SECOND INTERNATIONAL CONFERENCE ON
PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
UNIVERSITY OF ICELAND
DEPARTMENT OF ENGINEERING AND SCIENCE

LAKE MELVILLE ICE INVESTIGATION, LABRADOR

A. O. Nemec, Associate Professor
D. A. Mills, Assistant Professor
C. J. Langford, Project Manager
S. L. Jesseau, Research Assistant

Faculty of Engineering & Applied Science
Memorial University of Newfoundland
St. John's
Newfoundland
CANADA

INTRODUCTION

Lake Melville is a tidal lake in central Labrador 54°N; 59°W) approached from the Labrador Sea through Hamilton Inlet. The lake extends about 86 miles (155 km) in a southwesterly direction and has a maximum width of approximately 20 miles (36km), as shown in Figure 1.

For the past two years an intensive study of the formation and behaviour of the Lake Melville ice cover has been conducted. This research was directed towards determining the most favourable location and method of keeping an extended winter shipping track open through Lake Melville from the Labrador Sea to the port of Goose Bay at the western end of the lake, about 140 miles (235 km) inland.

PHYSIOGRAPHY

The shores of Lake Melville are bounded by fairly high land, especially to the south where hills reach an elevation of from 1000 to 2000 feet (305 to 610 m) and grade into the Mealy Mountains (3,800 feet; 1,158 m) about seven miles (13 km) inland. In general the lake is deep and comparatively free of shoals except at the northwestern end. In the main and widest part of the lake depths are irregular from 14 to 60 fathoms (26 to 110 m). In Goose Bay depths range from 20 to 30 fathoms (37 to 55m).

Salinity tests show that the waters of the lake are brackish, but samples taken in the entrances of principal rivers flowing into the lake are quite fresh. The tidal amplitude of the lake is approximately 2.5 feet (76 cm).

CLIMATIC CONDITIONS

At the western end of the lake continental climatic influences are most strongly felt. The mean monthly July temperature is 60°F and the mean monthly January temperature is 2.6°F. However, January temperatures have fallen to as low as -38.2°F, with wind chill factors down to -80°F. Slightly warmer winter and cooler summer temperatures prevail at the eastern end of the lake system due to a maritime climatic influence.

Freeze-up begins along the shores of the lake in early November and gradually extends out, breaks up and wanders about the lake. By Christmas a complete ice cover exists. Spring break-up is usually complete by lake May or early June. Figure 2 shows the earliest, mean, latest, and 1972-1973 dates of break-up (complete clearing) and freeze-up (complete coverage) on the Goose River, Churchill River, and Goose Bay and Terrington Basin at the western end of the lake.

PREVIOUS WORK

Both Canadian and U. S. government services have carried out hydrographic investigations in Lake Melville. Detailed studies in Goose Bay and in Terrington Basin have been conducted by Stevenson Hardkte Resources (1968) and Lee (1955). Ice research papers found in the proceedings of the international I.A.H.R. Symposium held in Leningrad, September 1972, yielded information on recent ice monitoring techniques.

EXPLORATORY PROBES, JANUARY TO APRIL 1972

Four exploratory probes were conducted in early 1972. In January, assisted by an icebreaker, snow and ice thicknesses at 37 stations along the length of the lake were measured. In February, March and April, travelling by snowmobile and helicopter, the stations were remeasured. A series of vertical cores through the ice cover were also examined structurally.

