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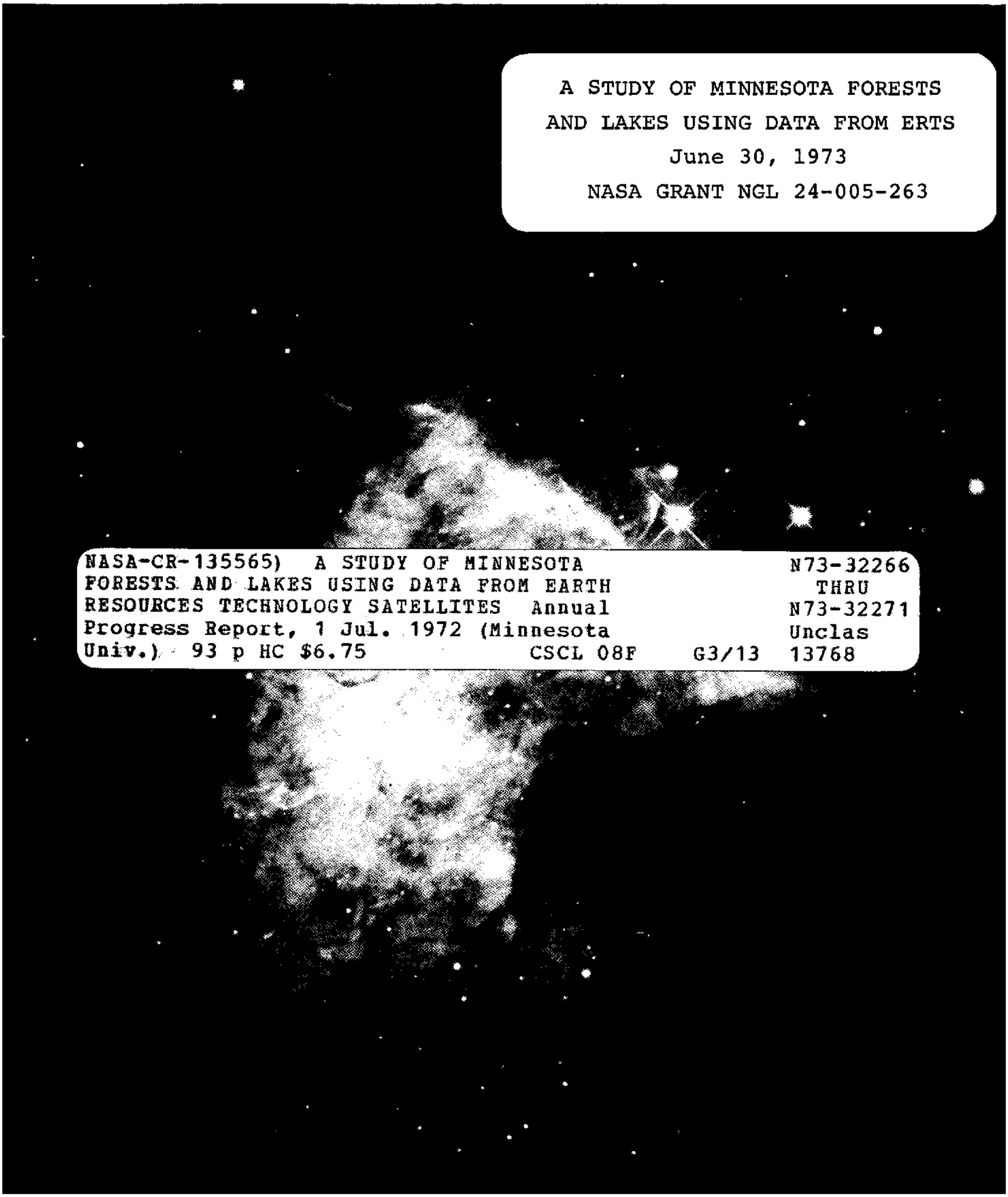

A STUDY OF MINNESOTA FORESTS
AND LAKES USING DATA FROM ERTS
June 30, 1973
NASA GRANT NGL 24-005-263

ON THE COVER — The area of the heavens around the Orion Constellation, shown in the cover photograph made through the 120-inch telescope of the Lick observatory, is also the region of observations with an infrared telescope developed by University of Minnesota astro-physicists. The infrared sensory equipment reveals stellar bodies that could not be studied by conventional telescopes, and it is expected to provide data on the birth of stars.

SPACE SCIENCE CENTER

University of Minnesota

Minneapolis, Minnesota 55455

"A STUDY OF MINNESOTA FORESTS AND LAKES USING DATA FROM EARTH RESOURCES TECHNOLOGY SATELLITES."

TWELVE-MONTH PROGRESS REPORT

June 30, 1973

Supported by:

NASA GRANT NGL 24-005-263

Submitted to:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546

SPACE SCIENCE CENTER

PROGRESS REPORT

7/72 through 6/73

FOREWORD

This report covers the first twelve-month period, 1 July 1972 to 30 June 1973 of support under NASA Grant NGL 24-005-263. The purpose of this project is to foster and develop new applications of remote sensing under an interdisciplinary effort with the general title "A Study of Minnesota Forests and Lakes Using Data from Earth Resources Technology Satellites." The following five reports reflect the progress recently reported prior to this date and the work proposed by new investigators for the coming year.

Laurence J. Cahill, Jr.
Director, Space Science Center

TABLE OF CONTENTS

"A PROPOSAL FOR PRECAMBRIAN MINERAL RESOURCE EVALUATION IN MINNESOTA UTILIZING ERTS IMAGERY"

by

Dr. Donald Davidson, Jr.
Department of Geology
Division of Science and Mathmatics, University of Minnesota at Duluth
Duluth, Minnesota 55812

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N73-32267

"Remote Sensing in Lake Superior Studies."

Investigator: Dr. Michael Sydor
Department of Physics

The surface water transport in the extreme western arm of Lake Superior is characterized by a localized surface current loop,[1] and a general eastward transport of the surface water out of the arm along the south shore of the lake.[2] This is accompanied by a cold water upwelling along the North Shore of Lake Superior. Our activities in the summer of 1971 and 1972 supported under a NASA Remote Sensing Program were concerned with the investigation of the transport processes at the tip of the lake in greater detail. Our project is a part of the continuing Lake Superior Studies at the University of Minnesota. The results of our water current measurements, and the measurements on thermocline activity at three stations located along the northern shore of Lake Superior from Knife River to Duluth, show that the bottom currents have a prevailing northerly direction at station 1, Fig. 1, displaying a broad area of upwelling south of Knife River. A well defined current pattern, somewhat smaller than anticipated from previous studies by T. Olson and T. Odlaug[1] developes in the area between the upwelling and Duluth. The upwelling serves as a turn around path for the cell currents. The current pattern was investigated using water current and temperature profile measurements in conjunction with ERTS Satellite data. It was found that an eddy loop developes near Duluth because of warm water pileup at the tip of the lake. The circulation pattern associated with the warm water cell displays a characteristic feature influenced by the winds and the depth of the cell. The circulation persists until the warm water is driven out of the area.

1. Lake Superior Studies, T. Olson et al, Minnesota Public School of Health.
2. Charles E. Adams, Jr., Proc. 13 Conf. Great Lakes Res., (862-879) 1970.

The knowledge of the summertime current patterns is important in that these currents are responsible for the sweeping out of the polluted waters near Duluth. The water currents tend to disappear in the winter, particularly with the development of ice cover on the lake, causing accumulation of polluted waters from the St. Louis River at the tip of the lake. This situation is potentially hazardous since three water intakes are located in the area. Little information, even of qualitative nature, was available on the winter water transport in the lake. The winter currents were very low and were difficult to measure on account of the lack of safe ice cover. Thus other methods for determining the winter transport had to be established. Since the water quality parameters for the St. Louis River are considerably different from those of Lake Superior, and the water quality at the Cloquet water intake located 2 miles off shore at the tip of the lake, could be monitored on a continuous basis, we decided to use the properties of the river water to identify suitable parameters for measurements of the rate of accumulation of the effluents under the ice. For this purpose, we had to examine the properties of the river water and its transport in the bay area first. Such data for the winter months was unfortunately nonexistent, thus we had to extend our measurements to the Duluth-Superior harbor area. The results of our studies give the yearly variation in water quality parameters for St. Louis River, indicating that the electric conductivity, transparency and dissolved oxygen could well serve as effluent tracers. These parameters were subsequently used to measure the effluent accumulation at the Cloquet water intake during the time of ice cover on the lake. Some results for measurement of ice cover are also discussed, including a prediction for ice breakup in the harbor. We were also involved in evaluation of an experimental bubbler system installed in December 1972 near the Superior entry to the lake. Only some of the data for the past year is presented here, sufficient we hope to serve as a progress report justifying our support from NASA for this program, and our subsequent request for manned aircraft remote sensing data for our area. Consideration for the practical aspects of our investigation to the community is outlined as required by the contract.

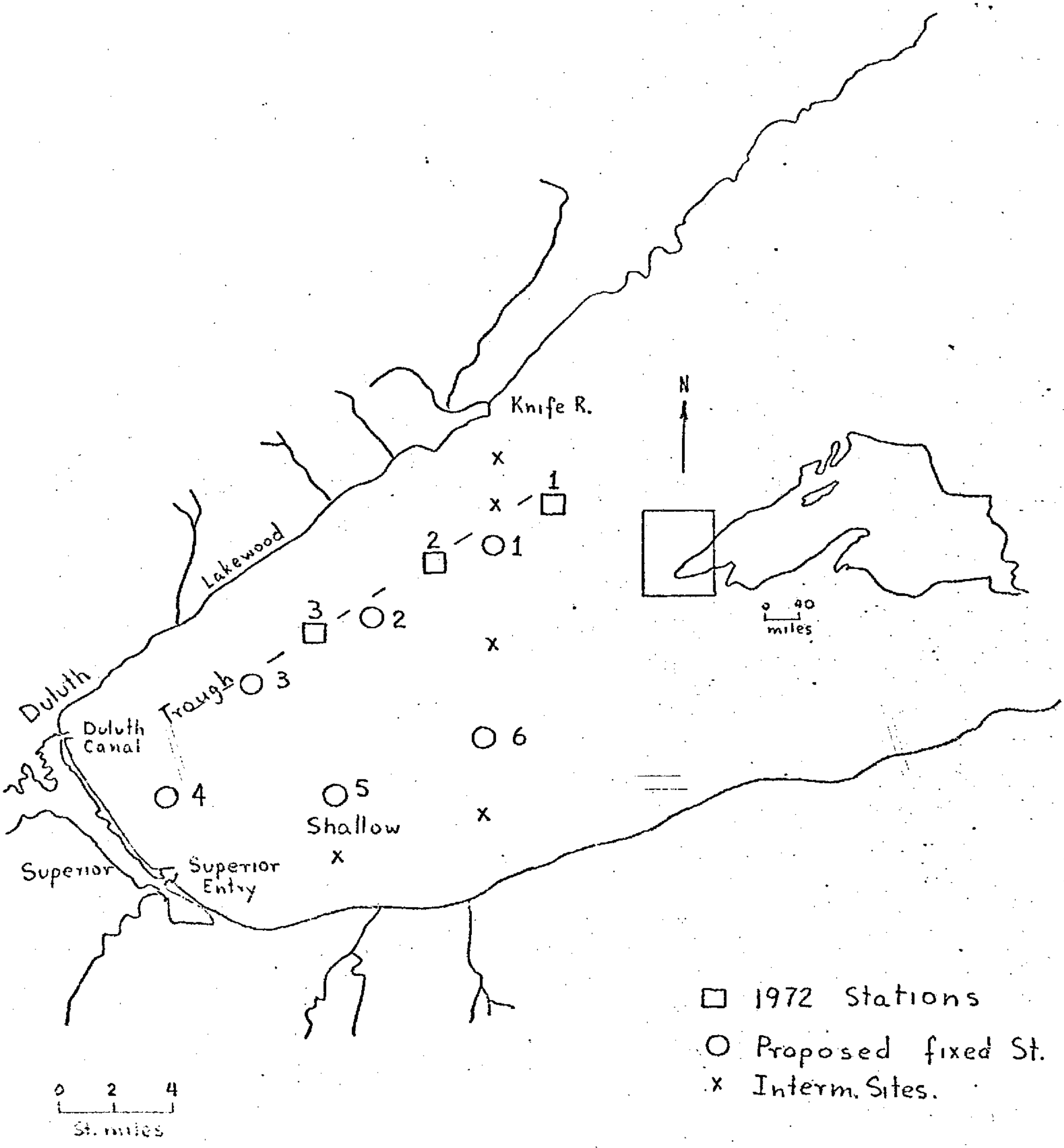

Knife R.
N
Lakewood
Duluth
Trough
Duluth Canal
Superior
Superior Entry
Shallow
1
2
3
1
2
3
4
5
6
0 40
miles
1972 Stations
Proposed fixed St.
Interm. Sites.
0 2 4
St. miles

Fig 1

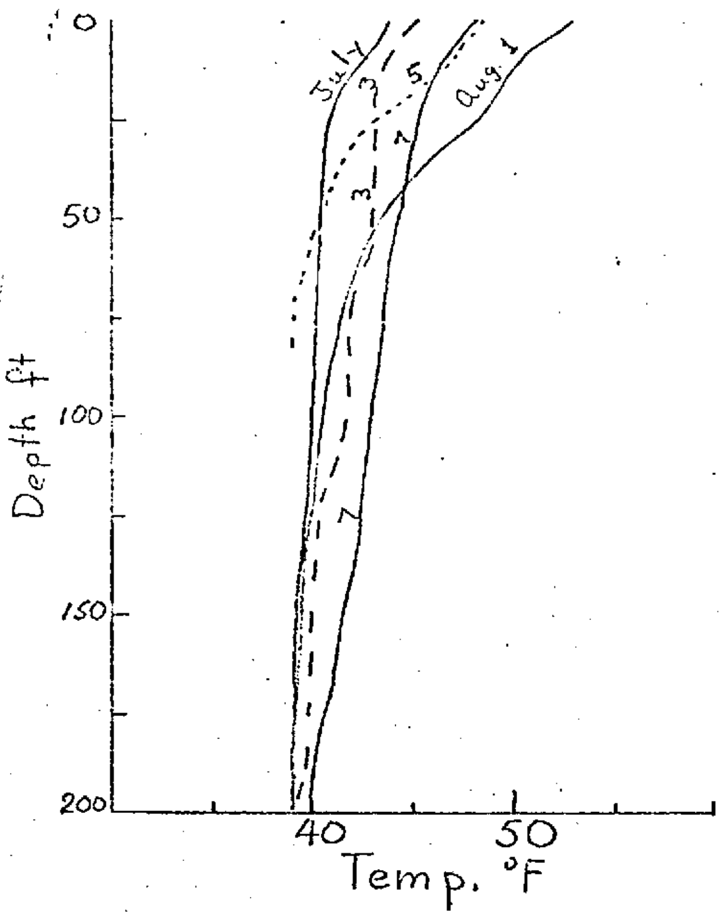
Results and Discussion

A series of temperature and water velocity profile measurements were made from July 25 to September 15, 1972, at the three stations located in the extreme western arm of Lake Superior to determine the nature of currents at the tip of the lake. Temperatures were measured using pressure operated bathythermograph usable down to 200' and thermistor probes for entire temperature profile. Water currents were measured using wand type current meters.

From the end of July until August 9, no pronounced steady stratification took place. A series of days with variable winds produced, under the influence of N.E. winds, warm water pileup at the tip of the lake, which was subsequently driven out by westerly winds. Considerable mixing took place in that period of time as shown by the temperature profiles taken at station #1 off Knife River for August 1-7, Fig. 2. Cold water near the shore was often closer to the surface indicating presence of upwelling. The currents below thermocline at station #1 often pointed due north at speeds ∿ 2 cm/sec. These seemed to be characteristically present at Station #1 through August and September. The upwelling diminished for times of prolonged N.E. winds. This broad area of upwelling off Knife River tends to contain the warm water cell developed at the tip of the lake. Such was the case for August 9 data when a distinct stable stratification developed after the prolonged N.E. winds for August 6-8. The temperature profile for the day Fig. 2, shows the stratification with slight upwelling detected by comparing the temperature profile for points 1 and 3 miles off shore. The accompanying thermocline activity Fig. 3 was characterized by internal waves which had a rather regular ∿ 50 min. period, Fig. 3. The crest of the wave was calculated to be ∿ 10 ft., using the temperature profile taken at the time of the crest of internal wave and at the slack time. The water velocity at depth below the thermocline was ~ 1 cm/sec. due N.W. The surface water velocity was towards west at ~ 4 cm/sec.

The ERTS image for August 12 shows the turbidity pattern for the period. The turbidity resulted from the lake bottom activity developed during the N.E. winds. The turbidity pattern indicates an eddy current at the very tip of the lake as shown in Fig. 4 and 5. This type of current pattern prevailed in the area from then on into August and September, and was verified with the current measurements at the stations. The stratification seen on August 9, persisted for August 11 though on that day the thermocline activity (Fig. 3) was not characterized by regular internal surges, but showed a steady shift in thermocline, as the cell deepened. Subsequent easterly winds caused an even further stratification as shown by temperature records from August 11 to August 28. Considerable precipitation occurred in mid-August, causing extensive turbidity plumes from the rivers. The edge of the turbidity plume off Knife River, on August 17, was ~ .7 of a mile away from the shore. The transparency profile of plume, measured using a homemade transparency meter (20 cm. light path, broad sensitivity peaking at 6000 Å.) shows that the plume edge consists of a tongue of ~ 10 ft. layer of turbid water riding up on top of the upwelling water, Fig. 5. (Secchi disc transparency on the clear side of plume was 25 ft., while inside the plume it was 2.5 ft. The plume deepened as the shore was approached, presumably from settling of coarser material. A presence of a separate shallow warm water layer is seen in temperature profile at Station #1 for August 17 and for August 23, where it is still discernible but somewhat obscured by a much deeper layer of warm water which was driven in by prolonged easterly winds following a torrential rain for August 20. The edge of this warm water bounded the region of the upwelling and displayed long Langmuir cells running parallel to the shore for one to two miles. The winds were consistently easterly until August 27. The profile for August 28 (Fig. 6), shows the stratification at the end of the month. ERTS data for August 30 again shows a well defined eddy loop quite similar to the August 12 pattern. The winds were westerly for the day, and the upwelling along the North Shore was pronounced as shown by the temperature profiles. Water velocity profiles are shown for August 30 and September 1. ERTS records of the turbidity pattern confirmed the direction of the measured surface flow. A comparison of temperature for a given station on these two days shows that the cell of warm water was still confined to the tip of the lake by the upwelling. The eddy current persisted further into the season in spite of westerly winds, but the cell became shallower as the warm water was transported out of the area as indicated by temperatures for September 7-12. The eddy current was again evident in the October 6 ERTS image, due to the prolonged easterly winds late in September and early October. The November 29 ERTS image shows that the loop current disappears altogether in agreement with the wind data which showed 4 days of strong westerly winds prior to the day the image was taken. No temperature profile records are available past September 14.

