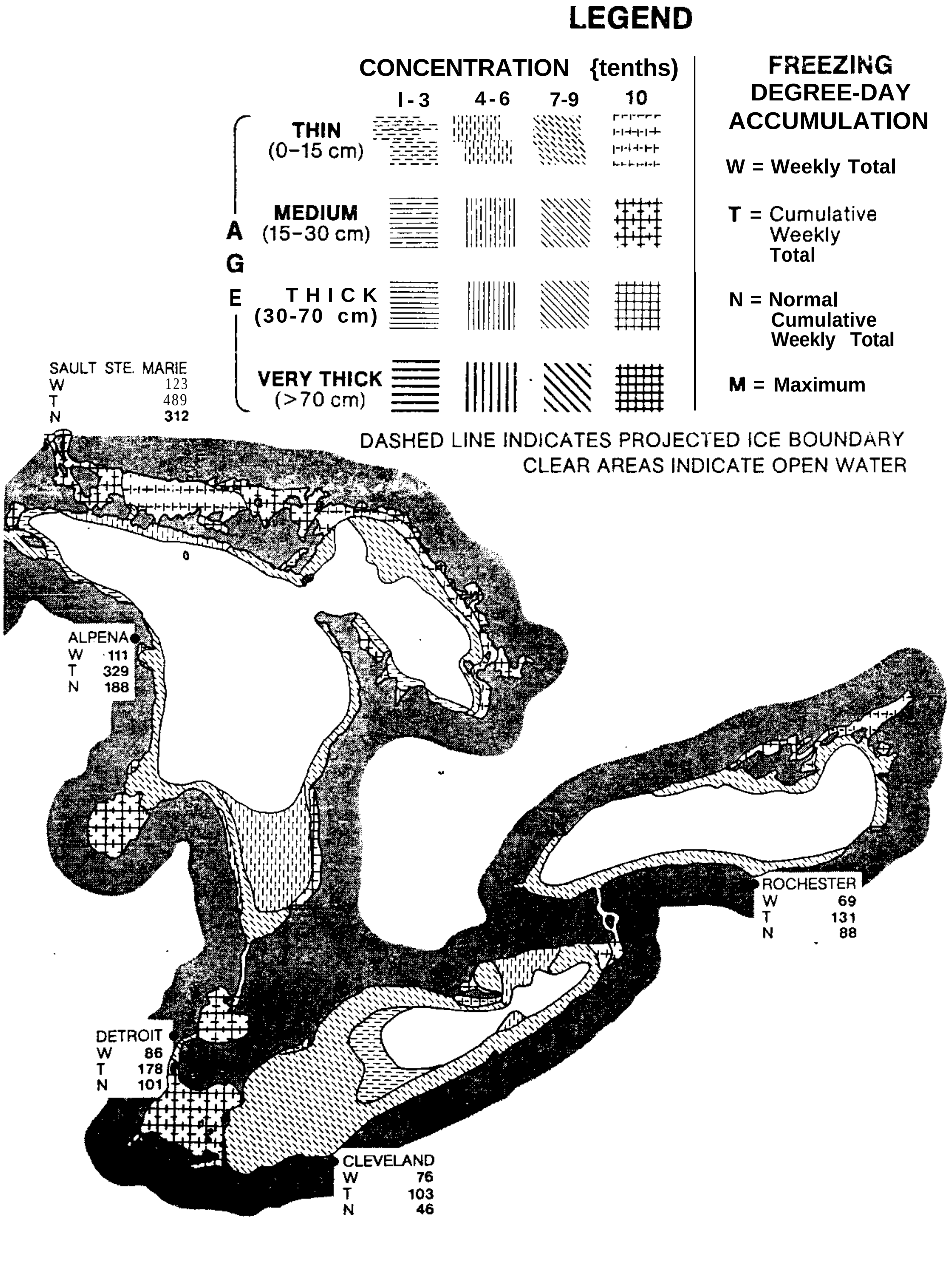


Figure 5e.--*Composite ice chart for January* **10, 1979** (con.].

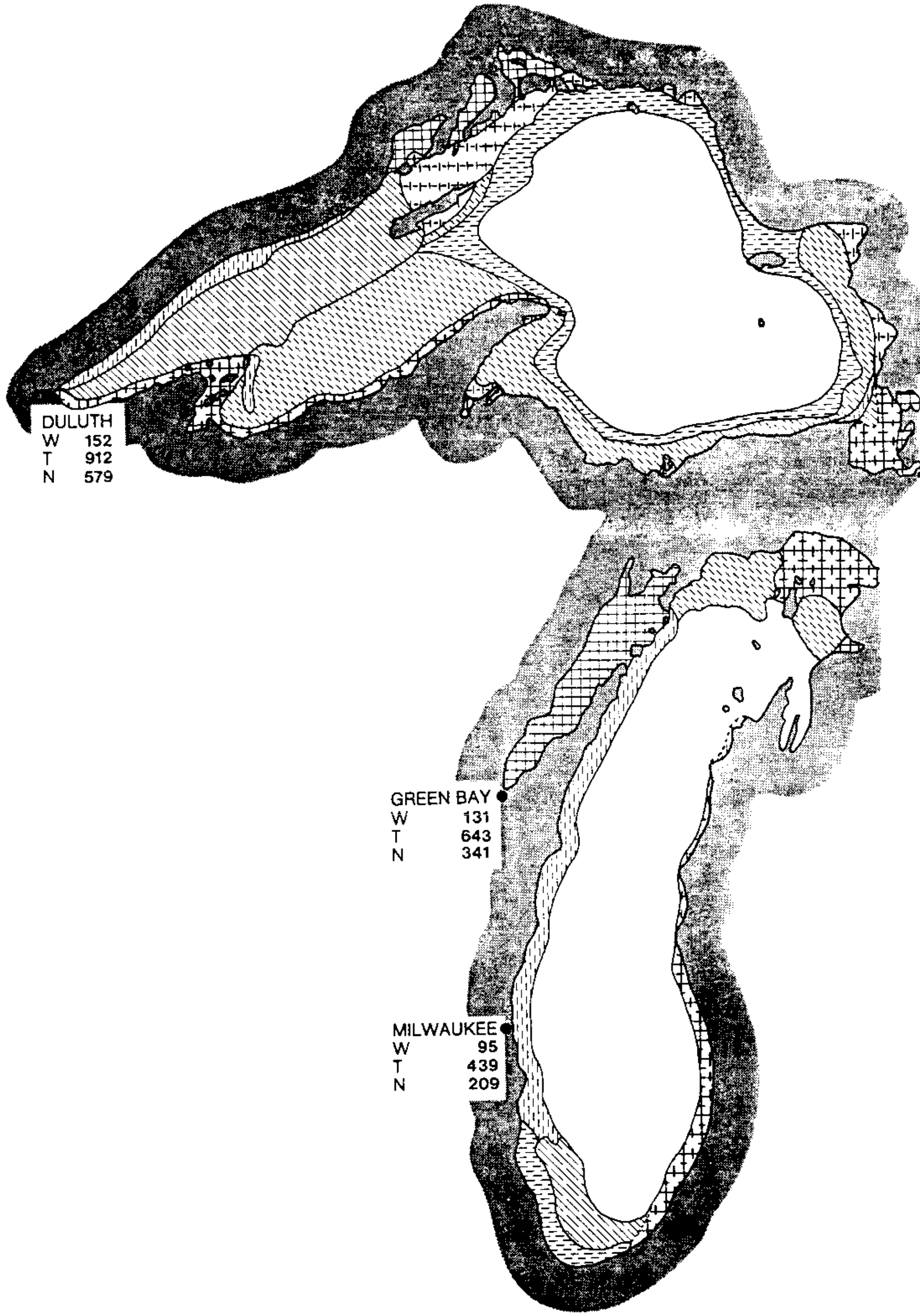


Figure 5f.--Composite ice chart for January 17, 1979.

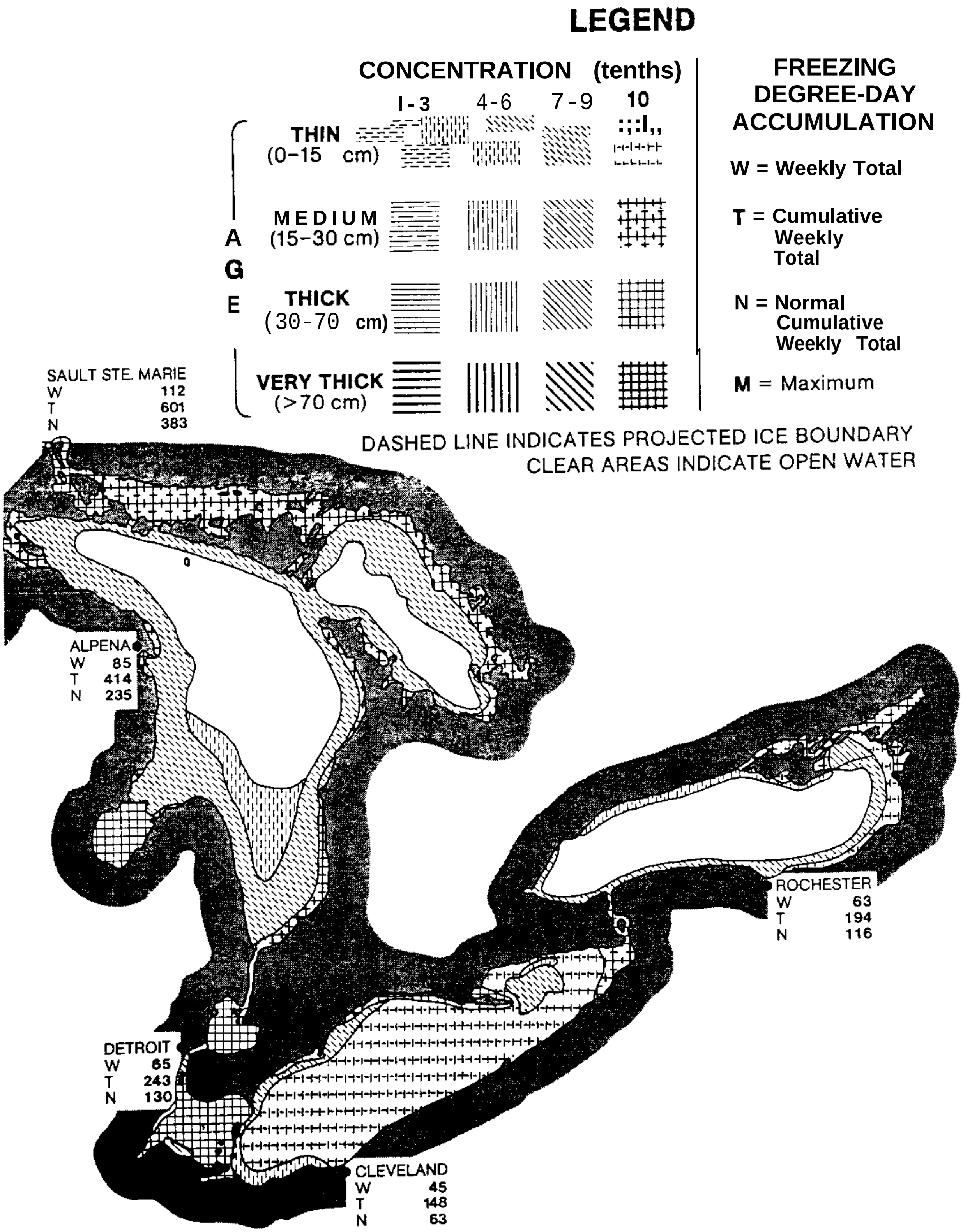


Figure 56.--Composite ice chart for January 17, 1979 (con.).

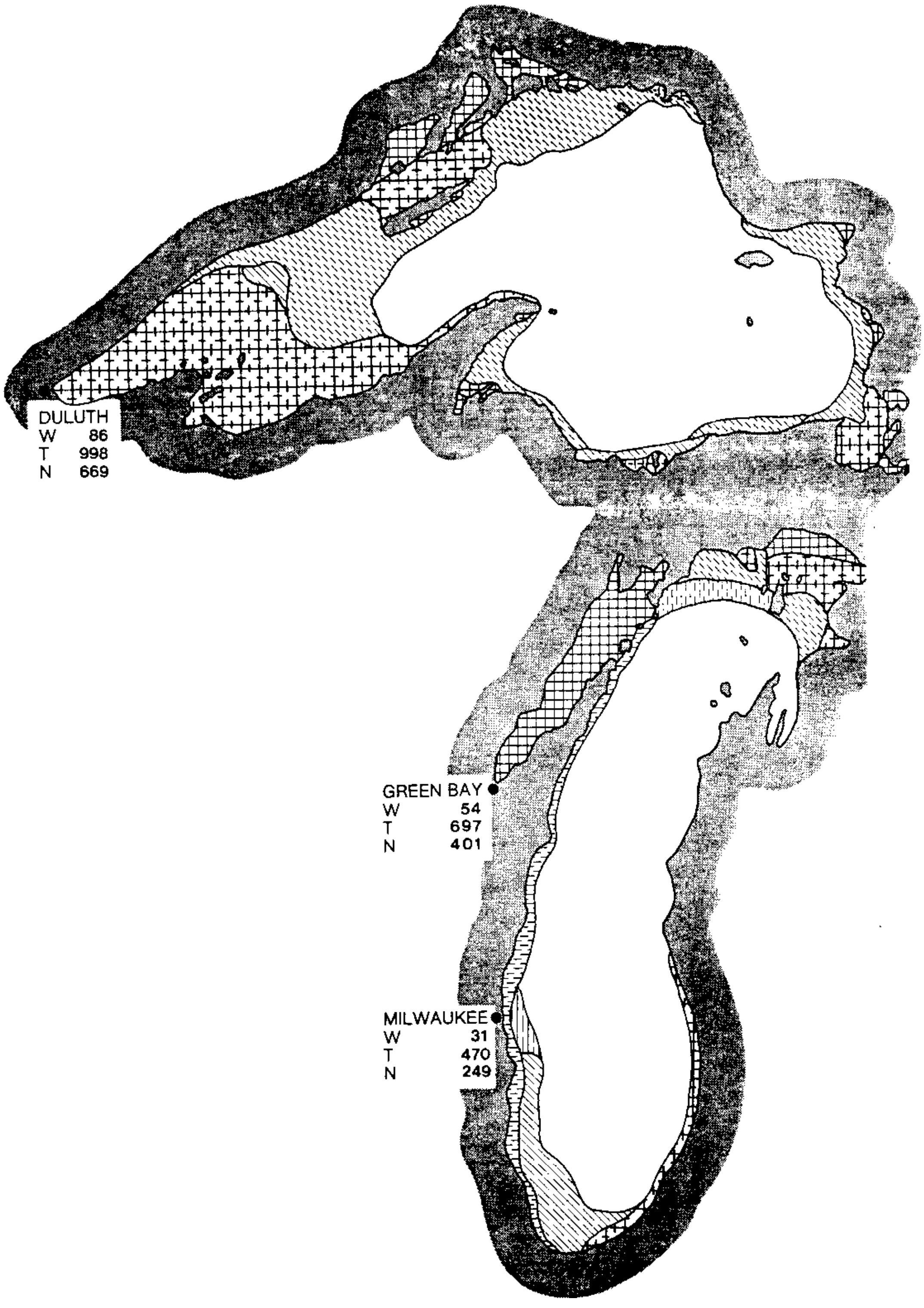


Figure 5g. --Composite ice chart for January 24, 7979.

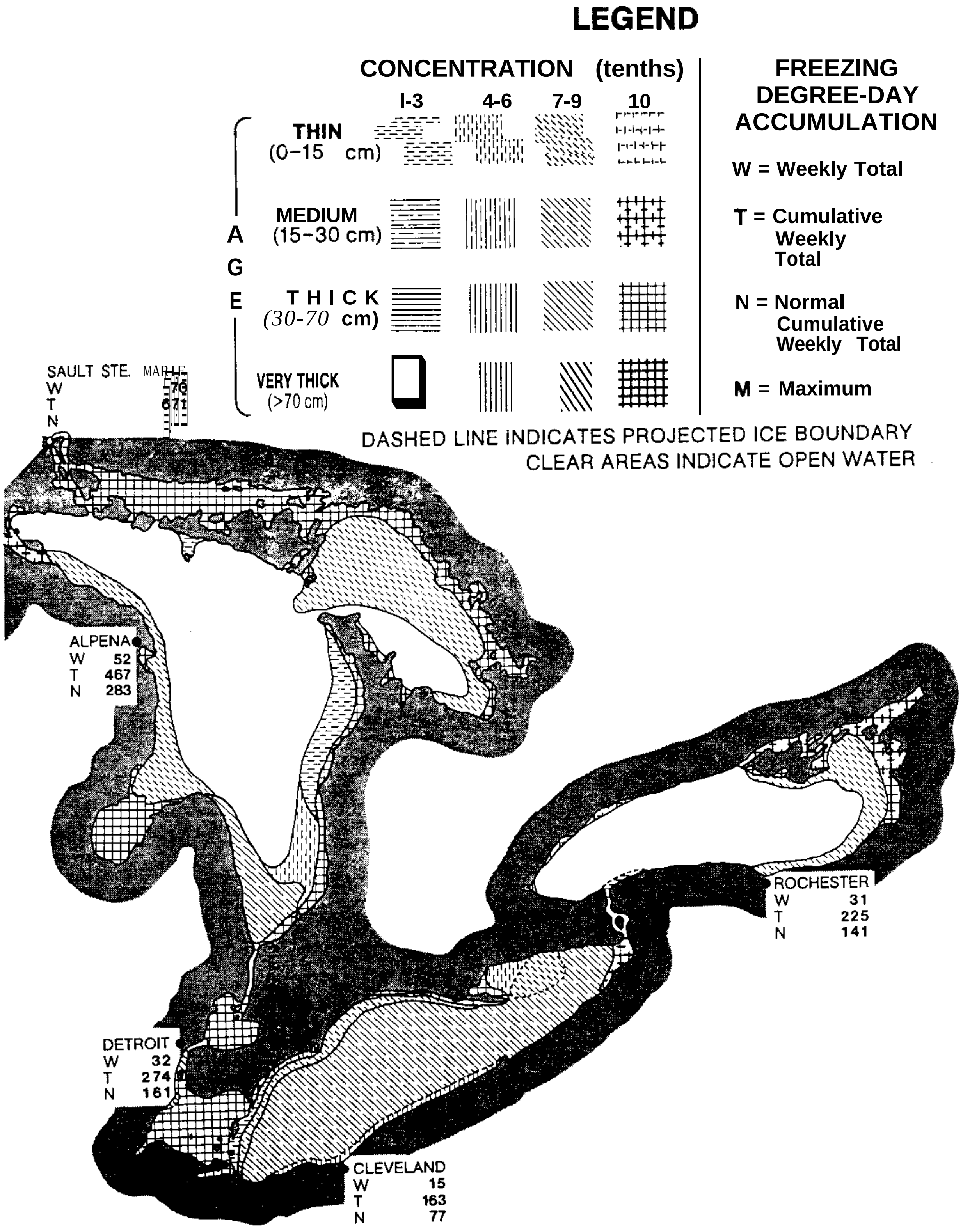


Figure 5g.--Composite ice chart for January 24, 1979 icon.).

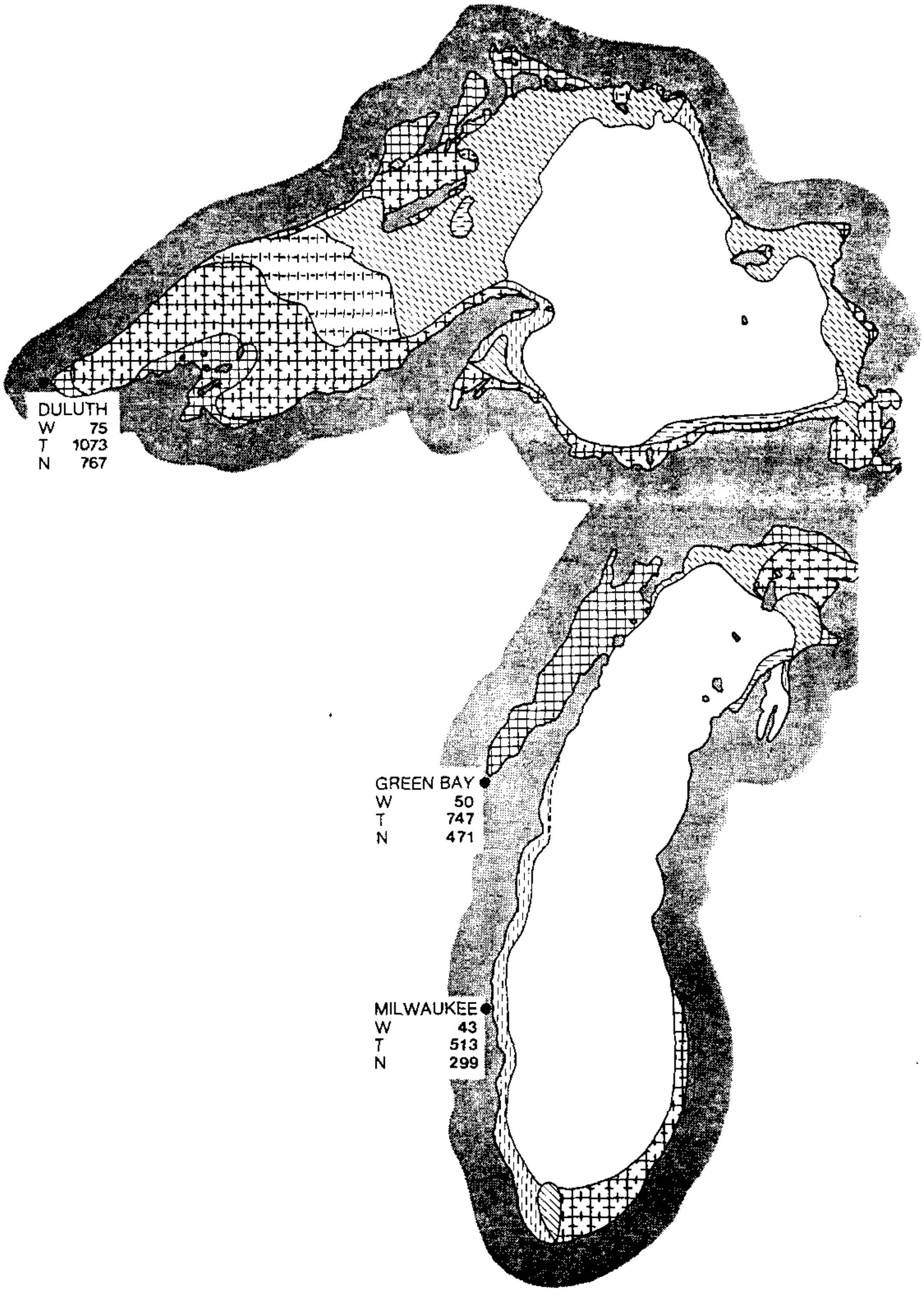


Figure 5h.--Composite ice chart for January 31, 1979.

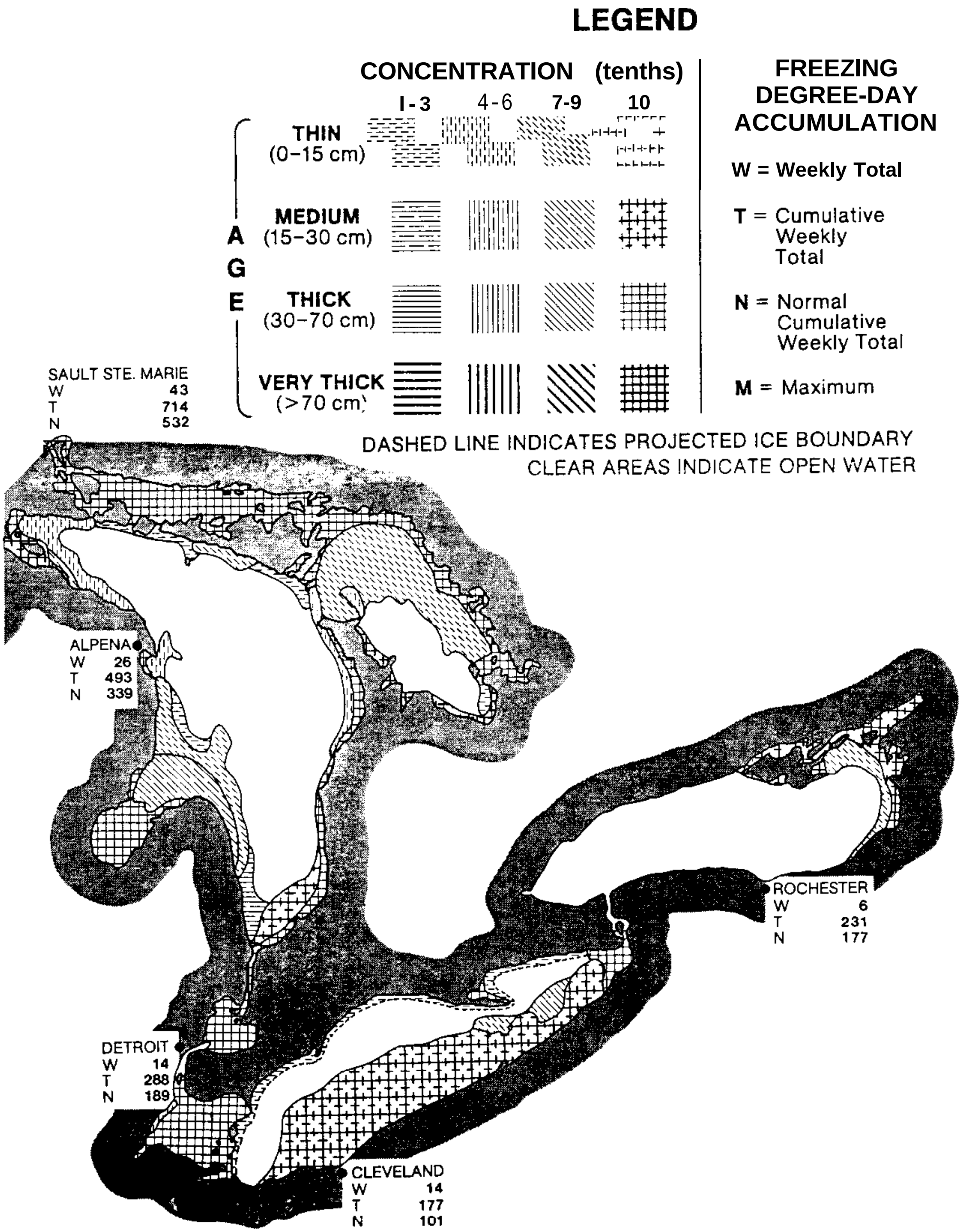


Figure 5h.--Composite ice chart for January 31, 1979 (con.).

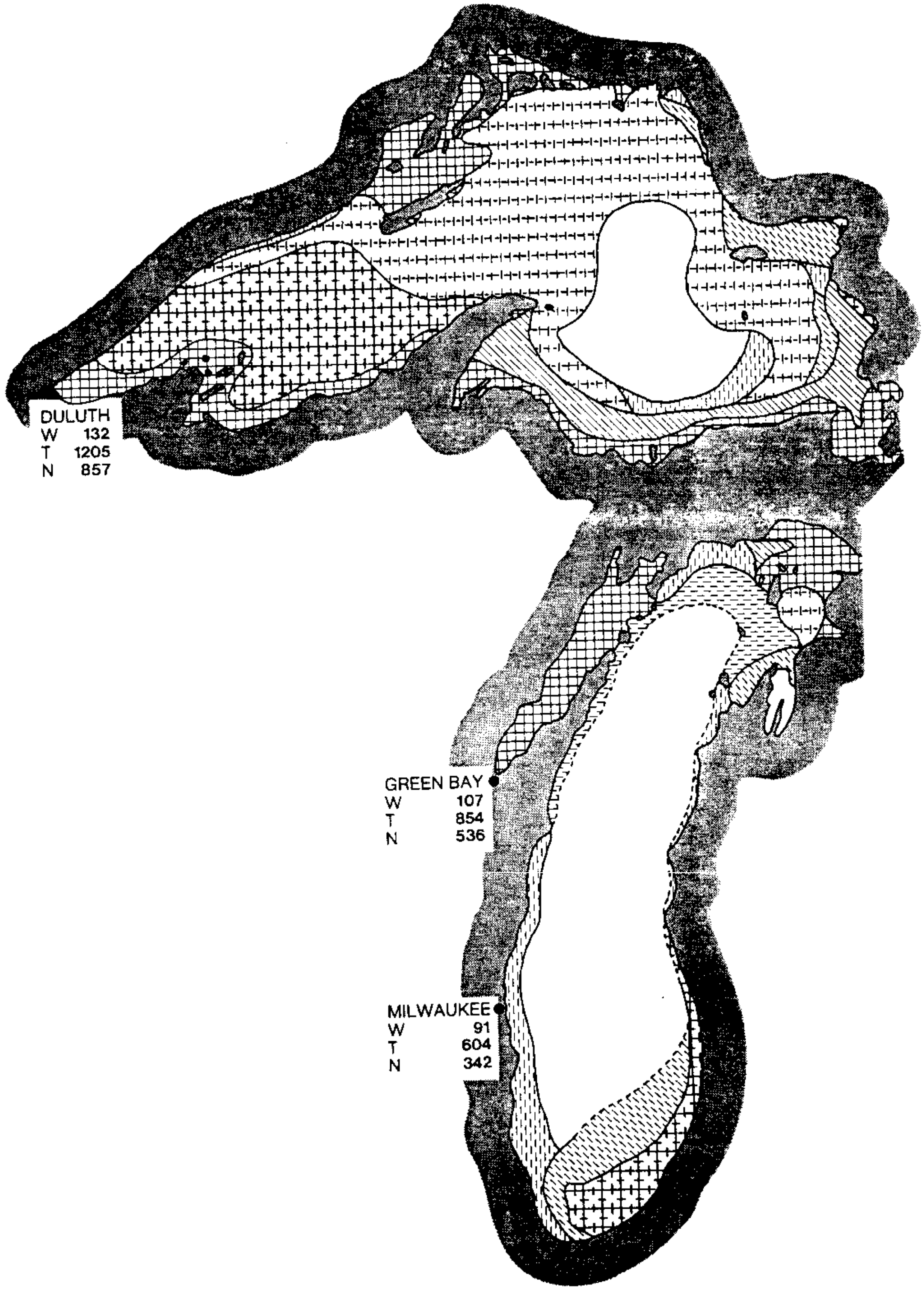


Figure 5i.--Composite ice chart for February 7, 1979.

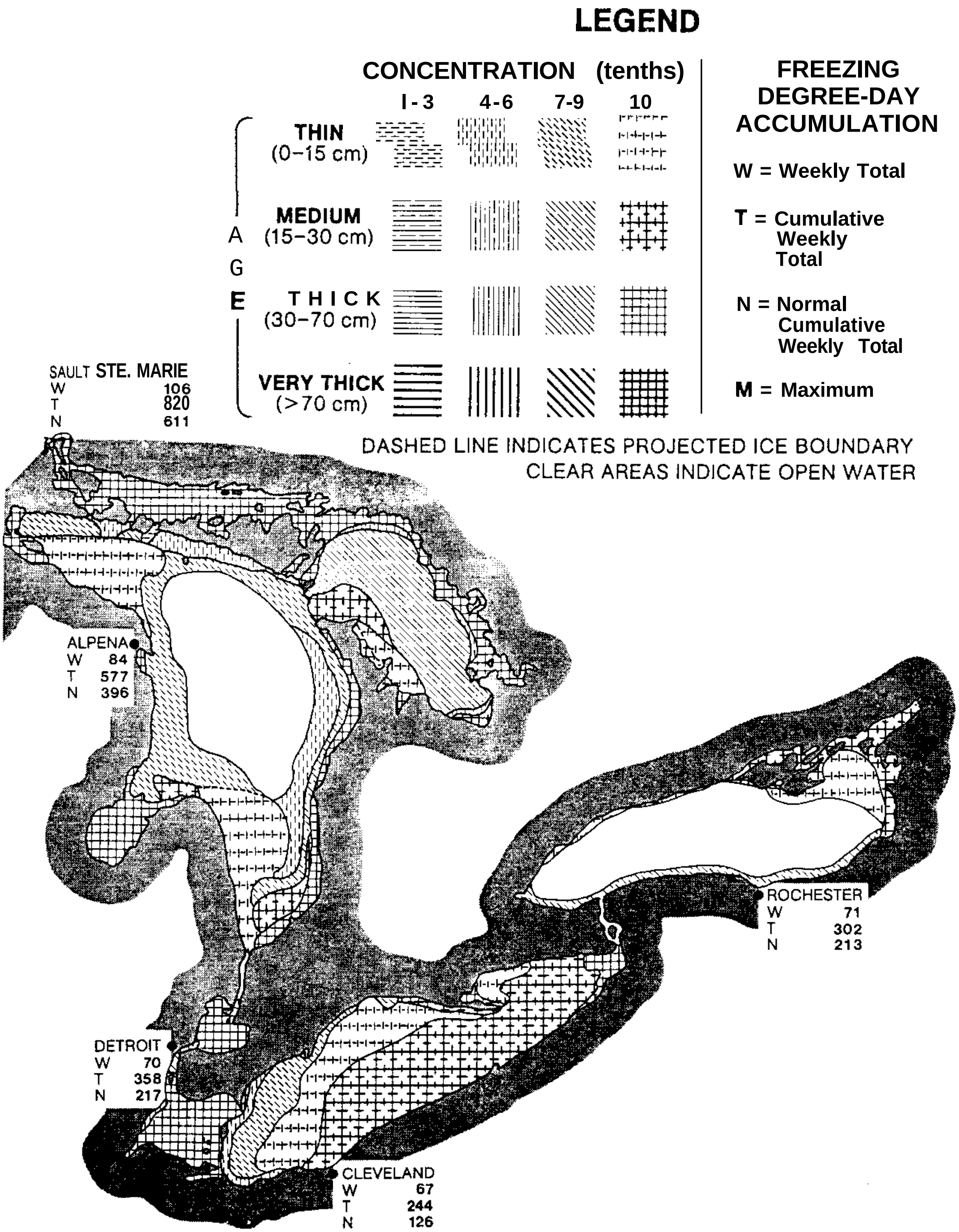


Figure 5i.--Composite ice chart for February 7, 7979 (con.).