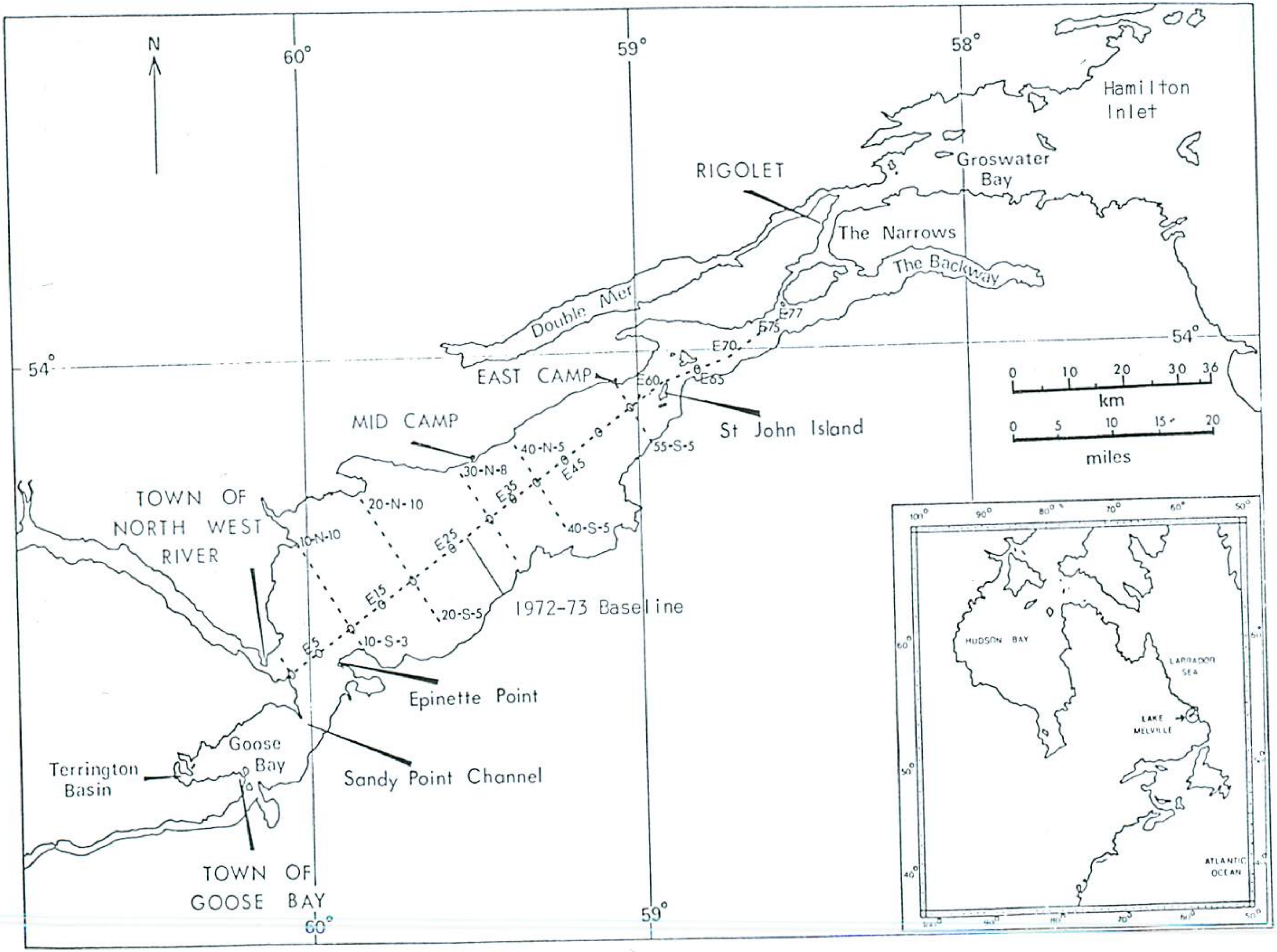

N
60°
59°
58°
54°
Hamilton Inlet
Groswater Bay
RIGOLET
The Narrows
The Backway
Double Mer
EAST CAMP
MID CAMP
St John Island
E77
E75
E70
E65
E60
55-S-5
40-N-5
E45
30-N-8
E35
40-S-5
20-N-10
E25
10-N-10
E15
20-S-5
1972-73 Baseline
E5
10-S-3
TOWN OF NORTH WEST RIVER
Epinette Point
Goose Bay
Terrington Basin
Sandy Point Channel
TOWN OF GOOSE BAY
0 10 20 30 36
km
0 5 10 15 20
miles
HUDSON BAY
LABRADOR SEA
LAKE MELVILLE
ATLANTIC OCEAN

Figure 1.

Break - Up (Complete Clearing) & Freeze - Up (Complete Coverage)

Earliest, Mean, Latest, 1972 - 73 Dates

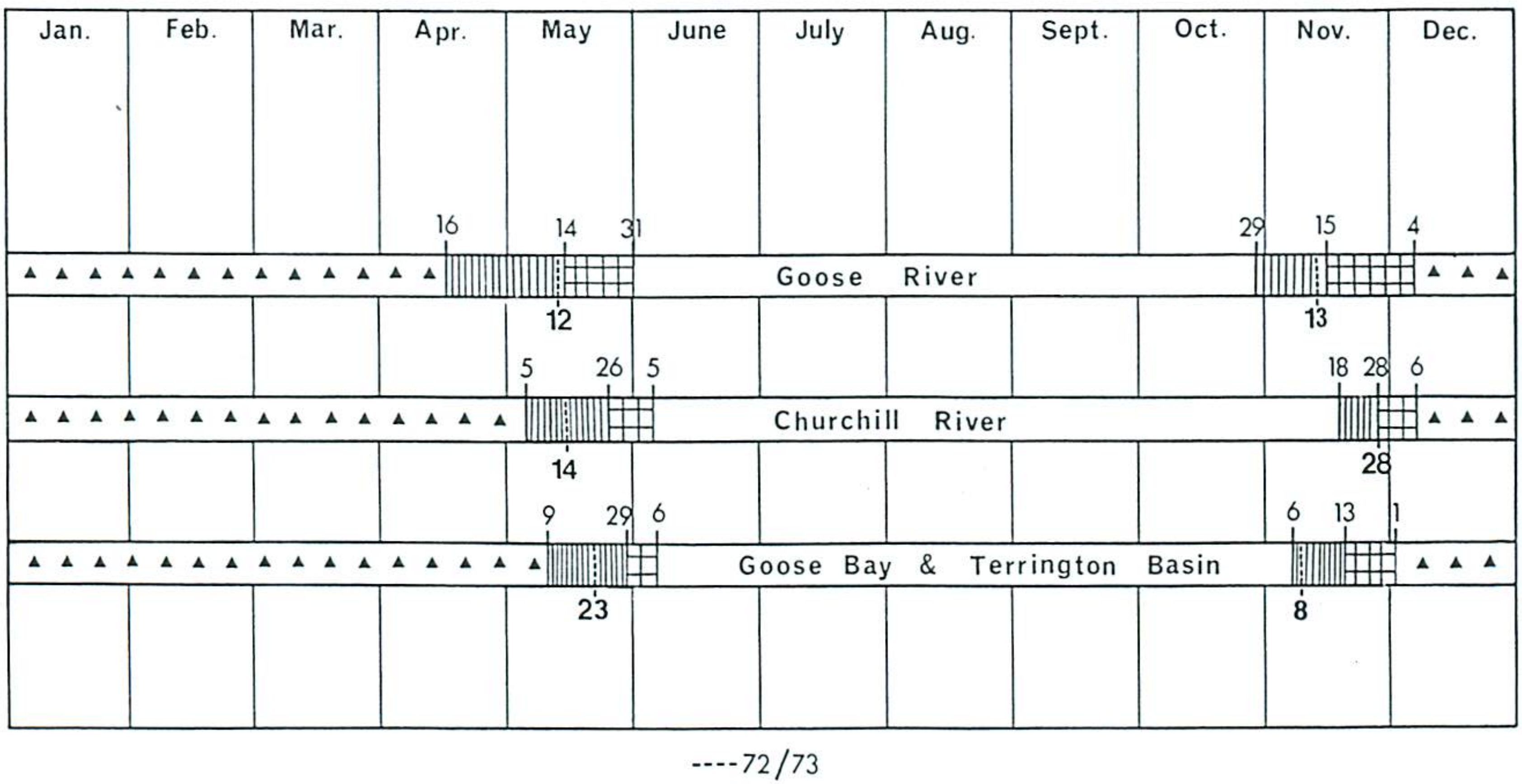


Figure 2.

From the evidence compiled, the following theory of ice growth on Lake Melville was formulated.