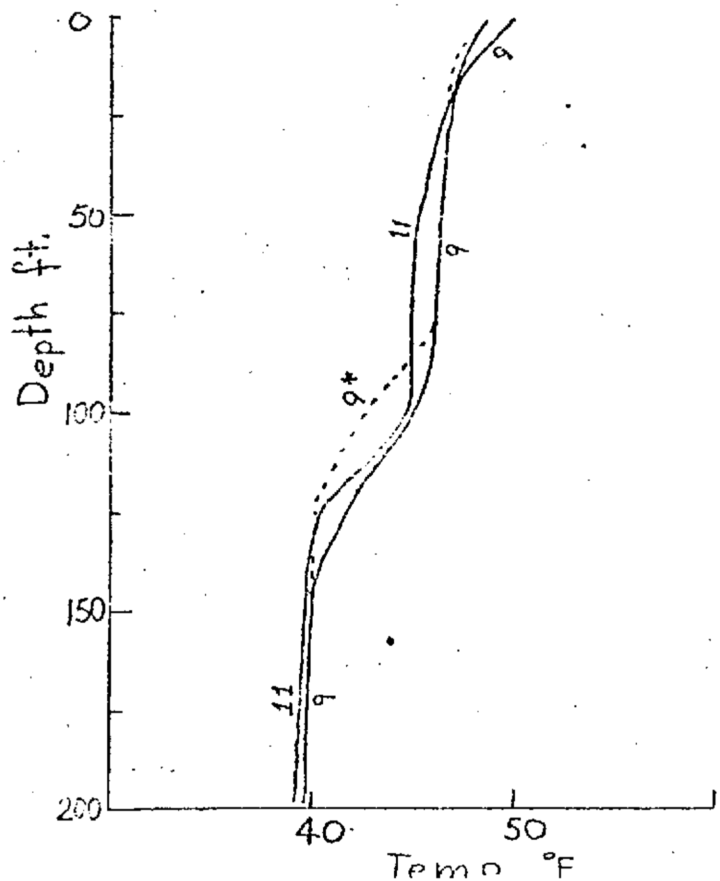
The data to date, tentatively established the general nature of the summer-fall currents at the tip of the lake. More stations are needed to measure the water velocity at sufficient number of points necessary for an analytical treatment of the transport. The proposed stations for future studies are indicated in Fig. 1.



Temperatures for Aug 1-7
Station #1
(Aug 5 taken near shore)

Winds

Date	Dir	Sp.	Av.	Res
Aug 1	NE	20 m.p.h.	9.9	8.9
2	NW	27	8.8	2.2
3	N	12	5	3.6
4	SW	19	6	8.0
5	SW	19	10.8	9.5
6	NE	27	9.5	8.7
7	NE	28	8.9	3.9
8	NE	29	8.8	6.5



Temperatures for Aug 9, 11

Winds

Date	Dir	Sp.	Av.	Res.
Aug 9	NW	11 mph	4.9	4.5
10	S	18	7.9	7.5
11	N	13	5.0	2.7

---9* taken 1 mile off shore
Others taken at station #1

Fig 2

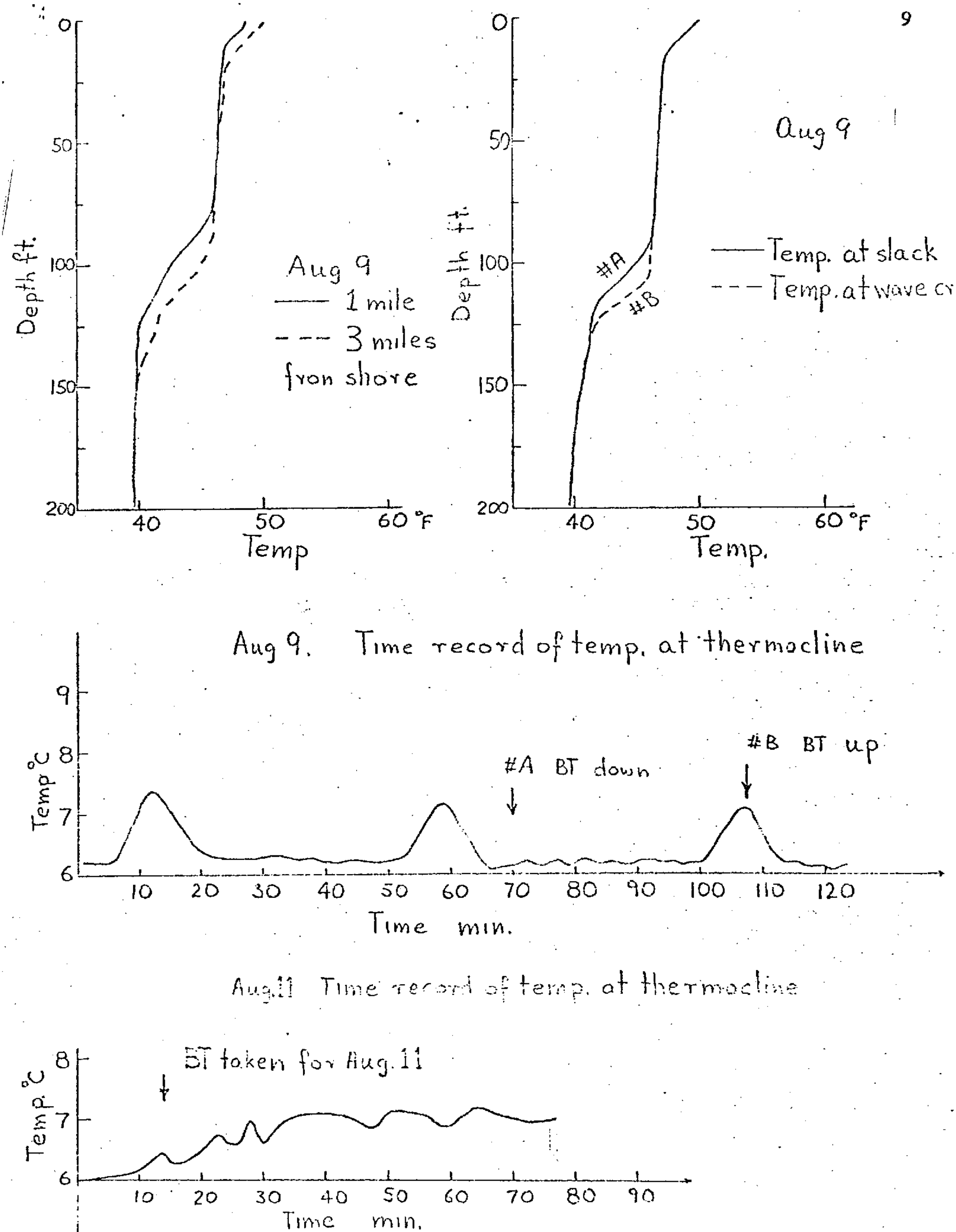
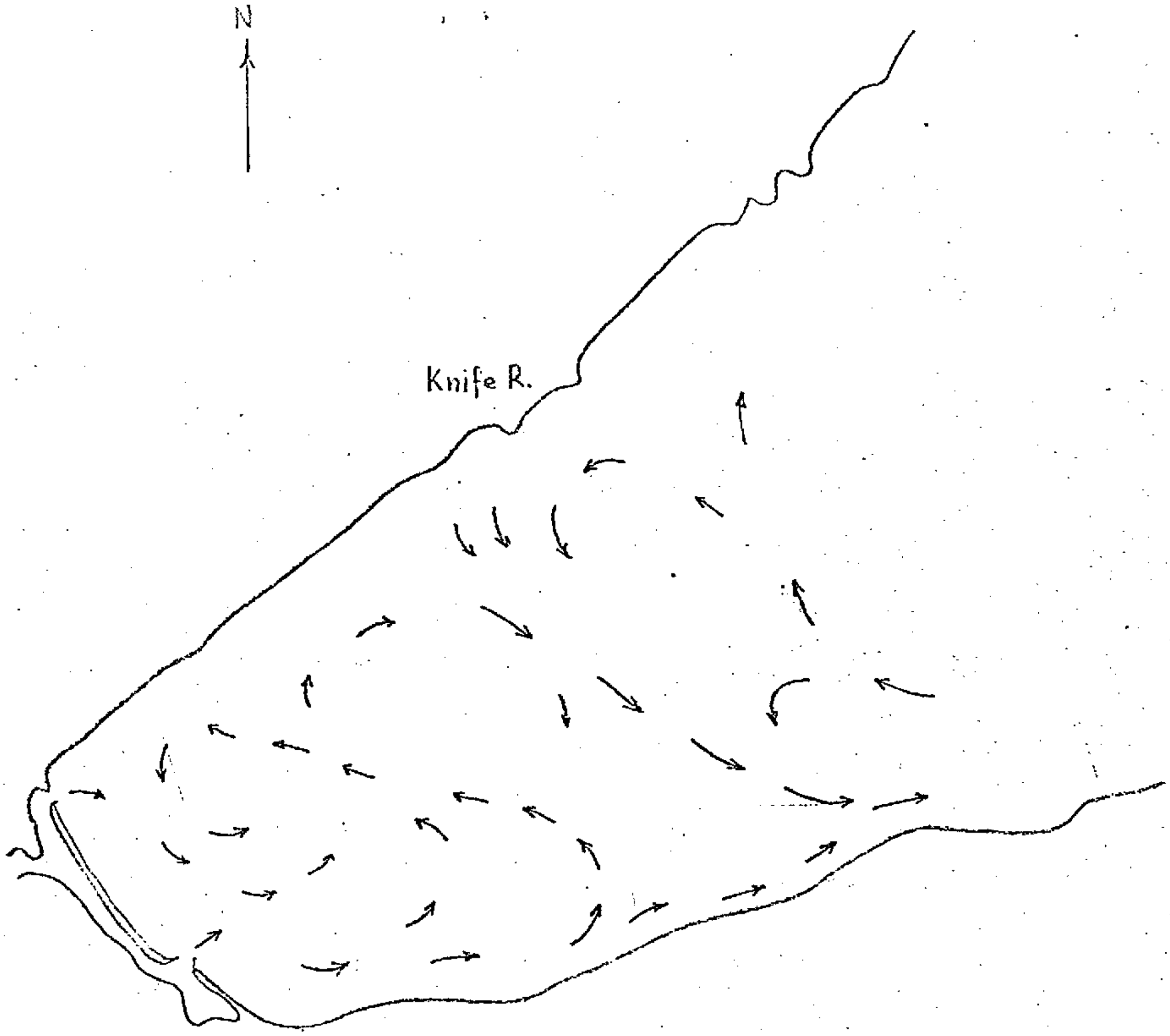
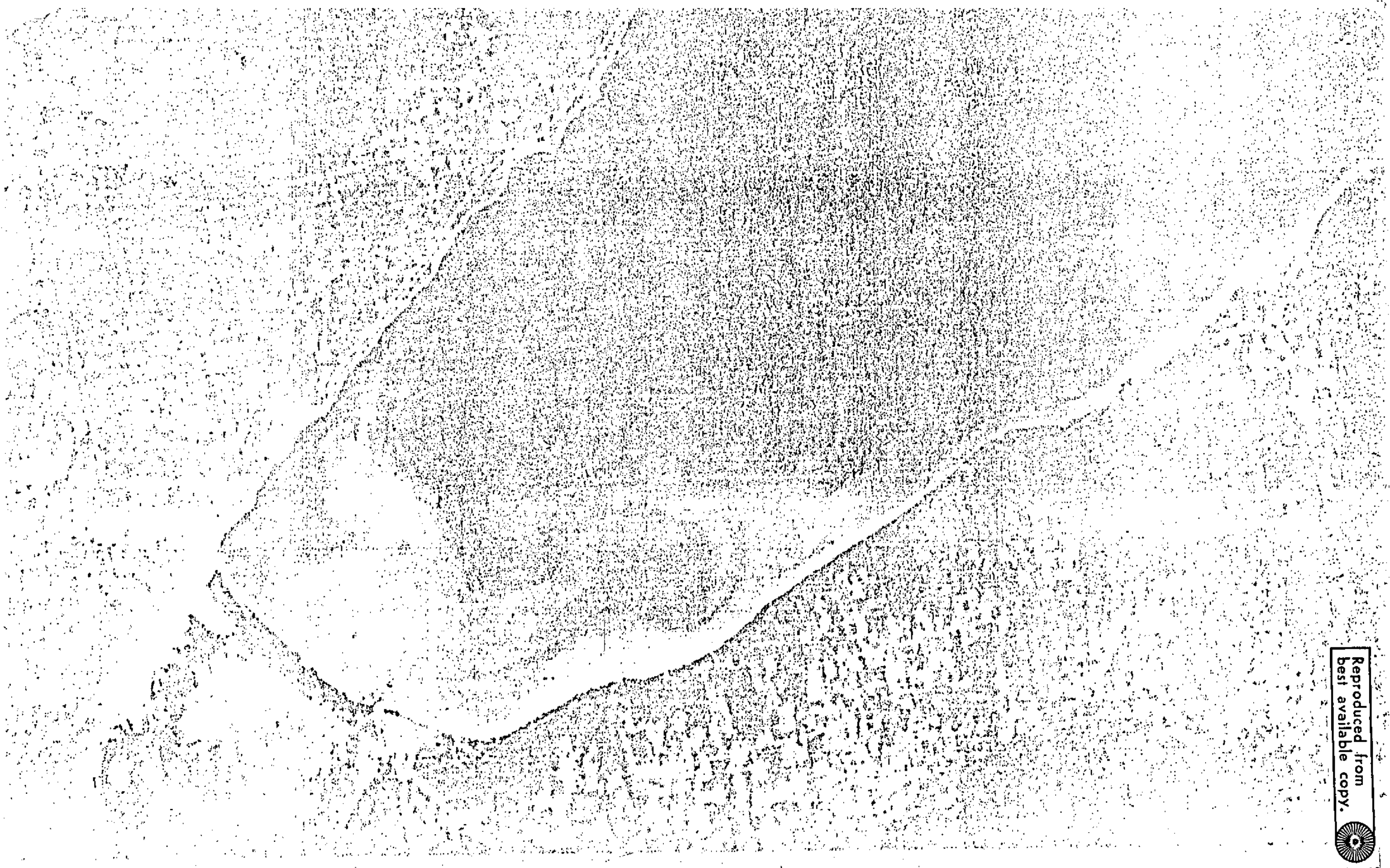

Depth ft.
0
50
100
150
200
40
50
60 °F
Temp
Aug 9
1 mile
3 miles
from shore
Depth ft.
0
50
100
150
200
40
50
60 °F
Temp.
Aug 9
#A
#B
Temp. at slack
Temp. at wave cr
Aug 9. Time record of temp. at thermocline
Temp °C
9
8
7
6
#A BT down
#B BT up
10
20
30
40
50
60
70
80
90
100
110
120
Time min.
Aug. 11 Time record of temp. at thermocline
Temp °C
8
7
6
BT taken for Aug. 11
10
20
30
40
50
60
70
80
90
Time min.

Fig 3



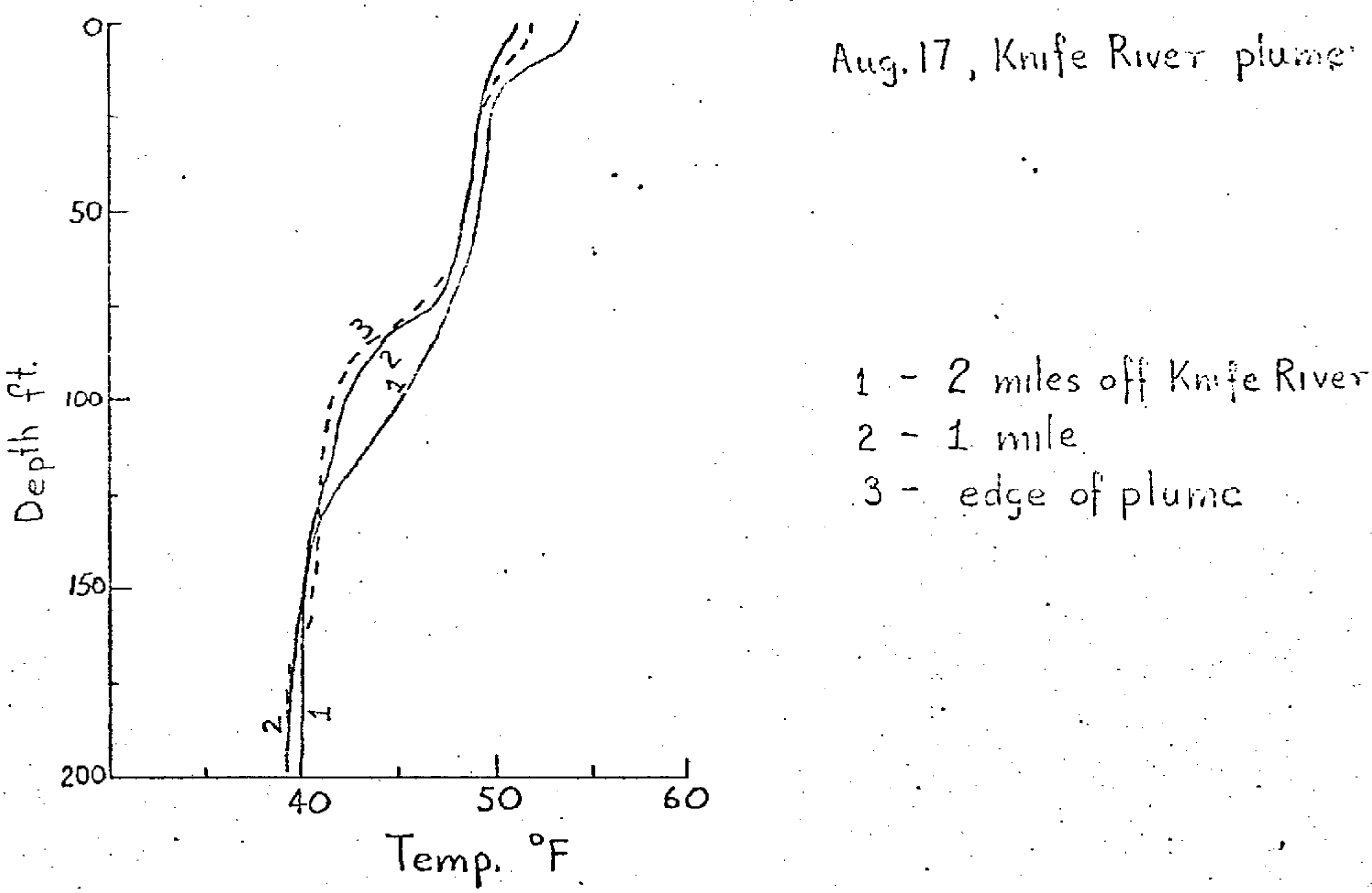
Surface current Aug 12 1972
from ERTS image

Fig 4



1W092-00 1W091-30

AUG72 C N47-19/W090-50 N N47-19/W090-47 MSS


Aug. 17, Knife River plume
Depth ft.
Temp. °F
0
50
100
150
200
40
50
60
1 - 2 miles off Knife River
2 - 1 mile
3 - edge of plume