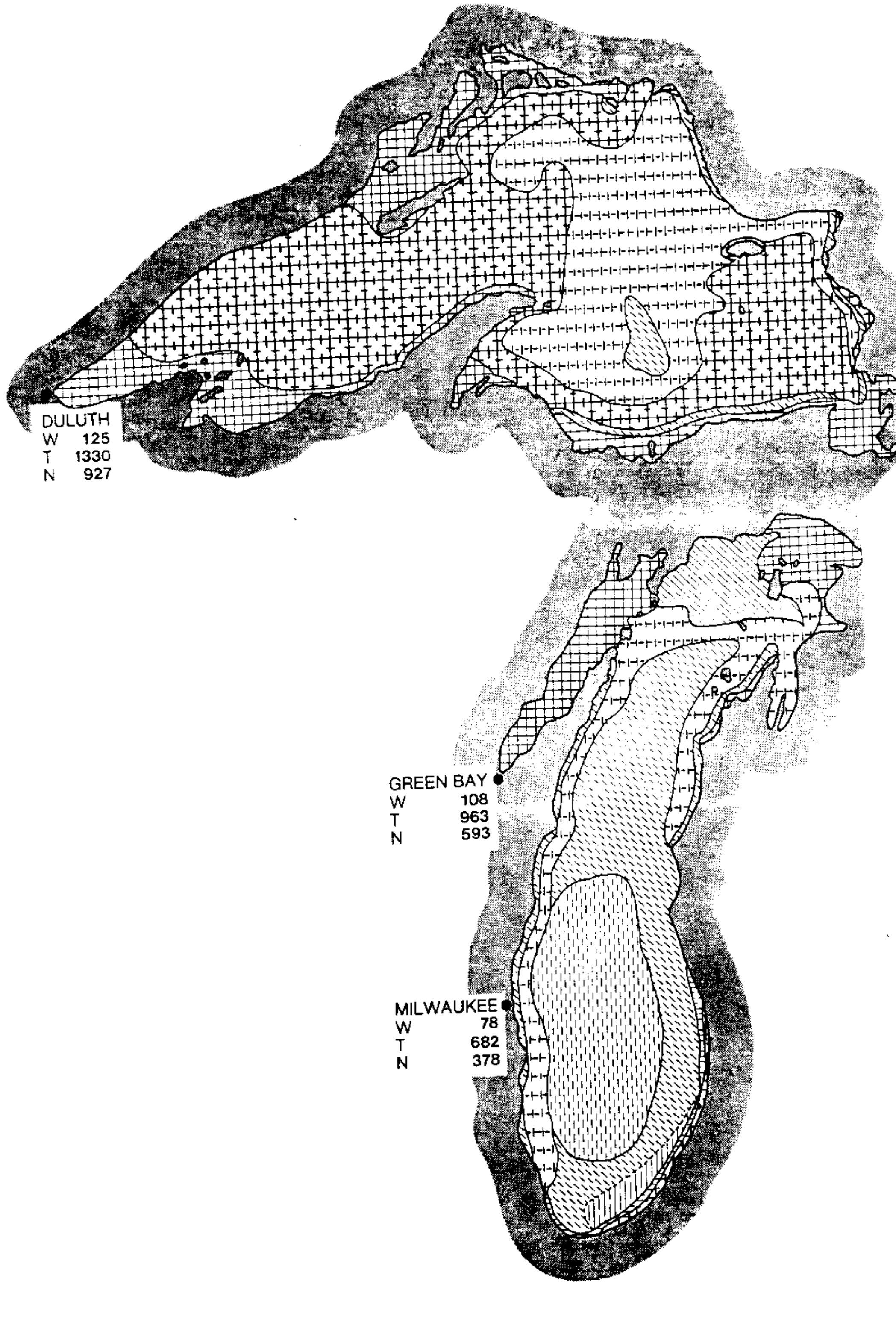


Figure 5j.--*Composite ice chart for February 14, 1979.*

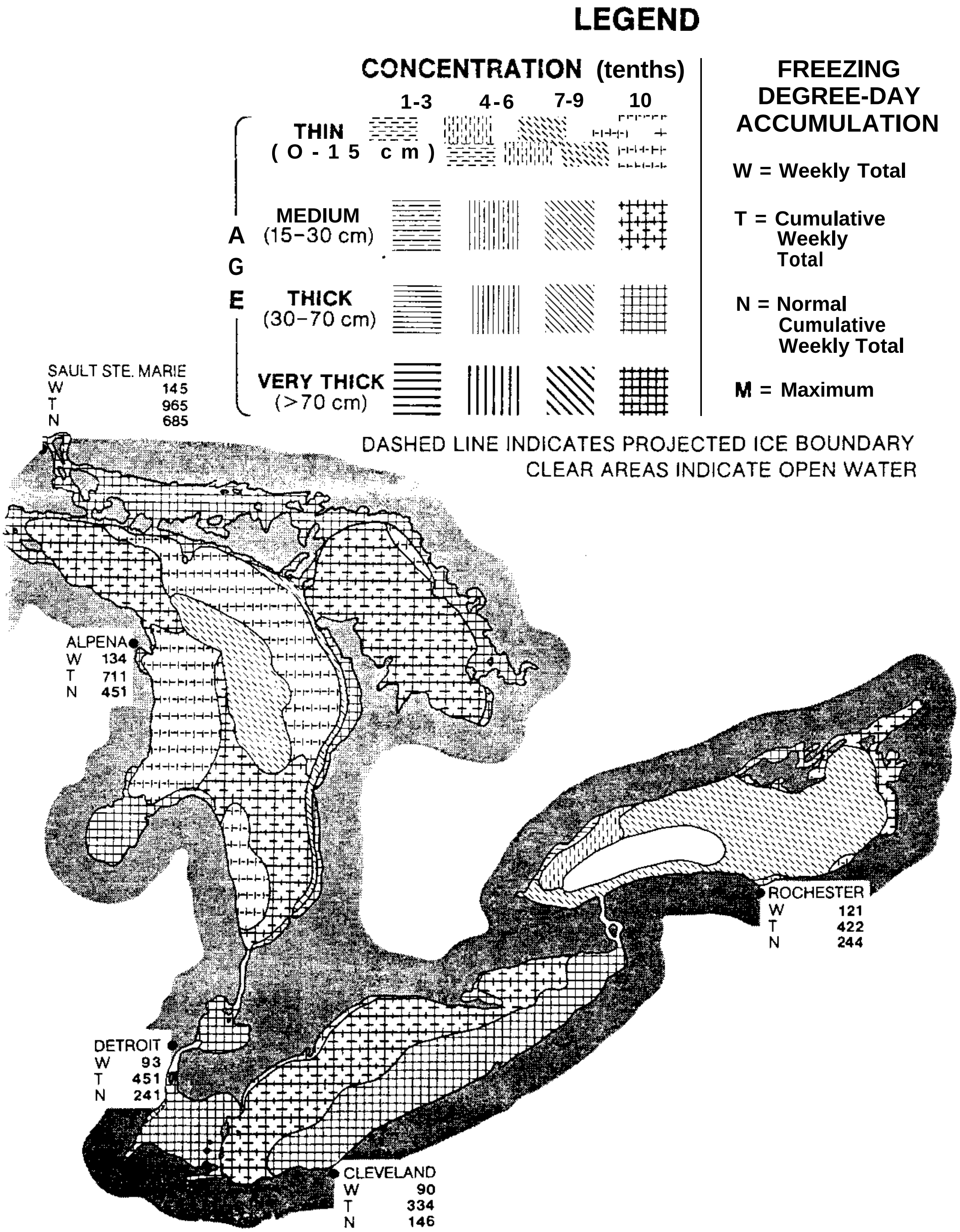


Figure 5j.--Composite ice chart for February 14, 1979 (con.).

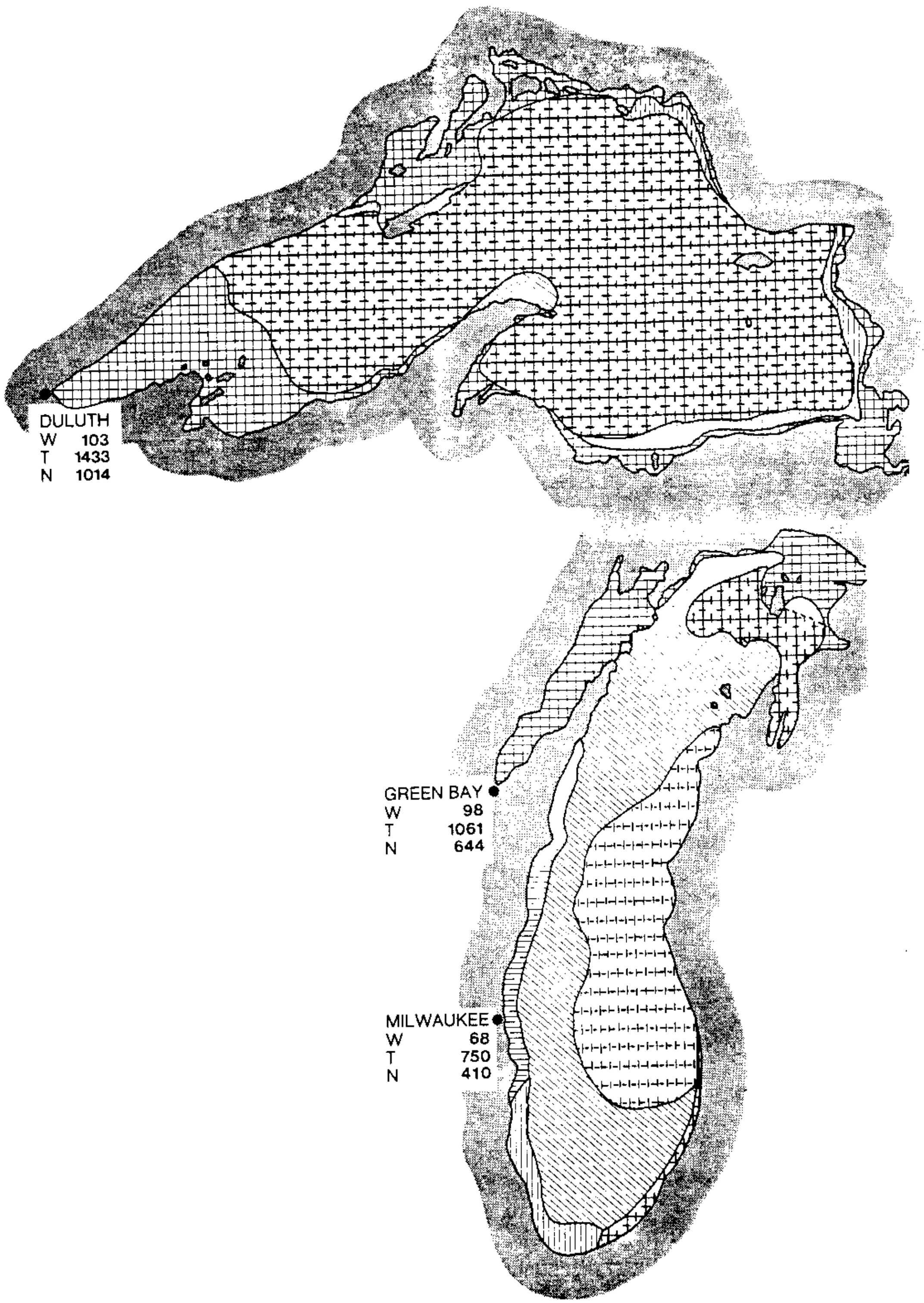


Figure 5k.--*Composite ice chart for February* 21, 1979.

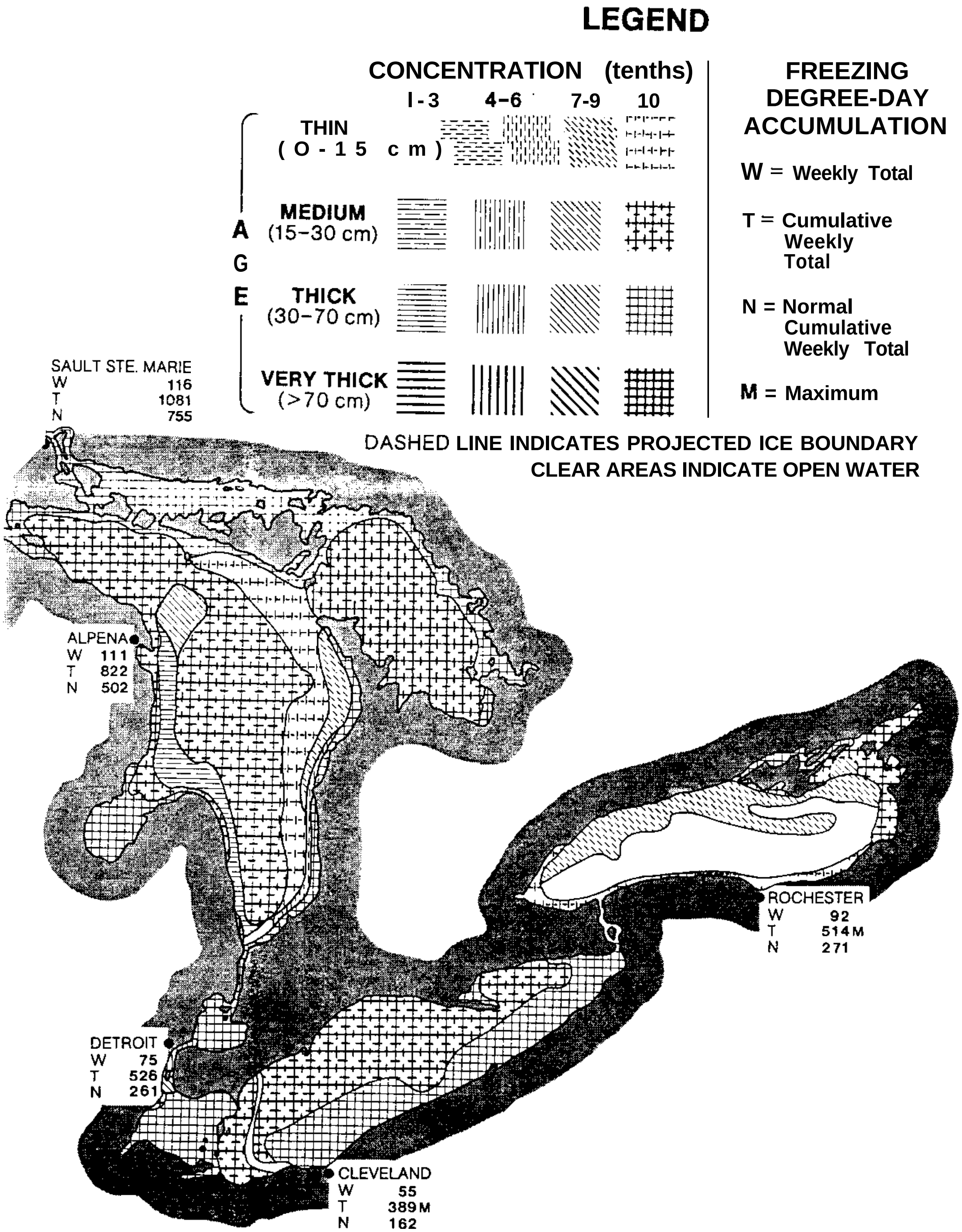


Figure 5k.--Composite ice chart for February 21, 1979 (con.).

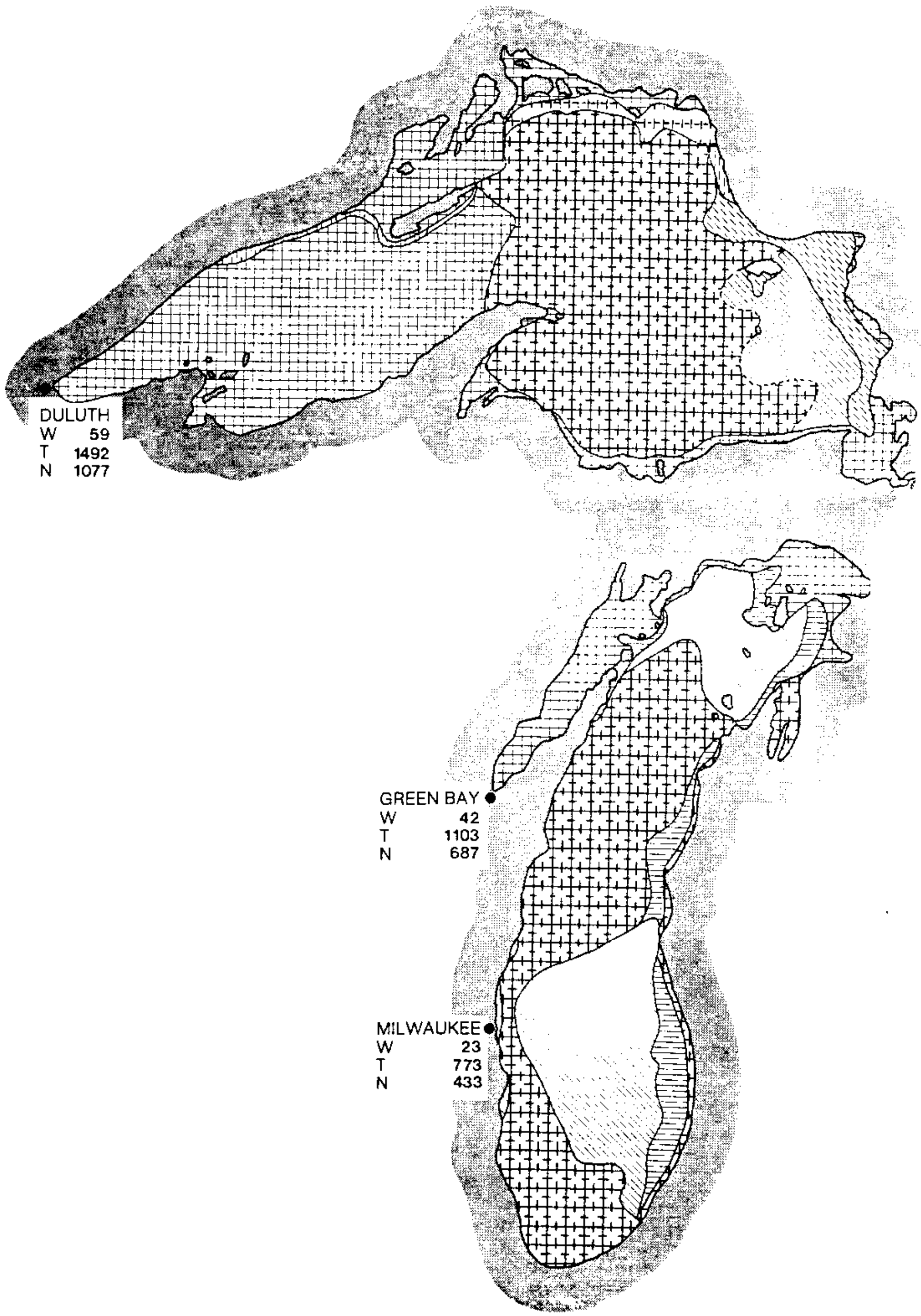


Figure 5l.--Composite ice chart for February 28, 1979.

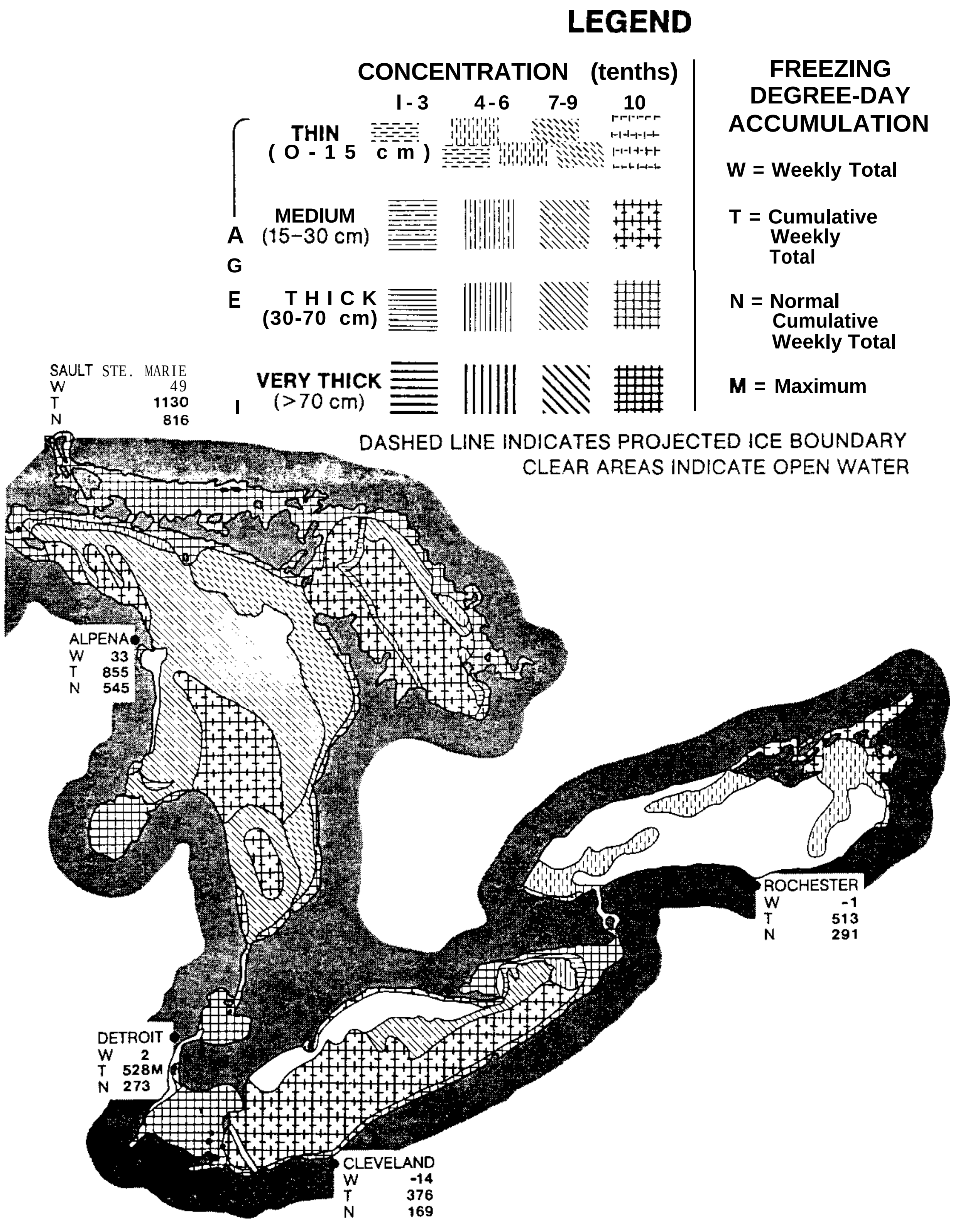


Figure 5l.--Composite ice chart for February 28, 1979 (con.).

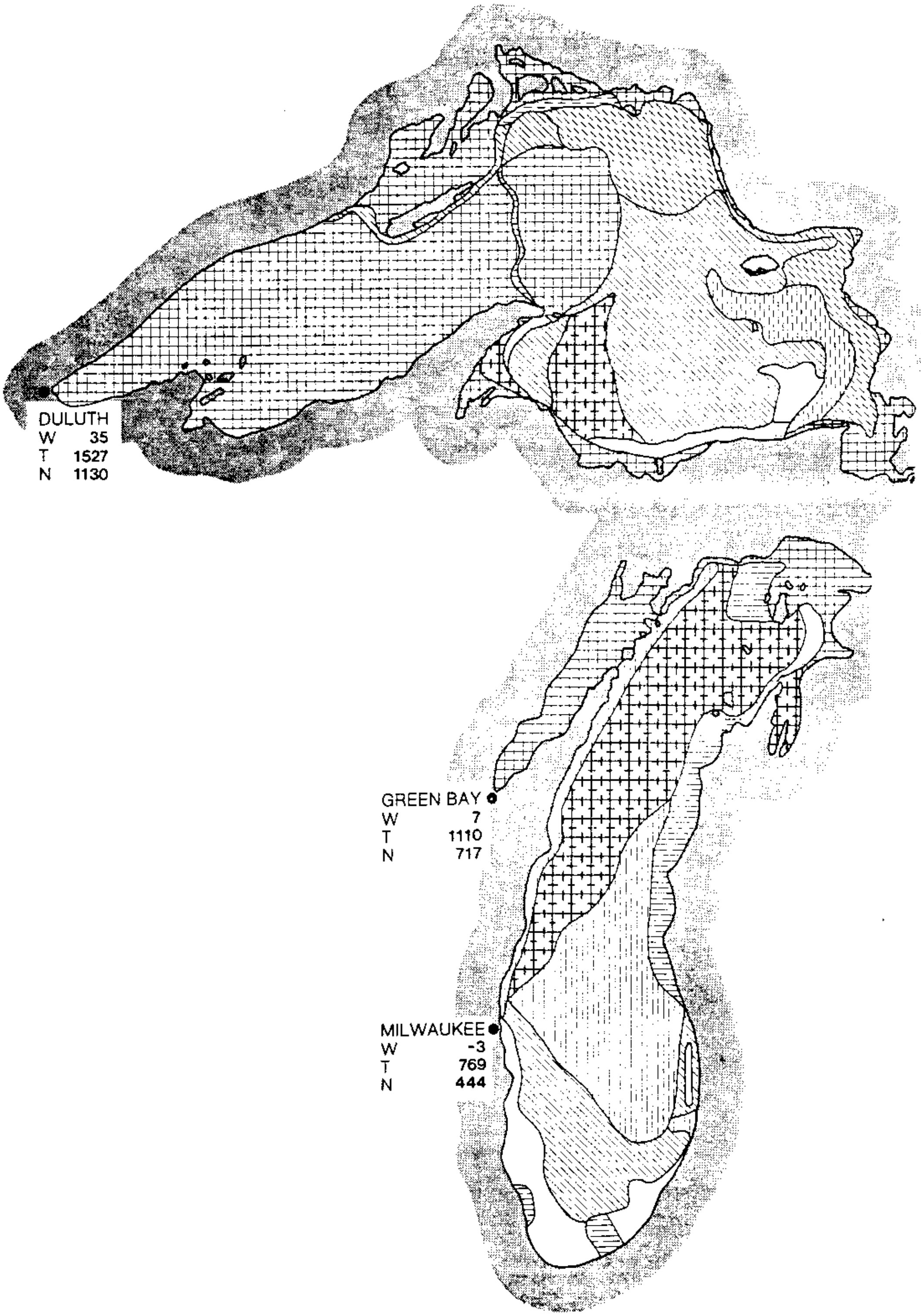


Figure 5m.--*Composite ice chart for March 7, 1979.*

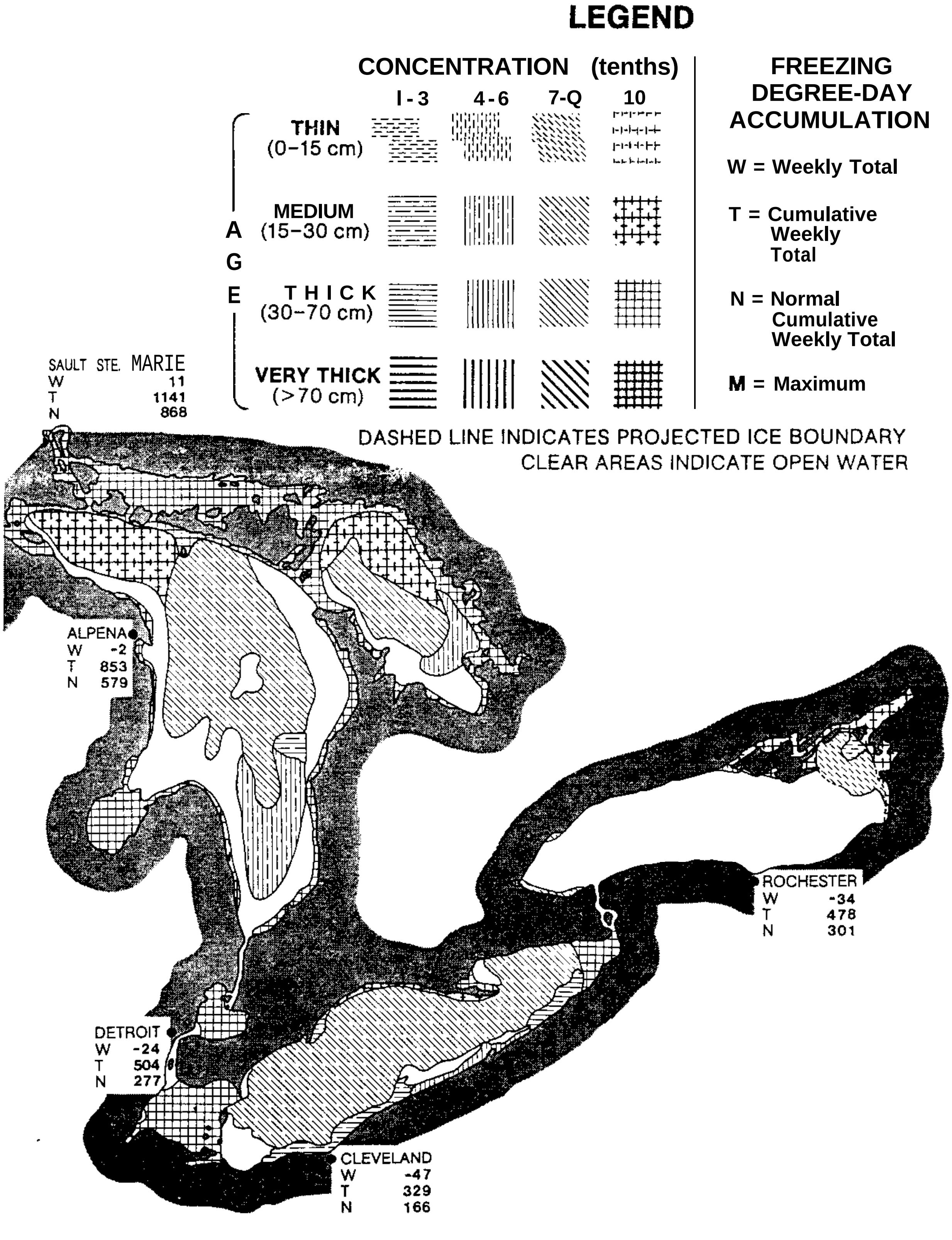


Figure 5m.--Composite ice chart for March 7, 1979 (con.).

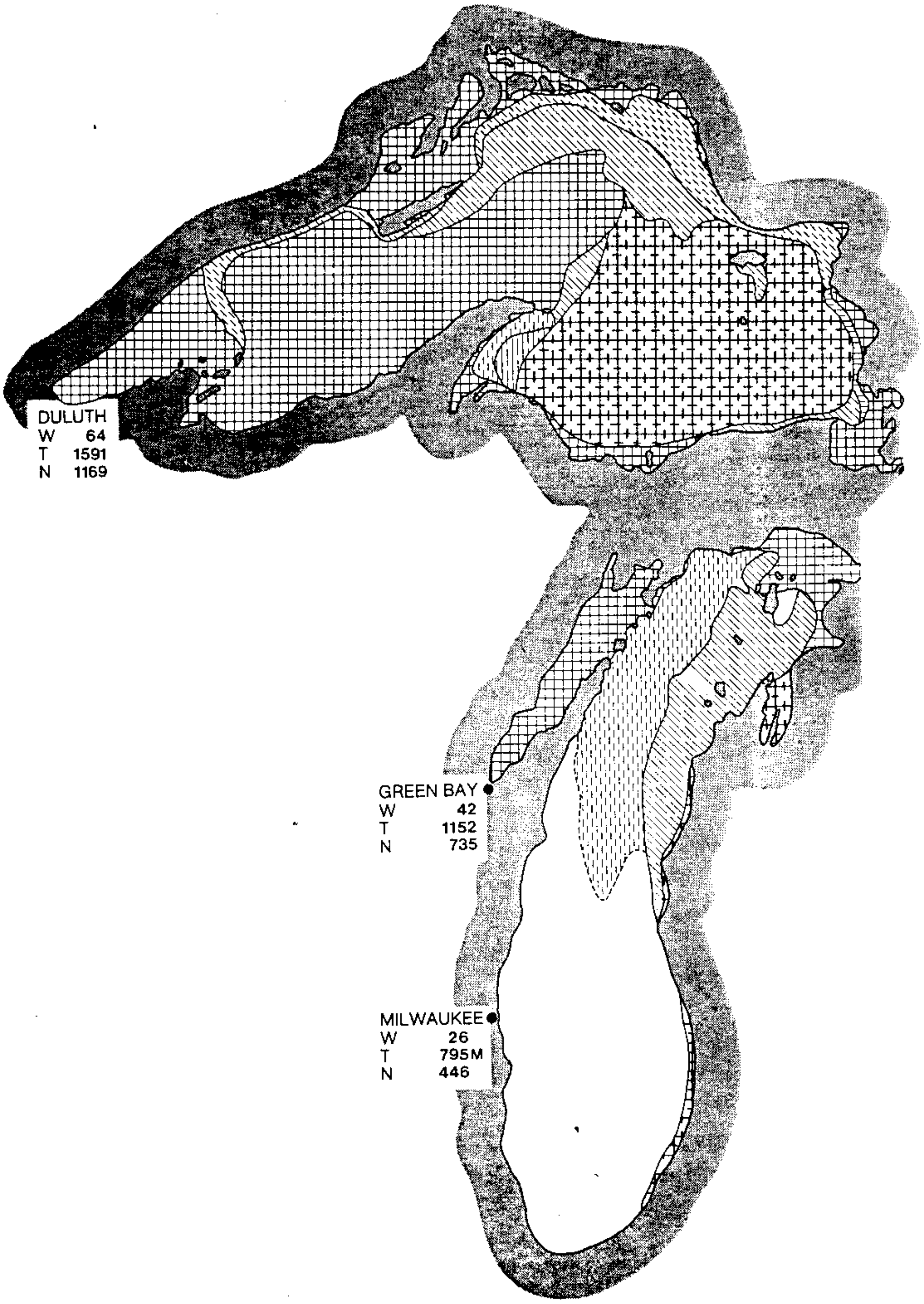


Figure 5n.--Composite ice chart for March 14, 1979.