1. Initial ice starts to form in November or December and continues to increase in thickness until the snow cover becomes an insulator, preventing water in contact with the bottom ice from freezing. If the snow cover is sufficient the thickness of initial ice may possibly start to decrease.

2. Rising and falling with the 2.5 foot (76 cm) tide amplitude, the ice surface cracks, allowing water to mix with the snow cover to form slush. The weight of snow on the ice is considerable and depresses the floating ice down into the water, causing water to flow up onto the ice surface. This is particularly noticeable when a hole is drilled through the ice. The water percolates upwards to the snow surface forming a slush cover which then freezes. This produces superimposed ice, or double ice as it is known locally. When frozen to its complete depth it of course adds to the total ice thickness.

3. Snow then begins to build up on top of the frozen slush until water again flows up to form slush and then to freeze. The cycle repeats many time during the winter depending on the combinations of snow, wind and temperature.

The above water structure consists first of initial hard ice. The snow cover is added until a third phase (slush) is formed. Frozen slush is the final phase added to the structure. Figure 3, a four phase ice structure profile diagram, shows the 1972 total thickness in inches and phase components for any specific time at some station on the lake. The diagram shown is not plotted from data but is synthesized from the data and observations on the lake.

1973 PROGRAMME

Method of Operation

The study was conducted from a base camp and laboratory at North West River and two small camps at the central and eastern end of the lake. Four meteorological stations monitored weather conditions along the lake system. Several "below ice" lake water

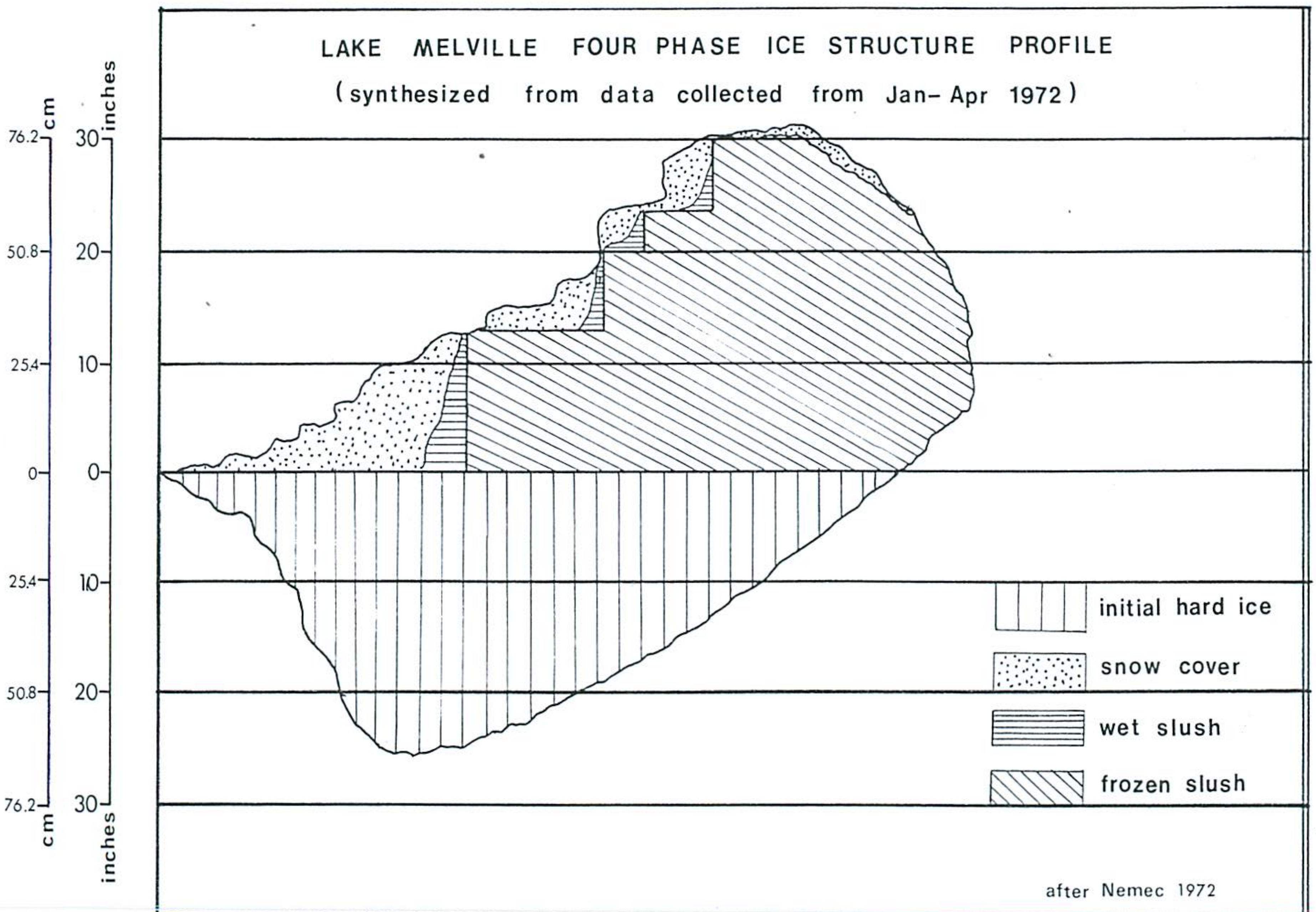

LAKE MELVILLE FOUR PHASE ICE STRUCTURE PROFILE
(synthesized from data collected from Jan– Apr 1972)
cm
inches
76.2
50.8
25.4
0
25.4
50.8
76.2
30
20
10
0
10
20
30
initial hard ice
snow cover
wet slush
frozen slush
after Nemec 1972

FIG 3

temperature, salinity and current measurements were taken. A 77 mile (138.6 km) long baseline was established in an east-west direction along the lake. North-south shore to shore section lines were set up at ten mile (18 km) intervals along the baseline. Over 100 stations were tested for in situ ice and snow measurements. Ice block and core samples were collected for laboratory analysis of salinity, density, crystal structure and fracture strength. Aerial reconnaissance and photography of snow and ice conditions were also completed.