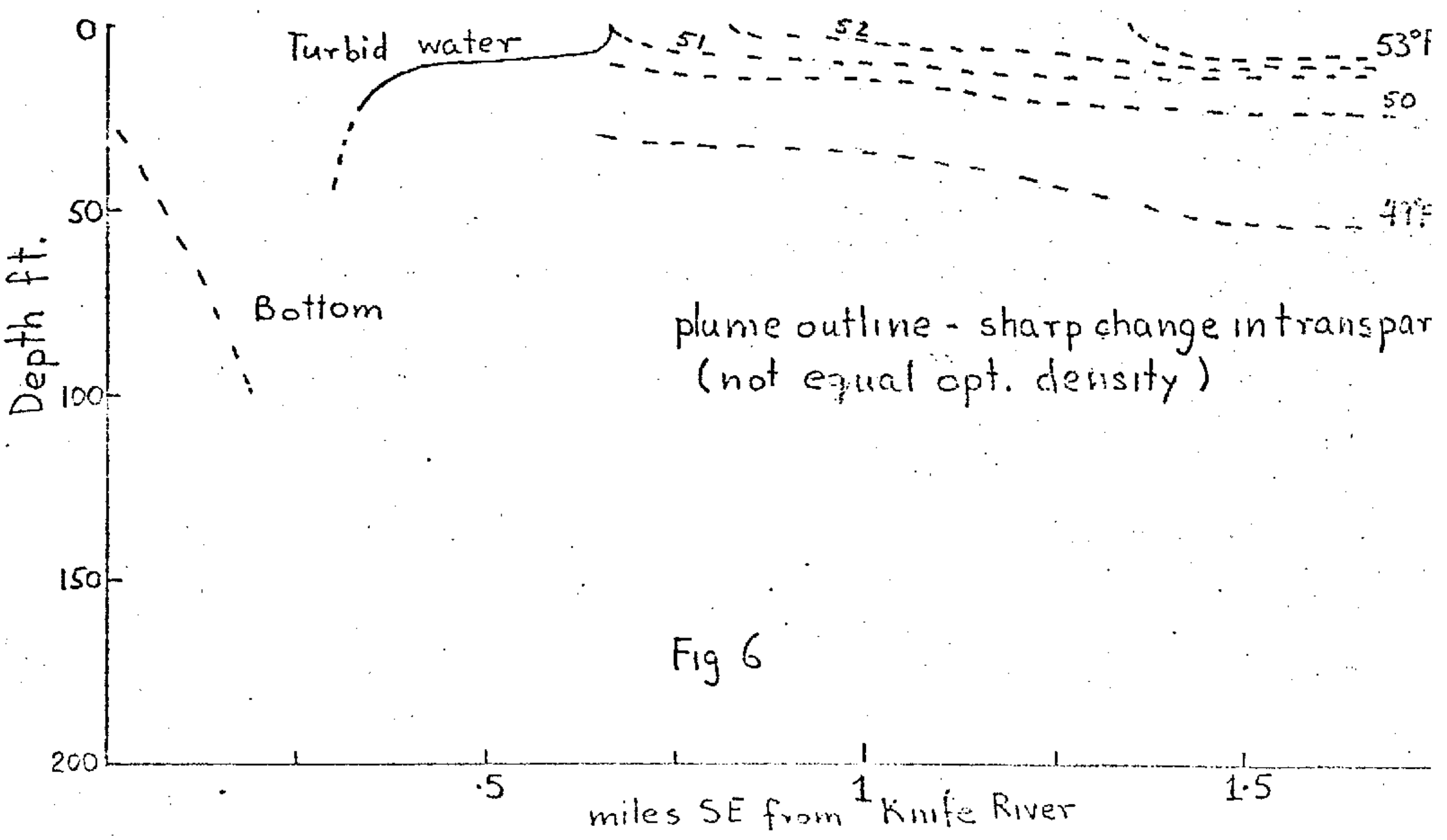
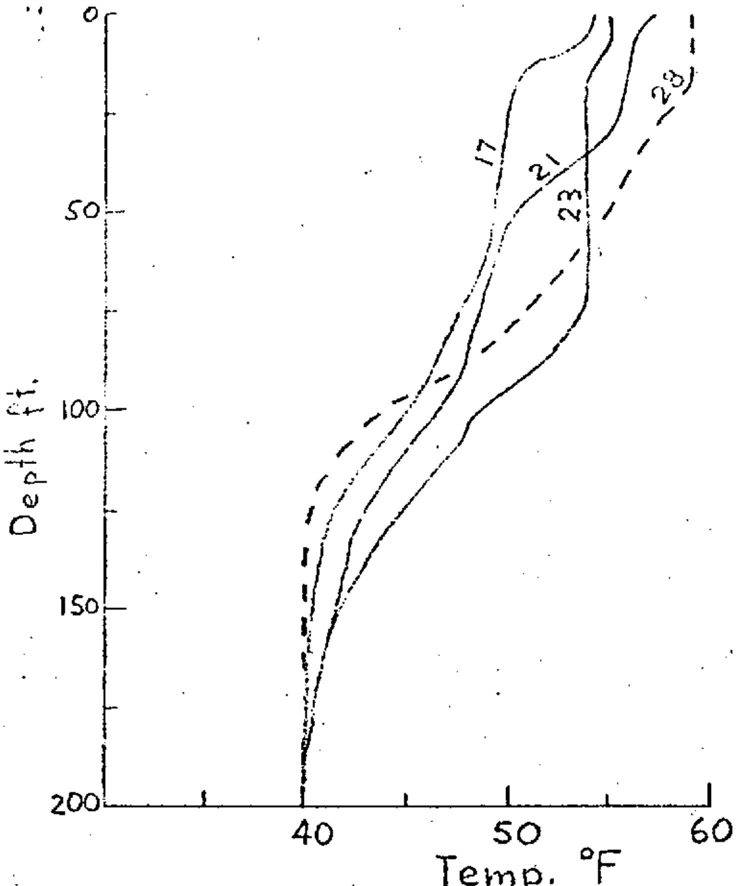

Turbid water
51
52
53°F
50
47°F
Bottom
Depth ft.
plume outline - sharp change in transpar
(not equal opt. density)
·5
1
1·5
miles SE from Knife River

Fig 6

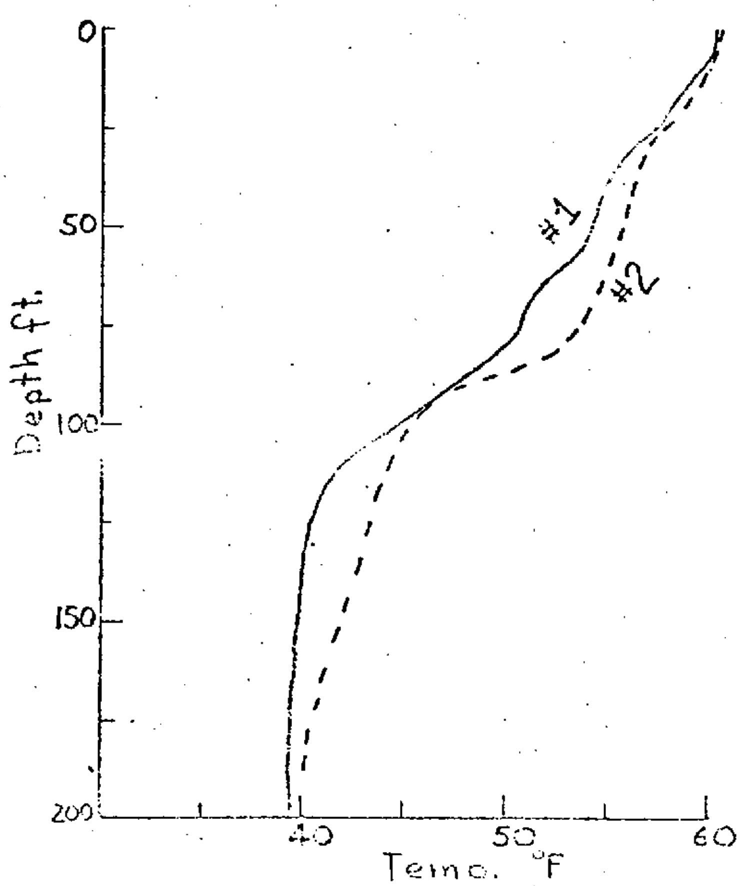


Temperatures Aug 17-28

Winds

Date	Dir.	Sp mph	Av.	Res. mph
Aug 12	SW	13	6.2	4.8
13	E	22	5.9	4.2
14	E	32	15.1	15.0
15	SE	25	11.8	10.6
16	NW	41	8.9	7.1
17	NW	13	5.5	3.8
18	N	14	6.6	4.3
19	E	17	8.2	8.0
20	NE	28	9.4	8.0
21	NE	23	9.2	3.5
22	E	22	8.8	6.8
23	NE	23	7.2	6.2
24	N	14	5.6	5.1
25	E	23	8.1	7.0
26	NE	16	6.3	3.4
27	W	11	6.2	5.7
28	NW	25	9.2	8.8

Aug 30, 1972 Station #1, #2

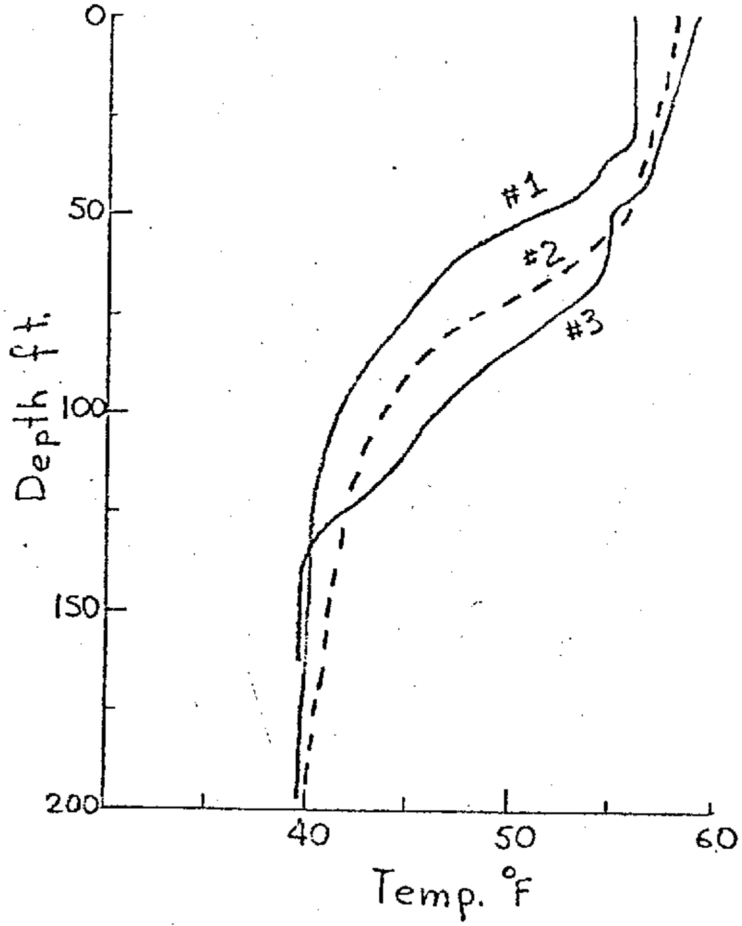


Water current (horiz.)

#1 Speed 4 cm/sec	due W	#2 Speed 4 cm/sec	due S
5	S	4	W
5	S	3	W
4	S	2	W
3	NW		
2	NW		
2	NW		
2	NW		

Fig 7

Temperatures at Stations #1, #2, #3, on Sept. 1, 1972



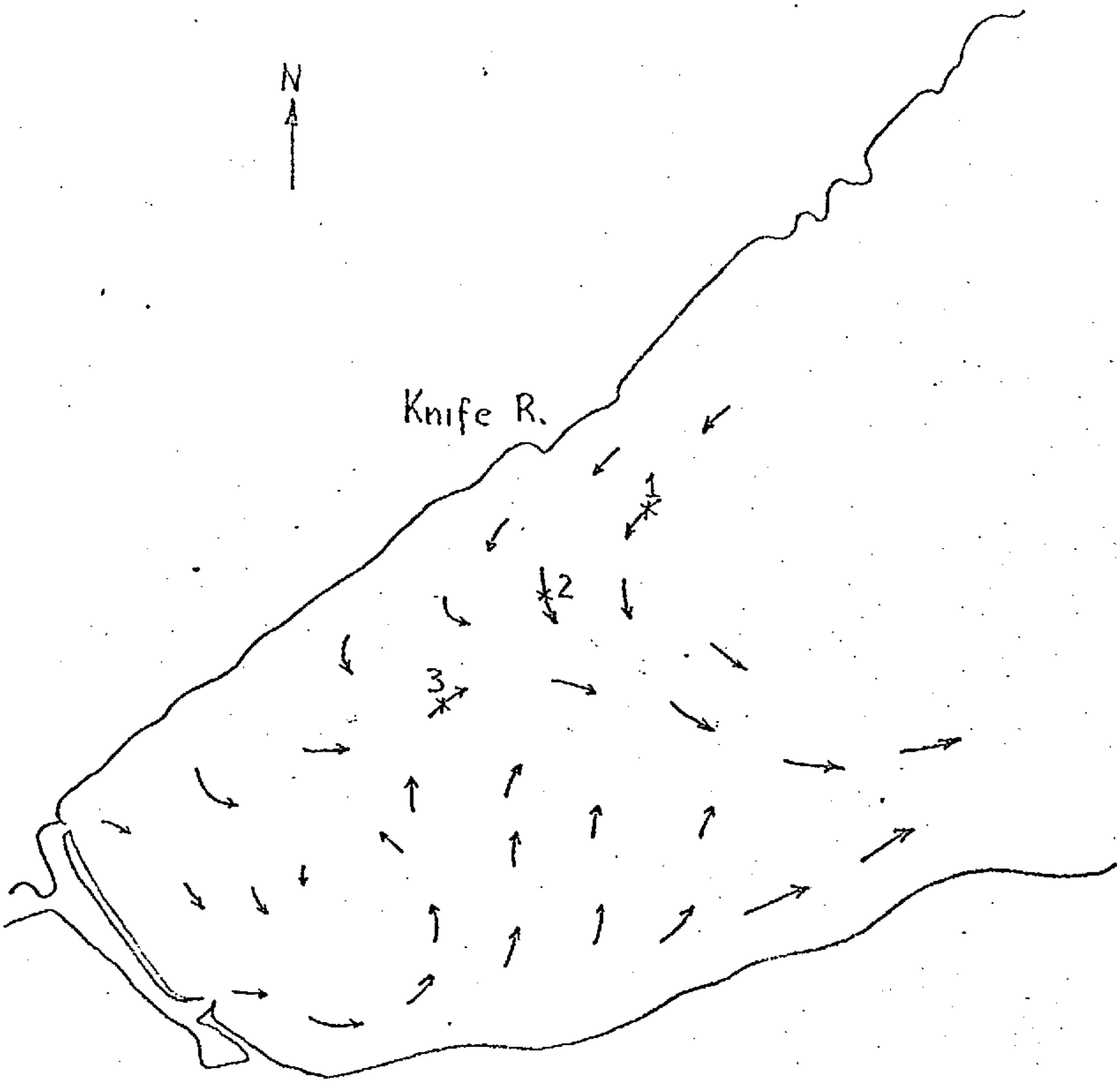
Water current

	Speed	due		Speed	due
#1	8 cm/sec	W	#2	7 cm/sec	W
	8	W		5	S
	6	W		5	SE
	7	W		5	SE
	6	W		4	SE
	3	W		2	E
	2	W			E

Winds

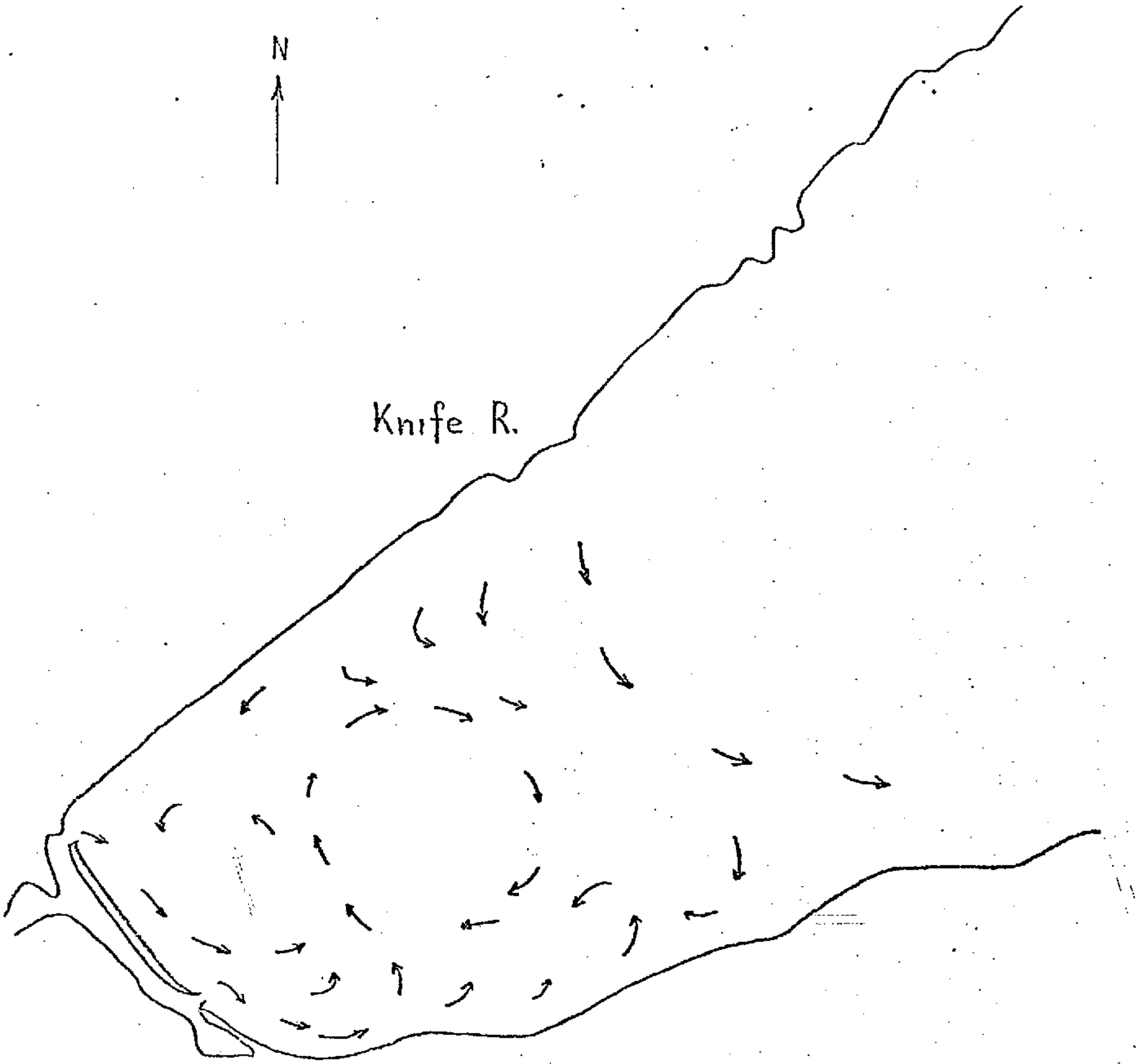
Date	Speed	Dir.	Av.	Res
Aug 30	26 mph	SW	11·2	11·0
31	27	W	12·7	10·0