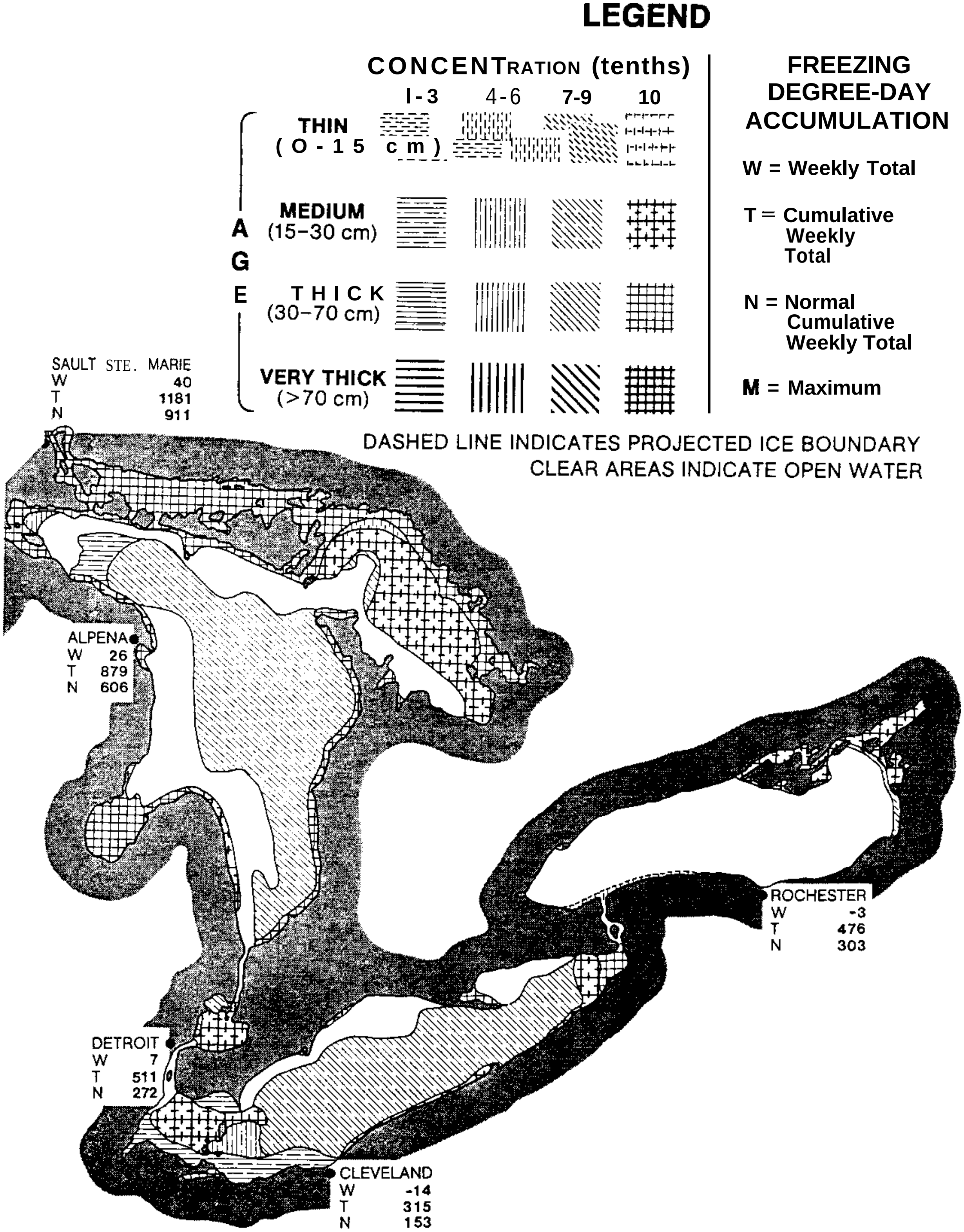


Figure 5n.--Composite ice chart for March 14, 1979 (con.).

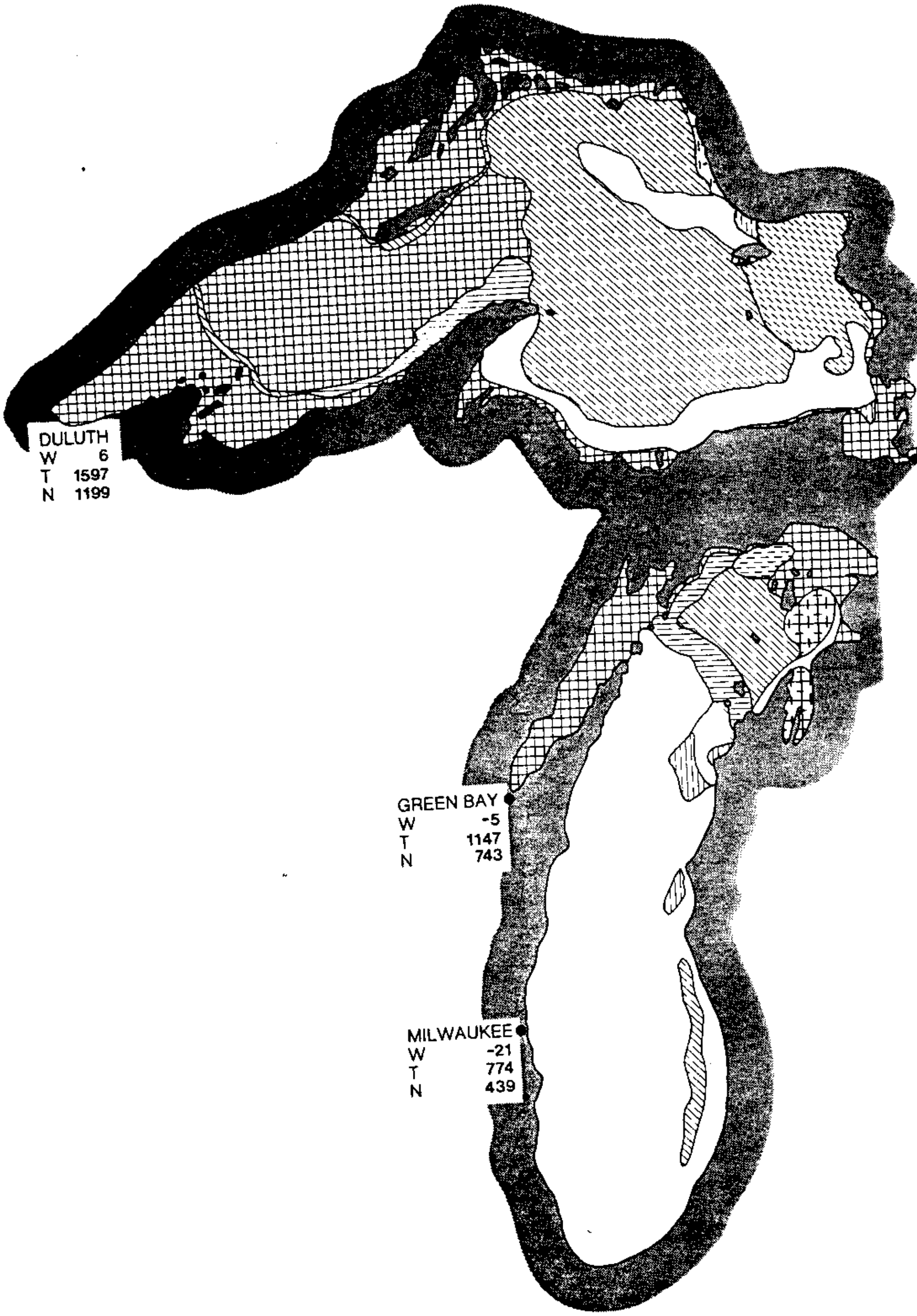


Figure 5o.--Composite ice chart for March 21, 1979.

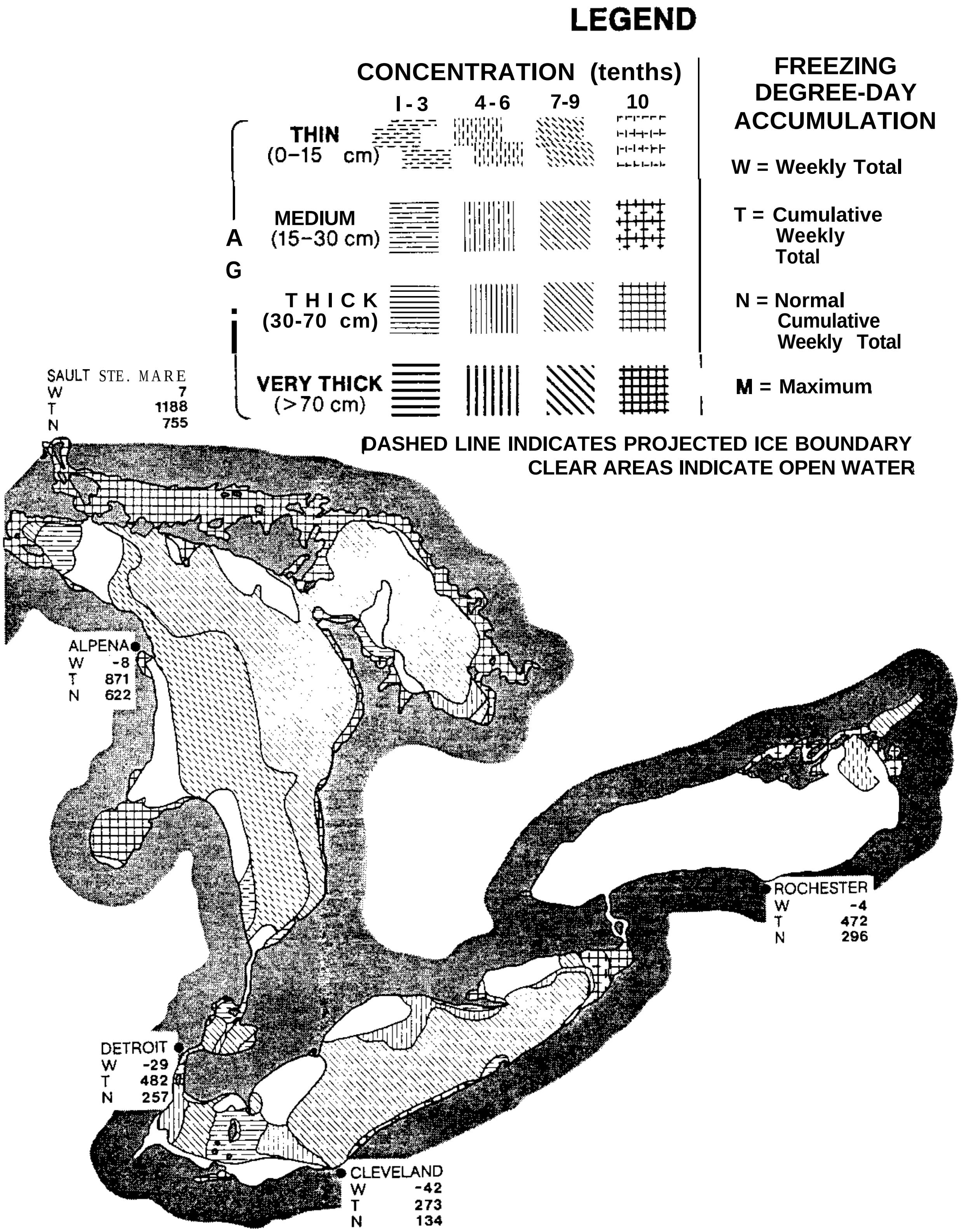


Figure 50.--Composite ice chart for Match 21, 1979 (con.).

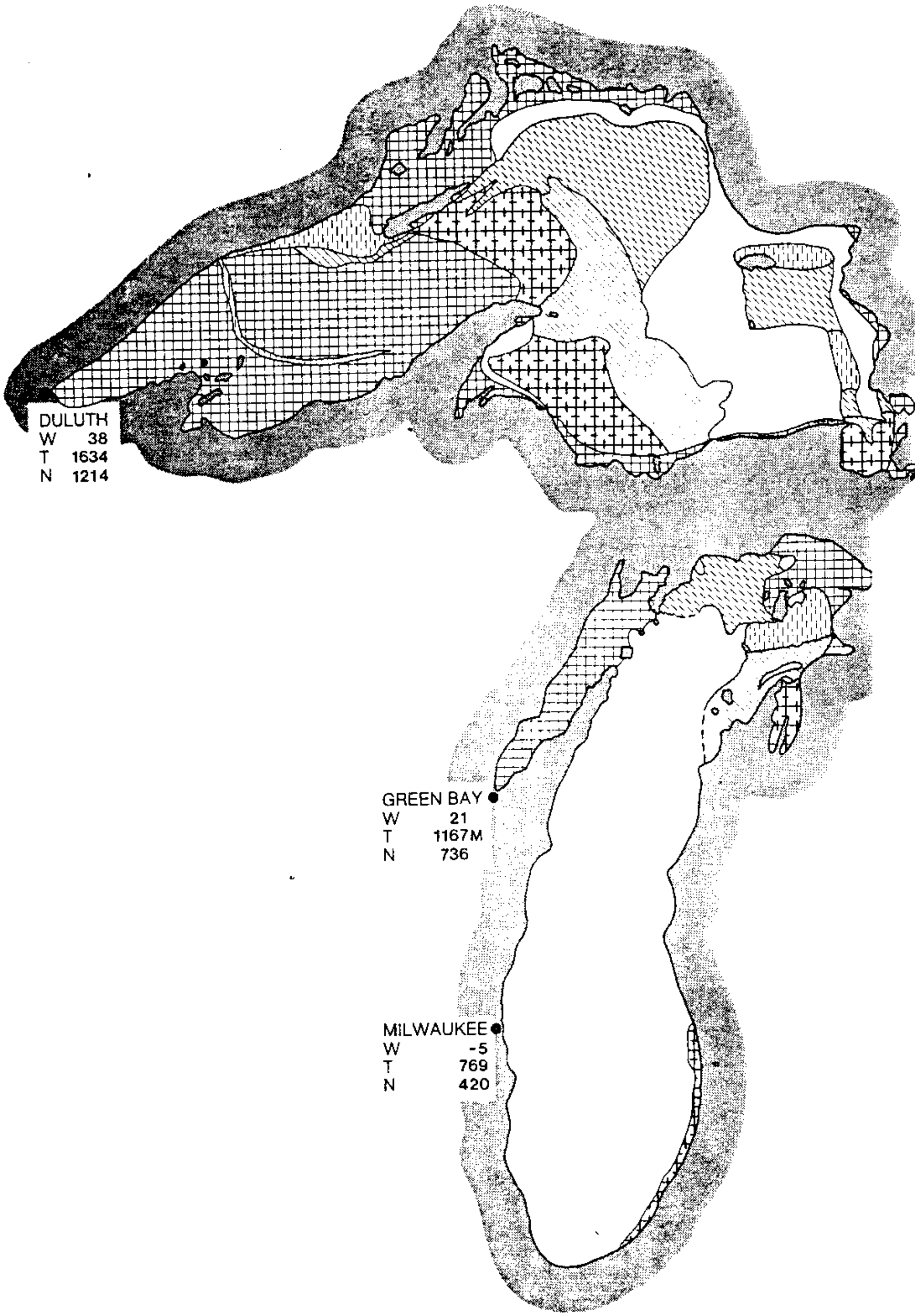


Figure 5p.--Composite ice chart for March 28, 1979.

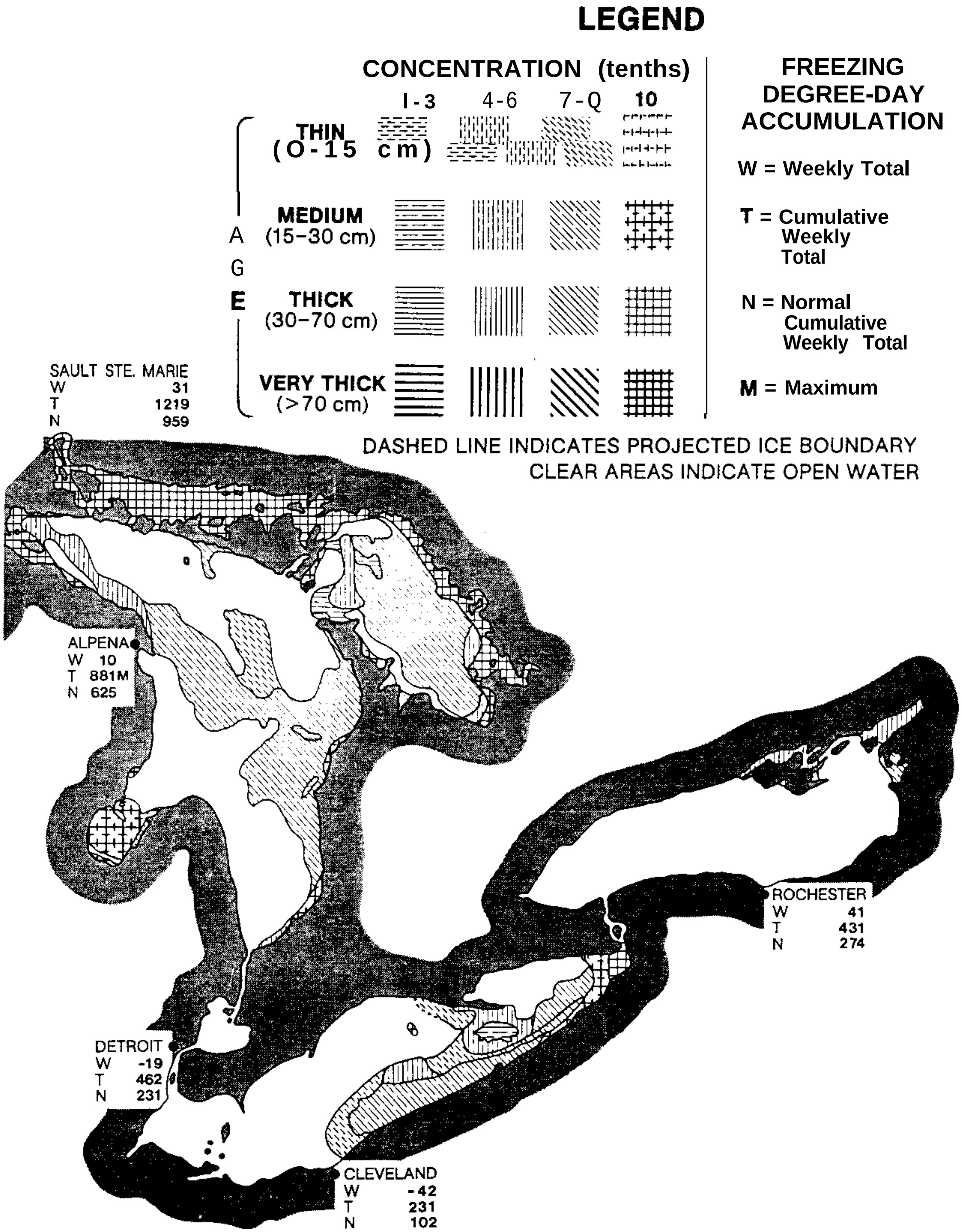


Figure 5p.--*Composite ice chart for March 28,* 1979 (*con.*).

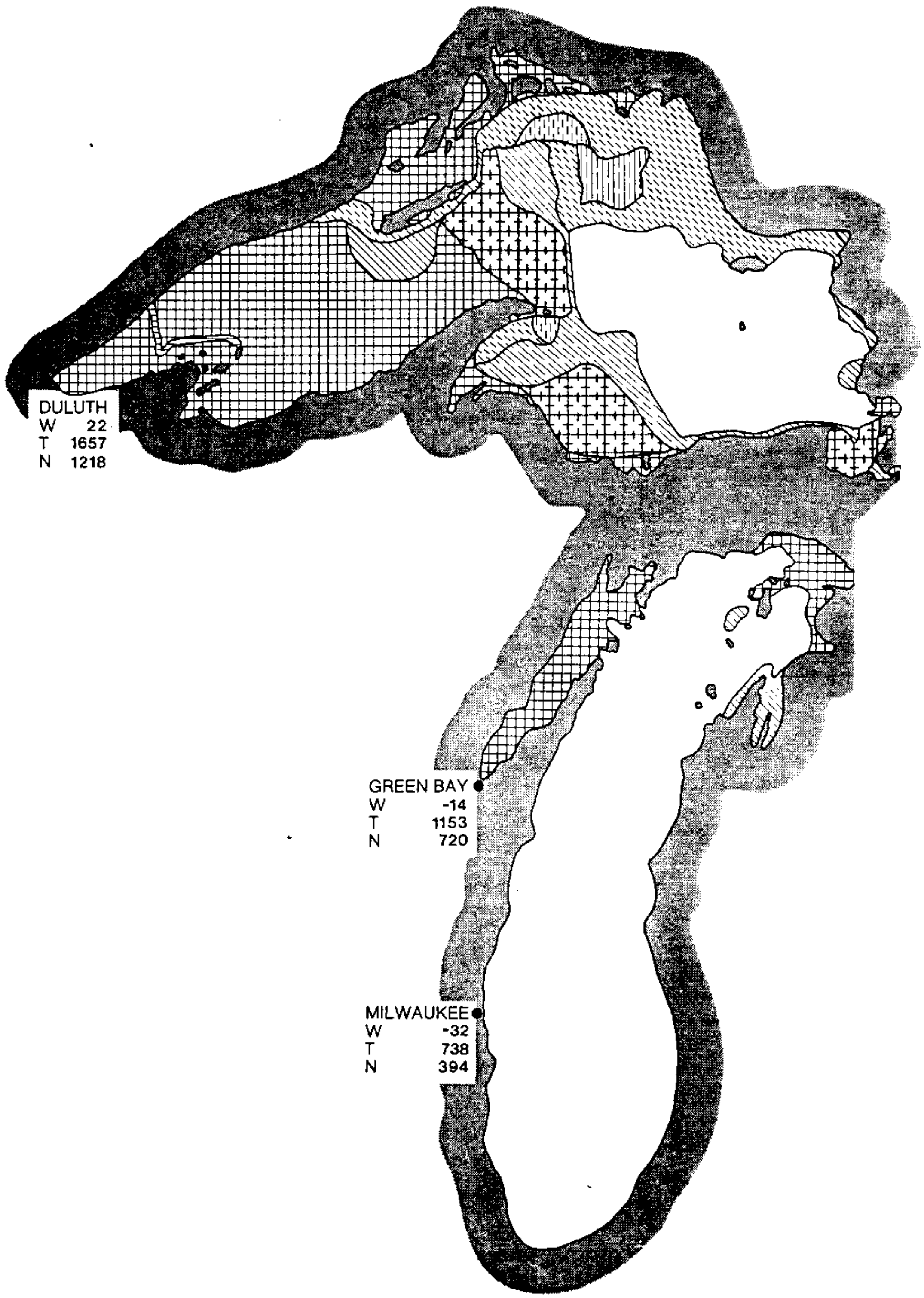


Figure 5q.--Composite ice chart for April 4, 1979.

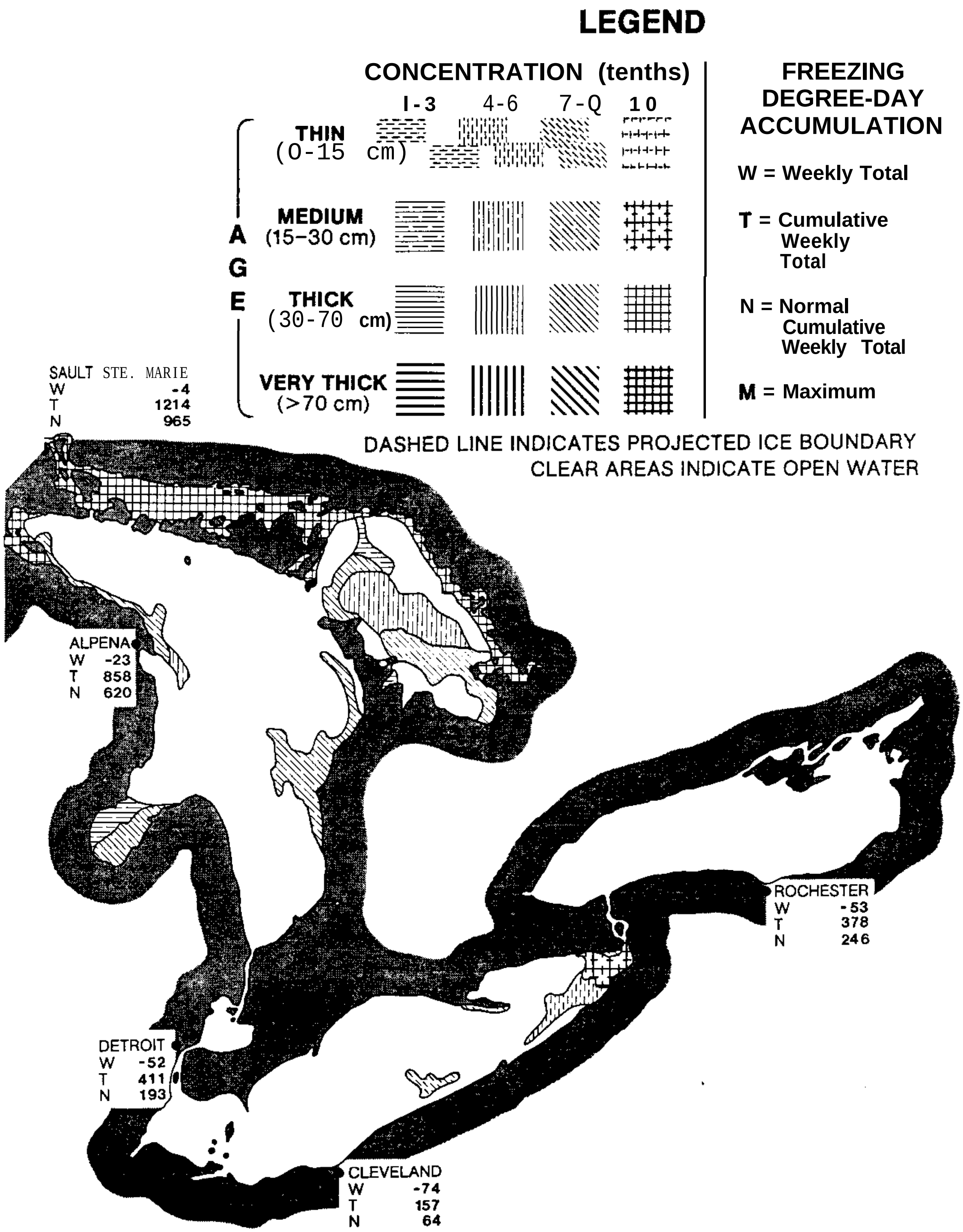


Figure 5q.--Composite ice chart for April 4, 1979 (con.).

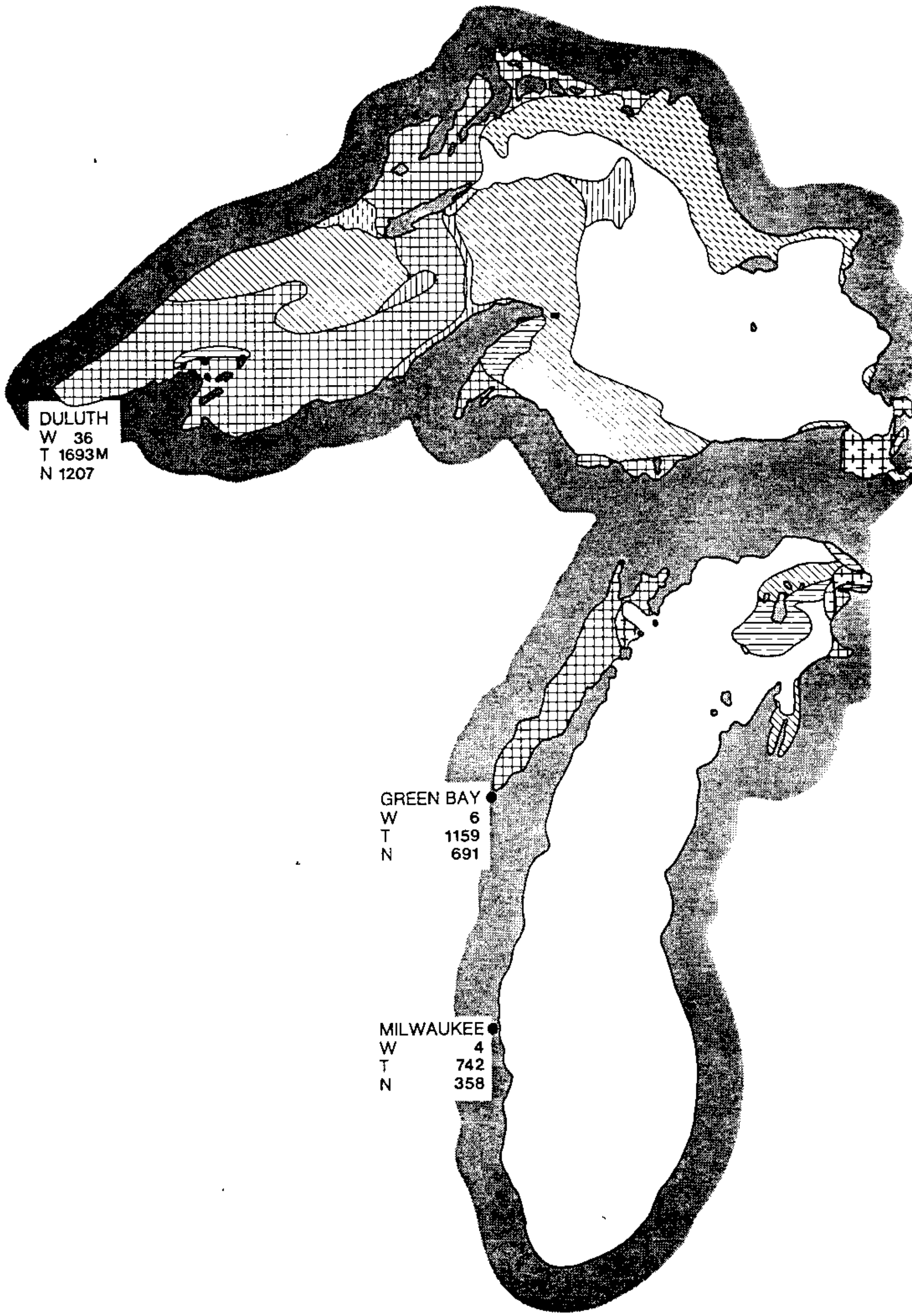


Figure 5r.--*Composite* ice *chart for April 11,* J979.

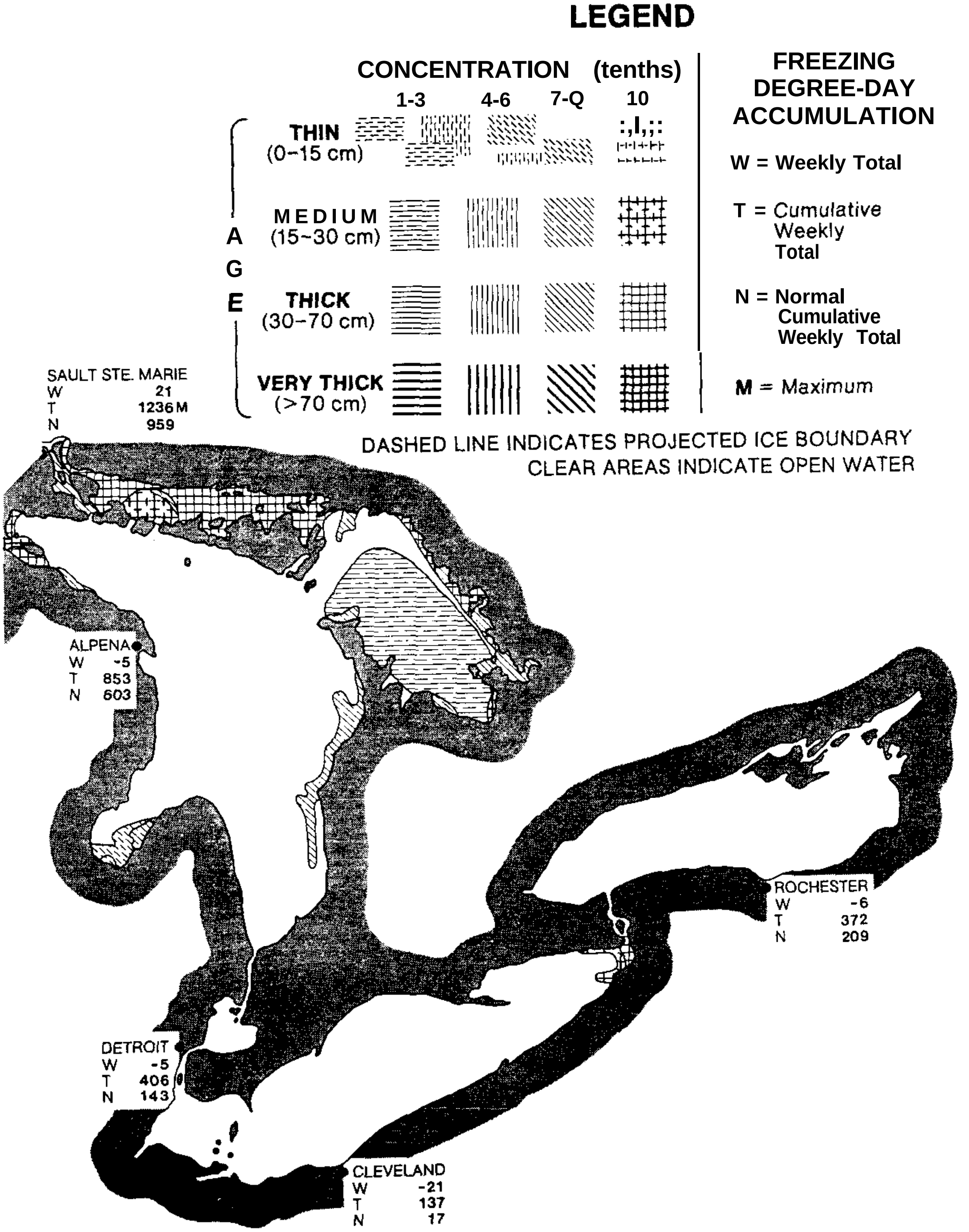


Figure 5r.--Composite ice chart for April JJ, 1979 (con.).