Meteorological Observations

Meteorological observations were recorded at Goose Bay, North West River, Julia Point (Mid Camp), and Rigolet. With the exception of Goose Bay, these stations were set up to provide specific climatic data for the ice studies programme.

Data collected over the study period showed that the period experienced a record cold October, and a colder than normal November, December, January and February. The minimum temperature was 7.8°F in October and -38.9°F in February, both record lows for these months. However, as nature will, temperatures for March through June were above average, setting records on the other side of the scale.

Precipitation varied. November and December experienced below normal precipitation, February had 9.7 inches (24.5 cm) above normal snowfall, while March and April were again below normal.

Prevailing winds were westerly from October through March. Wind speeds increased the further east one travelled down the lake, until at St. John Island the speed was very nearly double that at North West River.

Figures 4, 5, 6 and 7 show data obtained in 1973 superimposed over 1948-1954 data collected and presented by Lee (1955), comparing readings of the relationship of ice growth to degree days below freezing.

Oceanographic Observations

Three sets of current observations were taken through

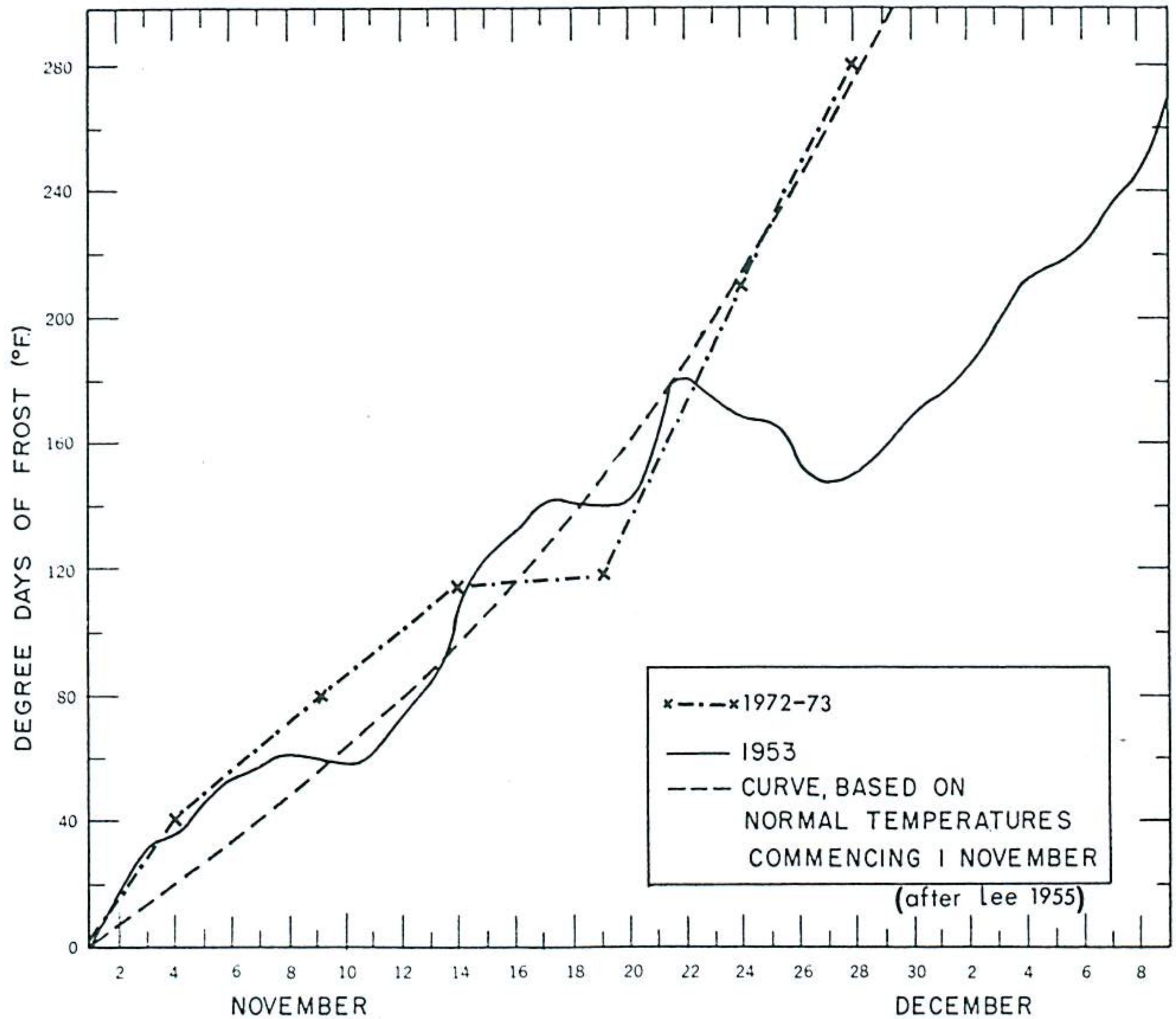


FIGURE 4 ACCUMULATION OF DEGREE DAYS OF FROST IN NOVEMBER AND DECEMBER 1953, COMPARED TO 1972-73 DATA

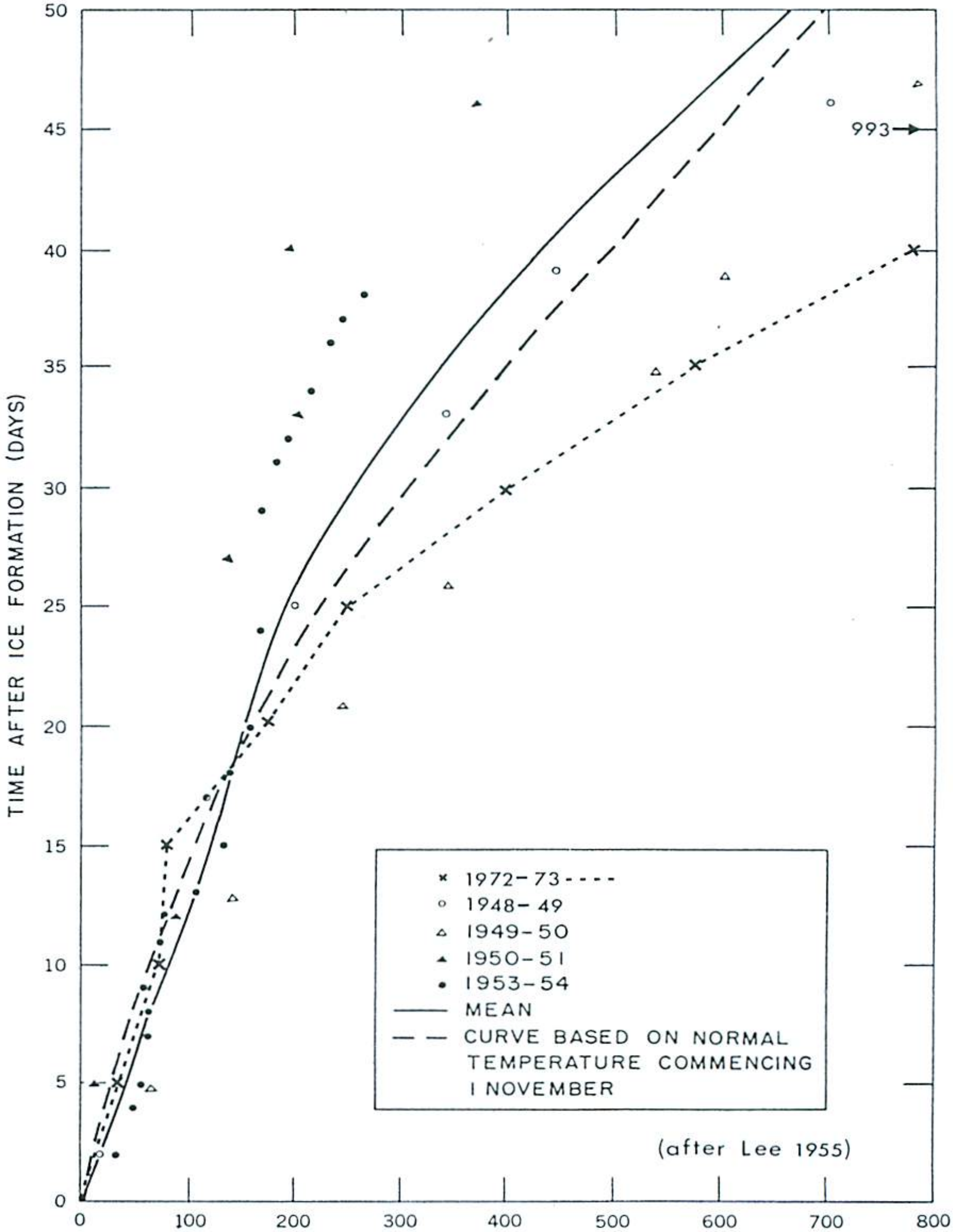
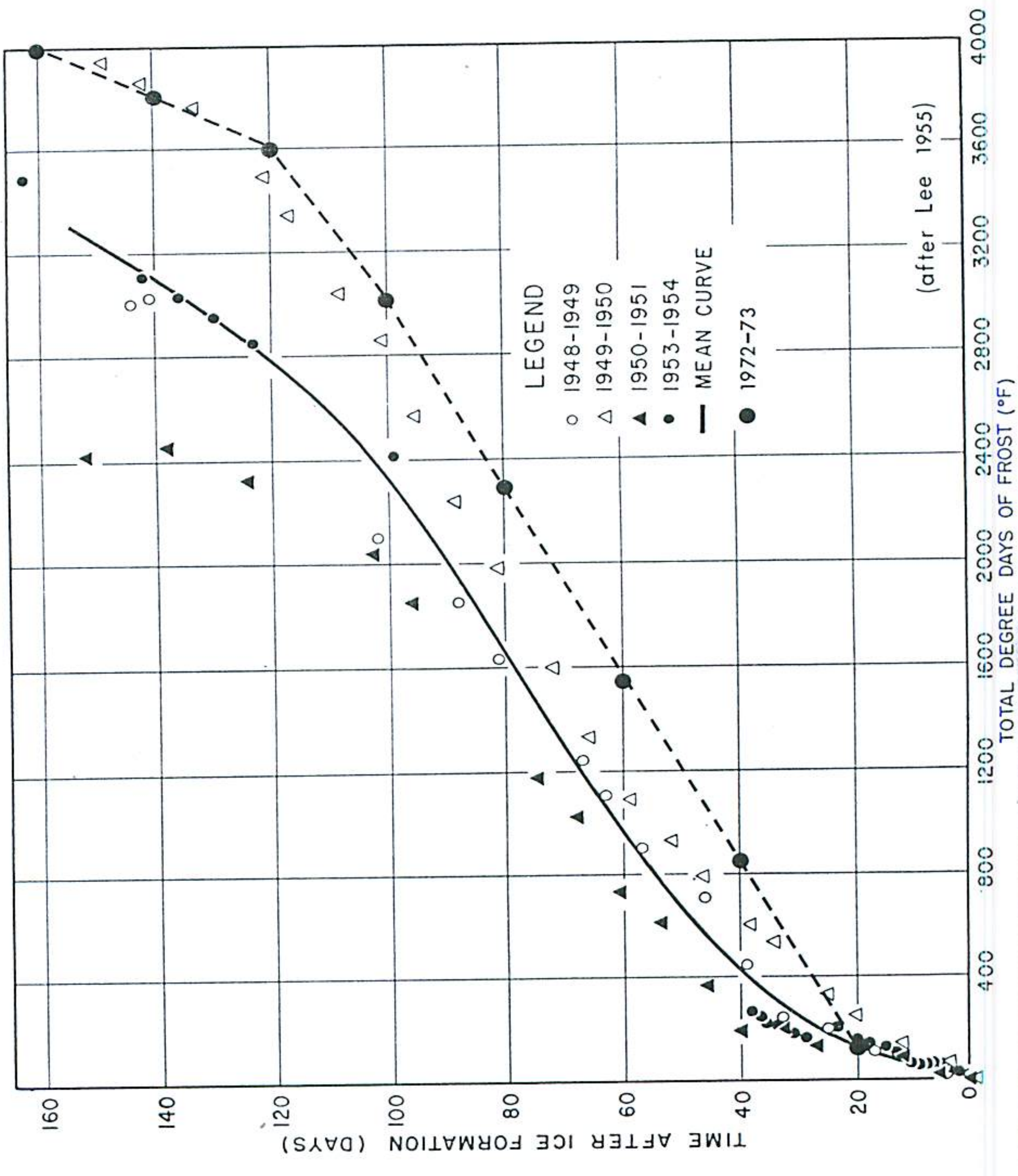