Fig. 8



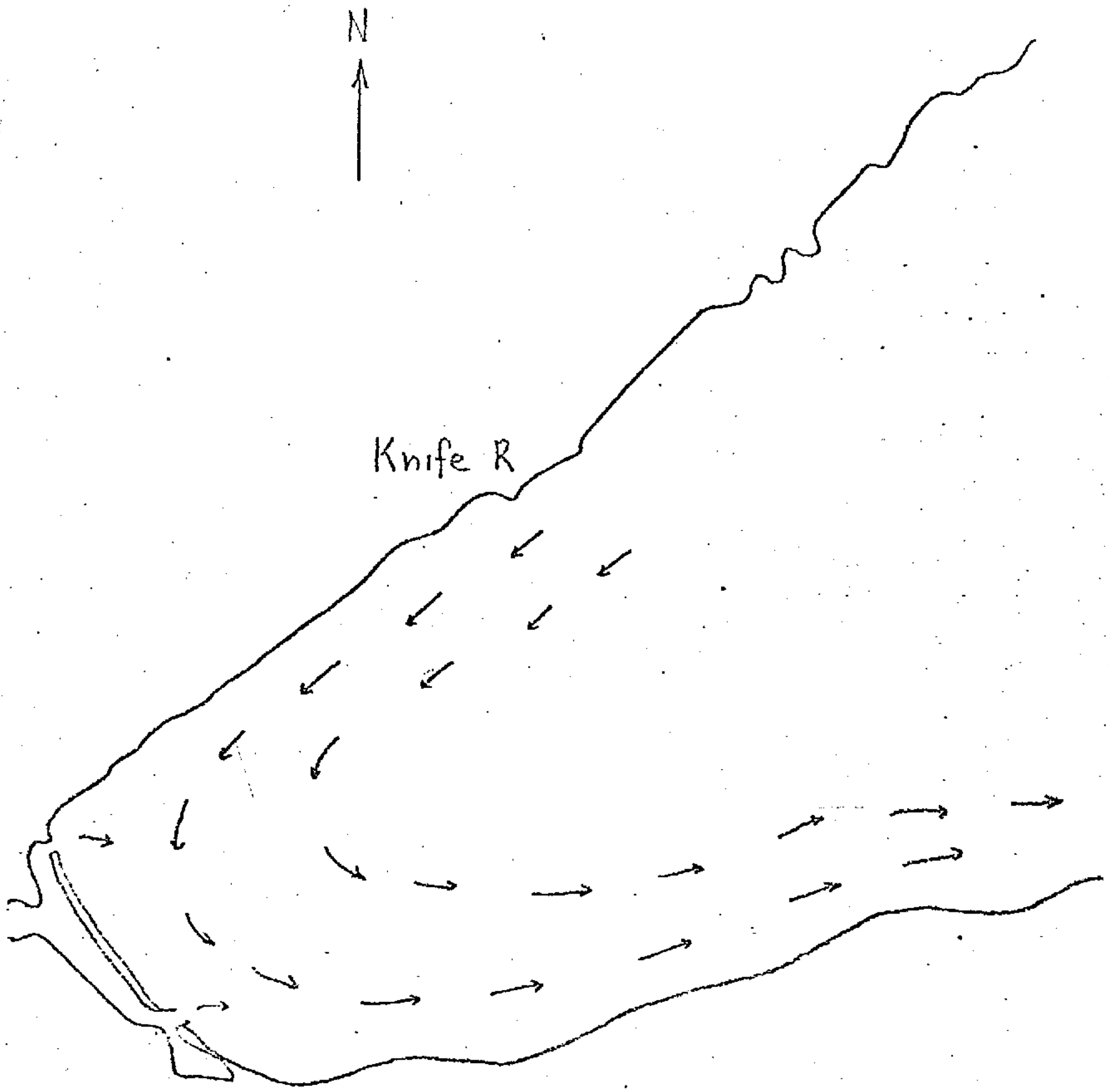
Aug. 30 Surface currents

Fig. 9



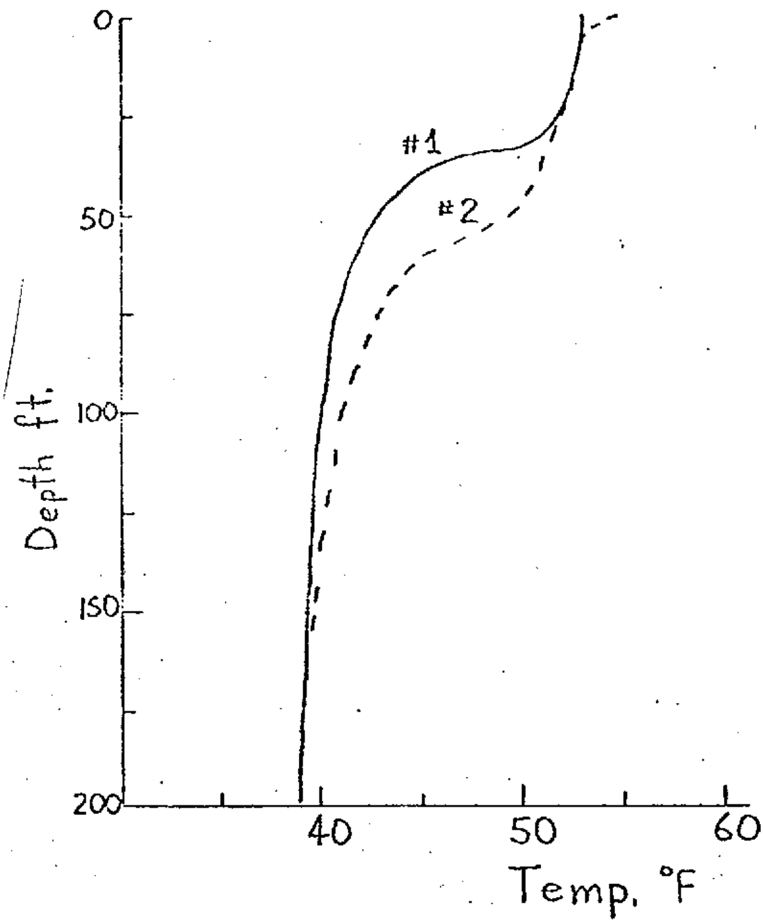
Surface currents from ERTS image Oct. 6, 1972

Fig. 10



Surface currents from ERTS image Nov. 29, 1972

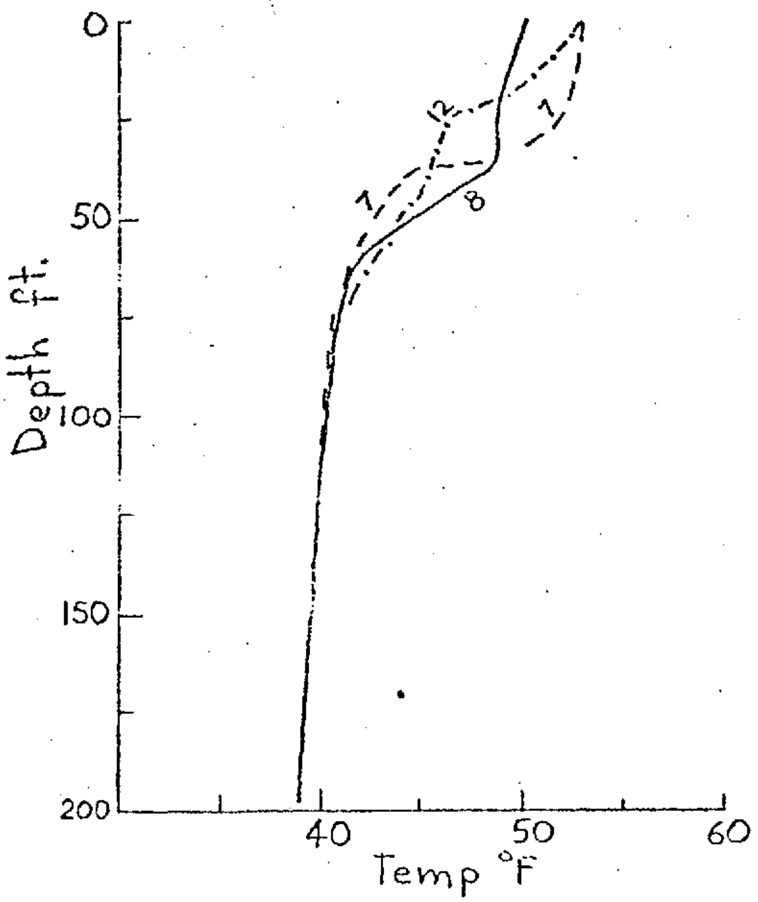
Fig. 11



Temperatures at station #1, #2, Sept. 7 19

Winds

Date	Speed	Dir.	Av.	Res.
Sep. 1	20 mph	NW	9.4	8.1
2	12	SE	4.3	3.0
3	16	S	5.2	4.7
4	19	NW	8.5	7.1
5	18	W	7.2	5.4
6	32	S	13.4	9.7
7	18	NW	7.8	7.3



Temperatures station #1 Sep. 7,8,12

Winds

Date	Speed	Dir.	Av.	Res
Sep 7	18 mph	NW	7.8	7.3
8	11	NW	5.9	5.4
9	15	S	6.6	5.9
10	22	S	11.4	10.8
11	13	N	6.2	5.1
12	26	NW	6.0	5.7

Fig. 12

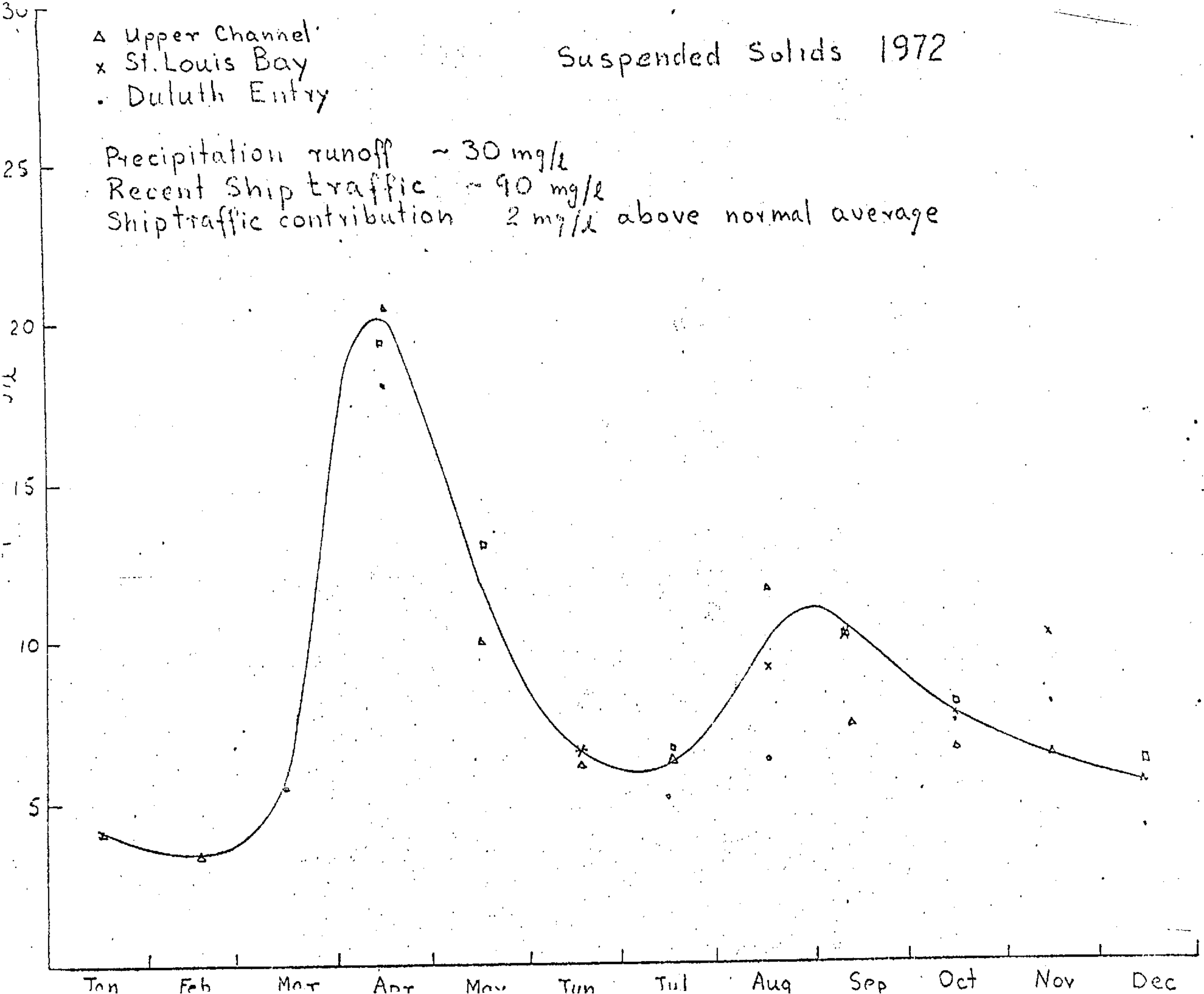
Wintertime Studies

To study the wintertime water transport in the area, through tracing of effluents, it was first necessary to establish which parameters were suitable as tracers. It was also necessary to examine the transport process within the Superior Bay itself, as the water quality parameters in the bay are influenced by lake water surging into the bay through the entries. Chemical analysis of samples would be the most reliable method for tracing the effluents. Unfortunately it quickly defeats any attempt at extensive measurements since the chemical analysis is tedious. We thus spent our effort on identifying the parameters which could be suitable for relatively quick measurements of concentration of the effluents in the lake. Figures 12-19 show the results for some of the water quality parameters measured on weekly basis for the year 1972. They indicate the expected correlation between suspended solids and turbidity, both showing the spring runoff effects. The temperature measurements indicate considerable inflow of lake water into the Duluth harbor area in May and June, Figure 16. The N.E. winds kept the ice cover at the tip of the lake until June 9, 1972. The turbidity generally dropped for the winter months when considerable settling occurred. Pronounced stratification with depth occurred as a result of settling of pollutants in areas where industrial dumping takes place. Drop in the dissolved oxygen at the bottom of the shipping channel was much greater than indicated in the seasonal variation shown in Fig. 15, which pertains to water values at 5 ft. depth. Table 1 in Figure 20 shows an example of chemical analysis for the surface and the bottom water in the channel. Figure 21 shows the map of the bay area. The suitable tracing parameters were established to be the dissolved oxygen, the electric conductivity, the turbidity and water color or transparency. A meter is being devised for quick quantitative measurement of the last parameter in situ. Figure 22 and 23 show the results for those parameters at the Cloquet intake. The times of poor water quality are evident from the graphs. To interpret these events, we consider how the water quality at the intake could vary, by examining the Table in Figure 24.

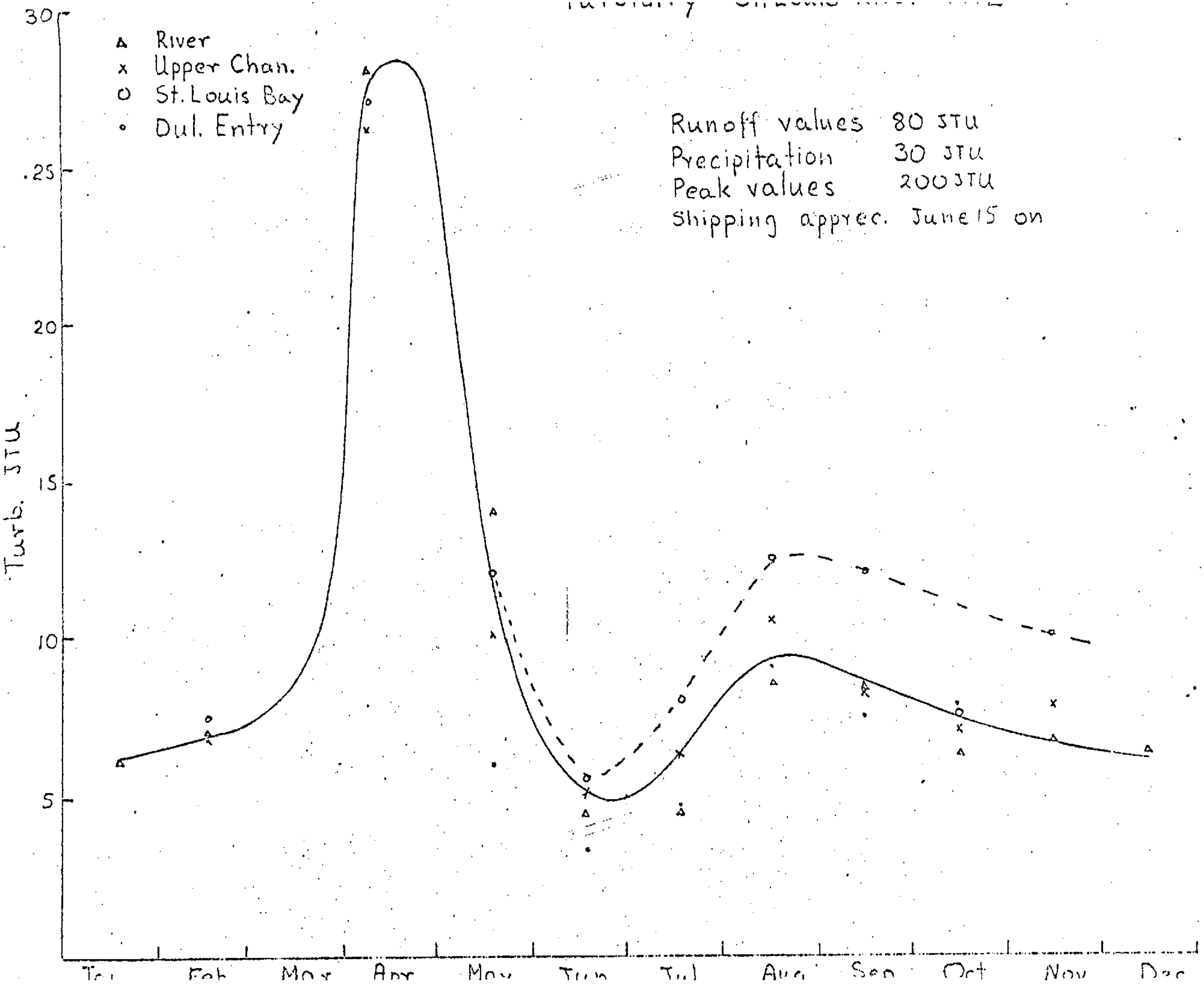
The natural storm activity should increase turbidity, conductivity and color, but not the dissolved oxygen since lake water is saturated with dissolved oxygen. Presence of the effluents in the lake water should on the other hand be characterized by an increase in conductivity and color and a decrease in dissolved oxygen leaving the turbidity relatively unchanged since effluents are relatively low in turbidity. Figure 22 and 23 show both types of events. It is seen that the latter type of event is displayed for the period of durable ice cover on the lake in late February. Odor in the lake water was detected at the same time. Pronounced odor characterizes the bay water. Lake water at other intakes was odor free. Temperature profile of the lake ruled out turnover. It is thus tentatively proposed, based on data shown in Figures 22 and 23, that cause of odor in late February 1973 at the Cloquet intake was due to St. Louis River effluents. Chemical tracing for next year should establish this better.

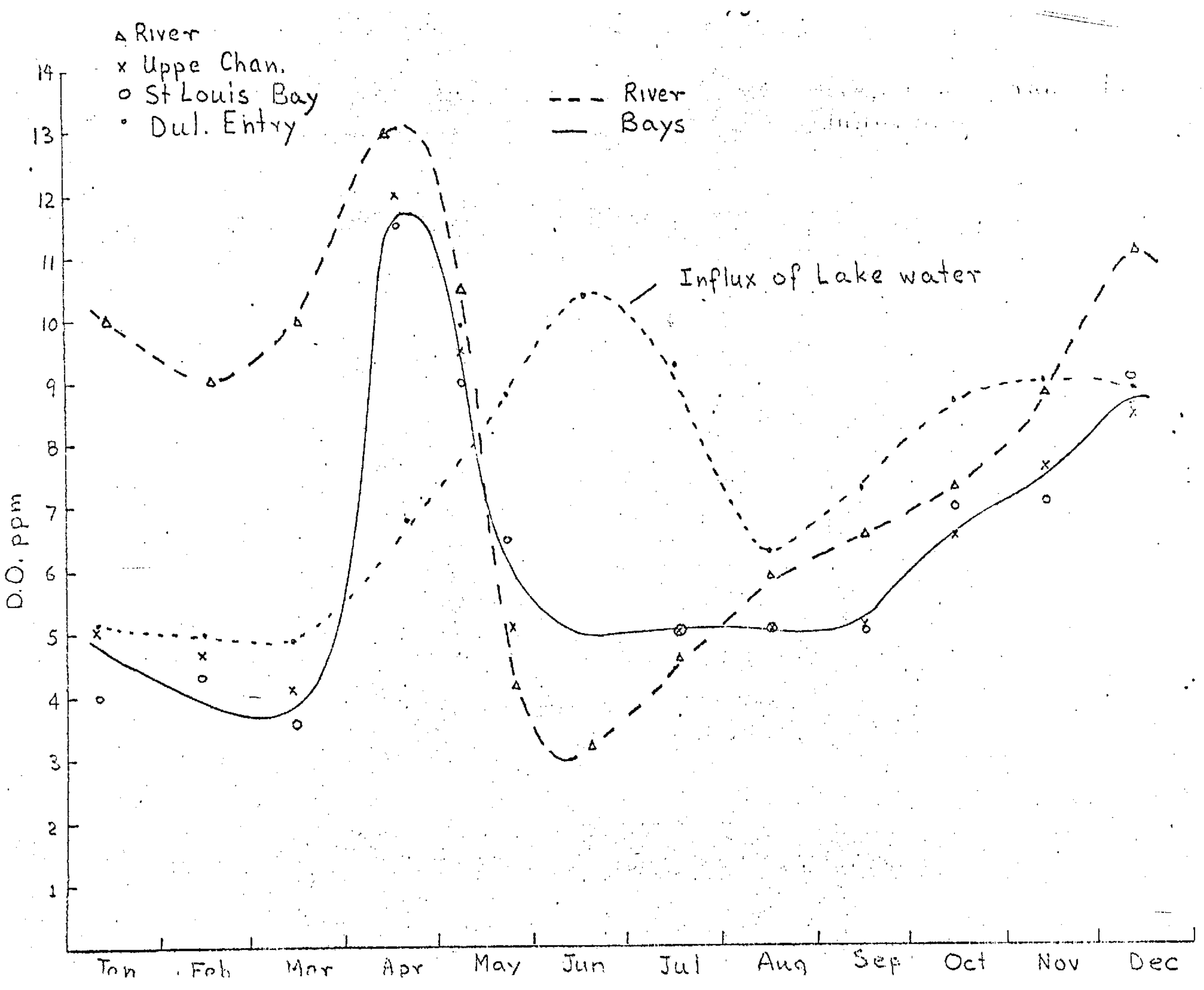
So far ERTS images for spring break-up are not available. It is hoped that subtle changes in images due to water color caused by the accumulated effluents can be discerned from the remote sensing data taken on days when the ice cover just begins to move out of the lake tip area. Should this be possible, an estimate of the extent of effluent accumulation could be made.