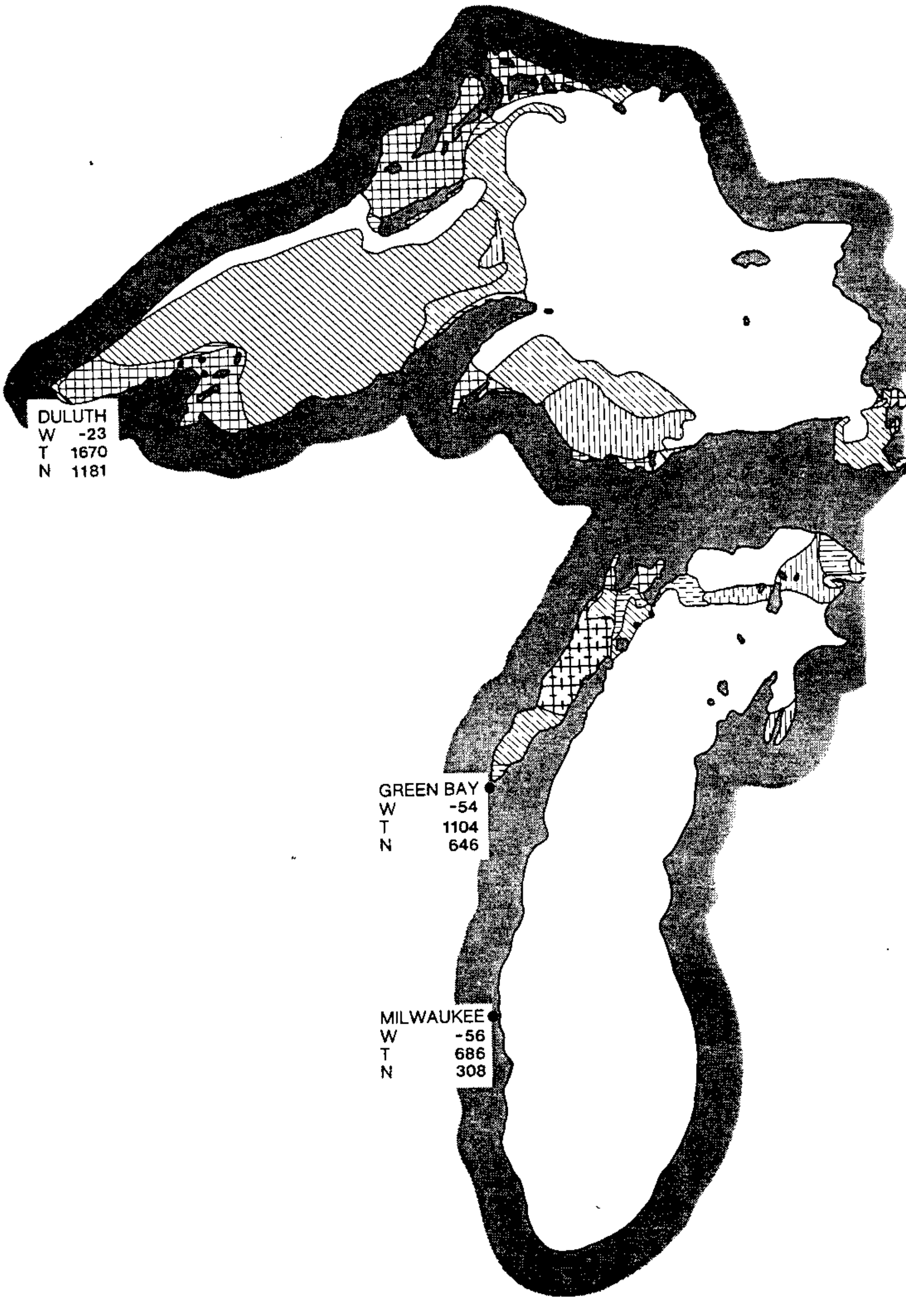


Figure 5s.--Composite ice chart for April 18, 1979.

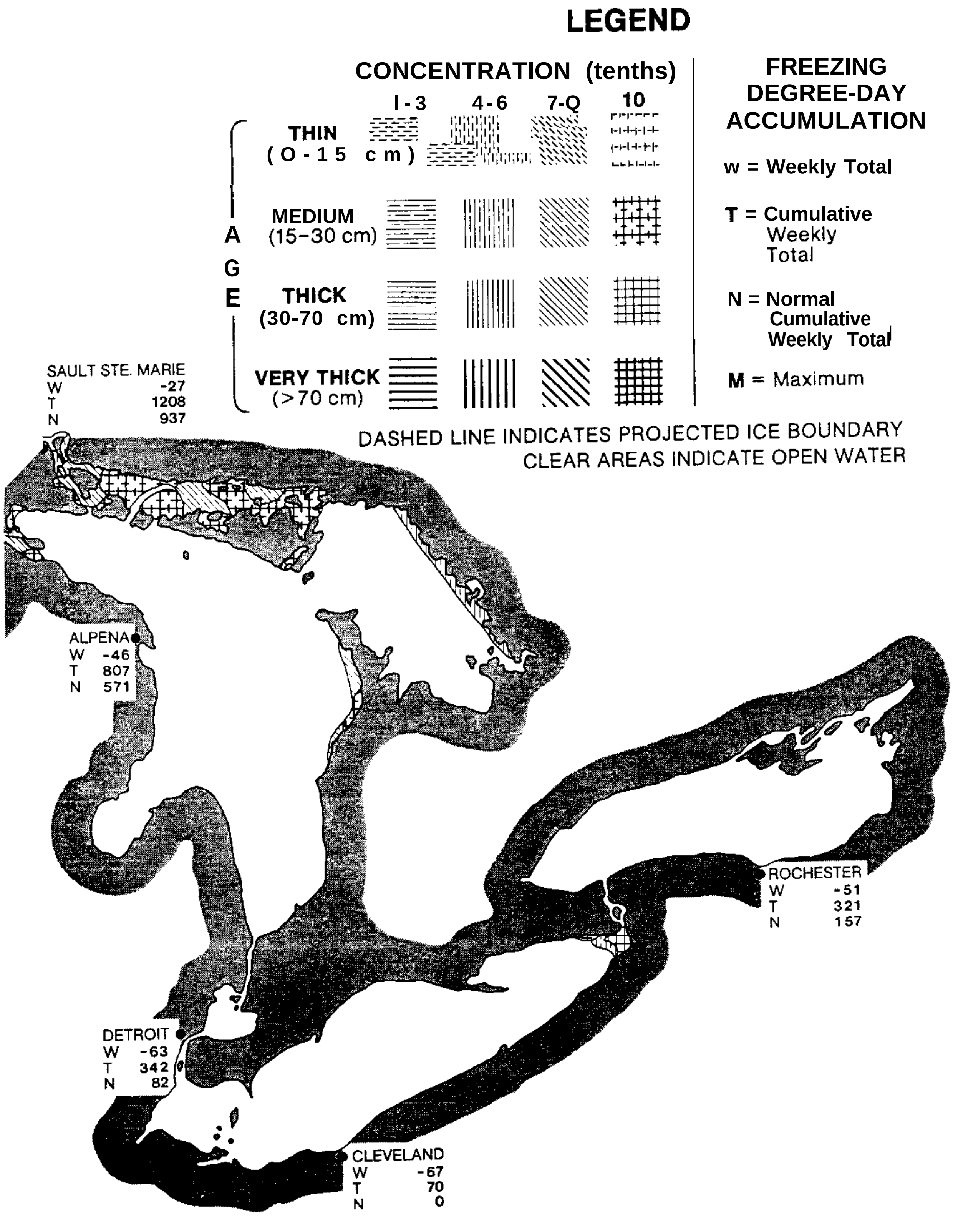


Figure 56. --*Composite ice chart for April* I b , *1979 (con.)*.

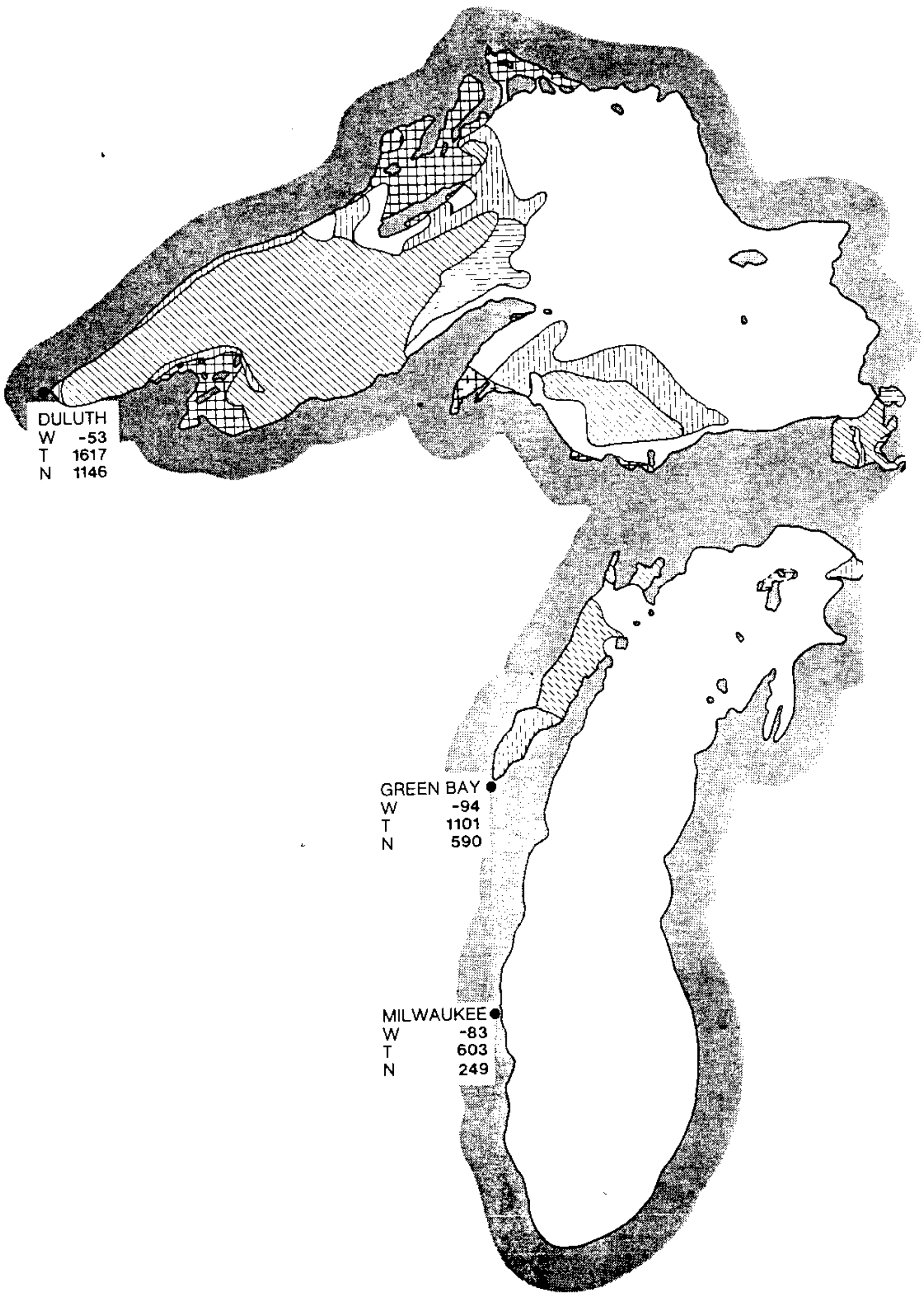


Figure 5t.--Composite ice chart for April 25, 1979.

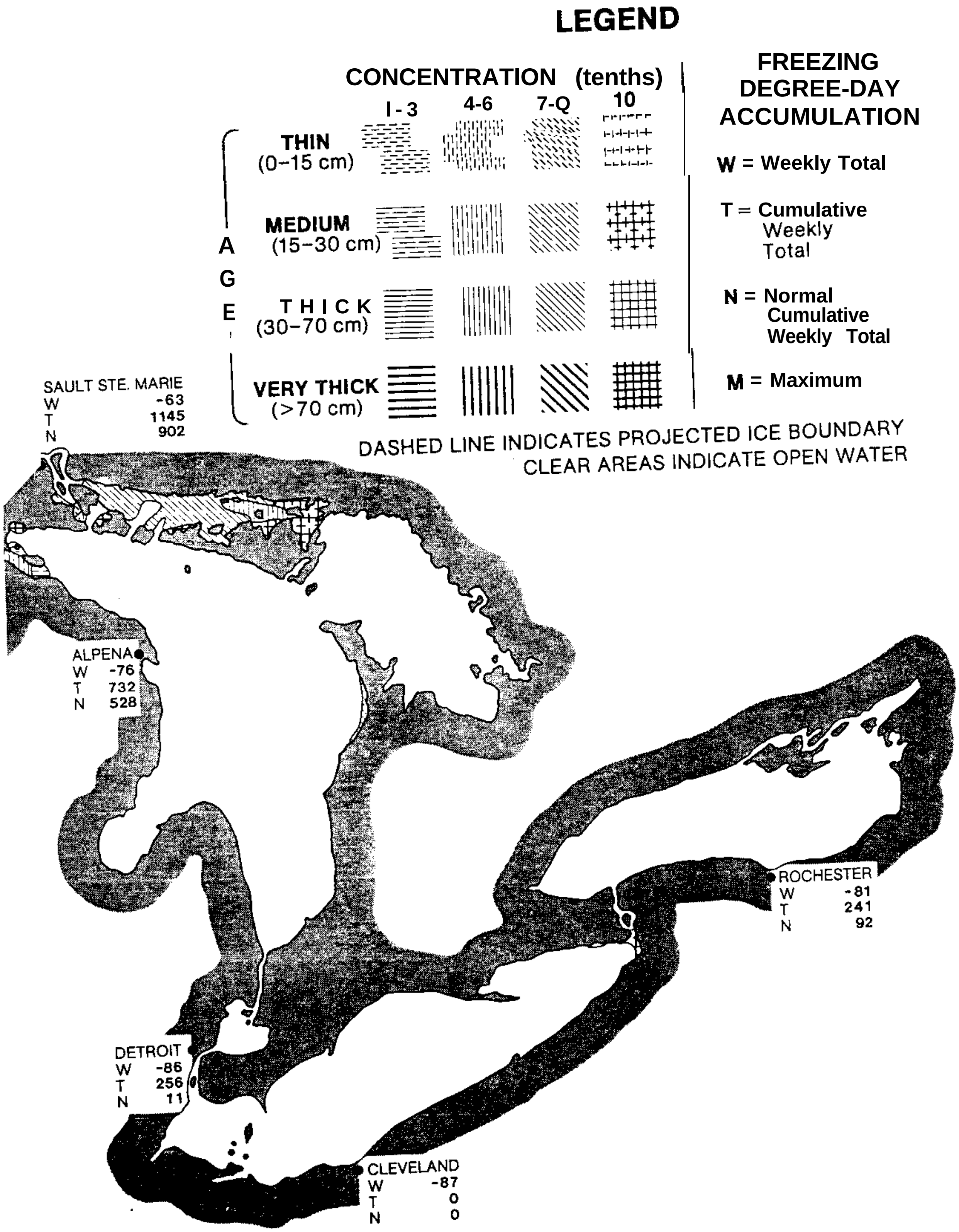


Figure 5t.--Composite ice chart for April 25, 1979 (con.).

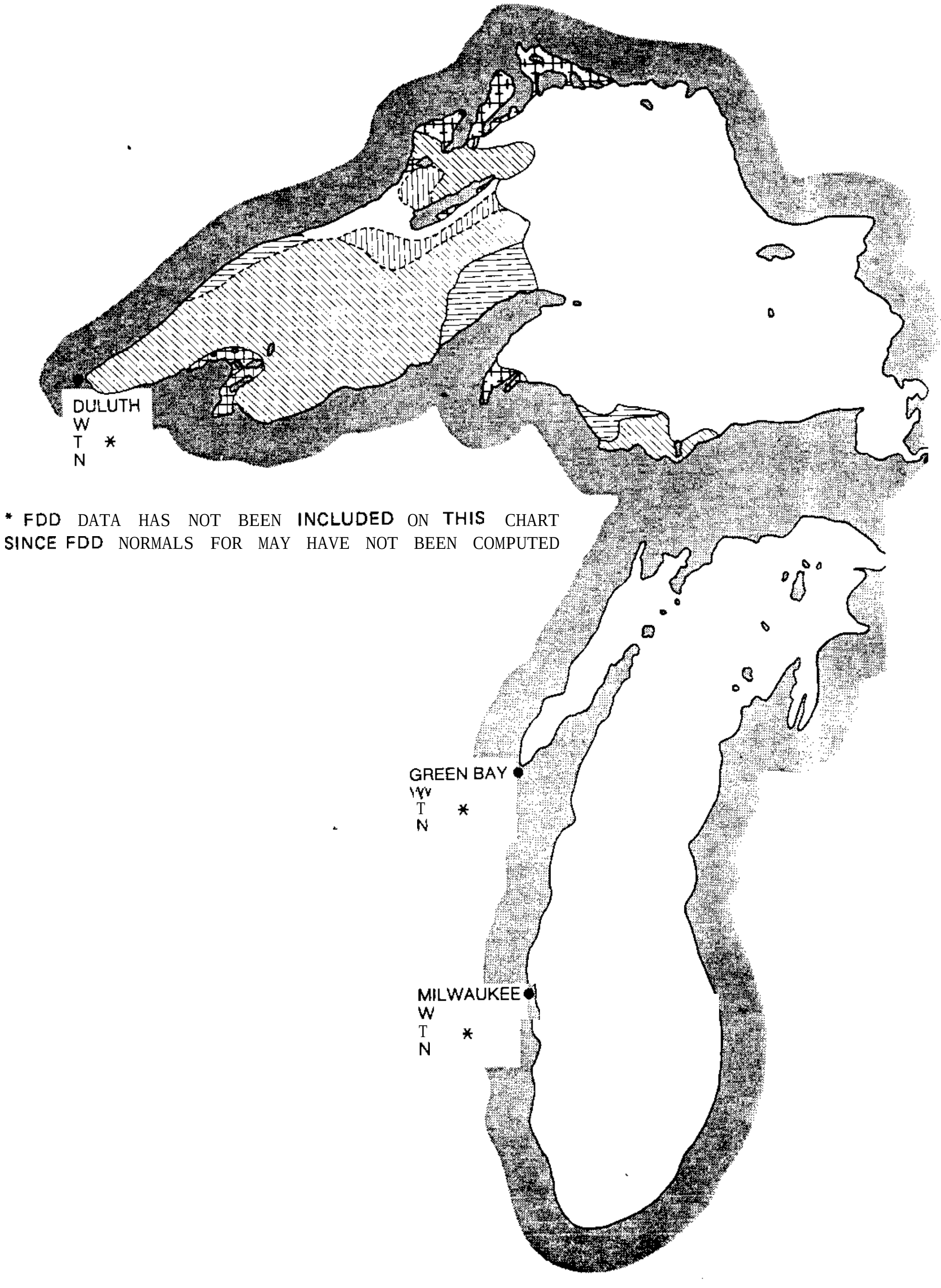


Figure 5u.--Composite ice chart for May 2, 1979.

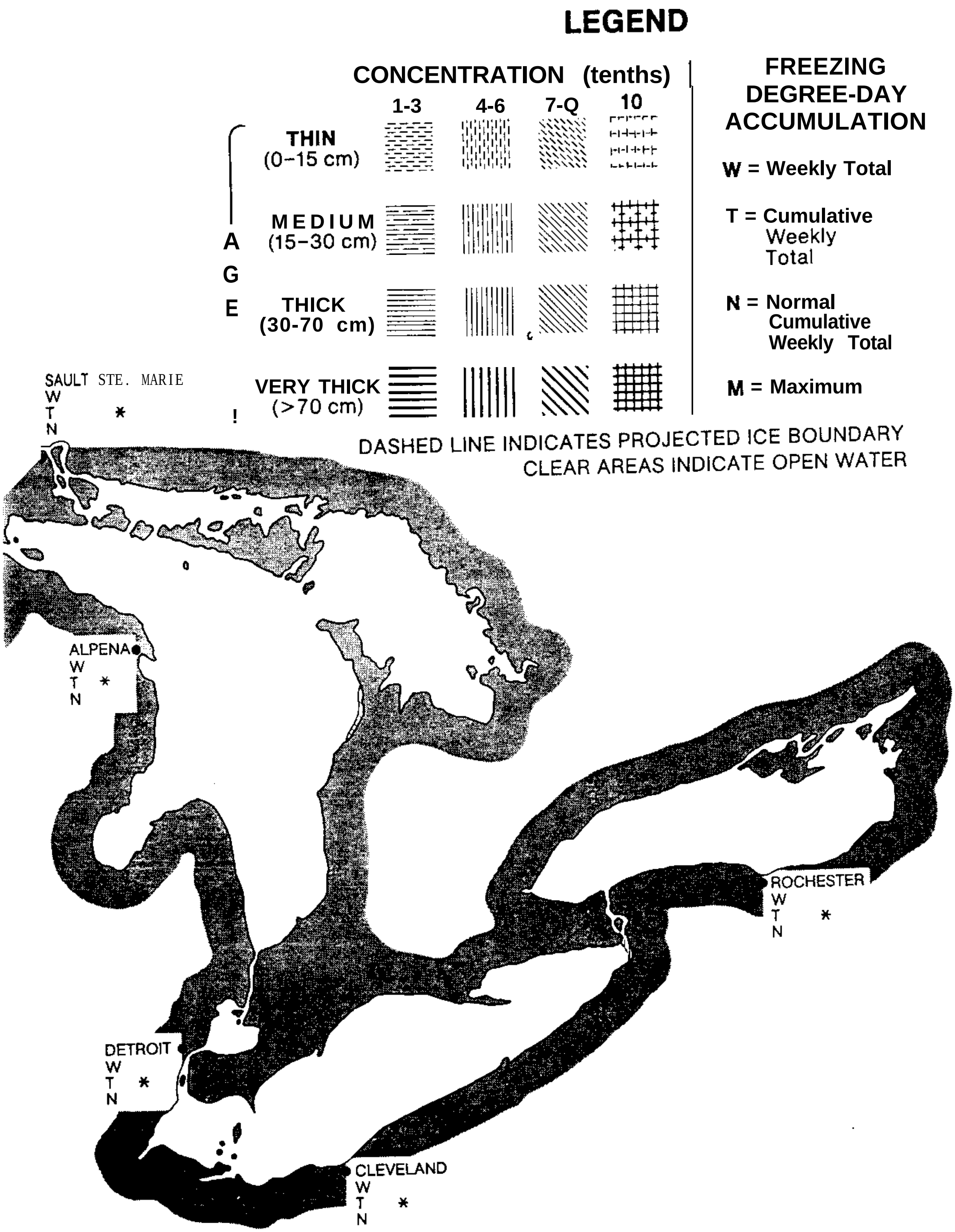


Figure 5u.--Composite ice chart for May 2, 1979 (con.).

Figure 6a.--GOES VISSR (visible) image for January 8, 1979.

Figure 6b.--GOES VISSR (visible) image for January 18, 1979.

Figure 6c.--GOES VISSR (visible) image for January 25, 1979.

Figure 6d.--GOES VISSR (visible) image for February 5, 1979.

Figure 6e.--GOES VISSR (visible) image for February 8, 1979.

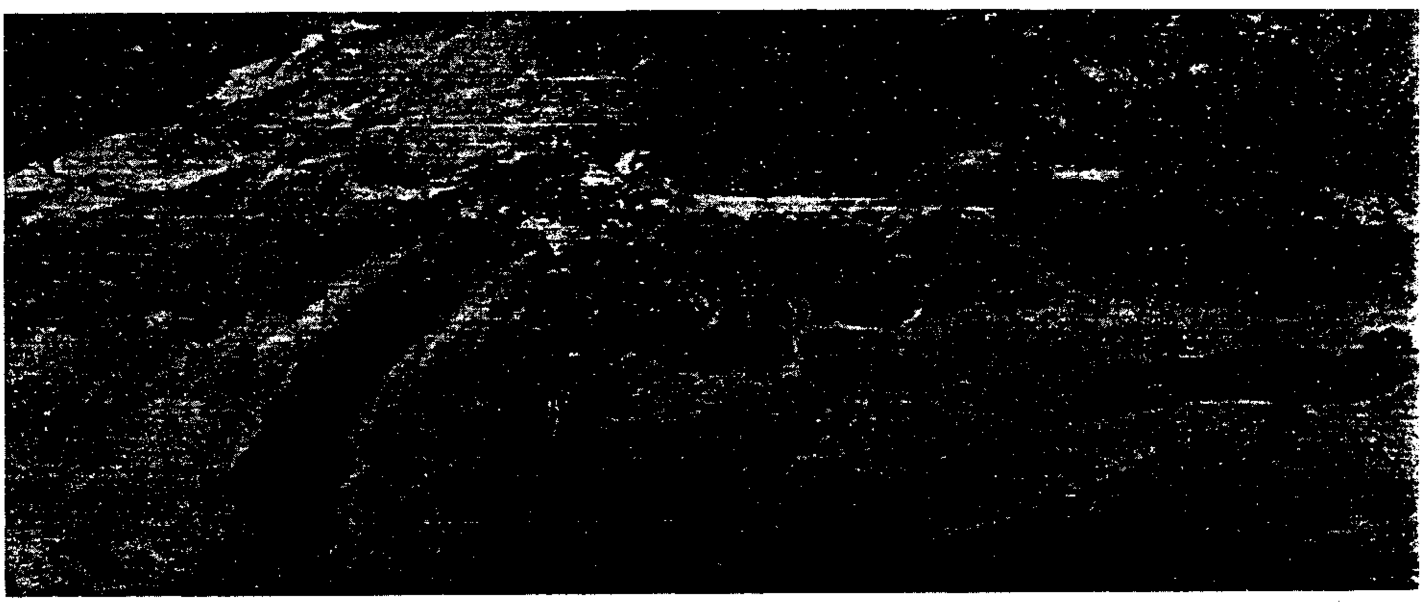


Figure 6f.--GOES VISSR (visible) image for February 9, 1979.

Figure 6g.--GOES USSR (visible) image for February 11, 7979.

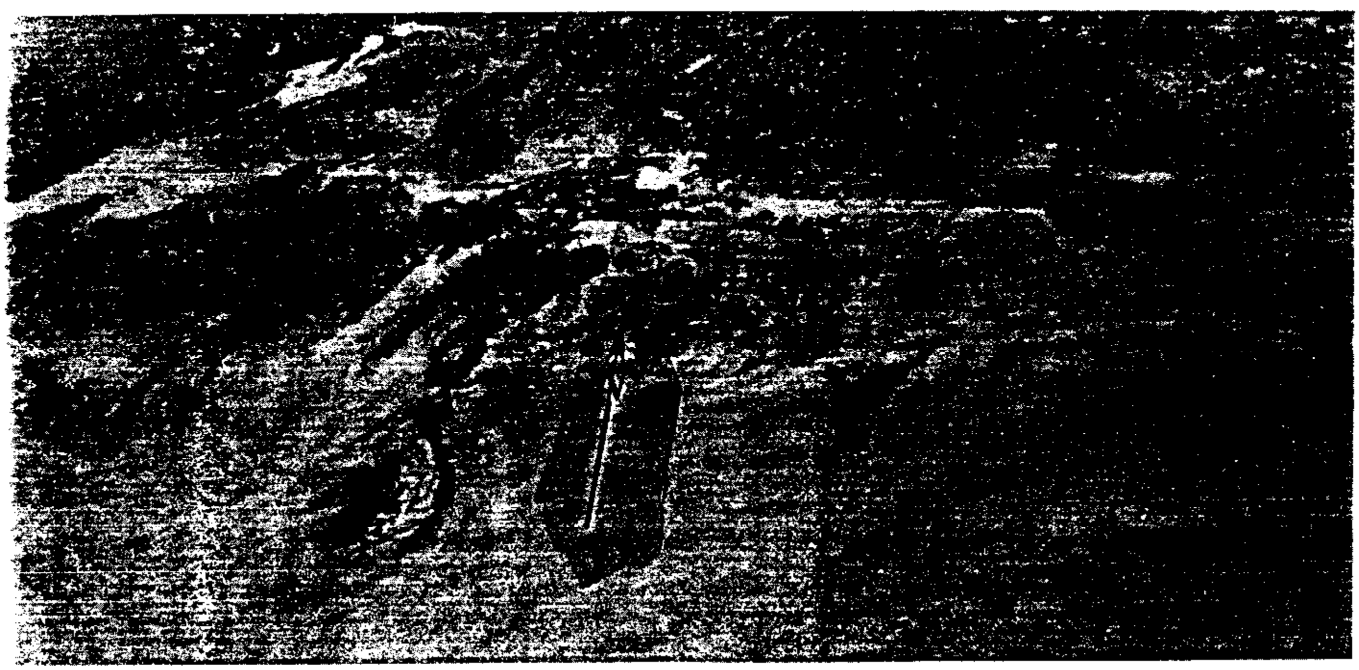


Figure 6h.--GOES USSR (visible) image for February 12, 1979.

Figure 6i.--*GOES* VISSR (*visible*) *image for February 13, 1979.*

Figure 6j.--*TIROS-N* VHRR (*visible*) *image for February 17, 1979.*

Figure 6k.--GOES VISSR (visible) image for February 18, 1979.

Figure 6l.--TIROS-N VHRR (visible) image for February 20, 1979.

Figure 6m.--TIROS-N VHRR (visible) image for February 25, 1979.

Figure 6n.--GOES VISSR (visible) image for February 27,1979.

Figure 6o.--TIROS-N VHRR (visible) image for March 6,1979.

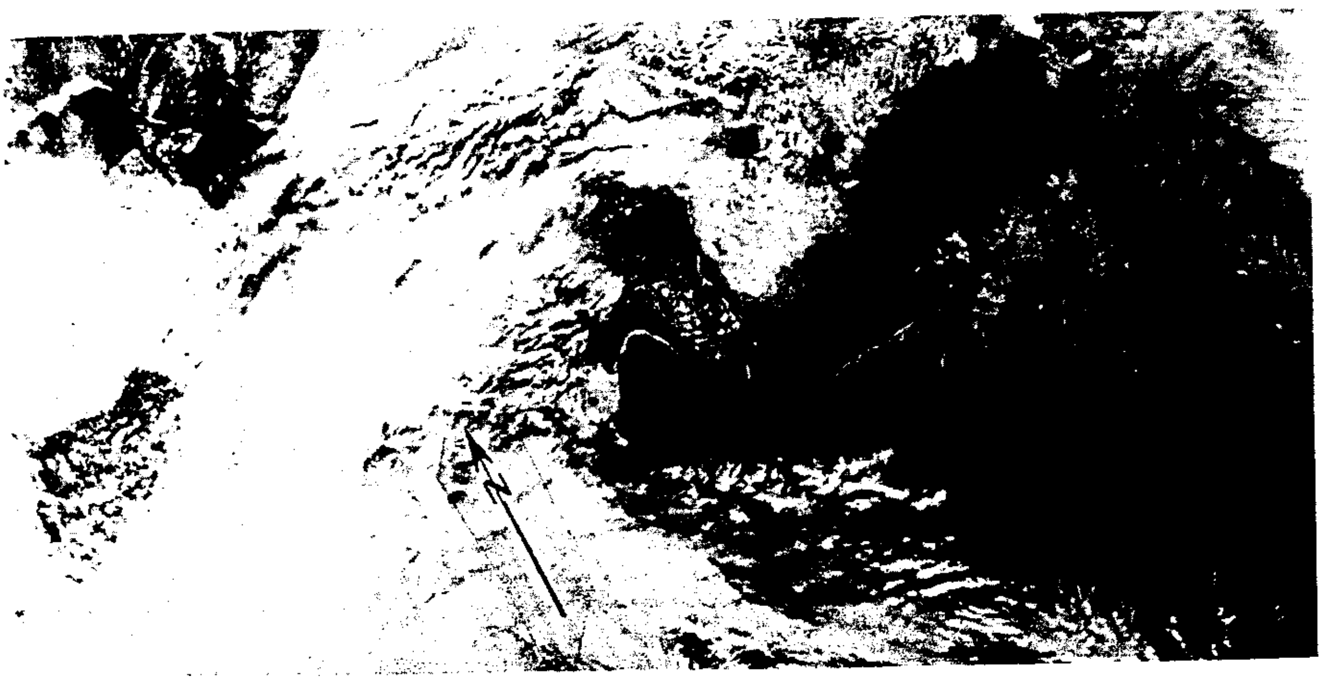


Figure 6p.--TIROS-N VHRR (visible) image for March 7,1979

Figure 6q.--*TIROS-N* VHRR (*visible*) image *for March 16, 1979.*

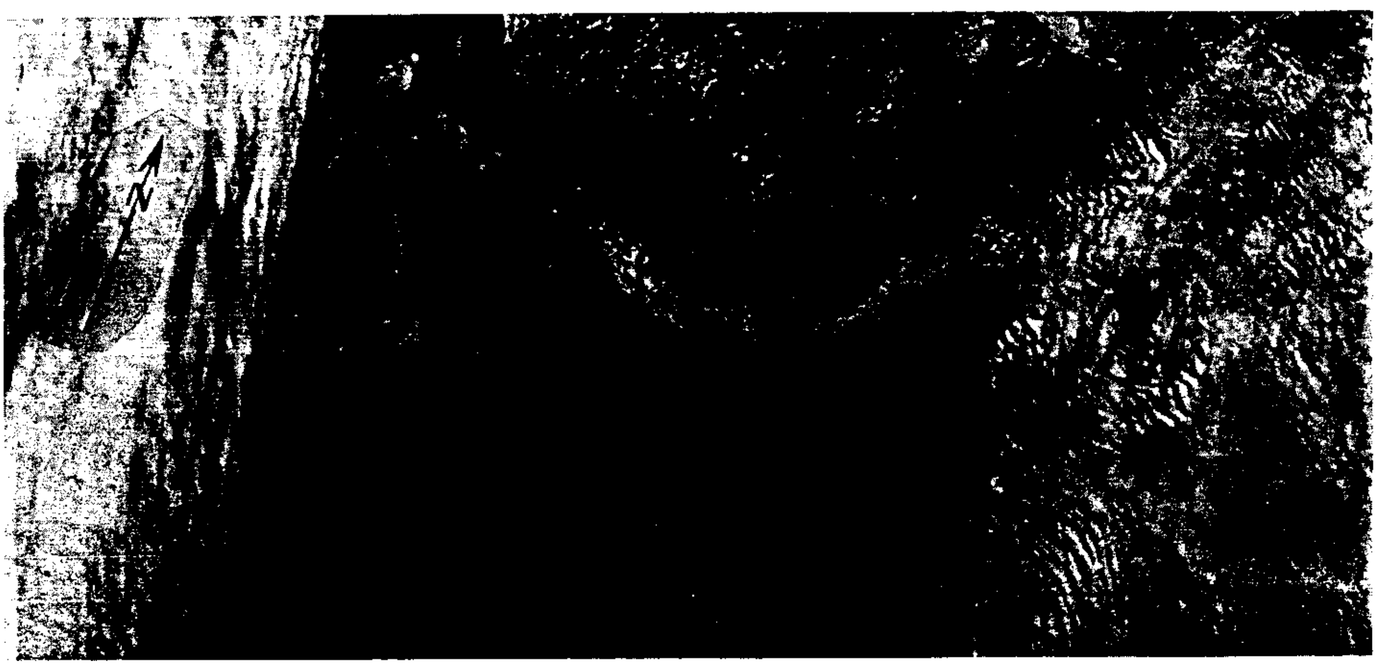


Figure 6r.--*TIROS-N* VHRR (*visible*) *image for March 20*, J979

Figure 6s.--*TIROS-N* VHRR (*visible*) *image for March* 27, 1979.