FIGURE 5 ACCUMULATION OF DEGREE DAYS OF FROST FOR THE FIRST 45 DAYS AFTER INITIAL ICE FORMATION


LEGEND
1948-1949
1949-1950
1950-1951
1953-1954
MEAN CURVE
1972-73
(after Lee 1955)
TIME AFTER ICE FORMATION (DAYS)
TOTAL DEGREE DAYS OF FROST (°F)
0
20
40
60
80
100
120
140
160
400
800
1200
1600
2000
2400
2800
3200
3600
4000

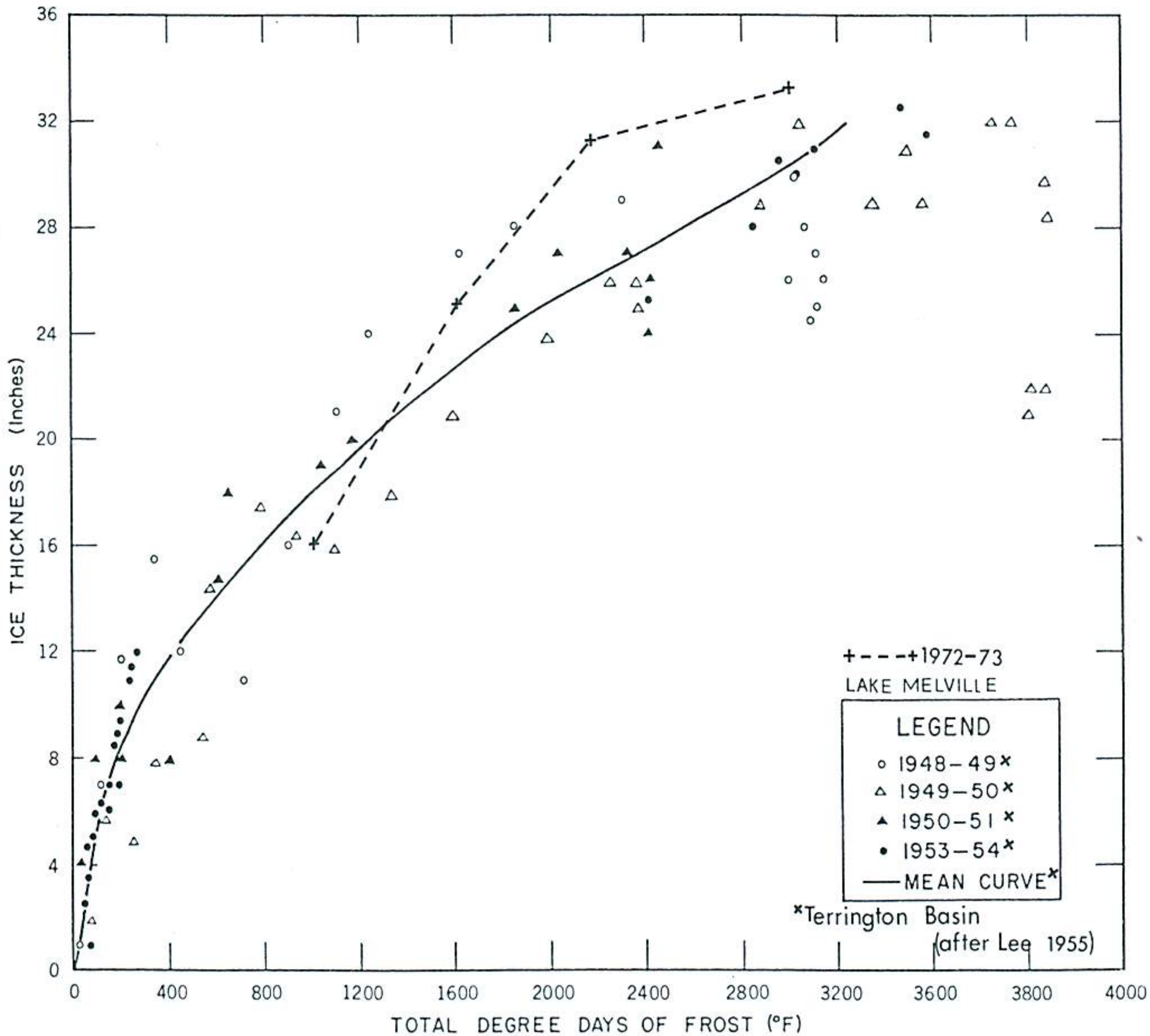


FIGURE 7: SEASONAL ICE GROWTH AS A FUNCTION OF ACCUMULATED DEGREE DAYS OF FROST.

the ice over periods of 24 hours. Site A was at the western end of the lake off Epinette Point, and sites B and C were half way down the lake and a few miles from shore on either side. The results showed an almost negligible current to be present at 40 feet (13 m) below the water surface. A bendix savonious rotor direct reading current meter was used and was checked frequently to ensure proper functioning.

Salinity and temperature measurements were also taken at these sites down to a depth of 300 feet (90 m). Again very little difference was seen between information taken at different times or at different observation sites.

Four current, salinity and temperature stations equally spaced down the lake were observed from an icebreaker prior to freeze-up. Two of these stations were re-observed in March. The only differences clearly identifiable were, as to be expected, in the top 60 feet (20m). The measurements, taken after ice formation, showed that water in the upper layer had become fresher and colder. This is thought to be due to an absence of wind mixing. The thermocline had migrated upwards from 60 feet (20m) to 30 feet (10m) below the surface, in all probability due to the same reason.