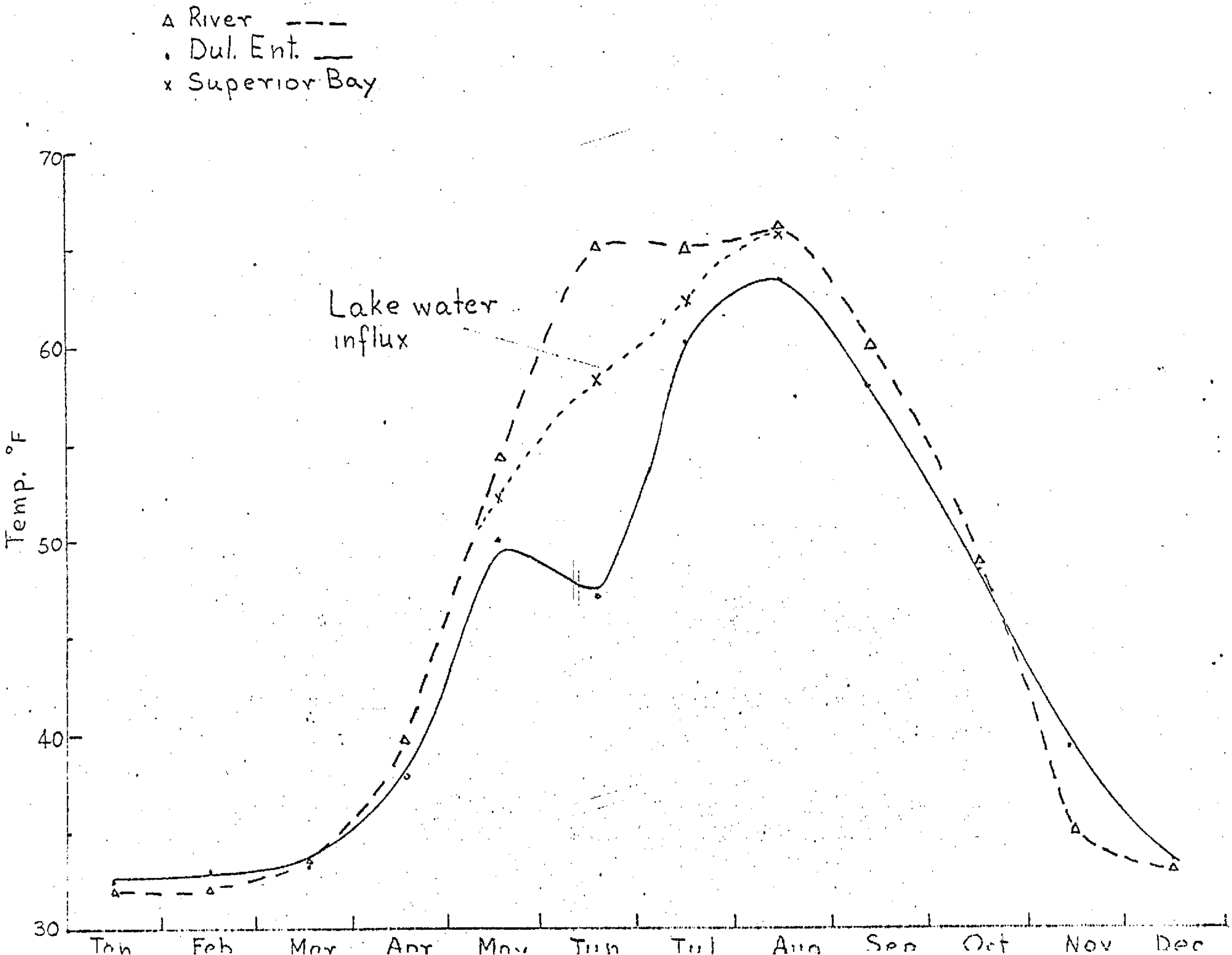
Such information would establish the location of crucial sampling stations. The remote sensing data supplemented by sampling measurements these points will allow for calculation of the transport coefficient for effluents in the lake. Extensive sampling could also do the job, however it would be prohibitive because of the large area that would need to be covered if the key sampling stations could not be predetermined. This year the safe ice cover lasted too short a time to collect sufficient data on sampling basis to analyze the wintertime concentration of effluents, at points other than the Cloquet intake.



Suspended Solids 1972
△ Upper Channel
x St. Louis Bay
· Duluth Entry
Precipitation runoff ~ 30 mg/l
Recent Ship traffic ~ 90 mg/l
Shiptraffic contribution 2 mg/l above normal average
30
25
20
15
10
5
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


River
Upper Chan.
St. Louis Bay
Dul. Entry
Runoff values 80 JTU
Precipitation 30 JTU
Peak values 200 JTU
Shipping apprec. June 15 on
Turb. JTU
30
25
20
15
10
5
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

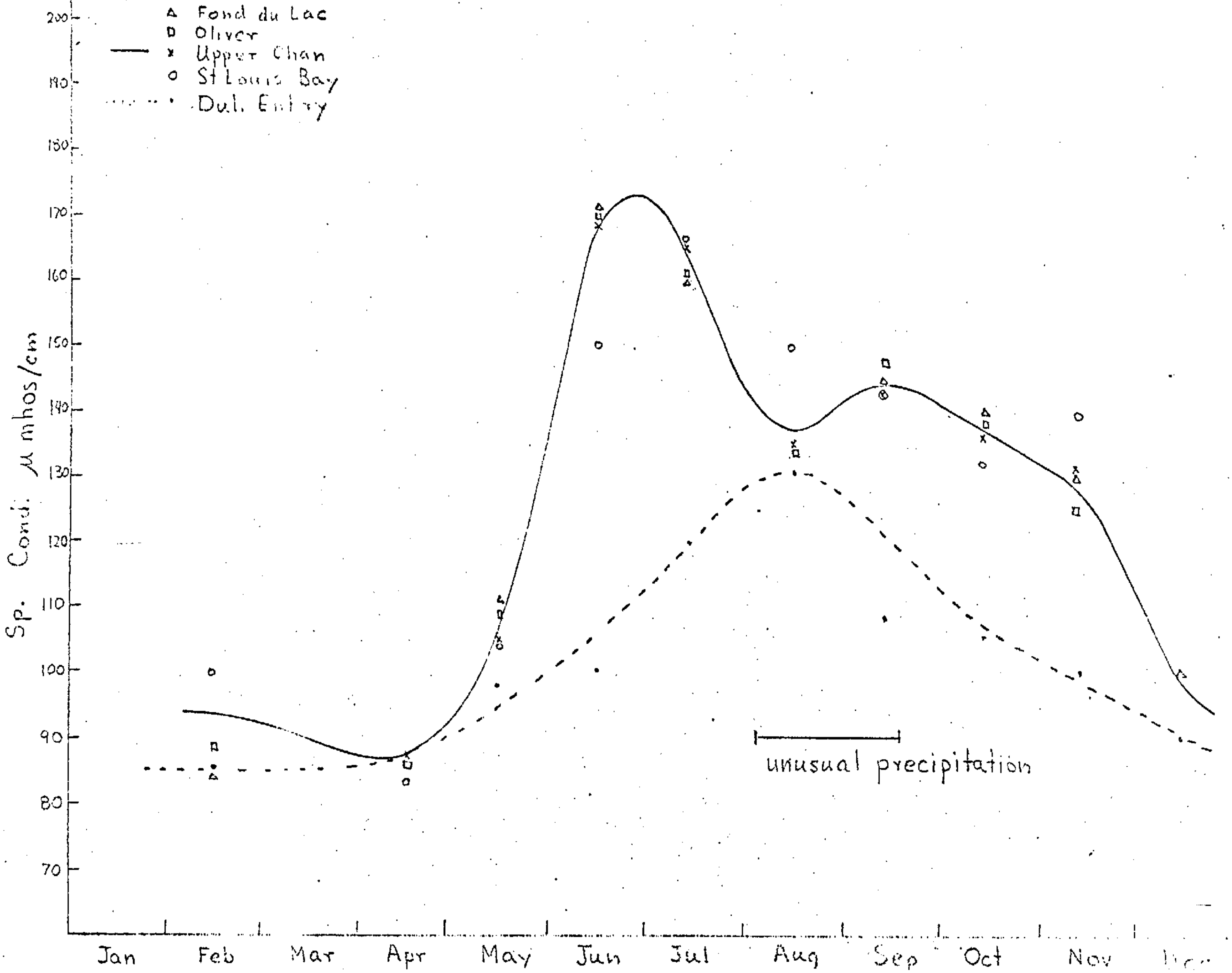

River
Uppe Chan.
St Louis Bay
Dul. Entry
River
Bays
Influx of Lake water
D.O. ppm
14
13
12
11
10
9
8
7
6
5
4
3
2
1
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec



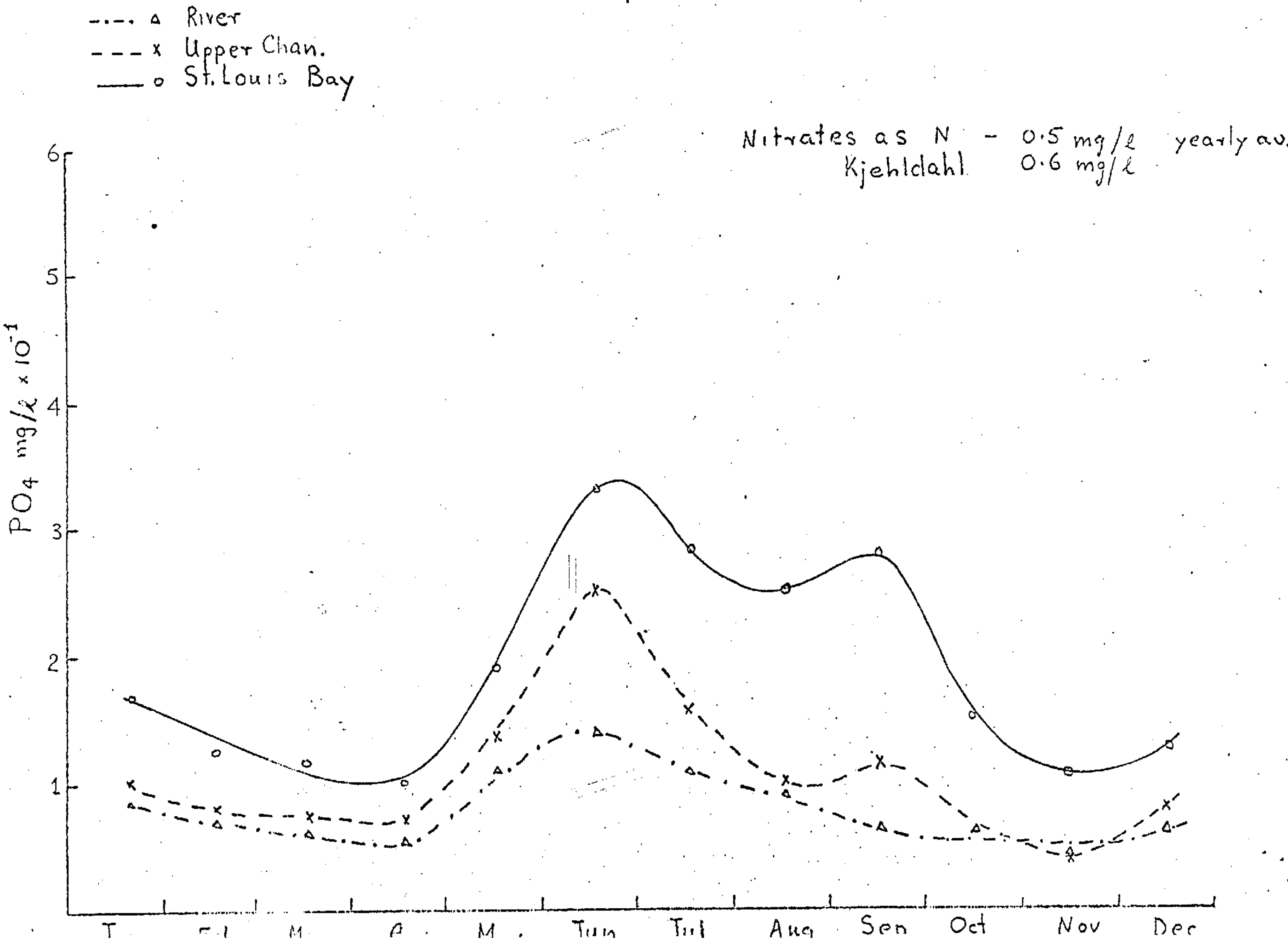
Δ River
. Dul. Ent.
x Superior Bay
Lake water influx
Temp. °F
70
60
50
40
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

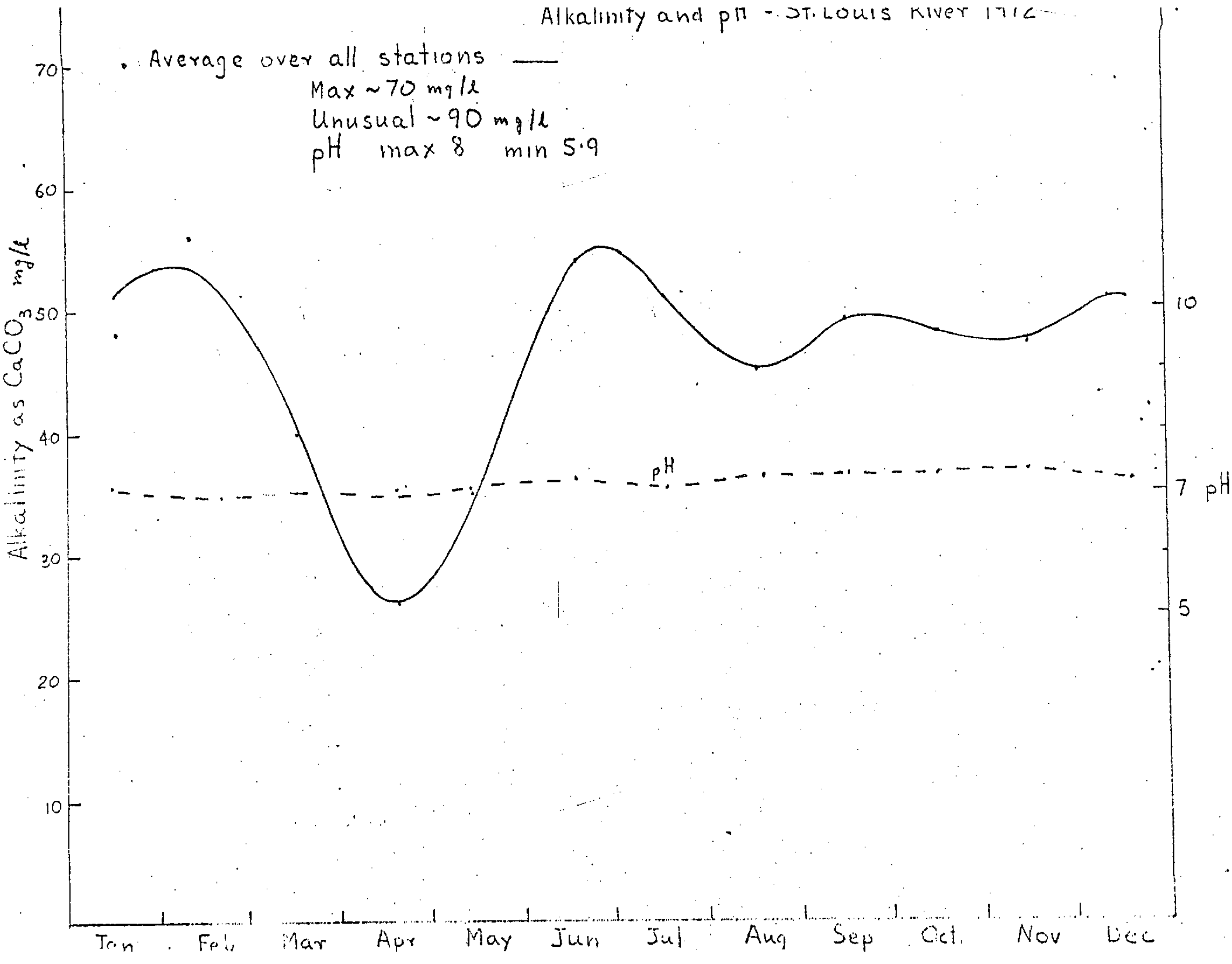
[redacted]

(See Temperature Curves)



Phosphate - St Louis River 1972





Alkalinity and pH - St. Louis River 1972
• Average over all stations ——
Max ~ 70 mg/l
Unusual ~ 90 mg/l
pH max 8 min 5.9
Alkalinity as $CaCO_3$ mg/l
70
60
50
40
30
20
10
pH
10
7 pH
5
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

	5' Depth	25' Depth
Map Location	Barkers Island	Barkers Island
Date	2-15-73	2-15-73
Sample Time	2 P.M.	2 P.M.
Temp C°	0°C	0.9°C
Turbidity	7 J.T.U.	8
Color	80 Color units	120
Dissolved Solids	175 mg/1	184
Susp. Solids	3.8 "	6.0
Ph	6.88 "	6.78
BOD	3.70 "	8.30
COD	68.4 "	86.0
Hardness	72 "	72
Alkalinity	64 "	64
Cholorides	10 "	10.5
Sulfates	13 "	16
Phosphates	0.25 "	0.46
Specific Conductance	92 μ mhos/cm	125 μ mhos/cm
D.O.	2.5 p.p.m.	0 p.p.m.

Table Fig. 20.