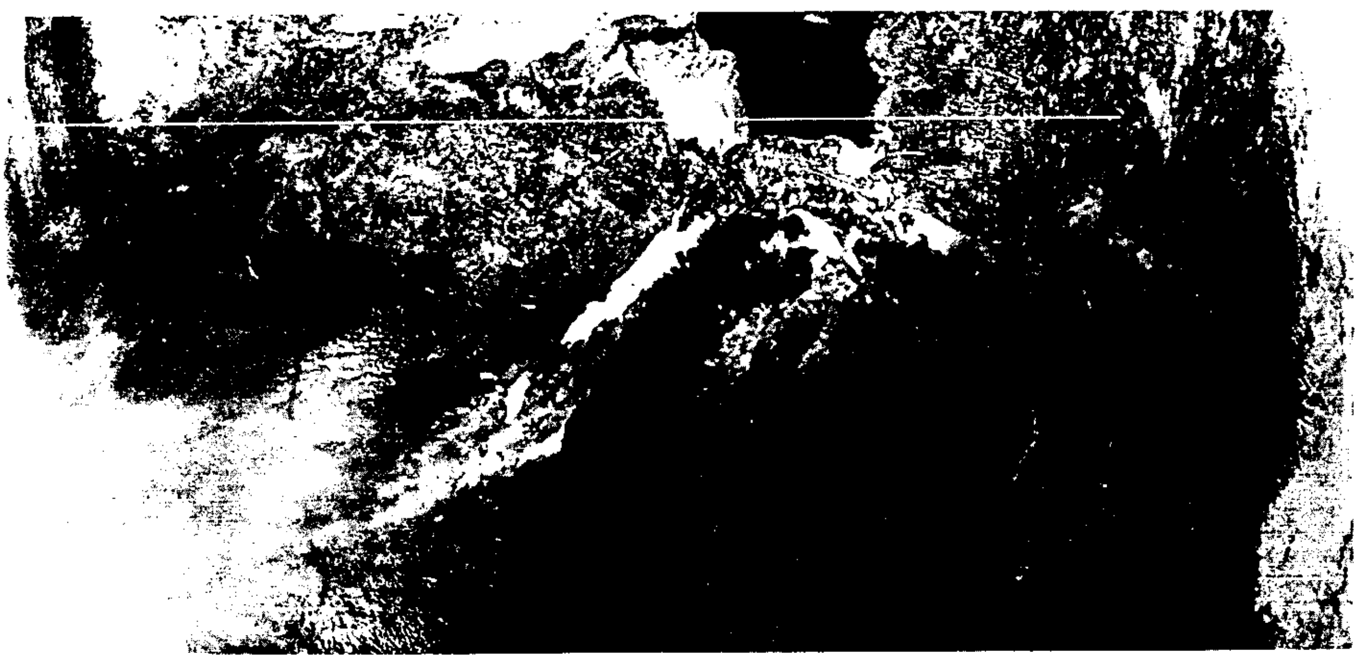


Figure 6t.--*TIROS-N* VHRR (*visible*) *image for April* 3, 1979.

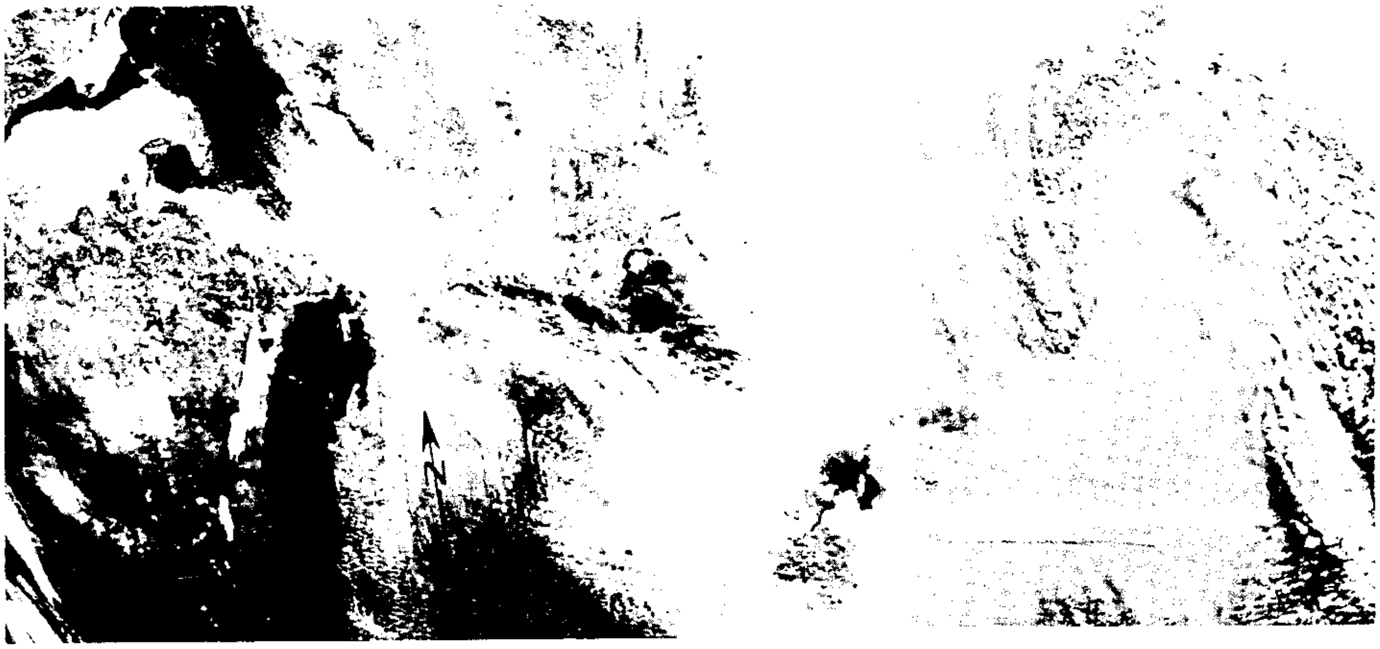


Figure 6u.--*TIROS-N* VHRR (*visible*) *image for April* 6, 1979.

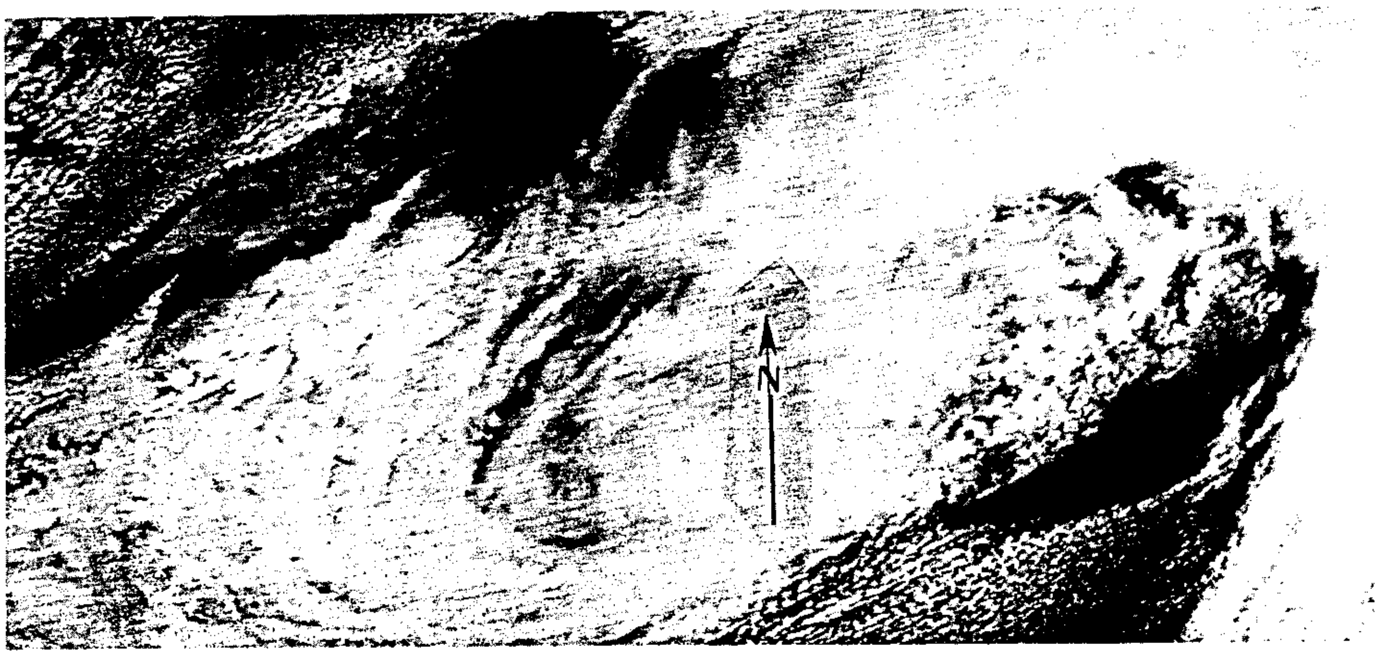


Figure 6v.--*GOES* USSR (*visible*) *image for April* 30, 1979

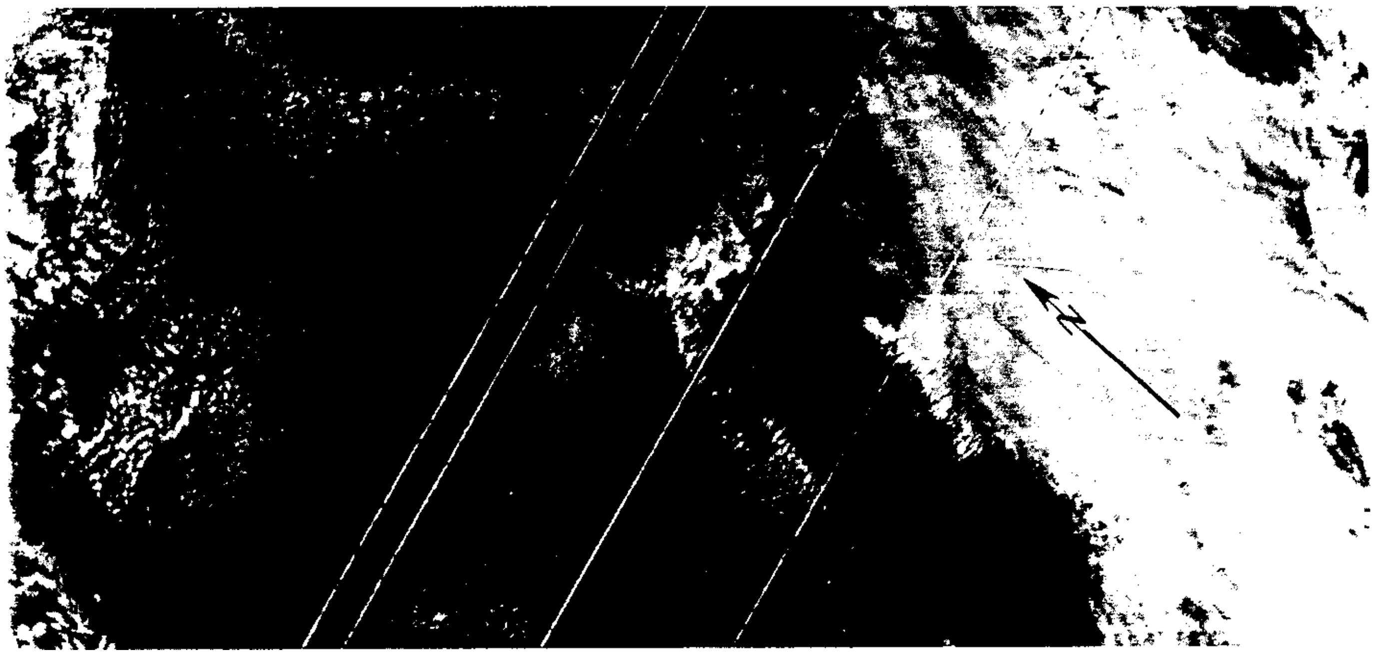


Figure 6w.--TIROS-N VHRR (infrared) image for May 12, 1979.

Table 6.--*Heat storage factor at month's end (°C)*

	1978				
City	August	September	October	November	December
Duluth, Minn.	-0.17	0.73	0.28	-0.48	-1.47
Green Bay, Wis.	-0.15	0.91	-0.14	-0.41	-0.96
Chicago, Ill.	-0.90	0.76	-0.69	0.22	-0.57
Sault Ste. Marie, Mich.	-0.32	-0.11	-0.70	-0.63	-0.94
Detroit, Mich.	-0.14	1.02	-0.30	-0.07	-0.08
Buffalo, N.Y.	0.49	0.47	-0.32	0.01	0.59

	1977				
City	August	September	October	November	December
Duluth, Minn.	-0.99	-0.83	-0.70	-0.46	-1.10
Green Bay, Wis.	0.34	0.34	-0.36	-0.41	-1.02
Chicago, Ill.	0.40	0.17	-0.36	-0.41	-1.27
Sault Ste. Marie, Mich.	-1.81	-1.38	-1.11	0.11	0.14
Detroit, Mich.	0.58	0.71	-1.10	-0.44	-1.09
Buffalo, N.Y.	0.35	0.45	-0.31	0.80	0.37

	1976				
City	August	September	October	November	December
Duluth, Minn.	1.15	1.03	-3.59	-4.95	-7.43
Green Bay, Wis.	0.71	-0.25	-3.08	-5.39	-8.60
Chicago, Ill.	-0.89	-1.15	-3.97	-5.79	-7.10
Sault Ste. Marie, Mich.	1.10	-0.30	-2.60	-4.05	-7.13
Detroit, Mich.	0.22	-0.64	-3.17	-4.89	-5.95
Buffalo, N.Y.	-0.55	-1.03	-3.12	-4.41	-5.12

3.2.2 Ice Formation and Breakup Phases

The sequence of ice formation and ice decay for the 1978-79 winter season is illustrated by the series of 21 weekly composite ice charts (figs. 5a-5u). These charts were compiled from available data as described in section 3.1. Freezing degree-days accumulations (°C) at eight representative locations are included on each of the composite ice charts. FDD data are an excellent parameter that provides a general indication of the winter severity. The FDD's were calculated from NWS data. In addition to the composite ice charts, 23 satellite images (figs. 6a-6w) document synoptic ice conditions for given dates throughout the 1978-79 ice cycle.

The winter 1978-79 produced ice in the shallow and protected areas of the Great Lakes in late November. Lake St. Clair was completely frozen over by January 10. The remainder of the Great Lakes reached their maximum areal ice coverage on February 17 when all of the Great Lakes were nearly 100 percent simultaneously ice covered. By mid-March, ice breakup began over the southern Great Lakes and they became mostly ice free by the end of April. In Lake Superior some open water appeared by the third week in March as the very slow ice decay began. Gradual ice breakup continued through the end of March and during April. Below-normal temperatures early in May slowed the ice decay in western Lake Superior and it was late in the month before the lake became mostly ice free.

3.2.3 The Ice Cycle on Lake Superior

Because of below-freezing air temperatures starting November 14, Lake Superior already had ice coverage by December 13 (fig. 5a). Ice was covering most of Black and Nipigon Bays and the northeast portion of Thunder Bay. Ice grew steadily in these and other shallow areas through the end of December as air temperatures averaged near -11° C (12° F). By December 20, ice was beginning to form around the Apostle Islands and along the eastern edge of Whitefish Bay (fig. 5b). One week later, on December 27, ice was also forming along the western shores of Whitefish Bay and over the remainder of Thunder Bay (fig. 5c).

For the first 3 weeks of January, air temperatures averaged near -22° C (-8° F), with minimum temperatures occasionally falling to -35" C (-31° F) and below. By January 3, ice had formed along the southern shore between Duluth and Ontonogan, and from the tip of the Keweenaw Peninsula to Whitefish Bay (fig. 5d). Ice also grew along the eastern shores between Michipicoten and Whitefish Bays as well as between Isle Royal and the Canadian coast. One week later, on January 10, shore ice had grown around the entire perimeter of the lake (fig. Se). Whitefish Bay was now 40 to 90 percent ice covered and ice was rapidly growing between Isle Royal and Thunder Bay. By mid-January, the entire western portion of the lake was covered with broken ice (fig. 5f). Fast ice had grown along the southern coast from Duluth to Copper Harbor, and was now covering the area north of Isle Royal as well as most of Whitefish Bay. The remaining ice around the perimeter of the lake had grown noticeably wider and thicker.

Air temperatures moderated somewhat during the last third of January and averaged near -12° C (10° F). Accordingly, the rate of ice growth became much slower than that of the previous 3 weeks. The only significant changes in the ice cover during this period were consolidation of the ice in the western portion of the lake and the establishment of fast ice along the southern shore between the Keweenaw Peninsula and Whitefish Bay (figs. 5g, 5h, and 6c).

Air temperatures again fell after the beginning of February, and averaged near -18° C (0° F) for the next 3 weeks. The lake responded quickly by producing extensive thin ice coverage over the eastern half of the lake (figs. 5*i* and 6*e*). However, in response to 3 to 7 kn west and northwest winds between February 7 and 9, two leads formed, one in the middle of the fast ice near Beaver Bay, and the other south of Isle Royal (fig. 6f). Because of the extreme cold, these leads refroze 2 days later (fig. 6*g*). By February 14, the persistent cold weather caused the eastern portion of the lake to become 60 to 100 percent covered with ice. Leads found along the eastern shoreline formed in response to 3 days of 2 to 7-kn easterly winds. During the next 3 days, this eastern lake ice consolidated very rapidly, and by February 17, the entire lake became nearly 100 percent covered, its maximum extent (fig. 6*j*). This total coverage was short lived, however, since 5 days later leads had developed from 4 to 8 kn east and southeast winds along the southern shore between Munising and Whitefish Point and to the north of Keweenaw Point (figs. 5*k* and 6*k*).

Although ice broke up due to wave action, air temperatures averaged near -8° C (18° F) after February 19 and the opened areas again became ice covered. By February 25, a wide lead formed from east of Michipicoten Bay to Whitefish Point in response to 5 to 7-kn east winds on February 22 and 23. Refreezing leads were evident along the northwest coast of the lake and southwest of Isle Royal (fig. 6*m*).

By the first week of March, this process of breaking up and refreezing produced ice coverage which varied markedly in thickness and concentration over the eastern half of the lake (figs. 5*l*, 5*m*, and 6*o*). Ice over the western portion had remained nearly intact, except for a lead from Beaver Bay to the Apostle Islands. One week later, on March 14, winds primarily from the west and northwest increased the width of this lead and extended it further southward toward the Apostle Islands (figs. 5*n* and 6q). These winds also compressed the eastern lake ice toward the southeast and produced leads along the northern coast and south of the Keweenaw Peninsula.

Between March 17 and 22, air temperatures rose significantly and averaged near 2° C (36° F). This warmth, in-conjunction with 4 to 13-kn south and southeast winds, broke up the eastern ice and pushed it northwards, creating a wide lead from Whitefish Bay to the Keweenaw Peninsula (fig. 5*o*). This warm weather also created a curved lead stretching westward from the Keweenaw Peninsula to the Apostle Islands, and then northward to the Canadian shore.

After March 22, air temperatures again declined and averaged near -5° C (23° F) until April 10. The only significant change in the ice coverage during this period was the dissipation of a portion of the eastern lake ice and some breakup of the thick ice to the west of Isle Royal (figs. 5*p*, 5*q*, 5*r*, 6*s*, and 6*u*).

After April 10, and for the remainder of April, air temperatures averaged near 5° C (41° F). The ice responded to this warmth by dissipating in most of the eastern portion by April 18 (fig. 5s). In addition, almost all of the fast ice covering the western end of the lake and Whitefish Bay began to break up. One week later, on April 25, ice also began to deteriorate in Thunder Bay and near Isle Royal (fig. 5*t*). By May 2, Whitefish Bay was ice free (fig. 5*u*). Broken to fast ice still covered the western portion of the lake, as well as Thunder, Nipigon, and Black Bays, but was rapidly melting. Ten days later, on May 12, only thin ice remained near Duluth and Chequanegon Bay; the rest of the lake was ice free (fig. 6*w*).

The ice season on Lake Superior began in early December and lasted until May 12, about 150 days, with maximum ice coverage of 100 percent occurring on February 17.

3.2.4 The Ice Cycle on Lake Michigan

In response to below-freezing air temperatures beginning November 18, ice formed in the southern end of Green Bay, over the Bays de Noc, and along the southwestern shore at Chicago by December 13 (fig. 5*a*). Ice grew steadily in these areas through the remainder of December as air temperatures averaged near -7" C (19" Fj. Toward the end of the month, ice began to appear along the extreme northern edge of the lake as well as in Sturgeon Bay (fig. 5*c*). The northern and southern portions of Green Bay ware covered by medium ice of 70 to 100 percent concentration on December 27, and thin ice began to form over the deeper areas of the bay.

During the first 2 weeks of January, air temperatures averaged near -20° C (-4" F) with minimum temperatures falling to -30° C (-22° F) and below. As a result, rapid ice growth occurred around the entire lake. By January 3, Green Bay was nearly frozen over except for a patch of broken ice covering the deeper areas. Ice was also partially covering the Straits of Mackinac and was beginning to grow westward toward Beaver Island. A thin ribbon of ice also extended along the entire western shoreline of the lake. This ice was highly susceptible to wind action and leads generally formed between it and the coastline. Such a lead can be seen on January 8 (fig. 6*a*), formed by 7 to 14 kn west winds over the previous 3 days. Two days later, on January 10, the area between Beaver Island and the Straits of Mackinac became frozen over (fig. 5*e*). Ice also began to form along the eastern shoreline, while ice along the southern and western shores grew thicker and wider. By January 17, the persistent cold weather had caused Green Bay to freeze over and further expanded the fast ice pack north and east of Beaver Island (figs. 5*f* and 6*b*). Fast ice can also be seen adhering to the eastern shoreline. However, ice along the southwestern end of the lake was transported northeastward as a result of 1 to 9-kn southwest winds between March 15 and 17.

Air temperatures moderated somewhat during the remainder of January, averaging near -8" C (18° F). This slowed the rata at which ice was growing and allowed wind-induced ice transport to occur more frequently. Except for the fast ice along the coast between Muskegon, Mich., and Gary, Ind., most of the eastern shore ice was removed by 4 to 9-kn northeast and southeast winds on January 20 and 23, respectively (fig. 5g). These winds also pushed the southern lake ice back toward the southwest shores, thus reducing the size of the lead there (fig. 6*c*). By the end of the month, persistent 6 to 12-kn northwest winds had compressed the ice in the southern portion of the lake (fig. 5*h*). These winds also removed ice from the northern portion of the lake and compressed it along the shores around Grand Traverse Bay.

Very cold weather again prevailed over Lake Michigan for the first 3 weeks of February. Air temperatures during this period averaged near -16° C (3" F), and minimum temperatures frequently fell to -25" C (-13° F) and below. By February 7, ice was rapidly growing over both the northern and southern portions of the lake, as well as along the west and east coasts (figs. 5*i* and 6*f*). Four days later, on February 11, ice began to cover Grand Traverse Bay (fig. 6*g*). By February 14, the entire surface of the lake contained ice of at least 40 percent concentration (figs. 5*j* and 6*j*).

Although air temperatures moderated to near -6" c (21° F) during the last weeks of February, ice over Lake Michigan continued to thicken and consolidate rapidly. By February 17, the entire lake was nearly 100 percent ice covered, its maximum extent (fig. 6*j*). By February 21, ice covered between 70 and 100 percent of the lake.

However, the effects of wind action on the ice was still evident. The leads along the western shoreline arose as a result of 7 to 15-kn southwest winds between February 19 and 21. By February 27, leads formed along the northern and eastern shores in response to 9 to 13-kn north winds on February 24 and 13 to 21-kn northeast winds on February 25 (figs. 5*l* and 6*m*). These winds also compressed the lake ice southward. At this time, the lake was almost completely ice covered, the ice being at its maximum extent.

During the first 2 weeks of March, air temperatures over the southern area of the lake averaged near 0° C (32° F) with maximum temperatures reaching as high as 7° C (45" F). As a result, a considerable portion of the ice over this part of the lake had broken up by March 6 (figs. 5*m* and 6*o*). In addition, 10-kn winds, first from the southeast, then from the southwest, during the previous 4 days had transported all lake ice northward, producing a large lead along the southern shore, while at the same time increasing the ice concentration over the northern portion of the lake. On March 13, 8 to 17-kn west and southwest winds again pushed the ice north and eastward end compressed it onto the eastern shore (figs. 5*n* and 6*q*).

For the remainder of March, air temperatures averaged near 5° C (41° F) with maximum temperatures as high as 20° C (68" F). This warmth caused further ice deterioration and permitted it to be easily moved about by the wind. By March 21, 3 days of 6 to ll-kn south and southeast winds pushed ice away from the eastern coast and produced leads over the northern portion of the lake and drift ice along the southern portion (fig. 5*o*). Three days later, 8 to ll-kn west winds again compressed this ice against the eastern coastline (figs. 5*p* and 6*s*).

By April 3, sustained warm air temperatures finally produced ice melt at the mouth of Green Bay (figs. 5*q* and 6*t*). Ice also began to deteriorate between Beaver Island and the Straits of Mackinac, as well as in Grand Traverse Bay. The remainder of the lake was ice free. Between April 7 and 11, 7 to ll-kn east-northeast winds broke up and transported westward a considerable portion of the ice between Beaver Island and the straits. Meanwhile, ice began to break up over the deeper areas of Green Bay. By April 18, only scattered floes remained in Grand Traverse Bay, and between Beaver Island and the Straits of Mackinac. Much of the ice over Green Bay had broken up and was beginning to melt rapidly. By the end of the month, the only ice remaining on the lake was drift ice at the straits and around Beaver Island, and rotten ice in Green Bay (fig. 5*t*). Lake Michigan finally became ice free on May 2.

Thus, the ice season on Lake Michigan began during the first two weeks of December and ended on May 2, lasting more than 145 days, with maximum ice coverage occurring near February 17.

3.2.5 The Ice Cycle on Lake Huron

Air temperatures around Lake Huron were mostly below freezing after November 18. Thus, ice formation had already begun by December 13, with ice adhering to the southeastern shore of Saginaw Bay and with scattered shore ice in the North Channel and Georgian Bay (fig. 5*a*). Ice grew steadily in these areas through the remainder of December as air temperature averaged near -6° C (21" F). By December 20, broken ice covered the southern half of Saginaw Bay, while fast ice had grown along its western shoreline. Thin ice of 10 to 30 percent concentration covered most of the North Channel and fast ice was adhering to the northeastern coast of Georgian Bay (fig. 5*b*). By the end of the month, the coverage of Saginaw Bay ranged from fast ice along the northern and southern shores to thin broken floes in the interior (fig. 5*c*). Much of the St. Marys River system was covered with thin ice while the North Channel was primarily 70 to 90 percent ice covered with some open areas over the deeper sections. The ice along the northern and eastern coasts of Georgian Bay had grown noticeably wider and further southeastward.

The rate of ice growth increased during the first 3 weeks of January as air temperatures averaged near -13" C (9" F) and minimum temperatures were -25° C (-13° F) and below. By January 3, more than half of the North Channel and Saginaw Say were covered with fast ice. Shore ice completely encircled Georgian Bay and extended along most of the western and southern shores of the lake (fig. 5d). One week later, on January 10, fast ice completely covered both the North Channel and Saginaw Bay. Ice was also beginning to cover the southern portion of the lake as well as the northeastern part of Georgian Bay (fig. 5e). The remainder of the lake and Georgian Bay were encircled by rapidly growing shore ice. By mid-January, Georgian Bay was approximately 60 percent covered and was separated from the main lake by ice north of the Bruce Peninsula. Ice around the remainder of the lake was considerably wider and more consolidated (figs. 5*f* and 6*b*).

During the remainder of January, air temperatures moderated to average near -4" C (25° F). This slowed the rate of ice growth and allowed wind-induced ice transport to occur. Most of the shore ice south of Manitoulin Island was removed by 4 to 15-kn winds. These winds also compressed the ice into the southern portion of the lake (fig. 5*g*). By January 31, west and northwest winds had compressed the ice on the east shore. These winds also pushed some of the ice away from the western shore and transported it toward the middle of the lake (fig. 5*h*).

Very cold weather prevailed over Lake Huron during the first 3 weeks of February. During this time, air temperatures averaged near -17" C (1° F) with minimum temperatures falling to -35° C (-31" F) and below. With this extremely cold weather, rapid ice growth occurred over the entire lake. By February 7, the only area of open water was near the center of the lake. All other areas were 40 to 100 percent covered by thin to medium ice (figs. 5*i* and 6*e*). One week later, on February 14, the entire lake was frozen over except for a small area of broken floes at the center of the lake, and a lead along the eastern shoreline (fig. 5*j*). Three days later on February 17, the entire lake was nearly 100 percent ice covered, the greatest extent of ice cover (fig. 6*j*).

Between February 19 and the end of the month, air temperatures warmed up and averaged near -4" C (25" F). This warmth slowed the growth of ice considerably and again allowed wind-induced ice transport to occur. Winds from the south at 4 to 11-kn on the 20th pushed all ice northward, producing a semicircular lead parallel to the western, southern, and eastern coasts (figs. 5*k* and 6t). Northerly winds of 8 to 10-kn between the 24th and 26th then pushed the ice southward creating leads along the northern shore and in Georgian Bay (figs. 5*l* and 6*n*). The ice was again transported northward by 5 to 15-kn southeast to southwest winds between March 2 and 6, producing large leads along the southern shores of the lake and bay (figs. 5*m* and 6*p*). Finally, 5 to 19-kn west and southwest winds between March 10 to 16 moved the ice eastward and compressed it upon the eastern shores of the lake and bay (figs. 5*n* and 6*q*). Both the North Channel and Saginaw Bay remained ice covered throughout this period.

During the latter half of March, air temperatures averaged near 2° C (36° F) with maximum temperatures as high as 17' C (63° F), causing a considerable portion of the lake ice to break up and dissipate between March 21 and 28. In addition, ice began to thaw along the southwest and southeast shores of Saginaw Bay (figs. *5o*, *5p* and 6s).

By the first week of April, all of the lake ice had melted except some broken floes west of Alpena and along the eastern shore (figs. 54 and *6t*). In addition, ice over both Saginaw and Georgian Bays had broken up and thinned considerably. Fast ice still covered the North Channel and the St. Marys River system. As above, freezing air temperatures continued, this ice began to melt and break up (figs. *5r* and *6u*). Elsewhere, only scattered to broken floes remained over central Georgian Bay, southern Saginaw Bay, and along the eastern and northwestern shores.

By mid-April, air temperatures were averaging between 8° and 10° C (46' and 50° F). This warmth initiated a rapid breakup of the ice in the North Channel and in the St. Marys River system (fig. *5s*), as well as melting the remaining shore ice in Saginaw Bay. By the end of the month, all of the lake was ice free, except for rotten ice over the North Channel and around the Straits of Mackinac (fig. *5t*). These areas were finally cleared of ice by May 2.

Ice began to form on Lake Huron in early December and lasted until the beginning of May, more than 140 days, with maximum extent of coverage occurring on February 17.

3.2.6 The Ice Cycle on Lake St. Clair

Lake St. Clair had thin shore ice by the second week of December (fig. *5a*). Persistent west and southwest winds during December 9 to 18 moved and compressed this thin ice onto the eastern shore (fig. *5b*). With air temperatures averaging below 0° C (32° F) the next week, thin broken to solid ice formed over the entire lake surface (fig. *5c*). This ice continued to grow and consolidate during the next 7 days as minimum air temperatures frequently fell to -20° C (-4" F) and below. The lake was prevented from freezing over entirely by 20-kn west winds on January 3 (fig. *5d*). By January 10, persistent cold air temperatures finally caused the lake to become completely ice covered (figs. 5e and *6b*).

Lake St. Clair remained 100 percent ice covered for the next 2 months. Then, in response to above-freezing air temperatures, which began on February 27, thawing began at the mouth of the Detroit River (fig. *5m*). Over the next 7 days, 10 to 15-kn west and southwest winds and 4" C (39° F) average temperatures produced thawing and breakup of ice along the entire western and northwestern shorelines (figs. *5n* and *6q*). By March 21, as air temperatures averaged near 10" C (50° F), only rotten ice remained on the lake surface (fig. *5o*). Finally, after having had some ice coverage for more than 103 days (December 14 to March 27), Lake St. Clair became free of ice on March 27 (figs. *5p* and 6s).

3.2.7 The Ice Cycle on Lake Erie

In response to near-freezing air temperatures since November 26, thin ice had formed in the shallow coastal area west of Pt. Pelee and along the extreme western shoreline by December 13 (fig. *5a*). Ice continued to grow slowly during the next 2 weeks as air temperatures remained near freezing. Thus, by December 27, thin broken ice covered the entire area west and north of a line extending from near Cleveland to Pt. Pelee and then eastward toward Port Stanley (fig. *5c*).

Except for a brief period of 3" to 9" C (37° to 48" F) air temperatures from December 30 to January 1, below-freezing conditions prevailed over the lake for the next 30 days. By January 3, a ribbon of thin ice had formed along the southern shoreline while the ice east of the Pelee and Kelleys Islands continued to expand eastward (fig. 5*d*). Ice also began to cover a significant portion of the shallow area north of Long Point. One week later, on January 10, the entire western basin area was frozen over, the usual ice plug at Buffalo had formed, and, with the exception of the open area over the deep waters south of Long Point, the reminder of the lake was covered with thin broken ice (fig. 5*e*).

The ice continued to grow and thicken rapidly in the next week. However, this ice was still susceptible to wind action. West and southwest winds of 4 to 13-kn had produced a semicircular lead stretching south from Port Stanley to the Kelleys and Pelee Islands and then east toward Cleveland by January 17 (figs. 5*f* and 6*b*). This lead separated two distinct ice areas and formed because the islands hindered the movement of ice from the western basin.

From January 25 through February 5, winds blew persistently from the west and southwest while air temperatures averaged near -2" C (28° F). As a result, ice growth and transport occurred simultaneously. As can be seen in figures 5*g* and 5*h*, the windflow gradually pushed the eastern ice pack onto the southern and eastern shores and enlarged the lead, especially along the northern portion of the lake. The freezing air temperature continually reformed the ice taken away from the northern shoreline.

During the first 2 weeks of February, air temperatures declined further, averaging near -12° C (10° F). Although winds continued to blow from the west and northwest during this period, ice gradually filled in this lead (figs. 5*i* and 6*g*). On February 17, the lake had attained its maximum ice cover of 100 percent (figs. 5*j* and 6*j*).

After February 19, a warming trend began. The associated -1° to 8° C (30° to 46° F) air temperatures initiated ice melt and again allowed wind-induced ice transport to occur. On February 21, 15-kn southwest winds produced a small lead stretching from Cleveland to Port Alma (fig. 5*k*). One week later, 14 to 19-kn northeast winds pushed the ice toward the southern shore and produced a lead from east of Pt. Pelee to Long Point (figs. 5*l* and 6*n*).