Ice Thickness Observations and Comparisons with 1972 and 1953-54 Data

Tables 1, 2, 3 and 4 list drilled ice, snow and slush thicknesses and in situ "hot wire gauge" ice, snow and slush thicknesses encountered during the 1973 study.

In January the 1973 ice thicknesses were an average of 10 inches (25 cm) greater than thicknesses found in January 1972. However, March and April values for flat ice reach parity.

Compared to the 1953-54 Terrington Basin ice growth study (Lee, 1955), and accepting November 5 as the average initial freeze date, the freeze rate on Lake Melville showed a similar rate of growth pattern. The Lake Melville pattern, however, occurred approximately three weeks later.

Summary

1. The 1972-73 winter was the most severe ice year within living memory. Both Sandy Point Channel and the narrows at Rigolet froze over, an unusual occurrence. North West River also froze over.

2. Maximum ice growth occurred about the middle of February and stayed relatively constant until the later part of April, when decay set in.

3. Ridging and rafting in the eastern end of the lake was exceptionally severe.

4. Frozen slush - superimposed ice did appear, as shown in Tables 1, 2, 3, and 4. However, it did not appear to the extent expected, based on the 1972 experience. Nor perhaps did it form in quite the same manner.

CONCLUSION

Our experience between 1972 and 1973 could not have differed more sharply, with 1972 considered a relatively normal year while 1973 was quite exceptional. This leaves many interesting questions to be answered in 1974.

REFERENCES

[1] Lee, O. S. "Local Environmental Factors Affecting Ice Formation in Terrington Basin, Labrador" Applied Oceanography Branch, Div. of Oceanography, U. S. Navy Hydrographic Office, Washington, D.C. Technical Report TR-24, December 1955.

[2] Stevenson Hardtke Resources "Port Facilities Goose Bay, Labrador", consultants report for Melville Forest Products Limited, 1968.

TABLE I

DATE	SNOW SLUSH ICE	DRILLED ICE THICKNESSES												
	E0	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	
J4	4 - 24	6 - 26	5 - 27	4 - 23	6 - 24	4 - 24	7 - 22	8 - 23	7 - 24	7 - 26	7 - 28	8 - 23	4 - 24	
J13	8 - 26	-- - --	-- - --	-- - --	-- - --	-- - 26	-- - --	-- - --	-- - --	-- - --	-- - 30	-- - --	4 - 27ˣ	J11ˣ
J19	5 - 28	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	
J21	-- - --	11 - 29	9 - 30	12 - 30	10 - 28	8 - 28	8 - 29	9 - 28	5 - 29	6 - 28	7 - 29	-- - --	-- - --	
J25	-- - 30	10 - 30	9 - 35	13 - 29	12 - 29	-- - 29	8 - 32	8 - 29	9 - 32	10 - 32	-- - 33	-- - --	-- - --	
F6	12 - 33	13 - 32	15 - 35	16 - 32	12 - 33	14 - 32	20'- 32	11 - 32	12 - 34	13 - 32	14 - 36	-- - --	-- - --	
M6	-- - --	-- - --	-- - --	24 - 36	-- - --	28 - 34	-- - --	-- - --	-- - --	-- - --	25 - 35	4 - 33"	17 - 34"	F7"
	E13	E14	E15	E16	E17	E18	E19	E20	E21	E22	E23	E24	E25	
J4	7 - 27	7 - 25	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	
J11	-- - --	-- - --	3 - 25	-- - --	-- - 25	-- - --	-- - --	3 - 24	-- - --	3 - 26	-- - --	-- - 34	11 - 32	
F7	16 - 35	14 - 33	12 - 33	15 - 35	7 - 33	16 - 34	14 - 35	16 - 34	-- - --	-- - --	-- - --	-- - --	-- - --	
F8	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	14 - 34	13 - 35	14 - 35	12 - 38	12 - 34	
F19	-- - --	-- - --	30 - 36	-- - --	-- - --	-- - --	-- - --	18 - 34	-- - --	-- - --	-- - --	-- - --	-- - --	
F20	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	20 - 33	
M30	-- - --	-- - --	21 4 38	-- - --	-- - --	-- - --	-- - --	21 3 37	-- - --	-- - --	-- - --	-- - --	20 6 35	
	E26	E27	E28	E29	E30	E31	E32	E33	E34	E35	E36	E37	E38	
J13	-- - --	-- - --	-- - --	-- - --	-- - 29	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	
J22	-- - --	-- - --	-- - --	-- - --	11 - 32	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	
J23	-- - --	-- - --	-- - --	-- - --	-- - --	3 - 37	2 - 60	12 - 32	-- - --	10 - 32	-- - --	5 - 34	-- - --	
J27	-- - --	-- - --	-- - --	-- - --	7 - NR	15 - 41'	22 - 65'	32 - 45'	20 - 36'	3 - 44	33 - 60'	20 - 38'	24 - 34'	F19'
F8	8 - 36	12 - 35	7 - 36	8 - 46	6 - 37	-- - --	-- - --	-- - --	-- - --	20 - 36'	-- - --	-- - --	-- - --	F19'

DRILLED ICE THICKNESS

	E39	E40	E41	E42	E43	E44	E45	E46	E47	E48	E49	E50	E51	
J23	-- - --	15 - 60	-- - --	1 - 36	-- - --	-- - --	0 - 40	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	
J27	-- - --	0 - 49	-- - --	-- - --	-- - --	-- - --	2 - 43	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	F19•
F20	20 - 36•	18 - 42	40 - 57•	10 - 40	24 - 56	16 - 59	15 - 43	24 - 34	13 - 59	21 - 60	9 - 40	18 - 38"	50 - 65"	F21"
M28	-- - --	-- - 42•	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	18 - 41	21 - 70▼	A4▼
M6	-- - --	19 - 41	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	

	E52	E53	E54	E55	E56	E57	E58	E59	E60	E61	E62	E63	E64	
F21	8 - 47	14 - 96	2 - 45	-- - --	14 - 47	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	
F22	-- - --	-- - --	-- - --	32 - 34	-- - --	14 - 53	12 - 60	14 - 52	18 - 53	27 - 45	8 - 60	6 - 51	6 - 46	
M6	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	25 - 46	-- - --	-- - --	-- - --	-- - --	
M26	-- - --	-- - --	-- - --	30 12 36	-- - --	-- - --	-- - --	-- - --	24 6 47	-- - --	-- - --	-- - --	-- - --	
A4	39 - 227	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	
M13	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- 2 60	-- - --	-- - --	-- - --	-- - --	