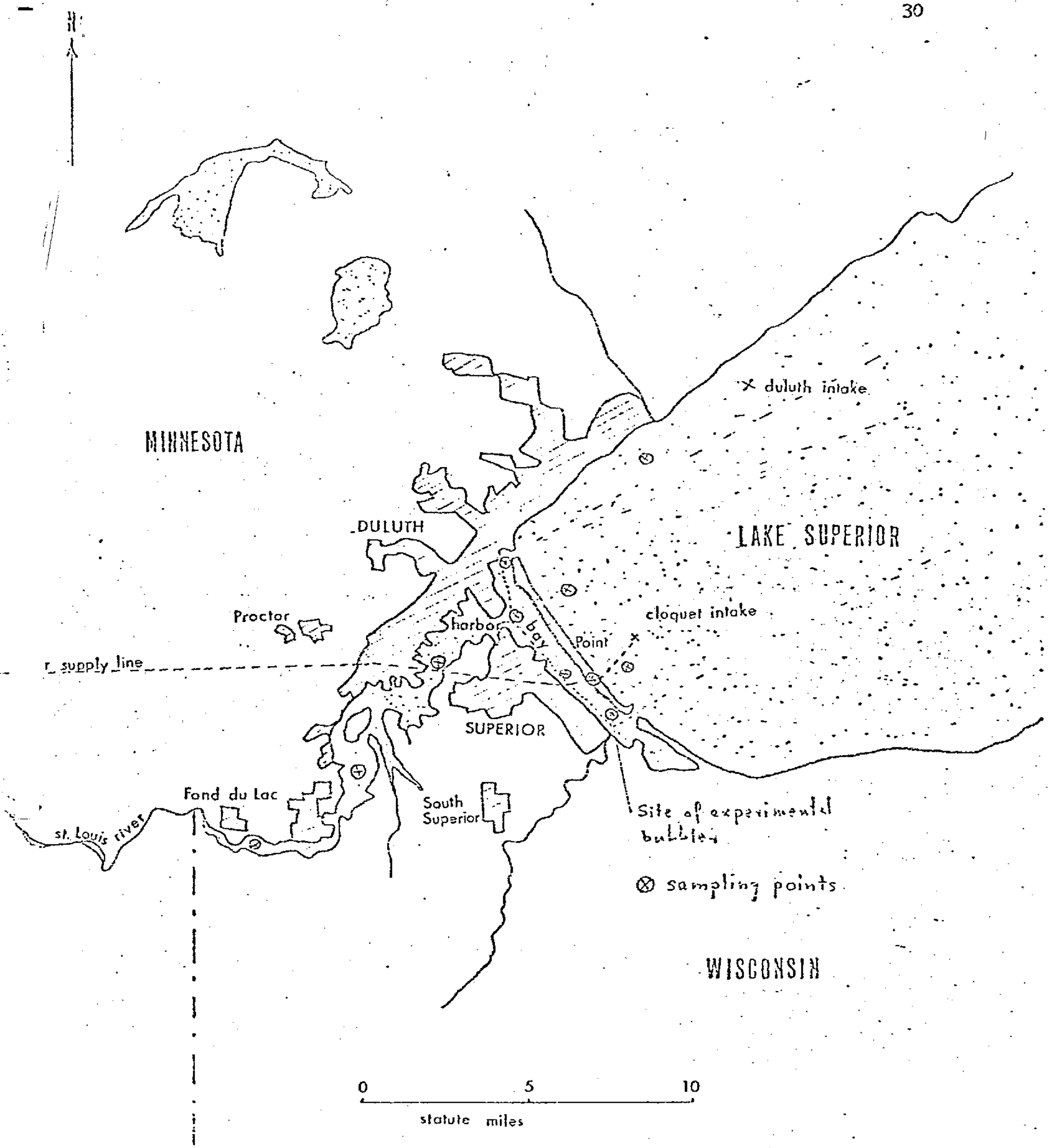
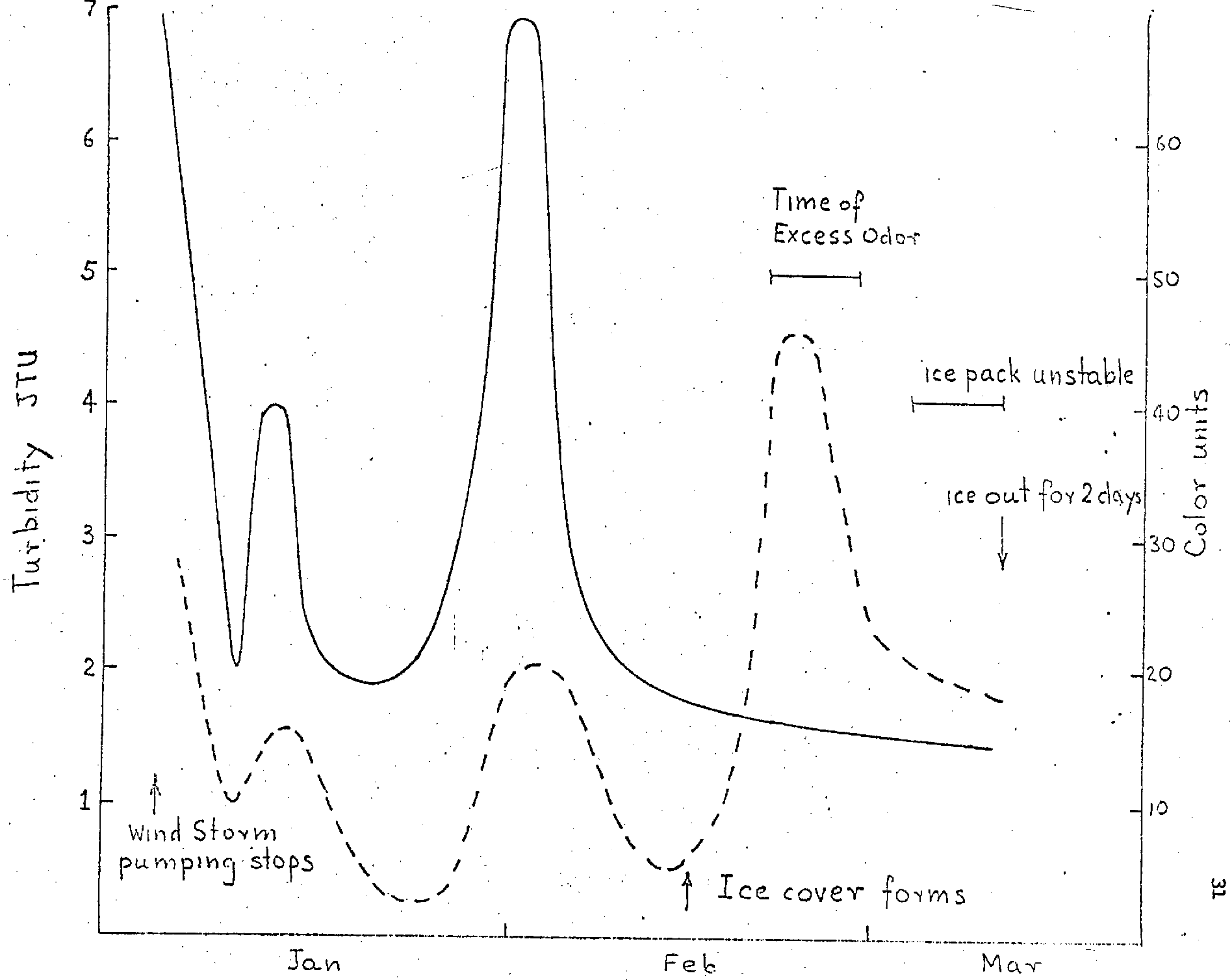

N
MINNESOTA
DULUTH
duluth intake
LAKE SUPERIOR
cloquet intake
Proctor
harbor
bay
Point
supply line
SUPERIOR
Fond du Lac
st. Louis river
South Superior
Site of experimental bubbler
sampling points
WISCONSIN
0
5
10
statute miles

Fig. 21.

[redacted]



Turbidity JTU
Color units
Time of Excess Odor
ice pack unstable
ice out for 2 days
Wind Storm pumping stops
Ice cover forms
Jan
Feb
Mar

Water Quality at Cloquet Intake 1975

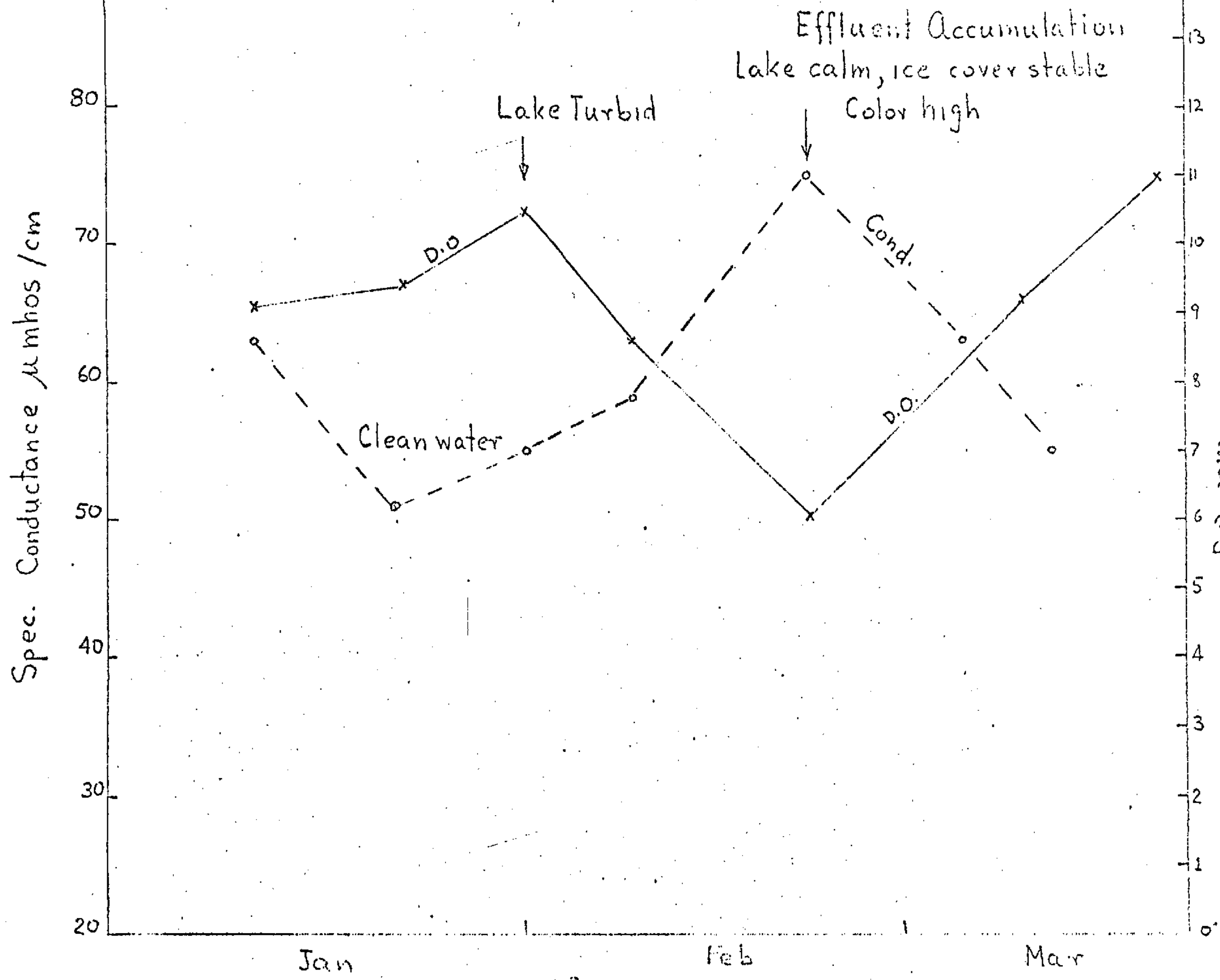


Fig 23

Table II

Normal Values for Water Quality Parameters

	Clean Water Values at Cloquet Intake	Winter Values at Superior Bay
Turbidity	2	6 JTU
Specific Conductance (at 1.5°C)	55	110 μ mhos/cm
Color	3	300 Color units
Dissolved Oxygen	11 ppm	2 ppm

Calibration of Conductivity Probe VSI 33 S.C.T.

KCl Solution	Temp.	Probe	Standard
.0005 m	23°C	75 μ mhos/cm	73.9 μ mhos/cm
.001 m	24°C	140 μ mhos/cm	145 μ mhos/cm
.01 m	24°C	1370 μ mhos/cm	1408 μ mhos/cm

Lake Water Station #1 (150 ft. depth)	90 μ mhos/cm	at 24°C (old sample)
Recent Cloquet Intake sample	95 μ mhos/cm	at 24°C
F. W. Q. Lab Intake	54 μ mhos/cm	at 1.8°C

Fig. 24

Ice Growth for Superior Bay

1) Formation: The problem of formation of first ice may be separated into two periods. The first is the cooling of the body of water to an isothermal state. The second is the cooling of the surface water from this isothermal condition ($\sim 4^{o}C$) to $0^{o}C$, and formation of a solid ice cover of $\sim$ 4 in. The figure 4 in. was chosen because once that thickness is reached, one is fairly assured that the cover is permanent. Experimental evidence shows that once the surface reaches 0^{o}, the first 4 in. of ice form very rapidly. For the first stage of cooling, Newton's Law of Cooling may be applied.*

$$\frac{dT_w}{dt} = k(T_a - T_w)$$

where T_w = H_2O surface temp.

T_a = air temp.

k = Constant of proportionality

t = time

$$dT_w + kT_w dt = kT_a dt$$

$$e^{kt}dT_w + ke^{kt}T_w dt = ke^{kt}T_a dt$$

$$\text{or} \quad d(T_w e^{kt}) = T_a d(e^{kt})$$

Integrating from $t = t_o$ to $t = t_n$,

$$T_w e^{kt}\Big|_{t=t_o}^{t=t_n} = \int_{t_o}^{t_n} T_a d(e^{kt})$$

let $T_w(t_n) = \tau_n$

$T_w(t_o) = \tau_o$

* M. A. Bilello, Ice Prediction Curves for Lake and River Locations in Canada. U. S. Army Command, Hanover, New Hampshire. July 1964

B. Rodhe, On the Relation Between Air Temperature and Ice Formation in the Baltic, Georgrafiska annaler, vol. 34, p. 175-202.

$$\tau_n e^{kt_n} - \tau_o e^{kt_o} = \int_{t_o}^{t_n} T_a d(e^{kt})$$

$$\tau_n = \tau_o e^{-k(t_n - t_o)} + e^{-kt_n} \int_{t_o}^{t_n} T_a d(e^{kt})$$

Write integral as a sum by breaking (t_o, t_n) into n equal short intervals, $\Delta t = 1$ day

$$\tau_n = \tau_o e^{-k(t_n - t_o)} + e^{-kt_n} \sum_{v=1}^{n} T_v (e^{kt_v} - e^{kt_{v-1}})$$

where T_v = Ave. value of T_a on t_{v-1} to t_v ,

i.e., $T_v = \frac{1}{\Delta t} \int_{t_{v-1}}^{t_v} T_a(t)dt \quad (\Delta t = t_v - t_{v-1})$

$$\tau_n = \tau_o e^{-k(t_n - t_o)} + \sum_{v=1}^{n} T_v \left[e^{-k(t_n - t_v)} - e^{-k(t_n - t_v + \Delta t)}\right]$$

$$\tau_n = \tau_o e^{-k(t_n - t_o)} + (1 - e^{-k\Delta t}) \sum_{v=1}^{n} T_v e^{-k(t_n - t_v)}$$

Selecting the period large, $t_n - t_o >> 1$,

$$\tau_o e^{-k(t_n - t_o)} \approx 0 .$$

To obtain a formula of iteration, replace t_o by t_{n-1}.

$$\tau_n' = \tau_{n-1}' e^{-k\Delta t} + (1 - e^{-k\Delta t}) T_n$$

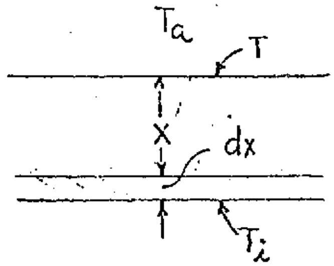
or $\tau_n' = \tau_{n-1}' + (1 - e^{-k\Delta t})(T_n - \tau_{n-1}')$

τ_n' is an "adjusted air temp."

Now the value of $(1 - e^{-k\Delta t})$ was found by trial and error such that $\tau_n' = 4^o$ for n = no. days from starting point for T_v to reach 4^o. The starting pt. was July 1 (any day several months before freeze-over would do) and τ_o' was taken to be the average temperature for the month of June. This was done on computer and found that $(1-e^{-k\Delta t}) = .99$ for the Superior bay. (This figure has not yet been calculated for the lake.) It was assumed here that this atmospheric heat exchange was not affected by winds and currents. When the bay has become isothermal, the water surface temperature will be much more sensitive to air temperature. It has been found experimentally that the formation of solid ice cover occurs after a set number of accumulated degree freezing days, (32°F base temp.) beginning from when the body is isothermal.† This experimental fact may be rationalized by assuming that during this second cooling stage the lake-water surface temperature is close to 32°F, and the rate of heat loss is proportional to $(T_a-32)^\circ F$, where T_a = air temperature (°F). This figure was 130 accumulated degree freezing days for the bay (Duluth-Superior). Using the figures $(1-e^{-k\Delta t})$ and 130 ADFD calculated from 1972 data, the formation of a solid ice cover was predicted within three days for the years 1969, 1970, and 1971. The temperatures used in these predictions were the actual temperatures recorded, but in practice one would use actual temperatures up to the day the forcast is made, and then use forcasted and average temperatures after that. Thus one would be able to increase the accuracy of the forcast as each daily average temperature is recorded. This should allow forcasting freeze-over (to within five days) about two months (or more in advance.

† G. P. Williams, "Correlating Freeze-up and Break-up With Weather Conditions" Canadian Geotechnical Journal. Toronto V. 2, #4 1965.

2) Growth: There are two major types of ice growth, black ice, which is formed from the freezing of lake water, and white ice, which is formed from the freezing of slush on top of the black ice. The amount of black ice (as a function of time) may be shown to be proportional to the square root of ADFD (accumulated degree freezing days). Consider a unit area of ice, thickness x.



$$\frac{dx}{dt} \propto \frac{(T_i-T)}{x} \propto (T-T_a)$$

Let $\frac{dx}{dt} = \frac{k_1}{x}(T_i-T) = k_2(T-T_a)$

where k_1, k_2 are constants.

$$\frac{x}{k_1}\frac{dx}{dt} + \frac{1}{k_2}\frac{dx}{dt} = (T_i-T) + (T-T_a) = T_i-T_a$$

$$\frac{x}{k_1}\,dx + \frac{1}{k_2}\,dx = (T_i-T_a)dt$$

$$\int_{x=o}^{x=s} \left(\frac{x}{k_1} + \frac{1}{k_2}\right) dx = \int_{t=t_o}^{t=t'} (T_i-T_a)dt$$

where $x(t') = S$ (the ice thickness is S at $t=t'$) and t_o is taken as the first day where ADFD(t) stays positive.

$$\frac{S^2}{2k_1} + \frac{S}{k_2} = \int_{t_o}^{t'} (T_i-T_a)dt = ADFD$$

For forced convection, $k_1 << k_2$ (due to motion of air over ice)

$$S^2 \approx 2k_1 \int_{t_o}^{t'} (T_i-T_a)dt \quad \text{or} \quad S \propto [ADFD]^{1/2}$$

For Superior Bay, $x(t) = (5.6'')[ADFD]^{1/2}$ (5.6" determined experimentally)

Since wintertime acquisition of data required ice penetration, the collection and examination of ice data itself could hardly be avoided, both for curiosity and safety reasons. Excellent data for one point on the bay was available[4,5] at the U. S. Army Corps of Engineers. Since our early measurements or ice cover indicated that 1972-73 ice growth was unusual, it was interesting to attempt to predict the freeze-up times and the break-up time, for this year using the available data. This year for moderate ice thickness (0-20") the growth of black ice was well correlated with the accumulated degree freezing days. The ice thickness was proportional to the square root of degree accumulated degree freezing days as can be seen from Figure 25. The reason the formula holds so well came about from the fact that this year negligible white ice had formed.[6] The departure from this relation past 20" in thickness could be attributed to river currents which are not steady on account of the lake, and the presence of the two entries. Also the effects of the lake ice cover on the air temperature on the bay and the unusually mild weather itself could account for this departure. It is seen from Figure 26 that the relation is not valid for years when the accumulation of white ice was not negligible. The prediction of ice breakup would depend on the ice type since thawing curves like the ice growth depend on the nature of the ice. Black ice shows regular growth and decay. Analytical description of formation of white ice and its effect on breakup time would be difficult at best. To predict the breakup time however, some effective description,

4. Private communication, Clarence Wong, U. S. Army Corps of Engineers at Duluth.
5. Mr. T. D. Brennan, U. S. Coast Guard.
6. J. B. Shaw, McGill Sub Arctic Research Laboratory.

accounting for white ice, was necessary. Records of plot of total ice thickness as a function of time for the past four years indicated that the turnaround time for ice growth on the Superior bay occurred on or before March 6. Thus a prediction of breakup based on ice thickness for that date could be made using average ice decay rates. The question arose as to what was the effective thickness of ice cover on that day, realizing that the properties of black and white ice so far as decay rates and mechanical strength are concerned, are quite different. As an approximation of an effective thickness, we took the thickness of black ice plus one half of the thickness of white ice. Often this value corresponds to ice thickness below water level, but the water level fluctuates on account of ice buckling. Upon assigning to white ice one half the effective thickness in terms of black ice, and averaging over successive readings for each year we obtained, Figure 27 which shows the total effective ice thickness for the past five years.

Once the turnaround in ice thickness occurs, it is seen that the ice decays at an average rate of .227 inches per day until it reaches a critical value. At such time parts of the bay where currents are large, open up, while the ice cover on Superior bay channel honeycombs and cracks, presenting little obstacle to ship traffic. This critical ice thickness for the mid area of the Superior bay is 15". Thus if one projects the decay of ice from the March 6 thickness, the latest maximum thickness date, to the 15" thickness, one arrives at predicted breakup as shown in Fig. 28. Since for 1973 the maximum in the ice thickness occurred more than a month early, it was interesting to use this method to predict the harbor opening of this year. Fig. 28 shows that the predicted date was March 22, which was correct, though shipping did not start until March 29. The shipping however depends on other factors, such as opening of the locks and the ice packing at the tip of the lake.