By the first week of March, air temperatures were reaching as high as 30" C (86° F). As a result, all ice began to deteriorate rapidly and became more susceptible to wind action. By March 7, winds generally from the south at 4 to 17-kn had removed the ice from portions of the southern shore and transported it northward (fig. 5*m*). Between March 11 and 16, west winds of 9 to 17-kn pushed all ice eastward, creating wide leads east of the islands and along the northern shoreline (figs. 5*n* and 6*q*). In addition, ice in the western basin began to break up and thaw generally from the coastline toward mid-lake.

For the remainder of March, temperatures ranged between 2° and 18° C (35" and 64° F). As a result, by March 21, all ice was in a state of rapid deterioration (figs. 5*o* and 6*r*). Between March 24 and 27, 9 to 15-kn west and northwest winds cleared all ice from the western basin and pushed the remaining lake ice onto the southern and eastern shores (figs. 5*p* and 6*s*).

One week later on April 4, only some drift ice and the ice plug at Buffalo were visible (figs. 5*q* and 6t). This plug melted gradually and had almost disappeared on May 2 (fig. 5*a*).

Thus, the ice season on Lake Erie lasted over 138 days (from December 13 to May 2), with the maximum coverage of greater than 95 percent occurring between February 14 and 17:

3.2.8 The Ice Cycle on Lake Ontario

The ice season on Lake Ontario began on December 20 when ice formed in the Bay of Quinte (fig. 5*b*). Because of relatively mild air temperatures through the end of December, ice grew slowly in this bay, but eventually became 100 percent consolidated by January 3 (fig. 5*d*). At this time, ice also began forming in the St. Lawrence Seaway and in Chaumont Bay. From January 3 to 12, air temperatures averaged near -11° C (12° F). This cold weather initiated rapid ice growth around the entire lake perimeter and further thickened and consolidated the ice in the St. Lawrence Seaway and other shallow areas (fig. Se). By January 17, continued cold weather produced fast ice along the eastern shoreline and further extended the northern and southern shore ice towards mid-lake (figs. 5*f* and 6*b*). However, between January 21 and 24, two storms passed near Lake Ontario. The associated flow of 19-kn west-southwest winds on January 21 followed by north-northwest winds of 5-kn on January 24 removed most of the ice from both the north and south shores and pushed ice into the eastern portion of the lake (fig. 5*g*). After the passage of these storms, air temperatures averaged near 2° C (36° F) and winds blew persistently from the west and northwest at 6 to 18-kn, removing all of the remaining shore ice in western portions of the lake and melting a considerable portion of the eastern lake ice (fig. 5h). Cold weather returned during the first week of February, however, and again produced ice around the entire lake perimeter (fig. 5*i*). During the period of February 9 to 18, air temperatures were particularly cold, averaging near -19° C (-2° F). As expected, marked ice growth occurred over the entire lake. Except for an open area in the western portion of the lake, the remainder of the lake contained mostly broken ice (figs. 5j and 6j). On February 17, the entire lake was 95 to 100 percent ice covered, its maximum extent. This extensive coverage was short lived, however, as 2 to 3-kn south winds and 0.4 to 4-kn east winds between February 19 and 20 furthered breakup from St. Catherines to Oswego (figs. 5*k* and 6*l*). After February 20, air temperatures of 1° to 4° C (34° to 39° F) and 12 to 15-kn east-southeast winds broke up and melted much of the ice (figs. 5*l* and 6*n*). In the first week of March, with air temperatures averaging near 5° C (41° F), 10 to 17-kn south and southeast winds pushed most of the ice into the area east of Prince Edward Point (fig. 5*m*). A return of freezing air temperatures during the next 2 weeks brought a halt to the rapid ice melt. Persistent west and southwest winds of 10 to 16-kn moved and compressed the ice initially east of Prince Edward Point onto the eastern coast (figs. 5*n*, 50, and 6*r*). After March 23, air temperatures of 16° C (61° F) restarted the rapid ice deterioration process, and by March 28 all shore ice was eliminated and ice was rapidly dissipating in all bays (fig. 5*p*). Lake Ontario was finally ice free on April 4 after having some ice coverage for 105 days (December 20 to April 4) (fig. 5*q*).

3.3 Comparisons With Previous Winters

Table 7 compares percent maximum ice extent for winter 1978-79 and for those given by Assel *et al.* (1979) for the Great Lakes during the past 16 winters. From Table 7, it can be seen that the 1978-79 maximum ice extent exceeded the past 16 winters on the Great Lakes. No comparison is made for Lakes Erie and St. Clair as they freeze over most winters. The simultaneous occurrence of nearly 100 percent ice cover of February 17, 1979, is a unique feature of the 1978-79 winter season. This is the first time such an occurrence has been documented with a high degree of scientific certainty (fig. 6j).

Table 7.--Comparison of maximum percent ice extent on the Great Lakes: 1978-79 and previous tinters

Winter	Superior, percent	Michigan, percent	Huron, percent	Erie, percent	Ontario, percent
1962-63	95	80	97	98	51
1963-64	31	13	32	91	12
1964-65	90	40	60	NA	10
1965-66	60	15	29	NA	15
1966-67	88	46	80	90	12
1967-68	90	30	50	98	10
1968-69	40	15	50	80	10
1969-70	80	30	50	95	17
1970-71	48	27	45	92	10
1971-72	95	45	70	95	20
1972-73	55	20	60	95	20
1973-74	70	20	65	95	25
1974-75	30	25	45	80	16
1975-76	40	20	50	95	20
1976-77	83	90	89	100	38
1977-78	82	52	89	100	57
1978-79	100	100	100	100	95
Mean	69	39	62	94	26
Standard Deviation	24	27	22	6	23
1978-79 - Mean	+31	+61	+38	+6	+69
1978-79 ice cover	above	above	above	NA	above

NA = Not applicable

4. EFFECTS ON GREAT LAKES COMMERCE

D. E. Boyce

The 1978-79 ice season on the Great Lakes for the third year in a row was severe and many records were broken throughout the lakes. For the first time in documented history, all of the Great Lakes were nearly frozen over simultaneously on February 17, 1979. The western lakes took the brunt of the winter with consistent cold weather and frequent very heavy snows, although overall, the lakes region was 1.5" C (2.7' F) colder than normal for the season--slightly milder than the previous year, and commercial cargo tonnages directly assisted were about half the previous season (table 8). However, many of the voyages were completed under very arduous conditions and vessel damage both to commercial ships and Coast Guard vessels was at an all-time high.

4.1 Fall Season

Demands during the fall for most of the common bulk commodities were the highest in 3 years. Coal tonnages were down somewhat, but iron ore, taconite, and grain shipments were up. Grain cargoes were up sharply.

As usual, the number of storms began to increase during the fall. By October, the number of ship wind observations over 30 kn had nearly doubled over the previous month. The strongest storm in October was centered over Lake Winnipeg on the 24th. Winds of 46-kn and 5-m (16-ft) seas were reported on Lake Superior by the *Mesabi Miner*. The *Charles M. Beeghly* reported similar conditions on Lake Superior on the 29th.

November 1978 began with unseasonably warm weather. On the 8th, a low-pressure area raced across central Canada, and winds from this system were measured at 56-kn on Whitefish Bay by the *Robert C. Stanley*. Winds over 40-kn were also reported over lakes Michigan and Huron. At mid-month, water temperatures ware normal or slightly above as a result of the prolonged mild weather. The first winter storm reached the Great Lakes on the 17th, and the *Mark* Twain was blown over and sunk in Lake St. Clair during the storm.

Very cold weather continued across the western half of the lakes the first week of December, and sub-zero temperatures (degrees Fahrenheit) were observed from western Lake Superior south across Green Bay and western Lake Michigan. The cold weather formed new ice in shallow water areas and thickened ice already in place. In Green Bay on the 9th, the *Sam Laud* was the first vessel of the season to require icebreaking assistance. The commercial tug Green *Bay* freed her the next day, but she got stuck again in the harbor channel. The tug Bonnie *Selvick* broke her loose on the 11th.

Several groundings were reported in December as the result of high winds or ice. The *Erindale* was aground briefly in the St. Clair cutoff on December 5, the *Troisdoc* on the St. Marys on December 7, the *Prindoc* near Amherstburg on the 13th, and the *Charles* M. *Beeghly* in Duluth Harbor on the 22nd.

On December 11, the Ice Navigation Center in Cleveland opened for the season, and began its normal operations to include dispatching Coast Guard icebreakers.

Table 8.—*Summary of Icebreaking Assistance*

Year	Direct assistance to industry, operations hrs.	Total cargo tonnage carried by vessels assisted	Total value of cargo carried by vessels assisted	Types of cargo carried	Number of preventative icebreaking missions
FY 1971	4,080	2,520,152	$ 53,965,269	Cement, coal, general	
FY 1972	2,447	2,276,384	61,862,404	Grain, iron ore, limestone	
FY 1973	1,341	1.470.995	27,977,811	Petroleum, taconite, grain	
FY 1974	3,872	1,681,127	45,640,302	steel, taconite, wood pulp	
FY 1975	2,575	3,662,653	10,933,614	Not available	177
FY 1976	2,775	2,937,083	97,465,465	Not available	256
FY 1977	5,942	4,556,724	125,142,602	Taconite, grain, petroleum steel, coal	47
FY 1978	6,863	9,507,274	98,982,105	Petroleum, taconite, cement, grain, steel	98
FY 1979	3,990	4,359,953	147,720,000	Taconite, petroleum, grain, coal, chemicals, cement	216

The first Coast Guard icebreaker assistance was provided in Saginaw Bay on December 11, when the Coast Guard assisted the M/V's *Nicolet*, *Parker*, and *Evans*. Two days later the Coast Guard cutter *Bramble* aided the *J. Burton Ayers* in Green Bay.

A major storm moved through the upper Great Lakes area December 12 and 13. Winds as high as 45-kn were reported on Lake Huron by the *Thomas Wilson*, and storm warnings were issued as far south as Lake Erie. Extensive damage was sustained near Sault Ste. Marie when the *John Sherwin* struck the ice boom in Little Rapids Cut.

4.2 Extended Season

Milder weather the week before Christmas generally halted major changes in the ice cover and the only direct assistance that was provided to commercial ships was on the St. Marys River, On the 22nd, the Lime Island Ferry was helped along by the Coast Guard cutter *Naugatuck*.

Downstream in the system on the St. Lawrence, preparations were under way for the traditional closing, which was scheduled for December 20. In order to prevent the rush of ships attempting to exit the Great Lakes during the final days, the seaway set December 6 as the final date salties could transit the Welland Canal upbound if they planned to leave the lakes. The final deadline for the Montreal-Lake Ontario section was December 15. Ships attempting to leave after the deadline would be accepted, but a $20,000 per day fine up to a maximum of $80,000 would be levied at the discretion of the seaway. The fines were later suspended due to regulatory problems and the closing of the Eisenhower Lock on December 20.

On December 20, only four vessels remained in the system, but serious ice problems had developed in the area above the Beauharnois Lock. There was also some last-minute drams when the Panamanian *Hand Fortune* entered the system after the deadline. It looked as if she would be headed for an unplanned winter on the lakes when U.S. seaway officials declined to allow her to transit the locks. However, after a meeting of officials and representatives of her owners, the ship was allowed to proceed, but at a cost of $10,000 in lieu of a fine and up to $30,000 in expenses.

One of the last ships upbound on the seaway was the new Coast Guard multipurpose 43-m (140 ft) vessel *Katmai Bay*, the first of six new cutters planned for the Great Lakes. She had traveled to the Great Lakes all the way from the West Coast of the United States where the new cutter class was built.

The extreme cold continued through the second week of January, and a major weekend snowstorm added to the misery and icebreaking difficulties. The *Benson Ford* was beset in the Livingston Channel for 3 days, before being freed by the tugs *Jomes Hannan* and *Barbara Ann* on January 11. The *Gemini* was trapped in the ice in Saginaw Bay on January 8. She took 3 days to reach the Dow Chemical docks even with the help of the Coast Guard cutter *Bramble*.

The "Monster Storm" of the winter roared through the central Great Lakes the weekend of January 13-14. New snow totaled 52.6 cm (20.7 inches) in Chicago--second only to their 1967 storm fall of 58.4 cm (23.0 inches). The 73.7 cm (29.0 inches) on the ground was an all-time record. It may have been short of the total on the ground during the "Winter of the Deep Snow" in 1830-31, when no total for

Chicago was recorded because the U.S. Army weatherman was off on maneuvers in Wisconsin that season. Two major incidents took place on Lake Michigan and nearby Green Bay during the storm. On January 12, the fish tug *San Joseph* became stuck in thick ice about a mile off of Chicago's Oak Street Beach. The crew radioed the Coast Guard that they did not know their position because of the low visibility, and their ship was being slowly crushed by the ice. Small search aircraft were unable to launch during the storm, but the Coast Guard ordered their C-130B aircraft with precision radio direction finding gear from Cleveland to overfly the area. This plane routinely flies ice flights over the Great Lakes each winter, and piloted by Commander Leon Thomas, located the tug by using the SLAR and radio equipment. The crew was rescued from the tug on the 14th by Coast Guard and Chicago Fire Department helicopters. No Coast Guard tugs were available because they had been deployed to Green Bay.

What started out as a routine icebreaking mission in Green Bay turned into one of the most dramatic events of the winter on January 13. The *Edwin H. Gott,* U.S. Steel's new thousand footer, left Bay Shipbuilding on her maiden voyage on January 12 under escort of the Coast Guard cutters *Arundel* and *Acacia.* She reached the open waters of Lake Michigan and the cutters returned to the bay to assist the *Jupiter,* the *Comoco Illinois*, and later the *Wilfred Sykes.* The *Arundel* became beset in a windrow near Minneapolis Shoal late on the 13th, and strong winds moved the ice and the ship toward the shoal. Rafted ice ripped through two windows in the Chief Petty Officer's quarters and tore away stantions on her main deck. The ice continued to pile up to the "01 deck," completely covering her stern and resulting in a 25° list. An estimated 20 tons of ice lay on her decks. The crew, fearing the ship's hull was about to crack under the weight and pressure of the ice, abandoned the vessel and walked by spotlight to the *Acacia,* which was also beset nearby by this time. The major Great Lakes icebreaker *Mackinaw* and the *Sundew*, as well as a helicopter from Traverse City, were diverted to assist, but the winds shifted before they arrived. Northwest winds rapidly loosened pressure and the ships were freed. The craw reboarded her and she limped to Sturgeon Bay for a complete inspection, which revealed $13,622 in damages.

Coast Guard vessels ware not the only casualties of the storm and ice that week. The *Benson Ford* reported $1,000 damage in Lake Erie, the *Putzfrau* $25,000 damage on the Cuyahoga River in Cleveland, and the *Adam E. Cornelius* $15,000 and the *Thomas* Patton $25,000 damage in Green Bay. The Gemini sustained $40,000 damage on a trip in Saginaw Bay on January 15th.

Unusually heavy brash ice in the area from the St. Clair River into Lake Erie continued to hamper shipping following the mid-month storm. The Arctic icebreaker *Westwind* was deployed to the area and relieved many of the problems. The *Katmai* arrived at her new home port of Sault Ste. Marie on the 16th, logging her first Great Lakes icebreaking assistance on the way, helping the *Mesabi Miner*. Coast Guard ship casualties in Lake Michigan left them short of active resources for heavy winter icebreaking. The *Bramble* was moved from the "Coal Shovel" area to Lake Michigan to serve "Oil Can." Canadian Coast Guard resources ware also short. The Canadian ship *Alogoway* was beset in Goderich, Ontario, for 2 weeks, and the cutter *Griffin* and the tug *Barbara Ann* assisted her.

Another drama unfolded on the lakes on Friday, January 20. A Flint, Mich., pilot returning from Boston, Mass., over Lake Erie encountered severe icing conditions and ditched his plane on the ice. Dennis Gravelie, the pilot, attempted to walk to safety on shore, but found that he and his plane were on a large floe.

Later that day the signal from his emergency locator transmitter (ELT) was picked up onshore and the Coast Guard was notified. The Coast Guard launched an HH-52 helicopter from their base north of Detroit, but it was forced back by heavy icing. A Canadian Coast Guard plane arrived early on the morning of January 20, and was relieved by the U.S. Coast Guard SLAR aircraft 1351 toward dawn as personnel at the Rescue Coordination Center in Cleveland enlisted the aid of a local civilian trafficopter pilot, Art Fantroy. Since the helicopter had no navigational equipment on board, the Coast Guard aircraft had to be used to slowly vector it through early morning fog to the crash site. About 9:30 a.m. Fantroy spotted the plane, landed near it, and returned the pilot to shore-some 22 hours after the crash. Fantroy landed with only minutes of fuel left, and later in the year was decorated with the second highest civilian award, the Silver Lifesaving Medal.

After 3 weeks of below-normal temperatures, milder weather reached the Midwest and Great Lakes Region. The ice cover stabilized or grew slowly until the last few days of January. The heavy ice already in place resulted in a continued need for icebreaking assistance. The Coast Guard logged 106 direct icebreaking assists through the end of the month. On the 30th the Coast Guard cutter *Naugatuck* lost her prop near De Tour, although Corps of Engineers divers managed to locate the wheel and it was reunited with the ship in the Sturgeon Bay shipyard. Two weeks time ware lost and damages amounted to $18,700. Commercial vessel damages were much higher. The Gemini was damaged for the second time in Saginaw Bay on the 28th at a cost of $100,000. *The Jupiter* reported $3,000 damage after transiting Lake Michigan the following day. On the last day of the month major damages resulted when the Arthur *M. Anderson* hit the icebreaker *Westwind* from behind near Ashtabula on Lake Erie. The *Westwind* was breaking track when it hit a pressure ridge and stopped suddenly. The *Anderson* was unable to change course in time to avoid the icebreaker. Neither vessel took on water, but the bow of the U.S. Steel ship was holed and her main and forecastle decks were buckled. Damages on the *Westwind* included buckling of her main deck and some smaller gasher. Costs for the *Anderson* were about $125,000 and for the *Westwind* over $172,000.

By far the coldest month of the winter was February, with temperatures averaging nearly 5.6' C (10.1' F) below normal across the lakes. The coldest area was around Lake Michigan. Shipping dwindled down to just a few vessels and icebreaking became almost a continuous operation to move them.

The second week of the month brought more snow into the Great Lakes to accompany the continued chill. The ice on Lake Erie became especially difficult during the first half of February. The U.S. Steel vessel *Roger Blough* smashed her way to within several kilometers of Conneaut harbor near the Ohio-Pennsylvania border. There she became beset on February 8 and was still there a week later. North winds persisted most of the period and ice jammed in 9-m (15-30-ft) ridges. The Coast Guard icebreaker *Westwind* worked throughout the period to provide relief. Finally, on February 16, the winds shifted and the *Blough* was able to move the last 300 yds into the main harbor for unloading. Meanwhile on the St. Clair River, the Harsens Island ferry service was ended temporarily by an ice jam near Algonac on February 12.

Damages continued to mount up on commercial vessels. *The Philip L. Clarke* reported $15,000 damage in Lake Michigan on the 12th. On Valentine's Day, the *Gemini* reported her third casualty of the season in Saginaw Bay. The repair bill for ice damage was the highest of the year and totaled a quarter of a million dollars.

Ice cover was continuing to expand and thicken throughout the Great Lakes. On February 15, the ore docks at Escanaba closed for the season, ending shipping into the Green Bay ares.

Late in the third week of February, a convoy of ships departed Sault Ste. Marie across Lake Superior for Two Harbors. Ice was tough all the way across the lake. Thicknesses ranged from 20 to 60 cm (8 to 24 inches). The Coast Guard cutter *Mesquite* and the icebreaker *Mackinaw* worked directly with the convoy consisting of *the Edwin Cott, John Munson*, *Philip Clarke*, and Cason *Callaway*. They finally arrived in the Two Harbors area on February 21 with "a damage list long enough to give any vessel manager nightmares" according to *Lake Log Chips. The Gott was* up-bound on her way to load her first cargo. She lost one of her twin rudders and damaged her side tank. Costs were estimated at $150,000. The *Clarke* sustained mechanical damage to a steering engine at $12,000 and the *Callaway* suffered hull damage amounting to $50,000, while the Munson, although not damaged, had a delay at the docks because of the damaged vessels. The tug *Edna* G. lost a prop blade while doing some preventative icebreaking in the harbor area. The delays and damaged ships resulted in a temporary pellet shortage at plants between Gary and Indiana Harbor.

On Lake Michigan, car ferry operations were severely curtailed by the heavy ice. On February 18, the *Spartan* got stuck just over a mile from the entrance of Milwaukee Harbor. The *Badger* freed her a few hours later. The *Edward Ryerson,* which was leaving Milwaukee, tried to help but she got stuck also. *The Ryerson* was kept busy moving from the southern end of the Lake to Milwaukee--a task normally left for the railroads, but heavy snows tied up their operations. On February 20, the *Viking* was beset in the entrance to Frankfort, trapping the *City* Of *Milwaukee* in port. The Acacia and *Raritan* helped them both out.

Milder weather and rain pushed into the lakes region from the south during the last week of February. Melting ice and snow broke ice jams on many of the rivers within the lower lakes watershed. The first seasonal flood relief operations got underway along the Ohio shoreline on the 25th. The Coast Guard dispatched the Coast Guard cutters *Kaw* and *Mariposa* to work on the problem. Both ships reported minimal progress due to gale winds and heavy brash ice and spent several days in the area before reaching the inner harbors off Lorain and Cleveland.

4.3 Spring Opening

The warmer weather, which carried into the first week of March, brought thoughts of spring weather to come to many shippers. The National Weather Service seasonal outlook for spring (March through May) indicated above-normal temperatures for most of the lakes region. On March 2, the first spring opening was noted as the annual "Coal Shovel" runs from the docks at Toledo to the power companies in Detroit began. The *Henry Ford II* opened the season with the help of the tug *William A. Whitney.* The next day, the icebreaker *Mackinaw*, which had been pounding ice for ships all winter, entered Sturgeon Bay Shipyard for $182,000 worth of work on her port propeller shaft. Most of the damage was sustained on the Lake Superior convoy escort late in February.

In the damage department, the *Roger Blough* sustained $5,000 damage on Lake Superior and the *Cason Callaway* reported $3,000. Damages totaled $26,000. Similar damages ware reported to the *Ojibwa* to repair her port main engine.

The third week had well-above-normal temperatures. Ice cover on Lake Superior diminished significantly for the first time, and loo-percent coverage remained only from Duluth through the Apostle Islands, behind Isle Royale, and in southern and eastern bays and harbors. In spite of eased conditions, the *Imperial St. Clair* returned to the Soo after an unsuccessful try for Thunder Bay, Ont., without an icebreaker. On March 27, the Leon Fraser punched a $4,000 hole in her bow on a trip across Lake Michigan to Escanaba. on March 28, the *H.M.* Griffith was the first upbound ship to transit the Welland Canal for the year. The first downbound ship was the *Taldoussac*. The ice was not the only thing that was melting; record snow cover in the Midwest was also reacting to the warm weather. As a result, numerous floods were reported in parts of Illinois, Indiana, and Michigan. Warmer weather brought open water to eastern Superior, but new ice formed in the western end. Only some drift ice was still around in northern Lake Michigan, the northeast third of Huron and in the U.S. waters of Erie from Fairport Harbor to Dunkirk. A solid ice plug remained from there into Buffalo. Saginaw Bay, Green Bay, and most of Whitefish Bay remained ice covered at month's end.

The St. Lawrence Seaway season got off to a normal start on April 2. The Finnish ship *Puhos* was the first foreign boat into the system. She called at the Port of Toledo on April 5--a new record early date. The annual clash between warm and cold air masses continued over the lakes during early April. An early spring storm swept through the southern lakes with a cold front on April 5 and 6. At Milwaukee the Clarence *B. Randall* broke loose from her moorings and wedged herself against a dock at Jones Island. The tug *Purves* and the *Arundel* kept her under control for the night. Later the same night, the Canadian ship *Labradoc* was caught in the storm, and 50-kn winds and 5-m (16-foot) waves reportedly shifted her cargo, causing a dangerous list about 40 km (25 miles) north of Fairport in Lake Erie. Most of her crew was airlifted from the vessel after daybreak, although Captain Ray Chambers attempted to sail her to safety along the north shore, but all efforts failed and he and the remaining crew of four left her at midafternoon. The ship proved tougher than the storm and remained afloat, and when the weather calmed the tugs *Atomic* and *Glenbrook* took her in tow and headed for Pelee Passage, where she grounded for a time in the shallow water, but finally made it to safety.

Early in April the Great Lakes were visited by a new Canadian icebreaker, the *Pierre Radisson*. She transited the seaway and headed for Thunder Bay, Ont., for a spring workout. On April 7, the Upper Lakes Fleet christened their new boat, the *Canadian Transport*.

Only slightly-below-normal temperatures highlighted the second week. Shipping picked up and so did icebreaking, and over 70 direct icebreaking assists were logged that week alone. The hard spring ice took its usual toll of ships during the mid-month. On Lake Superior the Fraser reported $4,000 damage, the *J.L. Mauthe* $10,000, the *Arthur Anderson* $5,000, the *Johnstown* $3,000 and the *Reiss Marine* $7,500 damage. On Lake Michigan, the *Benjamin Fairless* had a $1,500 damage and the *Jupiter* sustained $1,500 damage. The *Jupiter* also sustained $10,000 damage in Detroit.

Only about 25 vessels were directly assisted by Coast Guard tugs and buoy tenders during the last half of April, but numerous preventative icebreaking missions were performed that undoubtedly kept ships moving that would have become beset.

Below-normal temperatures in early May slowed the decay of the western Superior ice field, and it was late in the month before the last ice cubes disappeared from shipping lanes. The *Stadacona* had the honors of being the last vessel of the season to require direct assistance, being helped along from Duluth in the western lake by the Coast Guard cutter *Mesquite* and "Operation Taconite" was terminated on Lake Superior May 9.

4.4 Summary

For the third consecutive year, severe winter weather was observed throughout the Great Lakes Region. Conditions were especially severe in the western Great Lakes. A total of 114 vessels participated in the extended season operations, plus 10 foreign ships, and an estimated 25 fishing craft, down slightly from the previous year.

New regulations on the St. Lawrence Seaway System brought order to the annual exile of "salties" and no serious problems developed during December. In spite of the very severe midwinter conditions, shipping continued unabated from the upper lakes through the locks at Sault Ste. Marie. Damages, however, were at an all-time high as shipping continued to be pounded by ice. For the first time in documented history the Great Lakes were almost frozen over simultaneously on February 17, an event contributing significantly to the amount of icebreaking required by the Coast Guard icebreaking fleet. Cargo tonnage carried by commercial ships that were directly assisted by the Coast Guard was less than half the previous season. The figure is misleading, however, because the number of preventative icebreaking missions performed by the government fleet doubled this year. Commercial tonnage that benefited from these missions is unknown. The dollar values increased significantly from the previous season, but most of the increase can be accounted for by inflation and better record keeping by both commercial and government sources for this information.

All in all, it was a very tough and costly year for the Great Lakes marine industry and their government support forces.

5. ACKNOWLEDGMENTS

Icebreaking data and casualty information were supplied by the Ninth Coast Guard District, Cleveland. Ice information was derived from NESS satellite images, records of the National Weather Service Forecast Office, Ann Arbor, Mich., and the Ice Navigation Center, Cleveland, Ohio. The monthly wind and temperature data (Appendix C) was provided by the National Climatic Center and tabulated by Dennis F. Kahlbaum. Additional information was obtained from the Center for Archival Collections at Bowling Green, Ohio. The 700-mb charts were prepared by the National Weather Service. Surface weather charts are from the Daily Weather Maps Weekly Series, EDIS NOAA. The manuscript was typed by Ann Marie Dewitt, Betty Manoulian and Christine Weatherford. The composite weekly ice charts were analyzed by Dennis F. Kahlbaum and Bernard H. DeWitt with constructive assistance by Dr. Dennis G. Baker and Dr. Anita Baker-Blocker. Graphic production of the composite ice charts was accomplished by Kenneth M. Kurdziel. Extensive technical editing and organization of the manuscript was also accomplished by Kenneth M. Kurdziel.

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7. Appendix A. LAKE BOTTOM TOPOGRAPHY

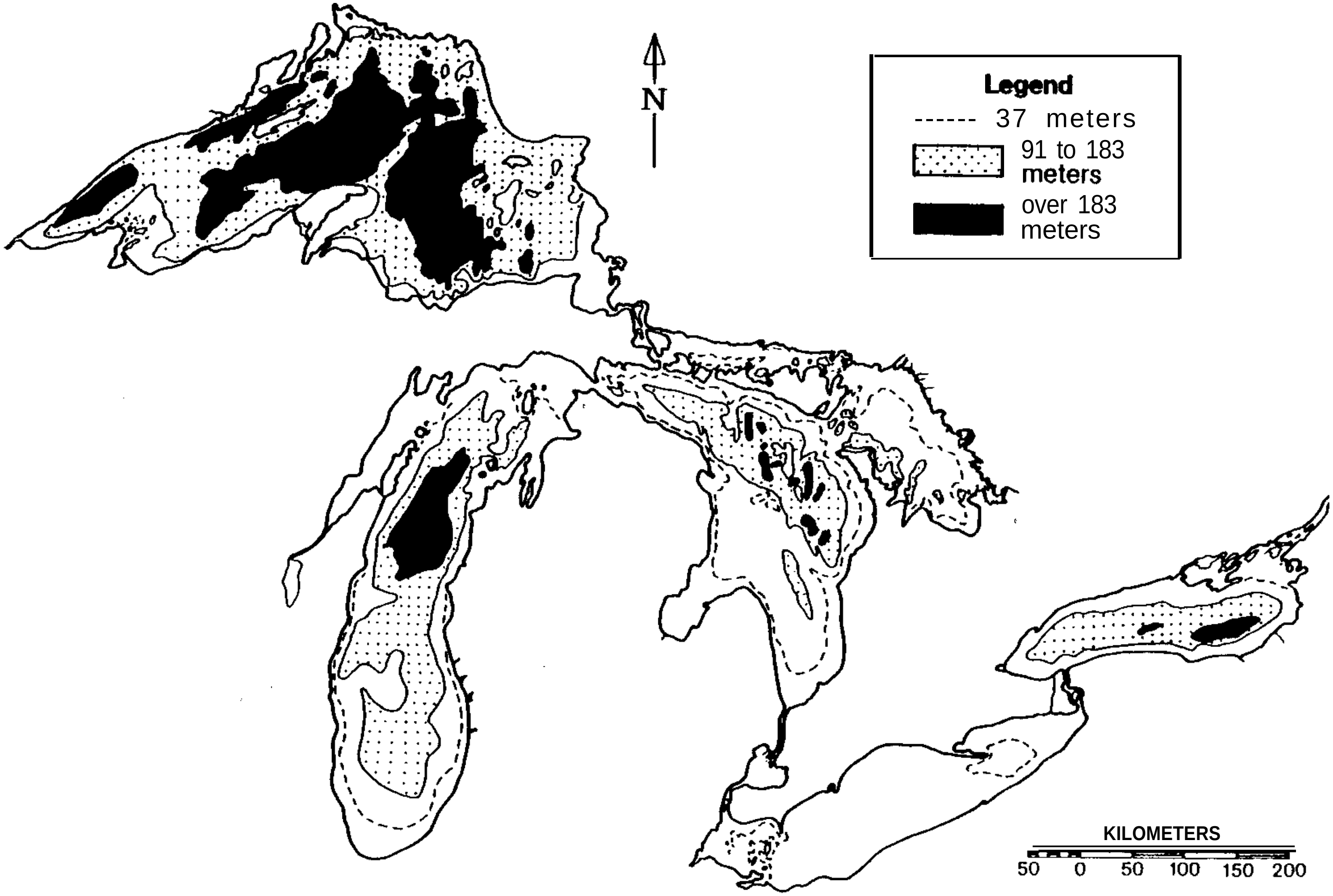


Figure 'I.--Lake *bottom topography (after figure* 3 in *Snider, 1974*).