	E65	E66	E67	E68	E69	E70	E71	E72	E73	E74	E75	E76	E77	
J28	8 - 44	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	8 - 101	-- - --	-- - --	
F22	-- - --	10 - 43	12 - 46	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	
M3	-- - --	-- - --	-- - --	24 - 56	24 - 57	14 - 72	-- - --	25 - 67	24 - 64	20 - 79	40 - 74	12 - 40	25 - 38	
M5	16 - 48	-- - --	-- - --	-- - --	-- - --	28 - 75	-- - --	-- - --	-- - --	-- - --	24 - 69	-- - --	-- - --	
M28	-- - --	-- - --	-- - --	-- - --	-- - --	19 3 --	-- - --	-- - --	-- - --	-- - --	24 2 --	-- - --	-- - --	
A1	-- - --	-- - --	-- - --	-- - --	-- - --	29 3 59	-- - --	-- - --	-- - --	-- - --	28 2 92	-- - --	-- - --	
A11	-- - --	-- - --	-- - --	-- - --	-- - --	10 5 63	-- - --	-- - --	-- - --	-- - --	20 3 61	-- - --	3 3 47	
A26	-- - --	-- - --	-- - --	-- - --	-- - --	14 3 84	-- - --	-- - --	-- - --	-- - --	12 2 68	-- - --	-- - --	
M13	-- 2 53	-- - --	-- - --	-- - --	-- - --	-- 2 67	-- - --	-- - --	-- - --	-- - --	-- 2 63	-- - --	-- - --	
M27	-- - --	-- - --	-- - --	-- - --	-- - --	-- 2 58	-- - --	-- - --	-- - --	-- - --	-- - --	-- - --	-- --	

TABLE III

DRILLED ICE THICKNESS

NORTH - SOUTH SECTION LINES

SNOW SLUSH ICE

STATION	J25	A3˙/A17	F7	A3	F8	M22/A3˙	F20	A3	F 22/A4•
N11	6 - 33	19 6 42˙	5 - 40	17 4 42		A17■			
N10	8 - 30	12 1 48	14 - 33						
N9	7 - 31		8 - 39						
N8	8 - 33		15 - 37		10 - 36	17 - 42■			
N7	7 - 32		17 - 36		13 - 36	19 1 44˙			S4½ 19 4 45•
N6	13 - 33		11 - 34		6 - 60				
N5	12 - 31		10 - 38		15 - 34		11 - 35	21 4 45	N4 14 4 43•
N4	10 - 32		18 - 33		13 - 42	15 - 40	12 - 38		10 - 38
N3	10 - 29		7 - 35		12 - 34		12 - 40		16 - 42
N2	10 - 27▽		6 - 35		5 - 34		16 - 42		-- - 44
N1	7 - 30		13 - 37		12 - 35		20 - 36		12 - 48
E10	-- - 33		E20 16 - 34		E30 6 - 37		E40 -- - 42		E55 -- - 34
S1	12 - 32▽		12 - 32		14 - 40		20 - 57		18 - 63
S2	16 - 30▽	27 - 33▲	18 - 33		12 - 34		-- - 45		16 - 54
S3	16 - 28▽		14 - 33		15 - 33	26 - 40	14 - 47		18 - 45
S4			12 - 34		13 - 35		17 - 40		18 - 53
S5			14 - 33	23 3 32^x	19 - 35	25 - 50⊡	24 - 44	24 2 52^x	N4½ 28 - 49

TABLE IV

HOT WIRE - ICE THICKNESS											
DATE	F19/F20'	F22	M1'M3	M2'/M6	M7	M22'/M23	M28'/M30	A1'/A10	A11	A26'/A29	M13
E0				24 - 35		8 - 42'	12 12 41	6 12 34		1 13 34	
E2-S2								17 8 --			
E5				28 - 34			17 7 33	13 8 33			
E10-N2					26 - 34		16 8 33	9 8 32			
E10				25 - 35			19 4 36	17 4 36		3 7 36	
E10-S2					27 - 33		18 5 33	12 8 33			
E15	30 - 36						21 4 38	16 5 38			
E20-N2								15 4 39			
E20	18 .- --						21 3 37	18 4 37		8 7 29	
E20-S2								19 8 42			
25	20 - 33'						20 6 35	17 5 35			
E30-N2						-- - 41	22 1 42	20 1 42			
E30							20 2 45	16 4 44		4 6 44	
E30-S2						-- - 42	21 5 40	17 5 41			
E35	20 - 36						23 - 47'		16 2 47	4 5 47'	-- 2 42
E40-N2	-- - 37'			16 - 42			18 2 45'		12 6 45	3 6 46'	
E40	-- - 42			19 - 41			19 4 44'		12 6 44	3 4 45'	-- 4 42
E40-S2	-- - 45'			21 - 39			20 2 41'		14 5 41	6 9 42'	
E45	15 - 43'						20 1 45'		9 8 46	6 4 46'	-- 2 42
E50	18 - 38'						18 2 41'		13 4 41	5 3 43'	-- 2 40
E55-N2		-- - 44		15 - 44'			17 4 48'		11 5 48	3 5 48'	
E55		32 - 34					30 12 36'		24 12 35	16 17 35'	-- 2 55
E55-S2		16 - 54		24 - 57			25 2 57'		16 8 58	10 7 58'	
E60		18 - 53		25 - 46			24 6 47'		21 7 47	15 7 47'	
E65		8 - 44					20 2 48'		12 7 48	10 7 48'	
E70			14 - 72				19 3 --'	29 -- 59'	10 5 63		
E75			40 - 74				24 2 --'	28 -- 92'	20 3 61		
E77			25 - 38				14 12 37'		8 16 37		
N.C.			24 - 46'						8 7 47	8 8 48	
S.C.			13 - 63'						11 8 63	5 10 63	