The measurements on the ice cover at the tip of the lake were made during the times of collection of water samples on the lake at points intermediate to the Cloquet intake. The ice cover on the lake was, however, minimal this year. It was hazardous for all except two weeks time. The ice cover on the lake was treated according to procedure of T. L. Richards.[7] Since the tip of the lake is open to the rest of Lake Superior, it could not be treated altogether as a separate body of water. If no major storms were present, the tip area could act like a shallow lake. Using characteristic parameters of antecedent heat, and accumulated degree freezing days, and the assumption that the tip of the lake behaved like a shallow lake, it is estimated that 100% cover would develop after about 800 accumulated degree freezing days, which would yield (averaged over records for 1967-73) the 100% freeze up date as January 15 and agrees well with projected growth of initial cover. However, due to wind storms, partial ice cover at the tip of the lake is often removed and new warmer water is brought into the area, initiating in effect a new ice growth period, Fig. 29. After an accumulation of ∿ 1000 degree freezing days, the entire lake cools sufficiently so that this factor is less important. Thus a durable cover over the tip of the lake forms after about 1,100 accumulated degree freezing days which falls at the end of January. Fig. 29 shows the ice cover for 1972-73, using ERTS data for the winter. The 100% area considered,

7. T. L. Richards, Monthly Weather Rev., Vol. 92, 6, 297.

is the tip of the lake from Knife River to Duluth. The ice thickness after freeze up seems to display growth proportional to the square root of the degree accumulated freezing days. Ice thickness data for this part of the lake is unavailable for other years. The main problem to navigation in so far as the ice at the tip of the lake is concerned, comes from ice packing due to ice driven into the tip area in the early spring by N.E. winds. This phenomenon for instance caused considerable difficulty to shipping in 1972, when the ice was piled up to 10 ft. depths, and remained in the area until June 9, 1972. Similar event caused 18" pack to develop late in March of this year. The extent of packing depends on the ice cover on the entire lake. Further consideration of this problem is planned with aid of the ERTS satellite data.

Ice Growth - Superior Bay 1972-73

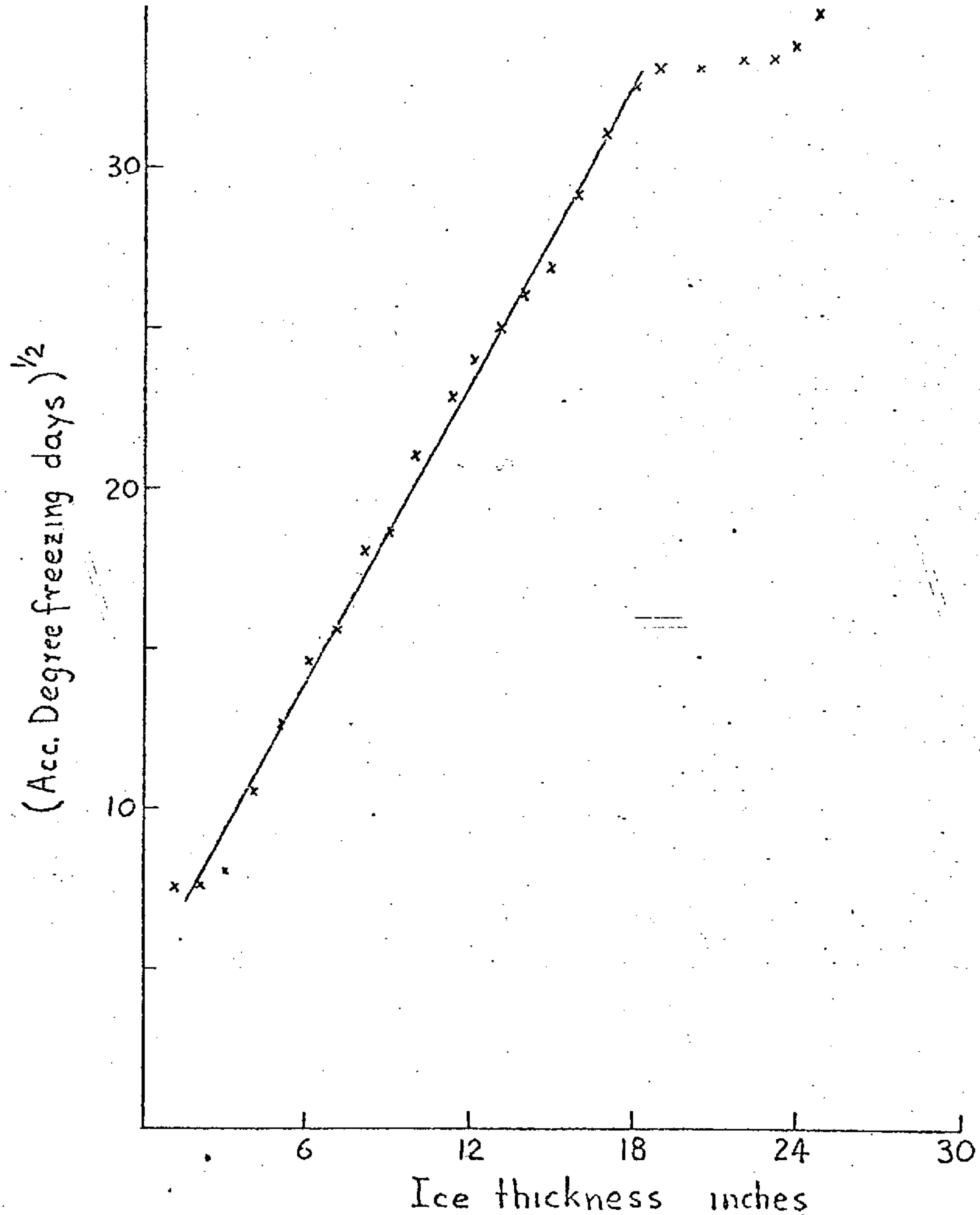


Fig 25

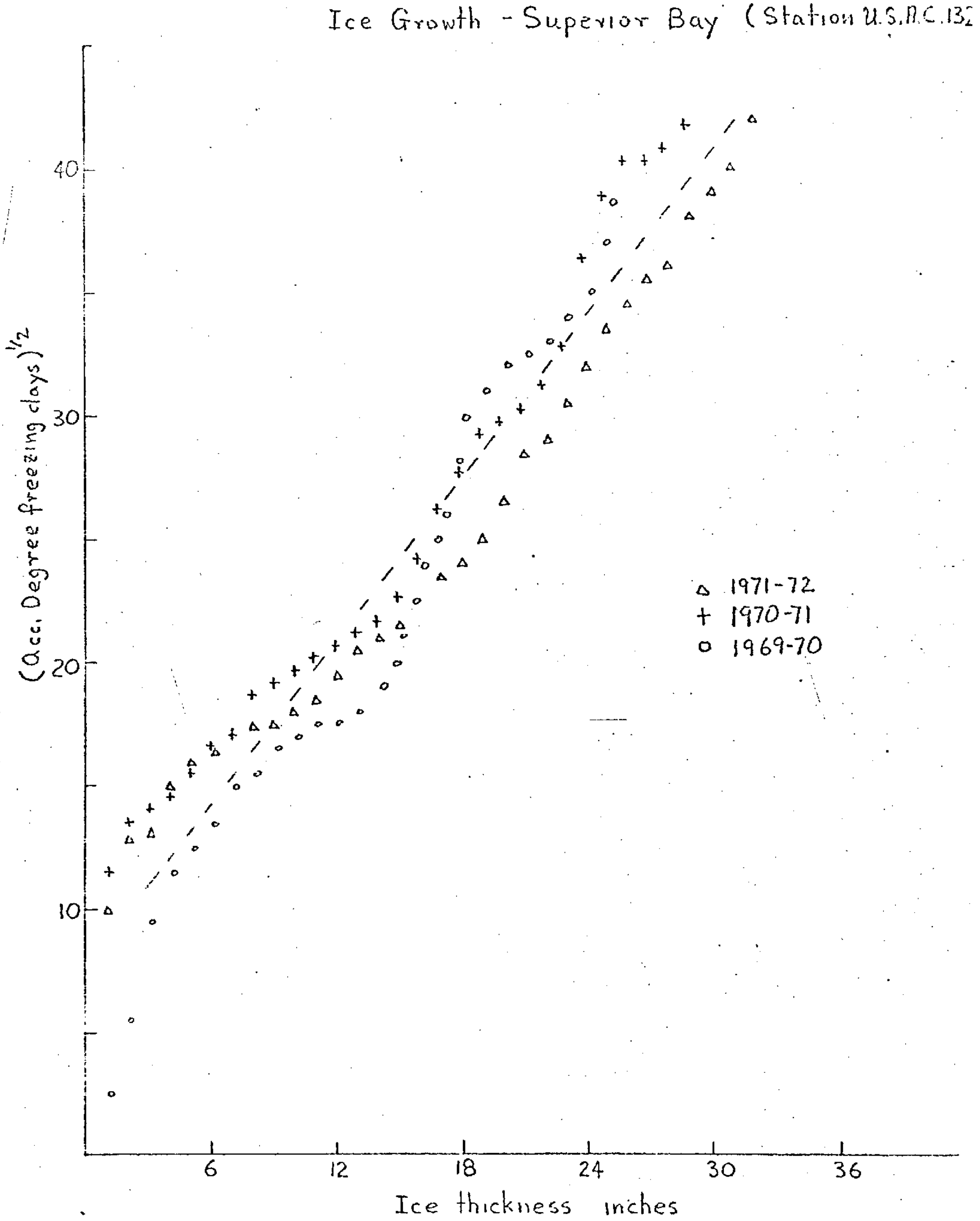

Ice Growth - Superior Bay (Station U.S.N.C.132
(Acc. Degree freezing days)^1/2
10
20
30
40
6
12
18
24
30
36
Ice thickness inches
△ 1971-72
+ 1970-71
○ 1969-70

Fig. 26

Black ice equivalent - Superior Bay

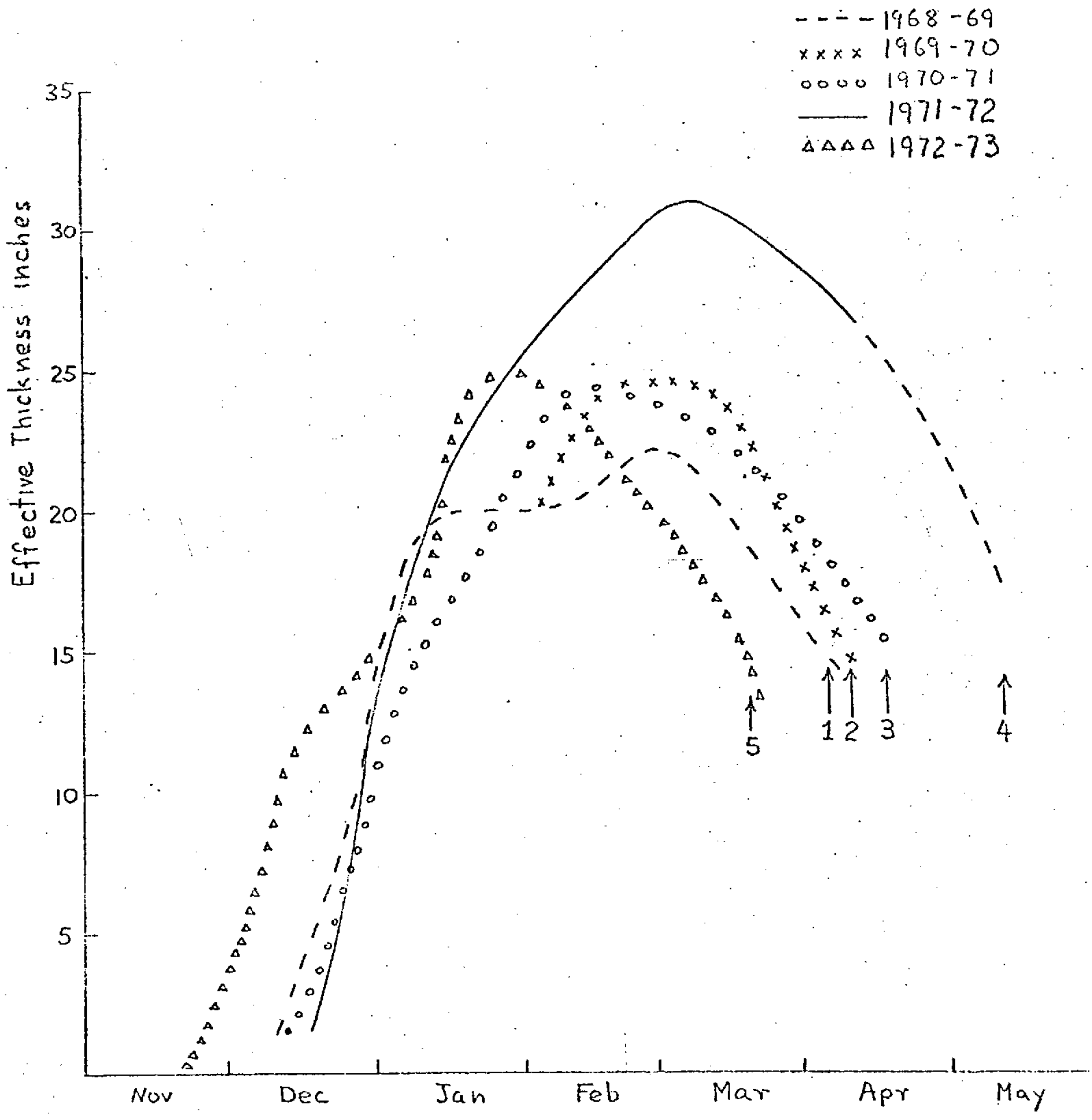


Fig 27

Harbor Navigability

	Date Open	Predicted
1969	Apr 11	Apr 4
1970	Apr 13	Apr 16
1971	Apr 14	Apr. 12
1972	~May 19	May 12
1973	Mar 21	Mar 22

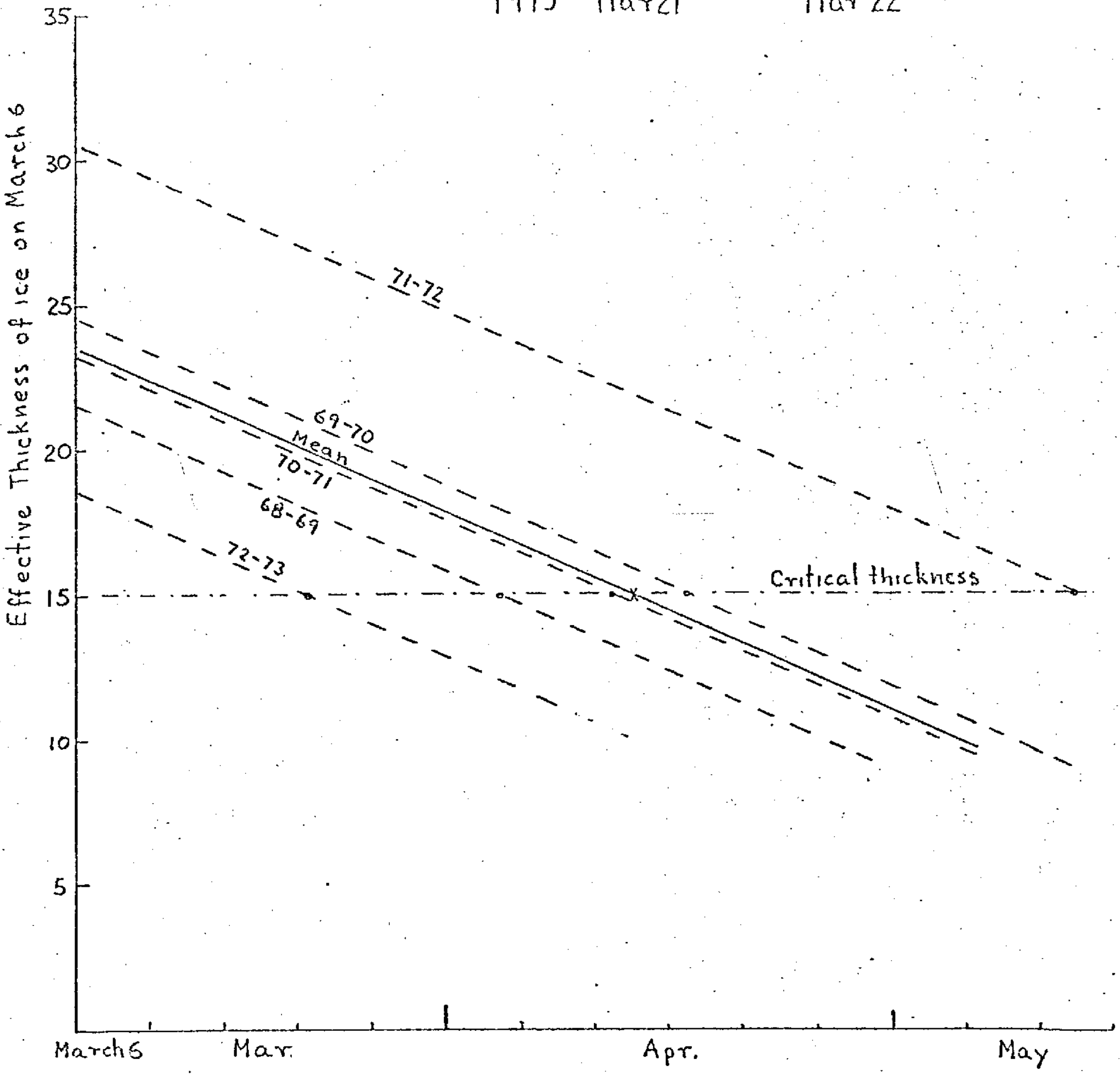
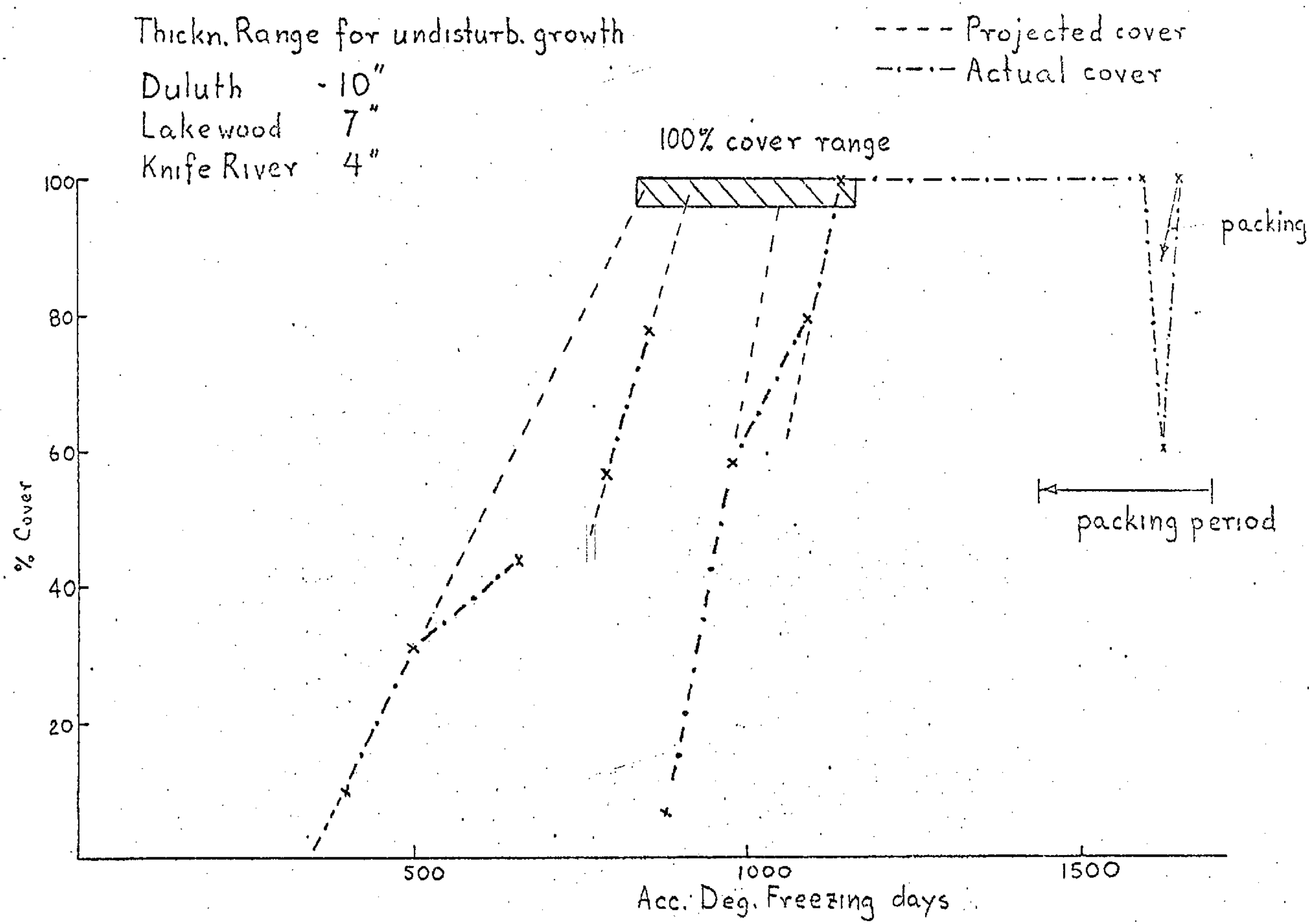
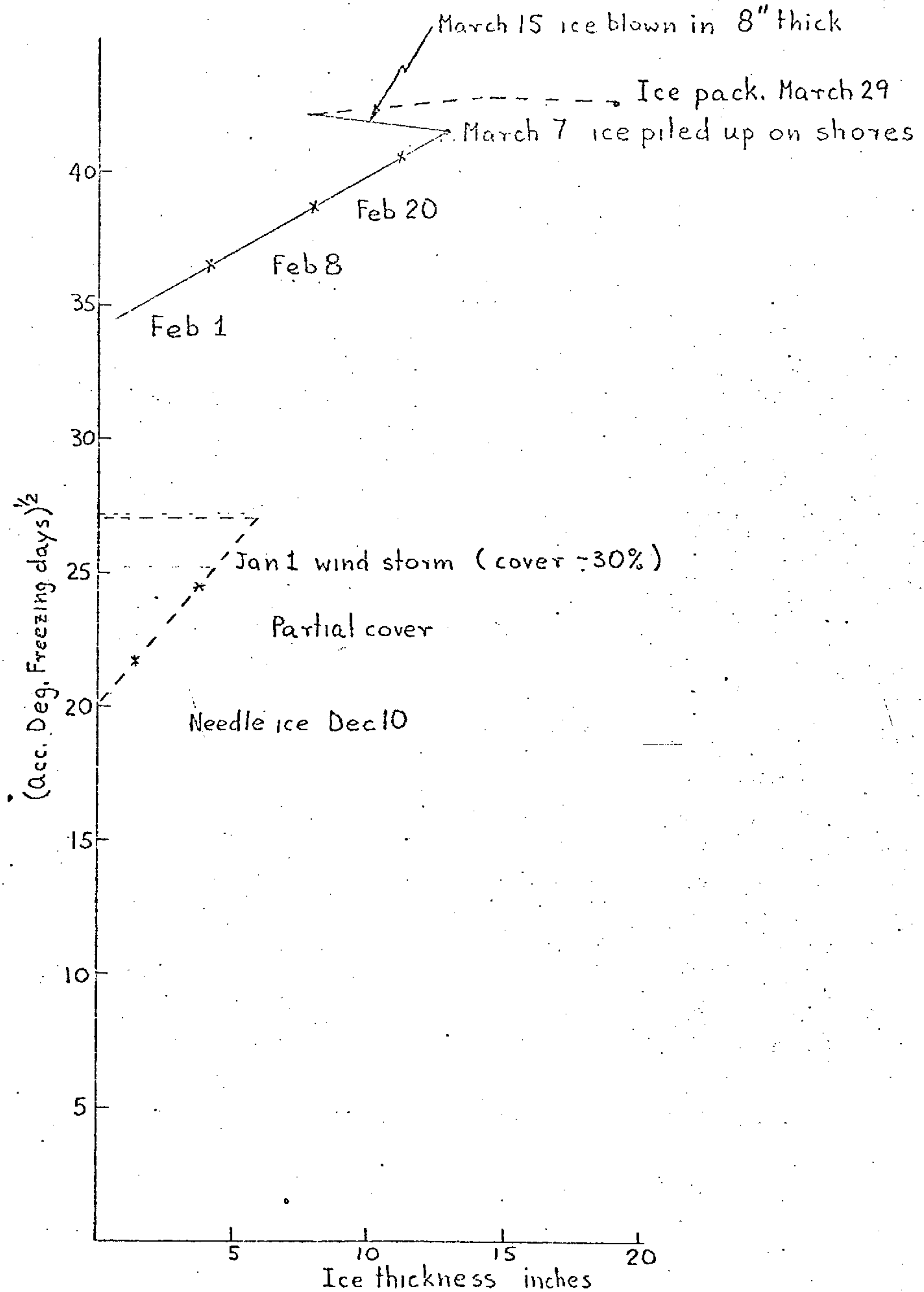