8. Appendix B. SURFACE WEATHER MAPS

8.1 Severe Storm Northern Lakes (November 8-V)

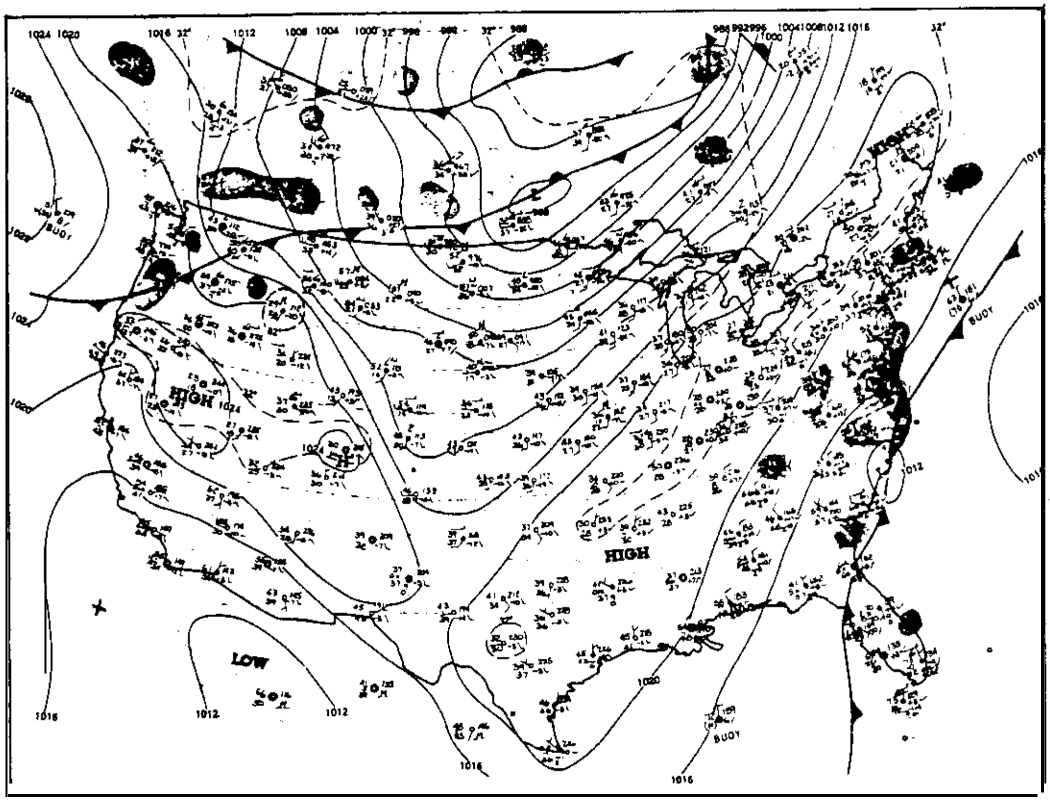
8.2 First Winter Storm (November 17-18)

8.3 Cold Air Outbreak (November 19-20)

8.4 Major Storm of Season (January 13-14)

8.5 Great Lake Nearly 100 percent Ice Covered (February 16-17)

WEDNESDAY, NOVEMBER 8, 1978



THURSDAY, NOVEMBER 9, 1978

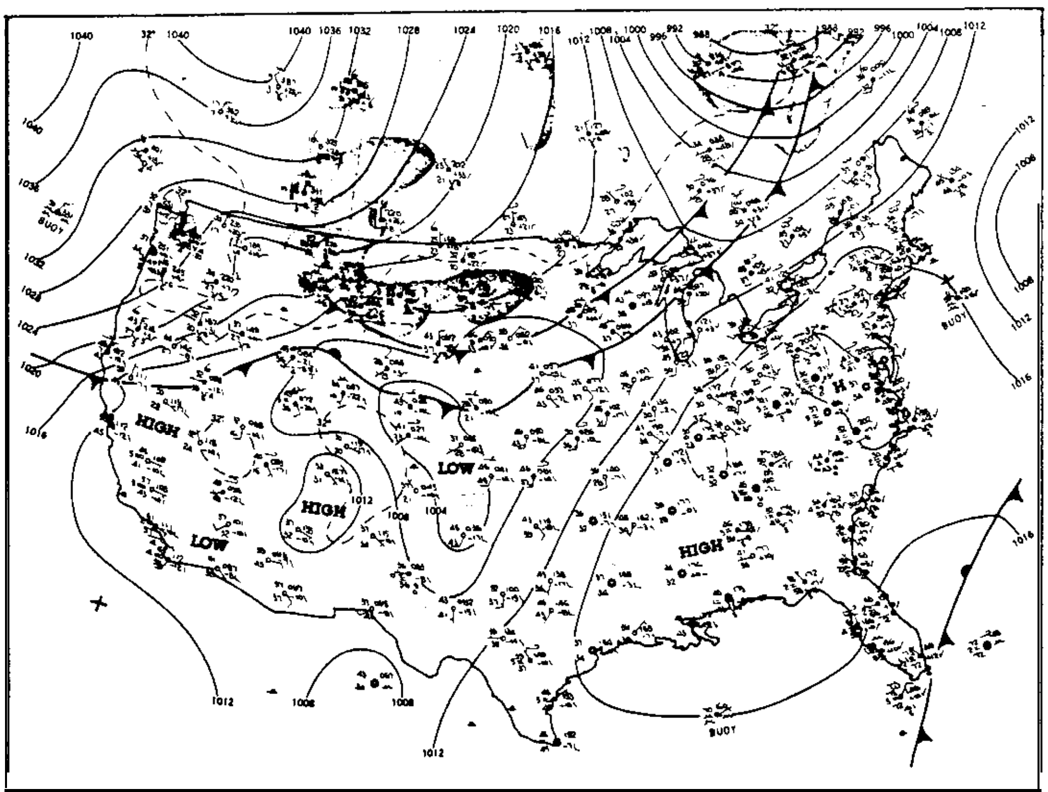
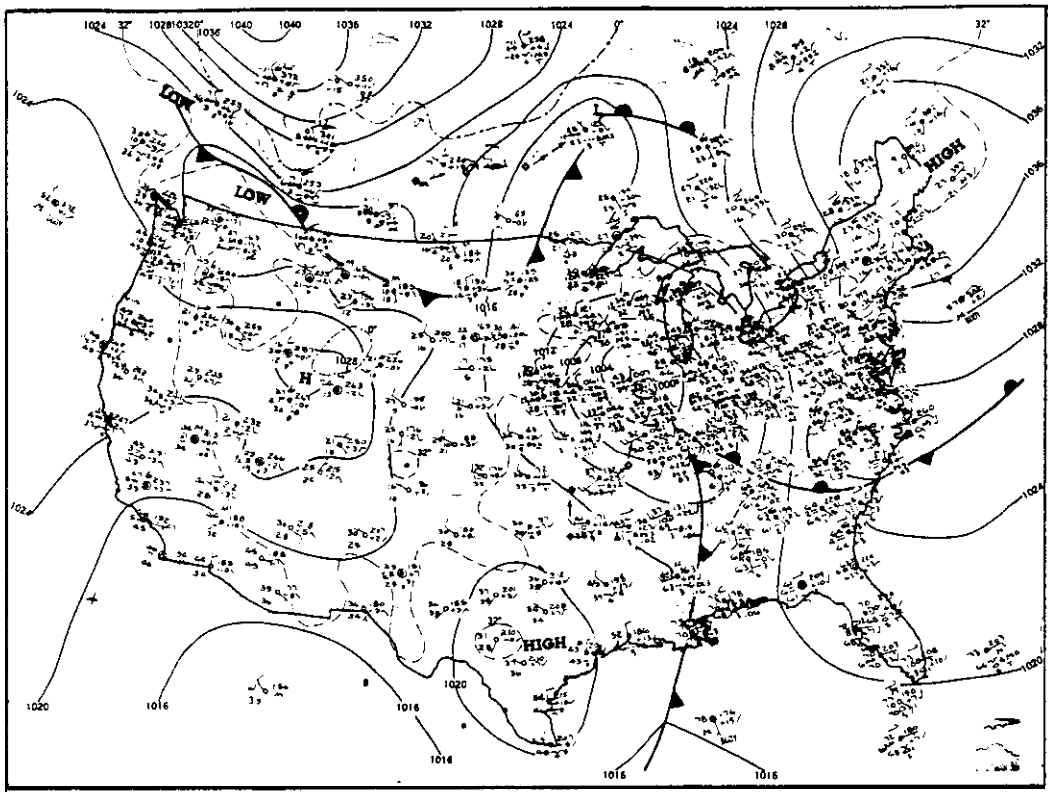


Figure 8a.--High Winds on northern Great Lakes on November 8-9, 1978.

FRIDAY, NOVEMBER 17, 1978



SATURDAY, NOVEMBER 18, 1978

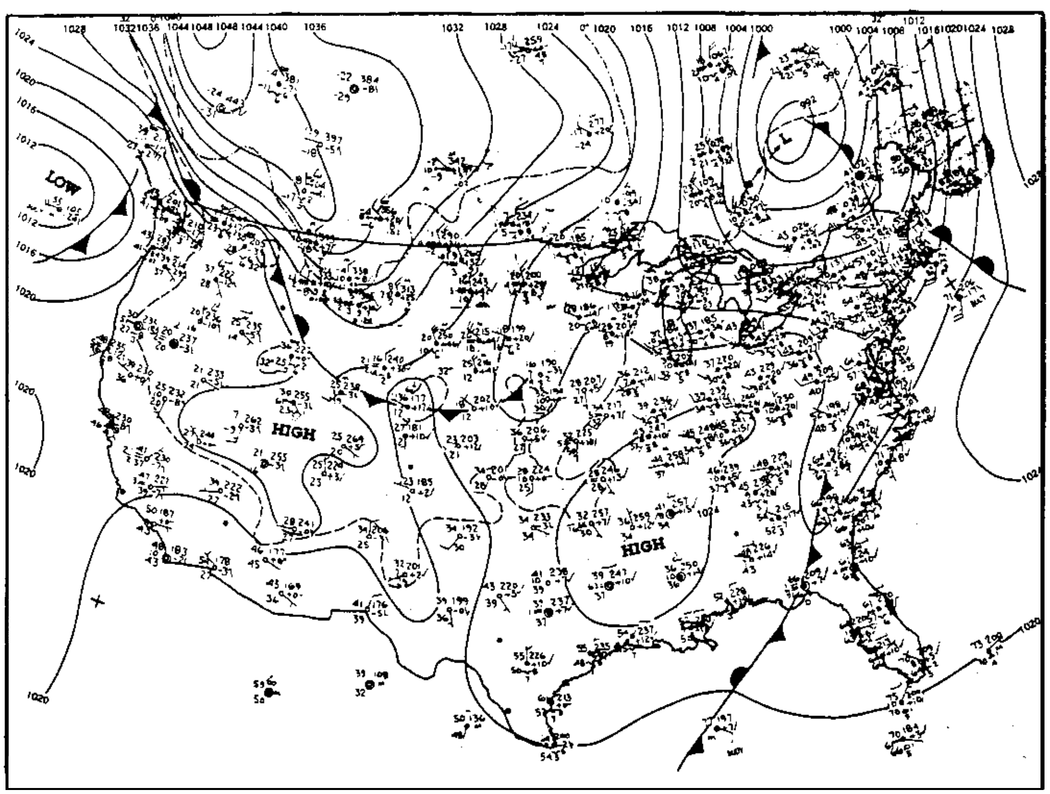
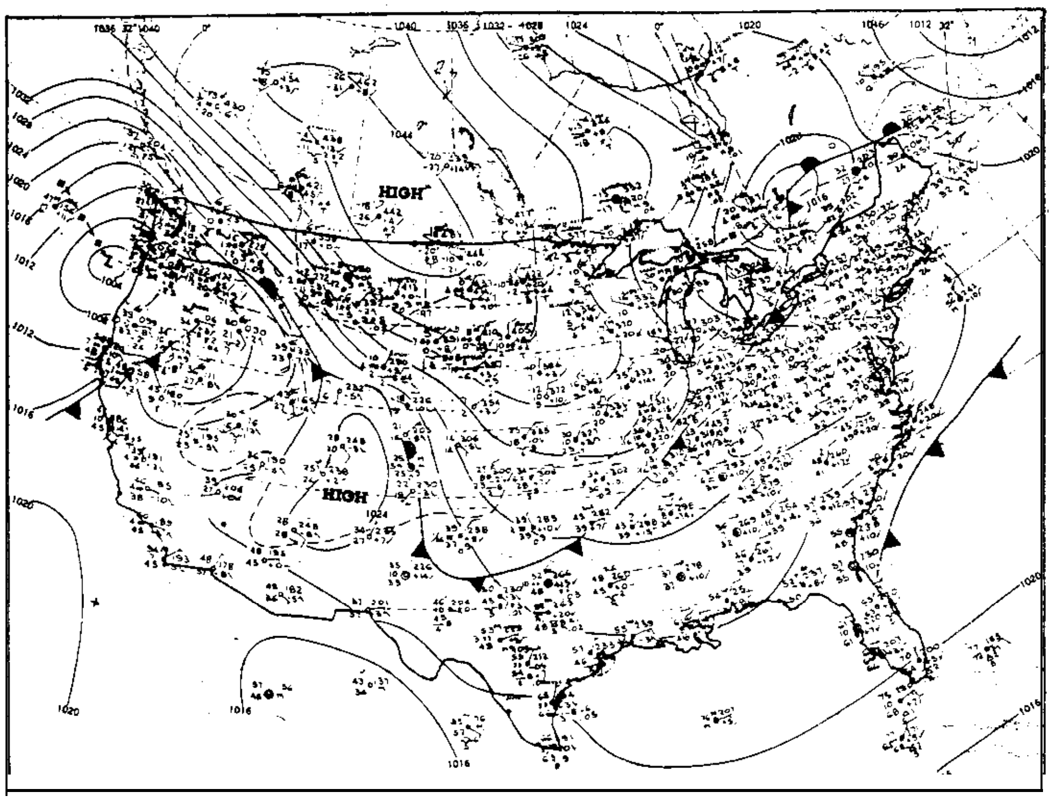


Figure 8b.--First winter storm reached the Great Lakes, November 17-18, 1978.

SUNDAY, NOVEMBER 19, 1978



MONDAY, NOVEMBER 20, 1978

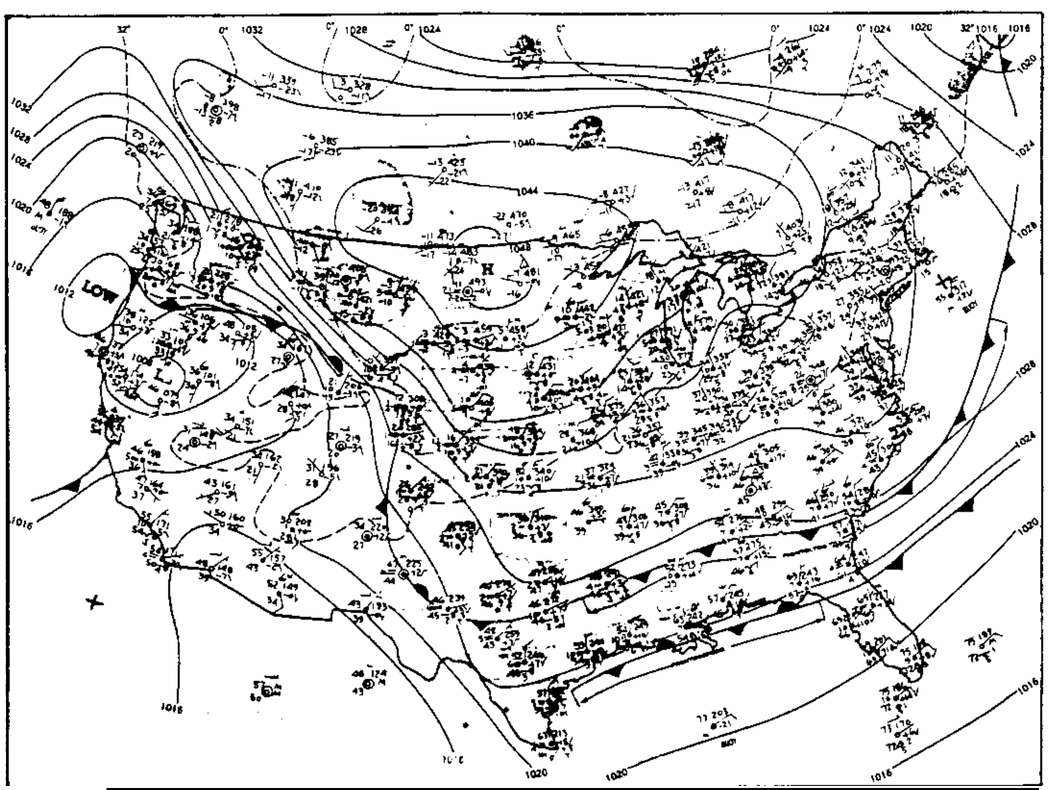
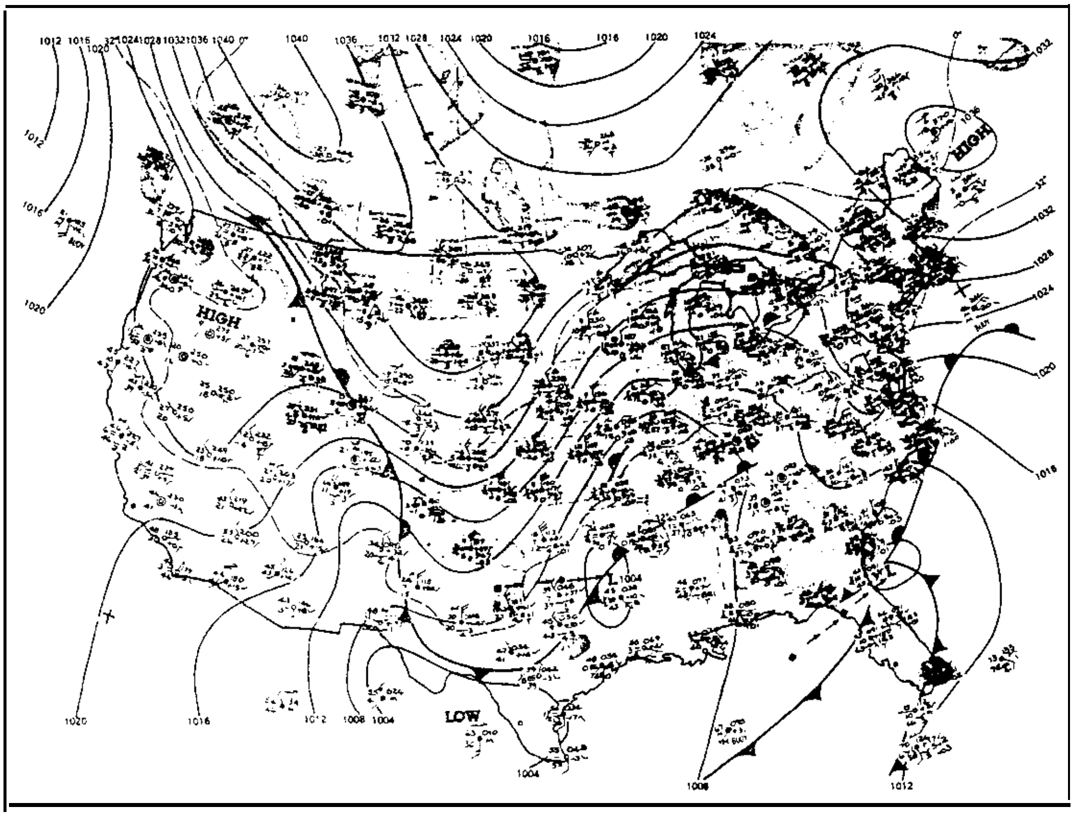


Figure 8c.--Cold air outbreak on November 19-20, 1978.

SATURDAY, JANUARY 13, 1979



SUNDAY, JANUARY 14, 1979

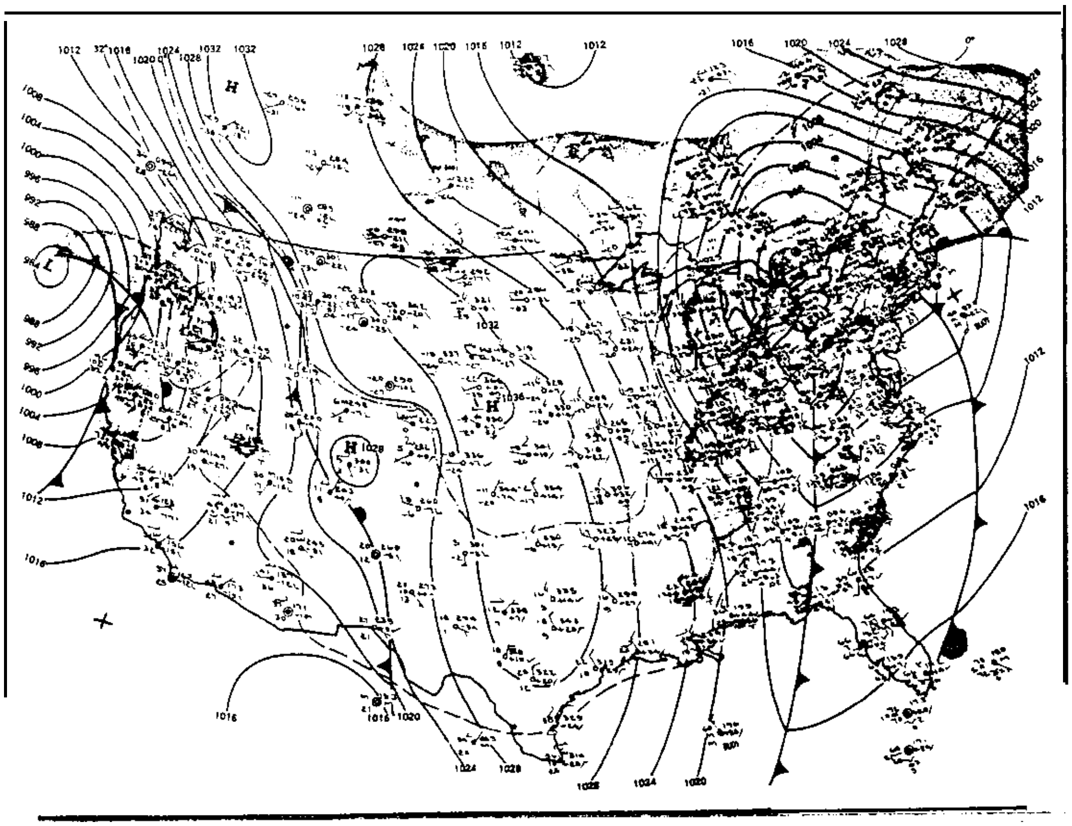
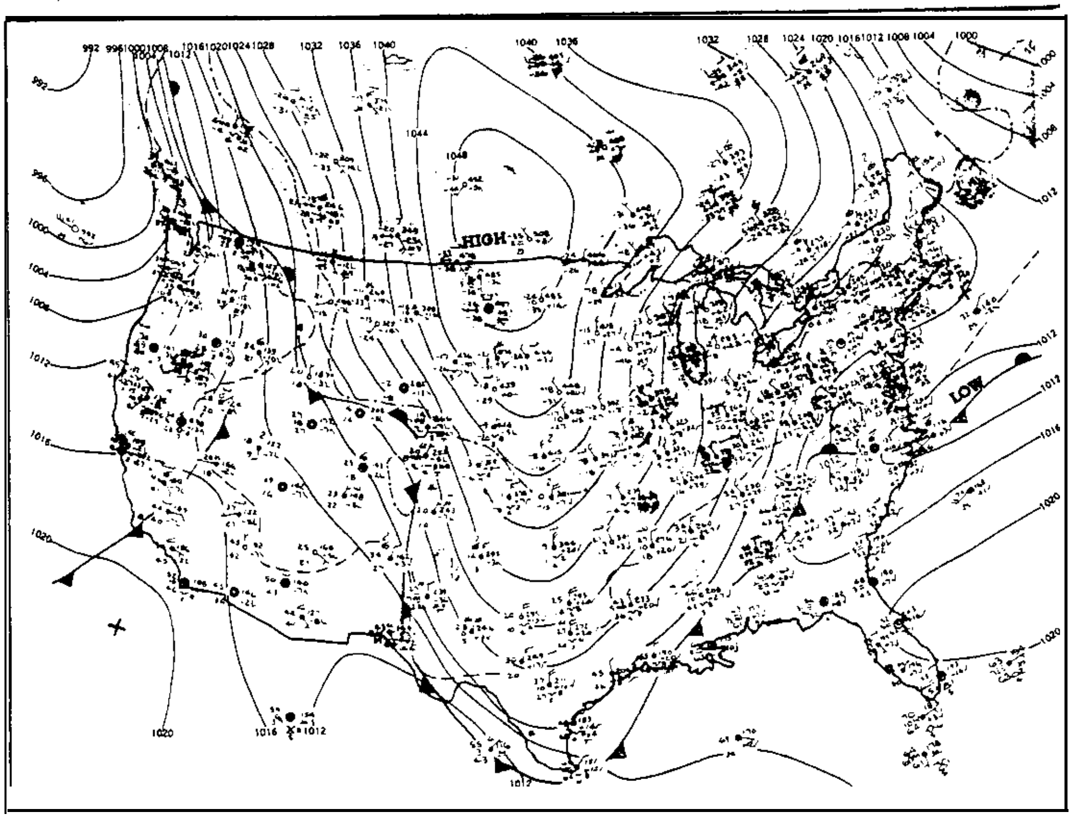


Figure 8d.--Major storm of winter season on January 13-14, 1979.

FRIDAY, FEBRUARY 16, 1979



SATURDAY, FEBRUARY 17, 1979

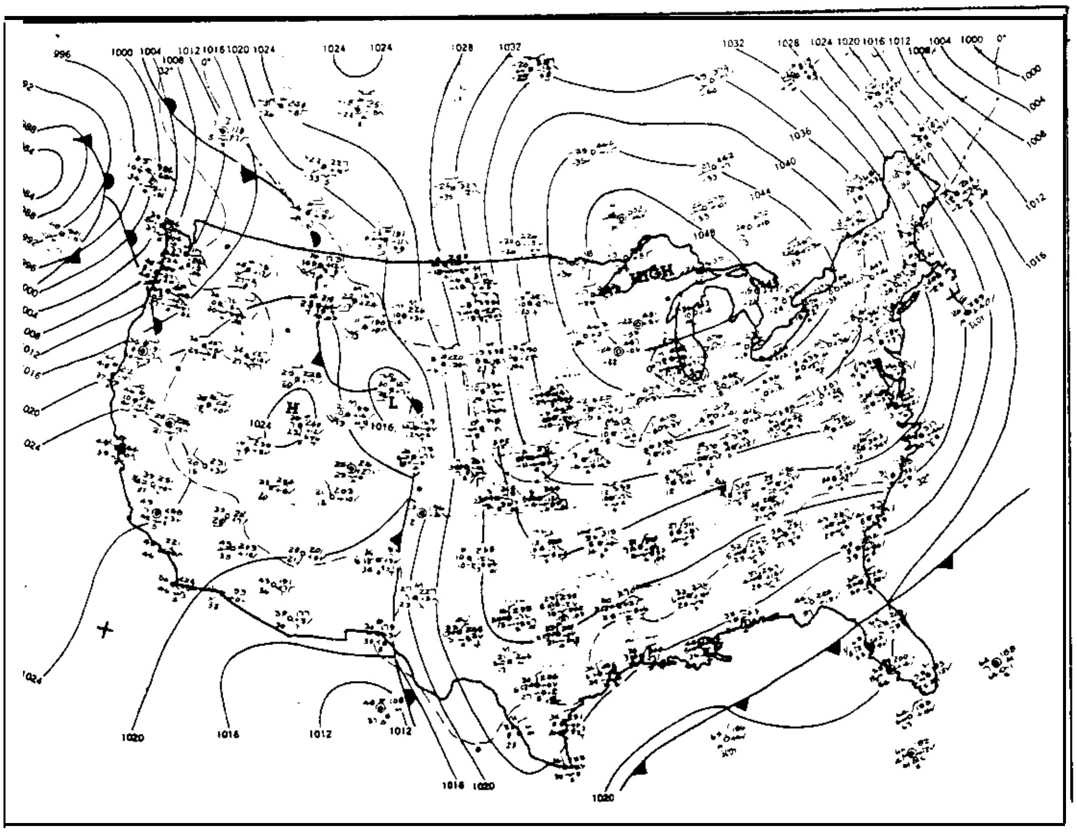


Figure 8c.--Coldest period on the entire lakes region on February 16-17, 1979.

9. Appendix C. DAILY AIR TEMPERATURE AND WIND SPEED AND DIRECTION

9.1 Duluth, Minn.

9.2 Sault Ste. Marie, Mich.

9.3 Green Bay, Wis.

9.4 Milwaukee, Wis.

9.5 Alpena, Mich.

9.6 Detroit, Mich.

9.7 Cleveland, Ohio

9.8 Rochester, N.Y.

Table 9a.--*Daily air temperature and wind speed and direction,* Duluth, *Minn.*

DAY	NOVEMBER TC	WD	WS	DECEMBER TC	WD	WS	JANUARY TC	WD	WS	FEBRUARY TC	WD	WS	MARCH TC	WD	WS	APRIL TC	WD	WS
	1.8	220	12.3	-16.7	280	8.6	-25.0	290	7.9	-13.3	200	1.8	-10.0	90	11.7	-2.0	90	9."
	10.0	210	2.3	-19.4	350	1.6	-27.2	300	8.2	-15.6	150	1.5	-5.0	100	6.5	-2.2	330	8.2
3	14.4	210	8.2	-8.9	350	1.2	-21.7	270	10.0	-21.1	22"	0.2	-2.2	20	4.0	-4.4	300	6.3
4	3.9	90	7.4	-0.3	240	11.6	-25.6	200	11.7	-22.8	31"	12.4	-2.8	360	12.9	-4.4	180	4.1
5	5.0	270	11.1	-9.4	270	12.9	-25.0	240	9.3	-23.3	130	4.4	-2.8	340	5.6	-6.7	290	12.2
6	1.1	290	7.5	-17.2	270	9.6	-17.2	250	11.7	-15.0	80	3.1	-5.0	240	3.6	-10.6	290	10.2
7	3.3	19"	10.2	-19."	270	5.9	-20.6	300	7.6	-20.6	330	5.1	-7.2	10	6.9	-4."	100	12.6
8	11.1	220	9.1	-10.3	250	7.0	-20.6	250	10.1	-21.7	350	2.9	-8.9	110	9.1	-2.0	70	R.7
9	3.9	30	5.0	-21.7	300	9.3	-22.2	300	10.0	-20.0	290	1.5	-10.6	280	11.5	-7.2	80	3.5
10	-0.6	60	12.7	-21.7	260	3.6	-25.6	310	0.1	-23.3	90	7.9	-17.2	290	12.8	'4."	"0	8.3
11	-5.0	10	8.3	-13.3	230	8.1	-26.7	210	1.6	-1'1.4	6"	1.6	-6.7	290	8.9	0.0	90	13.9
12	-3.3	100	9.4	-2.2	240	9.4	-16.1	60	3.1	-17.2	80	6.9	-7.2	110	2.3	1.1	80	16.6
13	1.1	200	5.6	-8.3	260	11.8	-20.0	330	8.9	-19."	80	9.9	-2.8	320	3.0	1.7	160	7.0
14	-3.3	270	13.1	-6.7	230	7.6	-26.1	290	10.3	-6.9	110	4.3	-11.1	300	14.0	2.0	260	9.1
15	-2.8	230	8.6	-3.3	260	11.8	-22.8	260	1.2	-13.3	340	7.2	-13.3	250	8.6	4.4	280	10.5
16	-3.3	170	3.1	-5.0	260	10.1	-23.3	90	4.9	-25.6	10	5.2	-1.7	220	12.5	3.9	350	3.6
17	-0.6	330	3.4	-6.1	260	6.3	-16.7	290	6.5	-23.3	110	7.9	2.8	150	0.3	3.3	80	5.3
18	-6.7	290	9.8	-4.4	90	15.1	-20.0	140	3.6	-17.0	110	7.7	2.0	100	10.3	5.6	110	9.8
19	-12.2	320	10.0	-7.2	110	15.3	-7.8	100	11.5	-12.2	170	6.7	2.8	110	9.9	10.0	110	10.7
20	-13.9	310	7.5	-6.1	330	3.3	-5.6	10	5.5	-6.7	100	3.0	0.0	210	9.0	6.1	100	3.0
21	-14.4	260	6.5	-8.9	250	7.0	-8.9	110	10.1	-3.9	330	3.9	1.1	240	9."	0.9	300	6.3
22	-12.2	130	3.9	-6.7	260	11.7	-11.1	350	5.1	-5.6	90	14.6	1.1	30	3.0	8.9	300	5.6
23	-5.0	350	0.8	-10.6	10	5.1	-15.6	350	6.9	-6.7	320	5.7	-2.2	340	13.4	6.7	100	8.2
24	-8.9	290	5.5	-17.2	340	8.8	-17.2	340	9.1	-15.6	60	6.0	-7.2	360	14.4	6.1	100	11.6
25	-6.7	3100	9.9	-17.8	320	6.3	-13.9	350	2.4	-13.9	100	7.0	-11.1	60	0.4	6.7	300	7.9
26	-6.7	90	1.2	-16.1	280	8.6	-10.0	360	1.9	-7.8	130	7.3	-0.9	50	1.8	5.6	350	6.3
27	-6.1	190	3.2'	-17.2	250	9.2	-7.2	10	6.7	-3.3	200	5.6	-0.9	190	5.4	3.9	350	4.9
28	-13.3	260	4.2	-7.0	110	15.3	-6.1	360	7.6	-6.1	80	8.3	-0.6	140	5.2	2.8	70	2.9
29	-12.2	270	8.7	-9.9	180	2.6	-11.1	320	6.1				-1.7	90	11.9	3.1	80	11.2
30	-18.3	270	11.4	-18.9	290	8.8	-13.9	330	6.2				-0.6	360	6.9	2.8	90	9.2
31				-21.1	320	7.9	-12.2	330	5.5				-6.1	80	5.5			

TC = AVERAGE DAILY AIR TEMPERATURE, DEGREES CELCIUS
AD = MEAN DAILY RESULTANT WIND DIRECTION, DEGREES FROM NORTH
WS = MEAN DAILY RESULTANT WIND SPEED, KNOTS

Table 9b.--*Daily air temperature and wind speed and direction, Sault Ste. Marie, Mich.*

DAY	NOVEMBER TC	WD	WS	DECEMBER TC	WD	WS	JANUARY TC	WD	WS	FEBRUARY TC	WD	WS	MARCH TC	WD	WS	APRIL TC	WD	WS
1	5.6	260	4.3	-10.6	250	7.1	-12.2	350	8.8	-12.8	120	9.7	-5.0	"0	4.9	-1.1	100	5.8
2	8.3	270	5.7	-11.7	10	1.9	-17.8	120	1.1	-17.2	110	0.7	-5.0	120	7.1	-0.6	350	5.1
3	9.4	120	4.1	-10.6	90	8.3	-17.2	240	8.9	-12.2	100	5.8	1.1	110	8.2	-0.6	293	5.3
4	10.0	110	3.6	-3.1	240	6.9	-16.7	250	11.5	-11.1	300	6.9	3.1	110	8.2	0.0	110	4.8
5	12.2	170	2.2	-2.2	250	10.6	-17.2	230	8.1	-21.1	310	5.6	0.0	210	4.8	0.0	140	4.0
6	4."	100	8.3	-6.7	270	9.5	-17.2	210	1.6	-20.0	100	10.1	-2.2	250	2.7	-3.1	310	18.9
7	2.2	150	2.4	-9.9	70	1.7	-19.4	190	1.8	-11.7	00	6.0	-2."	80	3.5	-7.8	320	5.6
8	5.6	200	9.7	-7.e	290	7.2	-18.9	170	2.7	-20.6	10	9.4	-1.7	100	6.0	-6.1	10"	4.8
9	8.9	300	6.6	-12.2	310	2.2	-11.9	290	6.0	-25.0	100	1.5	-0.6	110	7.7	-1.1	330	6.2
10	4.4	80	8.3	-16.1	220	1.6	-19.4	60	1.9	-21.9	310	1.1	-6.7	100	11.9	-2.8	290	4.1
11	-2.2	30	8.4	-12.8	140	1.0	-20.6	120	2.3	-20.6	110	6.3	-13.3	280	7.2	0.0	110	10.2
12	-4.4	80	1.1	-1.7	180	3.7	-11.3	100	4.8	-18.1	10	3.1	-8.9	110	5.4	1.3	110	16.4
13	2.8	120	9.1	-5.6	300	8.4	-10.0	50	7.1	-21.1	120	5.0	-1.1	140	3.4	3.1	110	9.9
1"	4.4	270	12.9	-0.9	170	2.2	-13.9	310	10.9	-15.6	110	11.1	-7.8	300	14.5	4.4	280	2.6
15	0.6	250	6.5	-5.0	240	3.0	-18.1	250	10.0	-15.0	110	9.9	-11.9	290	6.3	2.2	290	8.8
16	1.1	110	3.2	-4.4	290	3.0	-21.7	110	2.8	-21.7	160	5.7	-3.3	200	2.6	4.4	110	9.9
17	5.6	110	7.6	-3.9	320	9.5	-11.9	90	7.0	-27.0	110	0.7	-0.6	120	6.3	4.4	100	9.6
18	2.2	300	3.Q	-12.8	20	5.6	-22.2	10	1.4	-23.9	110	7.6	2.2	110	8.3	5.0	310	4.9
19	-5.0	310	9.6	-17.2	100	1.0	-16.1	110	9.4	-16.1	140	3.9	2.8	120	11.6	6.7	130	3.5
20	-11.1	40	3.0	-8.3	90	11.7	-8.3	90	0.0	-7.0	160	4.6	2.8	110	0.2	10.6	120	6.5
21	-8.3	180	0.6	-8.9	340	2.3	-7.2	360	5.4	-3.9	70	3.9	2.8	200	2.9	5.6	120	3.6
22	-1.2	140	2.0	-3.9	200	5.5	-7.8	310	8.9	-9.4	100	6.5	2.8	130	3.7	6.7	220	4.3
23	-0.6	90	4.2	-3.9	210	4.1	-5.6	110	7.8	-0.6	140	5.7	3.3	100	7.6	a.9	100	1.6
24	-3.3	310	9.3	-0.6	120	5.2	-2.e	80	7.2	-8.1	320	8.4	-2.2	40	11.8	13.9	110	6.1
25	-8.9	70	5.8	-5.0	280	10.9	-5.6	320	10.5	-15.0	350	2.4	-10.0	10	10.1	11.1	160	4.1
26	-11.1	80	6.7	-6.7	320	5.0	-2.8	350	5.6	-10.6	300	2.5	-11.1	320	10.1	5.0	120	7.0
	-8.9	80	10.2	-8.9	270	6.5	-1.7	60	7.0	-3.9	200	1.0	-9.4	310	4.1	1.9	150	7.1
28	-6.7	100	9.7	-13.9	180	2.5	-3.9	360'	7.9	-1.1	90	2.8	-9.0	110	10.0	1.7	130	5.5
29	-0.6	190	8.1	-7.2	110	13.2	-5.6	310'	12.6				1.7	10	1.2	3.9	100	4.8
30	-8.3	280	6.7	-2.2	10	1.0	-9.u	310'	6.4				1.9	100	9.7	4.4	50	6.9
31				-6.7	350	7.6	-13.9	310'	6.7				1.1	360	8.0			

TC = AVERAGE DAILY AIR TEMPERATURE, DEGREES CELCIUS
WD = MEAN DAILY RESULTANT WIND DIRECTION, DEGREES FROM NORTH
WS = MEAN DAILY RESULTANT WIND SPEED, KNOTS

Table 9c.--*Daily air temperature and wind speed and direction, Green Bay, Wis.*

	NOVEMBER			DECEMBER			JANUARY			FEBRUARY			MARCH			APRIL		
DAY	TC	WD	WS	TC	WD	WS	TC	WD	WS	TC	an	WS	TC	WD	WS	TC	WD	WS
1	5.0	220	7.c	-11.1	280	6.1	-14.9	110	11.7	-12.8	100	5.8	-0.6	50	5.6	1.7	10	10.2
2	10.0	210	6.5	-10.0	150	5."	-25.0	280	11.7	-10.6	220	1.4	-2.2	180	e.9	•0.0	350	9.6
1	11.1	210	7.6	-1.7	70	6.5	-22.8	240	11.6	-11.9	210	5.2	1.7	70	5.6	-2.2	210	5.4
4	8.1	40	4.9	-6.7	240	14.7	-22.6	260	10.2	-17.2	270	11.9	0.0	160	9.2	2.2	10	4.9
	10.6	240	8.2	-2.2	250	11.7	-25.6	220	9.0	-21.3	240	6.5	-1.1	160	4.2	-2.2	260	13.7
6	2.8	30a	7.6	-10.6	280	12.2	-20.6	220	10.8	-11.9	210	7.6	-2.2	200	5.0	-5.6	300	16.7
8	2.2	230	3.8	-12.2	350	5.4	-21.7	260	6.1	-15.6	290	15.2	-0.6	10	11.1	-2.2	100	6.3
	7.8	210	14.6	-14.4	290	7."	-21.7	210	10.4	-20.0	130	10.4	-1.7	40	1.7	0.0	60	10.0
9	8.9	40	4.7	-17.2	270	10.4	-17.2	270	8.9	-20.6	270	7.6	-4.4	210	9.9	0.6	10	9.9
10	9.4	50	7.6	-18.3	250	7.6	-21.7	200	10.9	-19.9	160	6.6	-11.1	270	12.9	1.1	60	7.1
11	2.2	10	11.5	-7.8	240	7.2	-26.7	210	5.0	-12.2	20	2.9	-10.6	250	9.5	2.R	90	13.4
12	0.6	40	8.4	-1.1	210	12.2	-16.1	30	9.6	-14.4	10	10.2	-6.1	220	6.3	10.0	120	11.4
13	7.8	200	8.8	-5.6	280	15.5	-8.9	20	14.0	-13.3	3"	5.7	i.7	220	11.5	7.8	210	10.1
14	0.0	270	13.8	-5.0	210	11.7	-17.8	300	12.1	-8.3	160	2.3	-7.2	120	14.9	5.0	260	8.6
15	-2.2	270	6.3	-1.7	230	10.1	-24.4	210	7.6	-10.6	40	8.6	-10.0	250	7.1	6.7	110	11.1
16	-1.7	80	1.8	-1.1	250	7.1	-22.8	20	1.0	-20.6	160	10.4	-2.R	220	12.2	8.3	340	6.9
J7	-3.9	10	6.9	-5.6	210	7.6	-19.4	280	8.9	-22.8	10	8.2	1.1	170	5.6	8.9	350	3.8
18	-0.6	270	13.1	-6.1	20	7.9	-16.7	360	3.2	-16.7	60	10.1	5.6	100	3.5	7.8	70	5.1
19	-3.9	300	8.6	-5.0	80	10.2	-16.7	90	8.4	-17.2	220	6.7	5.6	150	8.6	10.0	140	3.0
20	-7.2	360	9.5	-2.2	90	2.5	-5.0	50	9.0	-6.1	200	8.1	3.3	240	6.3	11.9	170	7.5
21	-8.3	130	7.6	-6.7	260	10.2	-3.9	340	10.9	-4.4	270	6.7	2.2	260	6.0	12.2	310	1.6
22	-6.7	360	2.6	-1.3	240	11.7	-6.7	250	7.0	-5.0	100	6.1	2.8	40	5.4	12.2	220	6.3
21	-1.1	320	3.1	-9.9	170	5.2	-4.4	120	1.9	1.7	210	9.9	2.8	10	12.4	14.u	70	5.1
24	-5.0	280	11.8	-6.1	320	7.3	-10.0	340	17.5	-7.2	20	11.7	-4.9	20	18.1	16.1	160	6.9
25	-3.9	280	4.7	-12.2	280	8.0	-12.2	280	8.2	-11.1	30	11.9	-6.7	10	13.5	15.0	210	7.2
26	-2.2	40	8.2	-12.8	280	9.0	-9.4	340	A.9	-8.3	150	1.5	-6.7	110	8.4	6.7	360	8.3
27	-1.1	50	6.1	-15.6	250	6.6	-2.0	10	9.6	-7.2	220	6.0	-7.8	240	4.1	4.4	10	7.9
28	-6.1	230	7.9	-8.9	120	8.2	-2.8	340	8.9	-4.4	190	1.0	-0.6	180	10.8	5.0	50	5.6
29	-1.9	230	15.2	-1.1	150	10.1	-5.0	320	8.8				2.8	10	7.0	2.2	110	6.5
30	-11.9	270	10.5	-4.4	120	5.0	-8.9	320	6.7				7.2	210	3.2	1.1	20	6.7
31				-9.4	10	11.1	-8.9	330	10.5				2.2	20	5.9			

TC = AVERAGE DAILY AIR TEMPERATURE, DEGREES CELCIUS
WD = MEAN DAILY RESULTANT WIND DIRECTION, DEGREES FROM NORTH
WS = MEAN DAILY RESULTANT WIND SPEED, KNOTS

Table vd.--Daily air temperature and wind speed and direction, Milwaukee, Wis.

	NOVEMBER			DECEMBER			JANUARY			FEBRUARY			MARCH			APRIL		
DAY	TC	WD	WS	TC	WD	WS	TC	WD	WS	TC	WD	WS	TC	WD	WS	TC	WD	WS
1	5.0	200	3.4	-5.6	310	4.3	-11.1	320	12.1	-9.”	310	1.8	0.0	360	3.9	2.2	SO	11.2
2	12.8	250	7.5	-5.6	20	6.2	-20.0	280	12.0	-0.3	210	5.2	-0.6	180	1.1	2.2	340	9.4
3	14.4	230	4.8	-1.1	170	2.5	-22.2	250	13.0	-10.6	260	0. 1	2.2	150	10.0	3.3	150	1.3
4	11.1	330	8.9	-6.1	240	17.3	-19.4	260	12.2	-17.2	280	15.5	2.2	220	9.5	3.3	30	6.2
5	13.9	230		-0.6	250	13.9	-22.8	260	1.2	-20.6	260	8.6	-0.6	250	8.1	1.1	250	14.0
6	7.8	320	9.6	-5.0	300	9.6	-18.9	240	10.3	-12.8	210	8.5	-1.1	220	6.9	-4.4	290	18.1
7	5.0	250	1.0	-5.6	340	0.7	-14.4	280	1.0	-11.1	300	10.2	1.1	10	2.2	-4.4	130	6.7
8	7.2	220	16.2	-10.0	300	10.3	-18.3	260	10.0	-15.0	320	12.5	1.7	320	4.0	-0.6	10	10.2
9	10.0	210	5.5	-14.4	280	10.2	-14.4	270	8.9	-16.1	210	9.3	-1.7	240	9.0	0.6	360	12.6
10	8.9	170	4.8	-17.2	260	9.5	-19.4	280	11.5	-15.0	330	7.2	-9.4	270	14.4	0.6	60	4.1
11	6.1	10	14.1	-6.1	230	6.3	-18.9	250	5.6	-9.9	190	4.9	-9.”	260	9.5	2.0	80	11.9
12	5.0	70	12.9	0.6	220	12.3	-10.0	220	3.0	-8.1	40	9.2	-3.9	230	8.0	10.G	140	9.2
13	10.6	190	11.2	-3.3	290	15.8	-5.0	10	13.8	-7.8	200	2.8	1.1	220	14.5	9.4	250	11.5
14	1.1	260	12.9	-3.3	230	15.2	-15.6	300	13.4	-5.6	160	8.9	-4.4	300	16.1	1.2	210	9.3
15	0.0	210	3.2	0.6	250	14.3	-21.7,	250	9.8	-5.6	GO	7.G	-7.8	210	10.0	6.1	300	12.1
16	1.1	70	5.3	-0.6	270	9.2	-14.4	250	3.1	-11.1	340	11.5	-1.7	230	11.Q	8.1	320	4.0
17	1.2	200	5.1	-2.6	250	11.9	-9.9	260	8.7	-13.9	80	12.9	2.2	180	8.3	1.2	90	1.4
18	3.9	260	13.4	-1.1	360	2.9	-10.0	300	2.3	-14.4	90	10.5	8.9	160	9.1	6.7	20	6.0
19	-1.7	310	8.2	0.0	100	13.2	-3.3	150	12.1	-16.1	200	7.2	0.3	140	1.5	10.0	130	4.0
20	-3.3	340	10.3	0.0	220	2.9	-1.1	340	3.5	-5.6	210	14.1	6.7	280	5.6	12.2	160	8.7
21	-3.9	330	7.9	-4.4	260	11.8	-2.8	320	9.9	-1.1	240	10.8	3.7	30	3.0	9.4	300	4.2
22	-0.6	10	3.5	-2.2	250	15.6	-6.7	250	7.u	-2.8	130	7.3		50	6.7	11.1	160	5.G
23	2.2	250	1.1	-1.1	200	9.1	-2.2	170	9.7	-0.6	240	1.9	7.8	150	9.7	11.7	90	2.6
24	-0.6	290	10.9	-2.2	260	5.5	-5.0	320	14.5	-1.3	10	13.7	-1.1	340	17.1	11.7	140	2.5
25	-1.1	300	6.2	-8.9	280	7.3	-11.7	290	10.2	-4.9	10	2 0.4	-4.4	330	14.0	16.7	210	8.1
26	0.6	80	11.9	-9.4	210	8.5	-1.8	310	1.3	-5.0	350	10.5	-3.9	330	7.0	8.3	340	8.9
27	0.0	60	9.0	-10.0	210	6.5	-2.2	360	1.3	-3.3	240	3.0	-3.3	210	0.8	3.9	30	6.0
28	-3.9	250	12.4	-4.4	150	14.8	-1.7	320	10.7	-3.3	120	2.8	4.4	170	9.9	4.4	10	9.9
29	-2.8	230	1'4.6	-0.6	160	13.8	-5.0	300	9.1				5.6	1 0	6.8	4.4	150	7.6
30	-8.9	280	8.8	-2.e	300	5.9	-8.3	290	7.0				11.1	230	11.8	5.0	310	6.9
31				-5.6	350	16.4	-6.1	320	9.6				3.3	360	11.4			

TC = AVERAGE DAILY AIR TEMPERATURE, DEGREES CELCIUS
WD = MEAN DAILY RESULTANT WIND DIRECTION, DEGREES FROM NORTH
WS = MEAN DAILY RESULTANT WIND SPEED, KNOTS

Table 9e.--*Daily air temperature and wind speed and direction, Alpena, Mich.*

	NOVEMBER			DECEMBER			JANUARY			FEBRUARY			MARCH			APRIL		
DAY	TC	WD	WS	TC	WD	WS	TC	WD	WS	TC	WD	WS	TC	WD	AS	TC	WD	WS
1	6.1	230	5.7	-7.8	230	6.5	-6.1	310	9.5	-9.4	310	11.9	-1.7	30	6.7	-0.6	GO	0.1
2	11.1	240	5.4	-8.3	290	3.4	-13.3	250	6.4	-13.1	280	2.8	-1.1	110	5.6	1.1	350	3.2
3	11.7	200	3.5	-3.3	10"	1.1	-15.6	220	11.5	-11.1	180	4.4	2.8	140	10.1	3.9	300	7.5
4	10.0	300	2.1	-1.1	230	13.2	-16.1	230	10.3	-10.6	210	10.1	6.1	160	10.4	0.6	50	5.6
5	13.3	210	5.1	-0.6	240	12.0	-17.2	210	7.9	-15.0	280	7.6	1.7	180	8.6	2.8	190	4.0
6	7.2	300	1.4	-4."	270	6.4	-15.6	200	8.9	-15.0	150	7.6	-2."	200	5.3	-3.3	290	10.5
7	2.8	200	1.6	-5.6	320	1.8	-15.0	210	3.8	-8.9	260	3.1	-1.1	90	4.5	-1.1	110	5.1
8	6.1	200	11.8	-4.4	290	6.5	-16.1	240	4.9	-15.6	310	10.1	-1.1	"0	4.1	-1.1	100	1.0
9	10.6	210	9.1	-8.9	250	5.8	-12.2	250	8.9	-21.1	250	0.9	-0.6	160	6.9	1.3	360	10.1
10	8.1	90	8.3	-10.0	230	8.1	-18.9	280	4.4	-22.2	340	4.6	-6.1	250	8.8	3.3	20	1.6
11	4.4	350	6.2	-1.8	200	8.1	-18.9	220	4.6	-21.1	180	3.e	-10.6	270	1.8	1.7	100	8.9
12	0.0	40	6.4	0.0	210	9.6	-15.0	160	2.1	-10.9	310	4.9	-6.1	210	4.9	1.2	120	13.8
13	6.1	160	8.5	-1.7	280	10.2	-5.6	20	1.3	-18.3	90	9.1	3.9	180	9.0	6.7	120	4.1
14	6.7	250	11.2	-2.2	230	8.0	-10.0	110	12.2	-16.1	190	9.1	-5.0	290	14.7	6.7	250	9.2
15	2.2	250	3.6	2.8	210	8.2	-12.8	230	8.2	-13.9	10	10.6	-10.0	210	9.5	5.0	290	9.0
16	0.6	130	1.9	-1.1	240	3.6	-15.6	260	2.6	-21.1	350	R.6	0.0	240	G.2	1."	110	10.1
17	5.6	150	11.4	-1.7	200	8.6	-7.2	240	3.8	-21.8	10	1.9	3.3	160	9.9	7.2	310	8.7
18	4.4	240	9.6	-10.0	360	4.5	-16.1	340	6.4	-25.0	110	3.4	2.8	120	6.4	5.6	150	5.2
19	-1.1	280	9.1	-11.7	320	2.1	-14.9	140	5.8	-16.7	200	1.0	3.1	130	8.2	1.2	100	3.6
20	-6.7	360	5.6	-1.3	120	8.3	-3.9	no	3.1	-3.9	180	1.4	3.9	120	6.7	10.0	150	5.9
21	-4.4	220	2.8	-4.4	290	7.1	-3.9	340	9.1	-2.2	210	3.9	5.0	250	1.6	0.4	260	3.6
22	-3.3	220	1.2	-1.1	230	9.6	-1.2	290	8.8	-9.4	150	1.0	3.3	110	4.7	0.1	60	1.2
23	0.6	310	1.0	-2.2	200	a.0	-5.0	160	8.2	3.3	110	6.4	6.1	130	6.3	10.0	130	4.3
24	-1.1	260	6.8	1.1	160	6.8	-1.7	40	6.7	-5.0	140	10.3	2.2	20	7.0	13.9	160	4.8
25	-5.6	320	4.8	-3.3	290	10.8	-3.9	310	11.6	-12.8	10	9.5	-7.8	340	9.6	16.1	100	10.8
26	-7.8	40	9.3	-5.0	270	5.5	-2.2	310	8.8	-8.1	340	8.2	-1.2	300	10.4	11.1	290	6.8
27	-5.0	90	10.1	-9.4	270	8.1	-1.1	360	5.8	-3.9	110	2.4	-5.0	290	4.4	5.9	140	10.4
28	-1.9	250	3.3	-12.2	220	0.2	-2.2	330	9.6	-2.2	140	9.0	-1.7	160	10.7	2.8	30	5.9
29	-2.2	200	12.2	-6.7	190	10.3	-3.3	300	12.2				4.4	330	1.2	2.2	110	1.1
30	-5.0	260	9.6	0.0	190	3.9	-5.0	100	10.2				R.9	110	5.3	1.7	20	8.0
31				-2.2	340	9.1	-8.3	320	10.9				4.4	320	10.1			

TC = AVERAGE DAILY AIR TEMPERATURE, DEGREES CELCIUS
WD = MEAN DAILY RESULTANT WIND DIRECTION, DEGREES FROM NORTH
WS = MEAN DAILY RESULTANT WIND SPEED, KNOTS

Table 9f.--*Daily air temperature and wind speed and direction, Detroit, Mich.*

DAY	NOVEMBER TC	WD	WS	DECEMBER TC	WD	WS	JANUARY TC	WD	WS	FEBRUARY TC	WD	WS	MARCH TC	WD	WS	APRIL TC	WD	WS
1	7.2	190	0.9	0.6	210	5.5	-1.7	140	9.1	-7.8	100	10.2	2.2	350	2.5	2.8	90	a.9
2	10.0	230	9.1	-2.8	10	5.4	-12.8	280	11.2	-9.4	260	5.1	2.2	100	1.8	7."	260	7.5
1	11.7	200	6.7	4.4	140	5.3	-16.1	240	18.1	-8.9	190	4.3	4.4	120	4.3	4.4	320	1.5
4	13.3	220	6.3	0.0	250	10.2	-12.2	250	16.1	-8.9	290	14.8	9.4	210	10.9	2.2	60	8.7
5	16.7	210	11.9	-0.6	210	10.8	-12.2	240	8.7	-15.6	260	7.7	1.7	240	12."	1.7	260	12.1
6	10.6	330	8.8	0.0	270	4.5	-12.8	230	7.8	-12.2	190	8.3	0.6	240	7.6	-1.1	293	25.1
7	4.4	350	8.2	1.1	70	5.2	-10.6	130	3.6	-7.2	290	6.5	1.1	110	5.6	-0.6	290	5.0
8	4.4	220	9.1	0.0	330	9.3	-11.7	260	9.3	-11.7	310	0.1	3.1	100	6.1	1.1	120	9.7
9	10.0	220	12.4	-6.1	300	11.1	-12.8	230	13.1	-15.6	100	6.9	1.1	190	5.6	1.7	20	11.2
10	7.2	180	5.5	-11.1	250	9.4	-11.9	260	8.2	-15.0	110	8.1	-1.9	270	15.6	2.8	190	1.0
11	6.9	330	2.1	-7.6	210	7.0	-15.0	160	2.1	-13.9	140	9.7	-8.9	270	12.1	1.7	100	11.5
12	4.4	50	14.0	1.7	220	11.2	-9.4	110	3.6	-10.6	60	10.1	-2.8	270	6.9	10.0	110	12.6
11	9.4	150	8.1	0.6	260	17.2	-3.1	80	7.4	-12.0	100	2.6	5.0	220	11.5	10.6	90	2.5
14	9.4	270	12.6	-2.2	240	15.2	-6.1	100	11.9	-11.3	120	10.0	-0.6	290	17.3	10.6	280	12.R
15	2.2	350	4.0	2.8	230	15.9	-18.3	220	11.1	-9.4	80	12.0	-6.7	120	13.1	7.2	320	11.4
16	2.8	10	7.1	0.6	250	8.2	-8.3	220	2.2	-11.9	20	10.4	-0.6	250	8.6	8.9	110	9.0
17	10.0	180	10.9	-0.6	290	11.8	-9.9	280	8.3	-18.3	70	9.3	4.4	190	5.4	0.3	150	7.1
18	2.0	240	11.7	0.6	310	1.1	-10.6	320	5.0	-19.4	100	14.4	8.9	130	3.6	7.8	10	2.9
19	2.0	110	6.1	-5.0	80	8.9	-10.0	110	9.9	-10.0	250	4.3	5.6	110	9.0	7.2	140	'2.I
20	-0.6	40	9.2	1.1	120	3.8	-1.7	70	5.7	-8.9	200	6.9	7.8	110	6.0	10.0	170	9.1
21	-1.1	50	8.7	-1.1	270	15.2	-2.2	350	10.2	0.0	250	12.2	9.9	130	1.7	11.1	210	2.2
22	1.1	160	3.7	0.6	210	11.6	-1.3	270	12.9	0.6	190	3.5	8.9	100	6.9	11.1	40	2.2
21	5.0	230	5.0	0.0	210	4.5	-1.3	140	1.6	3.9	190	4.8	12.2	160	9.1	13.3	190	3.8
24	3.3	280	13.2	1.7	150	4.5	-0.6	60	9.2	-0.6	30	9.5	6.1	200	9.6	14.4	160	1.3
25	1.1	300	7.1	-3.9	270	13.8	-2.8	110	17.5	-4.4	40	16.2	-2.8	260	9.6	16.7	210	8.1
26	-0.6	80	12.9	-6.1	270	7.6	-1.1	120	9.q	-1.7	20	15.1	-1.9	300	12.4	14.4	220	5.1
27	-2.2	so	10.8	-8.3	280	11.2	0.0	270	0.8	0.6	130	6.6	-1.9	310	6.3	8.3	10	4.7
28	-2.8	240	12.7	-10.0	160	2.0	0.0	320	11.1	0.0	140	1.0	2.8	180	10.2	6.7	80	6.0
29	-1.9	200	9.6	-3.1	120	9.9	-1.1	100	14.6				11.1	230	6.0	6.7	170	1.1
10	-2.2	270	9.e	2.2	170	9.3	-2.0	300	8.9				11.9	220	13.6	6.7	250	12.1
31				2.2	40	4.8	-6.1	310	9.6				8.9	330	7.8			

TC = AVERAGE DAILY AIR TEMPERATURE, DEGREES CELCIUS
WD = MEAN DAILY RESULTANT WIND DIRECTION, DEGREES FROM NORTH
WS = MEAN DAILY RESULTANT WIND SPEED, KNOTS

Table 9g.--*Daily air temperature and wind speed and direction, Cleveland, Ohio*

	NOVEMBER			DECEMBER			JANUARY			FEBRUARY			MARCH			APRIL		
DAY	TC	WD	WS	TC	WD	WS	TC	WD	WS	TC	WD	WS	TC	WD	WS	TC	WD	WS
1	6.1	J0	1.1	2.0	200	8.7	6.1	310	5.3	-9.9	310	13.6	5.6	200	10.3	5.6	30	6.3
2	8.3	220	6.e	2.8	20	5.9	-10.0	270	12.1	-10.6	230	7.6	4.4	200	3.2	12.2	230	0.0
3	12.2		4.3	1.2	170	11.6	-15.6	230	16.3	-7.8	190	6.6	9.4	160	12.4	5.0	360	6.4
4	12.8	210	2.5	6.7	230	14.8	-10.6	240	14.3	-8.9	240	14.0	13.3	170	18.4	5.0	100	1.4
5	16.1	190	8.5	2.2	210	12.9	-10.0	220	7.2	-15.0	240	10.1	4.4	230	9.1	5.6	220	13.0
6	12.2	310	2.5	2.8	240	4.2	-8.3	210	7.3	-11.7	180	7.6	2.8	2,0	0.2	0.6	270	23.1
7	6.1	20	7.7	7.2	130	4.4	-7.8	340	6.6	-1.9	230	3.9	6.7	120	2.5	0.0	320	6.0
8	5.0	220	7.2	5.0	350	7.5	-12.2	260	10.4	-11.7	270	8.1	3.9	20	7.3	5.0	140	7.0
9	10.0	200	10.2	-3.3	300	9.8	-11.9	220	15.0	-11.9	310	5.1	5.6	2"0	6.1	3.1	350	11.5
10	8.3	170	7.6	-0.9	240	11.9	-12.8	230	10.0	-14."	270	7.0	0.6	250	12.2	1.1	360	4.0
11	11.1	200	0.6	-5.0	190	10.5	-14.4	190	3.4	-15.0	160	4.4	-7.8	260	11.6	5.0	90	6.1
12	8.3	30	10.0	2.2	210	10.7	-6.7	120	3.9	-10.6	40	7.2	-1.1	300	6.7	16.7	150	7.9
13	11.7	110	9.6	1.1	250	16.2	0.6	110	6.9	-11.9	20	3.2	8.9	200	15.6	12.2	160	R.2
14	11.1	240	9.6	-1.7	210	14.2	-3.9	270	13.9	-10.6	130	7.0	J.9	270	15.8	11.7	240	11.8
15	3.9	220	1.1	3.9	220	17.5	-13.3	220	13.9	-5.6	40	8.3	-6.1	300	11.9	7.2	290	10.1
16	5.6	80	4.5	2.8	210	10.3	-6.1	220	4.3	-12.8	360	13.6	0.0	210	9.1	6.1	290	8.7
17	12.8	180	14.1	1.1	270	15.3	-1.1	230	10.2	-16.1	40	10.7	7.8	200	3.6	7.2	110	5.4
18	6.7	250	13.0	1.1	270	5.6	-7.2	340	10.2	-12.8	110	10.5	11.7	30	2.8	5.6	340	5.1
19	5.6	240	6.5	-2.8	70	1.7	-6.7	140	6.9	-8.1	220	5.7	9.4	50	6.2	5.6	340	2.6
20	3.9	IO	2.9	6.7	170	7.8	0.6	140	5.9	-3.9	180	10."	9."	"0	4.1	8.3	20	2.1
21	2.0	70	6.5	0.6	250	19.5	-0.6	340	9."	4."	210	14.9	10.0	30	5.3	14.4	190	1.0
22	3.9	190	2."	1.7	220	14.1	-2.2	260	12.0	3.3	190	1.3	11.1	30	4.4	8.9	320	2.8
23	8.3	210	9.i	0.6	210	5.8	-1.1	160	9.2	8.1	180	11.5	18.3	160	14.0	12.2	40	2.1
2"	5.6	270	12.8	3.3	160	8.3	2.2	170	5.5	1.1	10	9.5	8.9	200	8.7	15.6	120	1.5
25	2.2	250	7.9	-3.3	260	19.5	-1.7	290	16.1	-0.6	40	16.8	1.1	230	11.2	21.7	200	5.3
26	1.1	90	9.3	-5.0	240	7.3	-1.7	280	10.1	-1.7	20	11.7	-2.2	270	11.4	14.4	180	9."
21	2.0	150	5.0	-5.6	260	11.1	-0.6	230	2.6	-0.6	300	5.7	-3.6	330	4.7	6.1	150	5.6
28	0.0	250	11.5	-5.6	170	2.2	0.0	310	10.2	1.7	150	5.3	4.4	160	11.8	7.0	220	7.1
29	0.6	190	11.5	-1.1	130	7."	-1.7	280	12.8				16.7	200	11.2	6.1	50	2.1
30	0.0	260	9.9	3.3	180	9.2	-3.3	250	10.2				18.3	200	13.2	9.4	220	10.2
31				9."	170	8.2	-5.6	280	8.1				11.1	300	5.R			

TC = AVERAGE DAILY AIR TEMPERATURE, DEGREES CELCIUS
WD = MEAN DAILY RESULTANT WIND DIRECTION, DEGREES FROM NORTH
WS = MEAN DAILY RESULTANT WIND SPEED, KNOTS

Table 9h.--Daily air temperature and wind speed and direction, Rochester, N.Y.

DAY	NOVEMBER TC	WD	WS	DECEMBER TC	WD	WS	JANUARY TC	WD	WS	FEBRUARY TC	WD	WS	MARCH TC	WD	WS	APRIL TC	WD	WS
1	6.1	150	2.7	0.6	210	5.1	6.1	240	8.2	-10.0	300	15.0	5.0	110	5.0	3.3	50	7.6
2	8.9	230	10.0	-0.6	270	9.1	-2.8	290	8.5	-9."	280	13.9	3.3	260	4.7	8.3	170	11.5
3	10.6	350	0.2	0.0	120	7.1	-12.2	240	15.5	-10.0	240	4.9	5.6	160	9.1	3.9	260	10.5
4	12.8	220	5.4	6.7	230	14.8	-11.7	240	13.1	-8.9	240	10.9	8.9	170	14.9	2.8	110	7.4
	15.0	200	5.6	1.3	230	10.2	-12.2	230	8.7	-12.2	250	21.5	6.7	230	6.3	4.4	240	14.2
6	11.1	240	6.3	3.3	210	6.6	-8.3	100	4.9	-11.1	240	6.6	1.1	220	4.9	2.2	240	24.8
7	5.6	300	5.5	5.0	110	3.6	-7.2	160	2.2	-9."	80	6.1	1.7	350	2.1	-0.6	27"	16.0
8	5.0	200	6.5	5.0	310	4.6	-7.0	270	8.9	-9."	250	17.5	0.6	300	2.1	-1.1	70	0.7
9	9.4	220	8.9	-2.8	280	8.7	-11.7	220	11.5	-17.2	260	11.5	2.8	150	4.6	0.0	40	10.7
10	9."	130	1.9	-6.1	250	16.2	-10.6	220	9.3	-16.1	240	2.8	1.3	240	10.9	'0.6	280	10.1
11	8.9	250	3.2	-5.t	220	8.5		220	4.2	-20.6	310	4.2	-5.0	210	14.8	0.6	80	1.5
12	5.0	50	7 . 6	0.0	200	7.0	-11.2 -13.9	130	5.9	-18.3	140	1.3	-4.4	270	14.5	6.1	70	6.9
13	6.1	150	7.9	2.8	220	15.1	-1.7	90	8.6	-18.9	310	6.6	3.3	180	9.9	0.3	120	12.6
1"	10.6	220	12.9	-1.1	250	11.8	-1.1	250	11.5	-20.0			2.2	240	15.5	9."	180	0.1
15	1.9	250	7.3	2.2	220	72.9	-10.6	240	16.0	-15.6	JO	11.3	-10.0	280	16.1	6.1	200	11.1
16	2.8	90	3.6	3.3	210	8.2	-11.1	230	0.0	-15.6	10	9.2	-3.9	240	11.6	5.6	290	9.1
17	7.2	150	12.1	0.6	280	16.7	-7.2	220	1.7	-22.8	320	8.2	1.3	280	3.7	8.3	280	11.0
18	9."	250	16.7	-6.1	300	11.7	-8.9	80	11.4	-20.6	110	4.1	2.8	20	3.6	6.7	310	10.7
19	4.4	260	10.1	-8.3	260	10.4	-12.8	120	8.1 2.6	-9."	170	2.0	2.2	40	5.7	7.2	310	8.5
20	-0.6	330	6.7	-0.6	120	7.5	-5.6			-7.2	190	3.6	4.4	110	3.8	6.7	120	1.2
21	-2.8	110	1.7	2.8	250	16.3	-1.1	330	4.1	-0.6	220	7.4	5.0	10	2.2	11.7	150	4.2
22	-1.7	130	6.1	1.1	220	9.0	-2.8	250	16."	1.1	270	7.2	8.3	70	2.3	11.1	260	7.6
23	3.9	150	10.7	-0.6	260	8.4	-1.7	140	5.0	3.3	150	12.5	12.2	150	10.2	10.6	290	1.6
24	6.1	270	11.7	-0.6	120	7.5	1.1	100	10.1	3.3	290	3.6	16.1	140	15.8	14.4	JO	2.1
25	0.0	310	11.6	-2.2	280	a.5	1.7	330	5.6	-2.2	50	12.6	6.1	250	11.5	18.9	160	5.7
26	-5.0	20	6.5	-6.1	250	12.7	2.2	300	11.2	-2.8	JO	13.2	-1.7	250	15.5	16.7	160	11.9
27	-2.2	100	10.5	-5.6	250	16.3	1.7	260	6.3	-1.1	300	7.6	-2.2	270	13.2	8.9	230	10.4
28	1.1	250	9.0	-10.6	270	8.0	0.6	280	9.8	-0.6	210	4.8	2.2	170	8.0	8.3	260	3.1
29	1.1	170	8.2	-12.2	140	2.7	-1.1	280	17.8				11.7	210	7.7.	5.6	270	4.4
JO	-0.6	250	12.4	-2.2	120	5.4	-1.3	290	13.7				11.7	160	0.6	7.8	210	1.5
31				4.4	130	6.4	-7.2	280	11."				11.1	240	8.5			

TC = AVERAGE DAILY AIR TEMPERATURE, DEGREES CELCIUS
WD = MEAN DAILY RESULTANT WIND DIRECTION, DEGREES FROM NORTH
WS = MEAN DAILY RESULTANT WIND SEEED, KNOTS