Fig 28

Ice Cover - Tip of Lake Superior



Ice Growth - Tip of Lake Superior 1973



Our measurements on the effects of the experimental bubbler were performed as supplementary information to the data collected by the National Biocentric Corporation, which was charged with assessment of its operation for the U. S. Army Corps of Engineers. Five sampling points were established in the area of bubbler as shown in Fig. 30. The measurements of water quality parameters at these points was used for the evaluation purposes. Intensive measurements were made for three sampling days, one each before, during and after the operation of the system. We also took data on several other dates as part of our investigation of the bay. The auxiliary stations used for our own purposes are shown in Fig. 30.

The assessment of the operation of the bubbler so far as ice cover was concerned, was based on the ice growth data for points adjacent to the bubbler.

Fig. 31, curve 1, shows the ice growth for area upstream from the bubbler. Curve 2 on the figure shows the estimated growth of ice over the bubbler area if the area was not disturbed. This was done by using the same functional dependence for ice growth over the bubbler area as for station #5. Initial values for ice thickness were based on measurements made before the bubbler was installed. Curve 3 shows the actual ice values over the bubbler affected area. Two discontinuities occurred; one on January 4 because of a wind storm which caused considerable surge of lake water into the bay, breaking up the ice cover; and one on January 15 because of unusually mild weather, at that time the bubbler perforated the ice, creating open water right over the bubbler outline. For more normal conditions the bubbler area, including the section right above the bubbler outline, were frozen over. The ice right above the bubbler outline was, however, substantially weaker and remained in that state even after the bubbler operation ceases.

When the bubbler was shut off, the ice cover quickly returned to near normal projected thickness. The weaker area directly over the outline of the bubbler formed a pressure ridge about 2 ft. high. When the thawing period began this ridge area deteriorated first, showing open water a week earlier than adjacent areas.

Based on this years performance then, (year unusual in character) it is estimated that the breakup of ice in the bubbler area was speeded up by one to two weeks on account of the weakened section formed directly above the bubbler. Even in the absence of the weakened ice and the subsequent pressure ridge, one could estimate that the ice cover over the bubbler should deteriorate sooner. It displayed many imperfections in growth, (characterized by trapped air and discolorations giving appearance of entrapped algae growth) and its final thickness was about 2 inches lower than projected normal thickness. This according to the thawing curves, Fig. 28, would make the bubbler area navigable 8 days sooner than the adjacent area on the Superior bay.

The assessment of the effects of the bubbler on water quality was difficult. The location of the bubbler was chosen for its anticipated aid to shipping as such the choice was excellent. The area does, however, have the problem in that it is not a homogeneous body of water. Fig. 32 shows that the bubbler is located at the junction of the muddy Namadji River and the much less turbid St. Louis River. The proximity to the lake entry also complicates the problem as the lake water periodically flows into the bay. Some assessment of the effects of the bubbler on water quality can be made, however, particularly if comparisons are made for selected sampling stations.

We limited most of our measurements only to those physical parameters which could be easily taken in situ, and for which we felt pertinent relations to water mixing could be established and discussed. (Other measurements were performed by Biocentrics, Inc.)

Basically, one would like to assess the effect of the bubbler in preventing the natural settling of pollutants, and on its possible reintroduction of settled out material into the water. The question in this case was whether the mixing was largely due to the bubbler or due to the natural mixing processes at the junctions of the rivers and the lake entry.

Aerial data was most useful in this case. Fig. 32 gives good indication that the site #1 on the bubbler should reflect the properties of the St. Louis River. One would expect the same from site #5. These two sites could then be compared. The station at the tip of the bubbler, off the old ore dock, could serve as an indicator of lake water surging into the bay, the surges do indeed occur, as evidenced by the water current observations at the Superior entry, and water percolating through the ice cracks in the slip of the old ore dock. It is anticipated that the prevailing water flow in the area; except for areas right next to physical protrusion, such as the U. S. Army Corps pier, is normally laminar. This is somewhat borne out by the results obtained for the times of sampling after the cessation of bubbler operation.

The data in Figs. 33-39 show that a normal profile with depth for the conductivity and the dissolved oxygen had developed by December 13 for the Superior bays. Considerable settling is shown by the depth profiles for the site off Barkers Island, which is downstream from the Superior sewage plant. The first intensive sampling day was December 21, Fig. 34, 35. The bubbler area was open. The tugboat, Illinois, courtesy of Great Lakes Shipping Company, was used in collecting the data. The data for December 21 shows that the water in the bubbler area is well mixed, particularly if comparison of the shape of conductivity profiles is made for sites #1 and #5. Furthermore, the average conductivity of water was substantially higher at site #1 indicating extra conductive suspended material either due to bubbler action or the vessel traffic. Site #5 was not appreciably disturbed by the tugboat on the sampling day. The results for subsequent days show water quality parameters for Barkers Island site and the upper channel. The upper channel displays little variation of conductivity with depth. Generally pronounced conductivity profiles were present primarily in the Superior bay and the St. Louis Bay where major sewage and industrial waste sites are found. The next day of extensive measurements was January 15, Fig. 36, 37. The data for the day shows again considerable mixing at site #1 as compared to site #5. The ship traffic had stopped by January 4, 1973, and water current was downstream on that day. The day was unusually warm and the ice directly above the bubbler was either well perforated or was showing open spots.

The oxygen over the bubbler area had increased ~ 2 ppm on the average. This would depend mostly on the rate of flow of water over the bubbler. The oxygen profile was determined using proble measurements and Winkler (Alkali-Iodide Ozide) analysis on samples every 5 ft. depth for the extensive measurement days. The comparison of the conductivity curve for site #1 and #5 shows that the average conductivities for the sites are nearly the same, unlike the case for December 21.

One could then deduce that the water at site #5 become well mixed by the time it reached site #1, but if the increase in average conductivity on December 21 was due to bottom sediments being resuspended, then by January 15 the process was no longer taking place and though the bubbler was preventing settling, it was not adding new conductive bottom material to the water on that date. The station off the tip of the bubbler reflects the parameters similar to those at station #5 while station #3 seems to reflect the regular winter conditions at that point which changed little later on. In the areas away from the bubbler, a slight temperature gradient had developed by that date. This was typical of the temperature profile later on, and may well be of considerable importance in improving the effectiveness of a bubbler operating in mid-winter. The profiles for January 30 and February 6 displays depth variation in the parameters after cessation of bubbler operation. Some natural mixing is indicated on February 6. The data for February 13 shows the results for the times well after the operation of the bubbler has stopped, so does the data for later days. It is noticed that for times after cessation of operation the bubbler area generally displayed stratification indicative of the upstream conditions on the Superior bay. Station #1 and #5 show small differences, particularly in the temperature profile. Natural mixing may have been the cause of this. The effect is relatively small however compared to mixing indicated during the bubbler operation. The available data thus suggests that the bubbler introduced 1-2 ppm dissolved oxygen into the water at the site #1 and sufficiently mixed the water to distribute the conductive ions almost uniformly with depth. The initial operation monitored on December 21 seems to have also caused substantial increase in the average conductivity of the water, perhaps by resuspending the settled out particles. However, the cause of this cannot be established since considerable turbulence was caused by vessels operating in the area. A more intensive study for a bubbler, located further away from the entry, should be made particularly with regard to the effects of bubbler on the bottom material. The operation should also be extended to the entire winter to see how the bubbler operation improves with the natural development of temperature gradient in the channel. This could shift the ice breakup to a much earlier time.

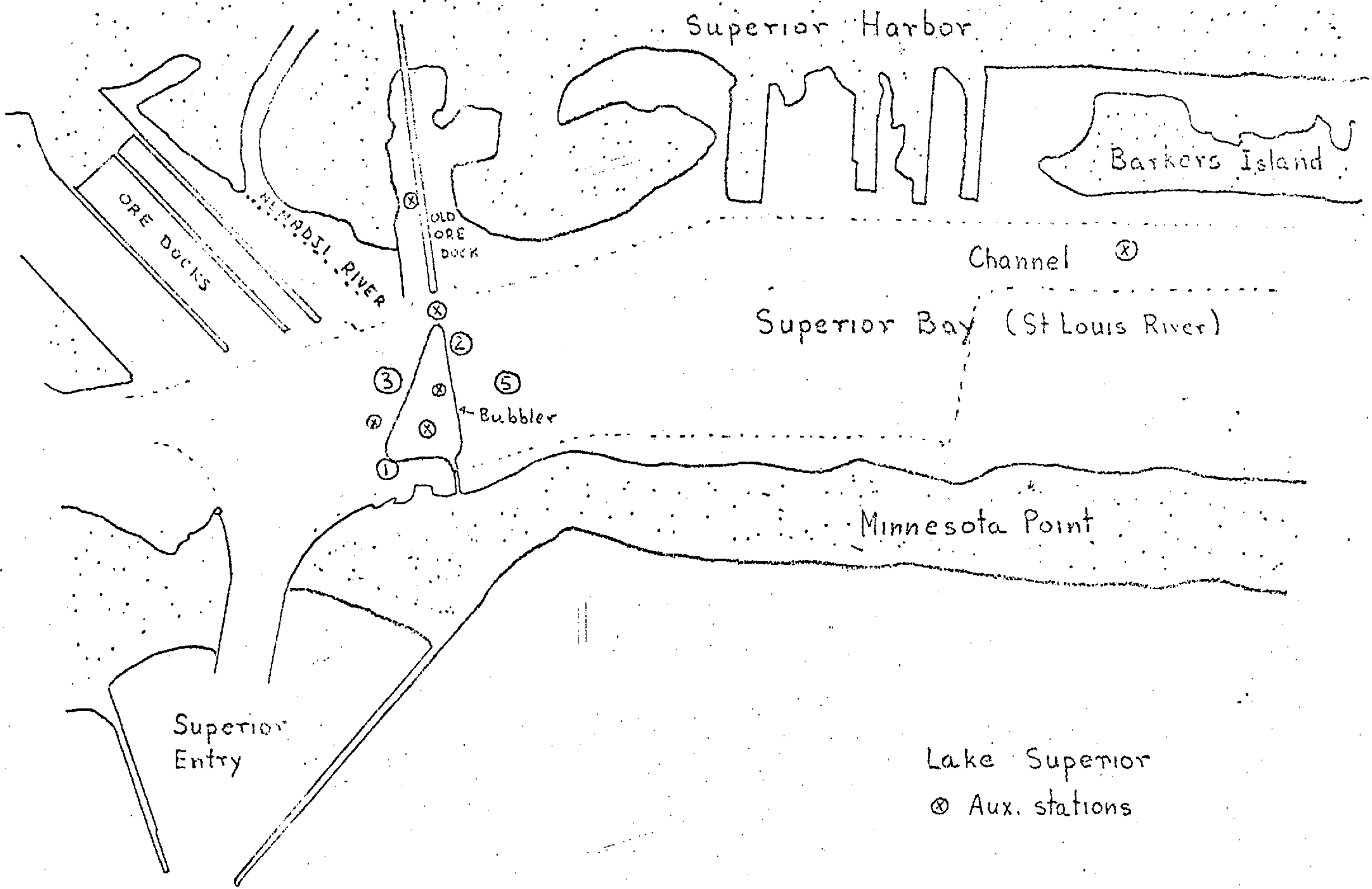
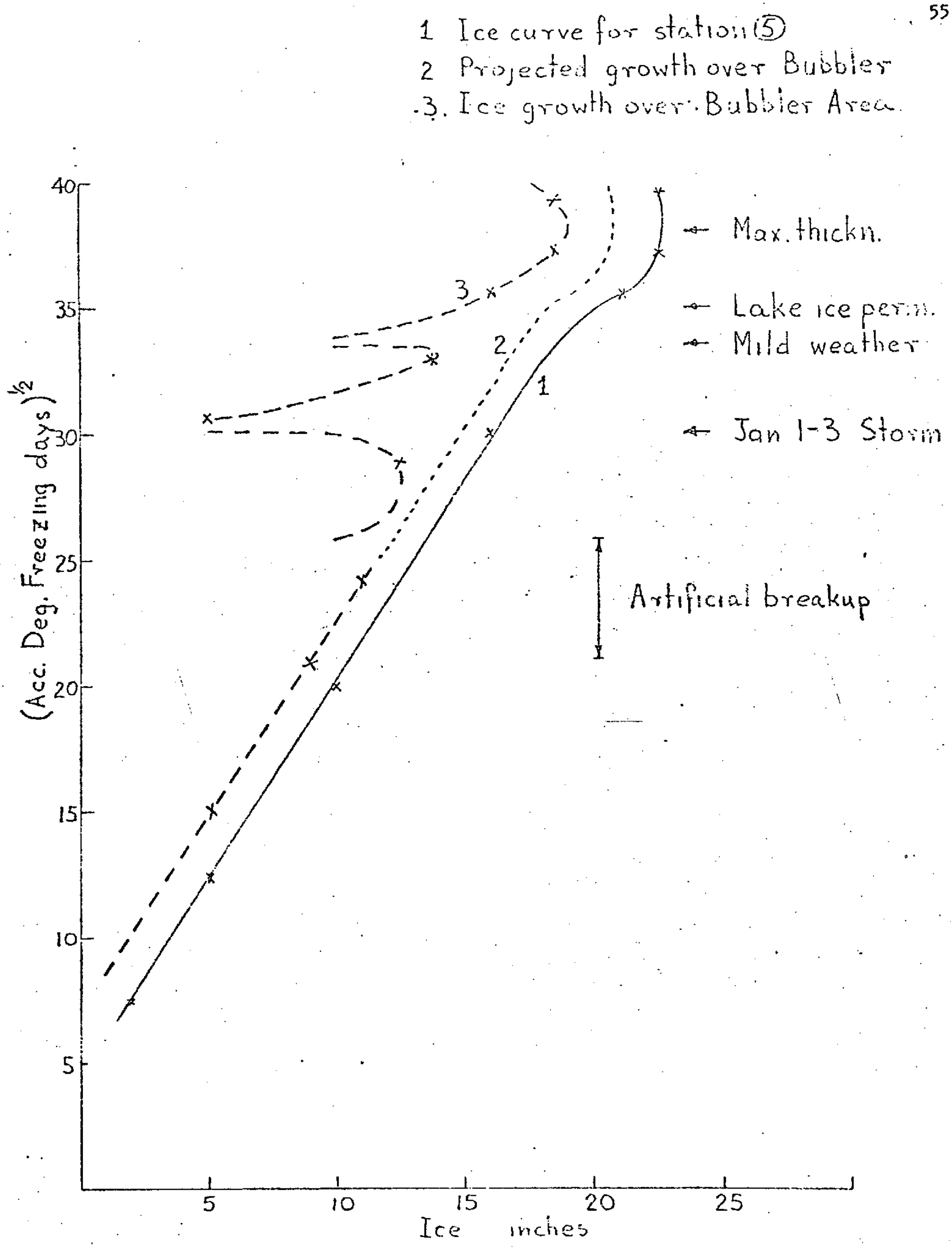
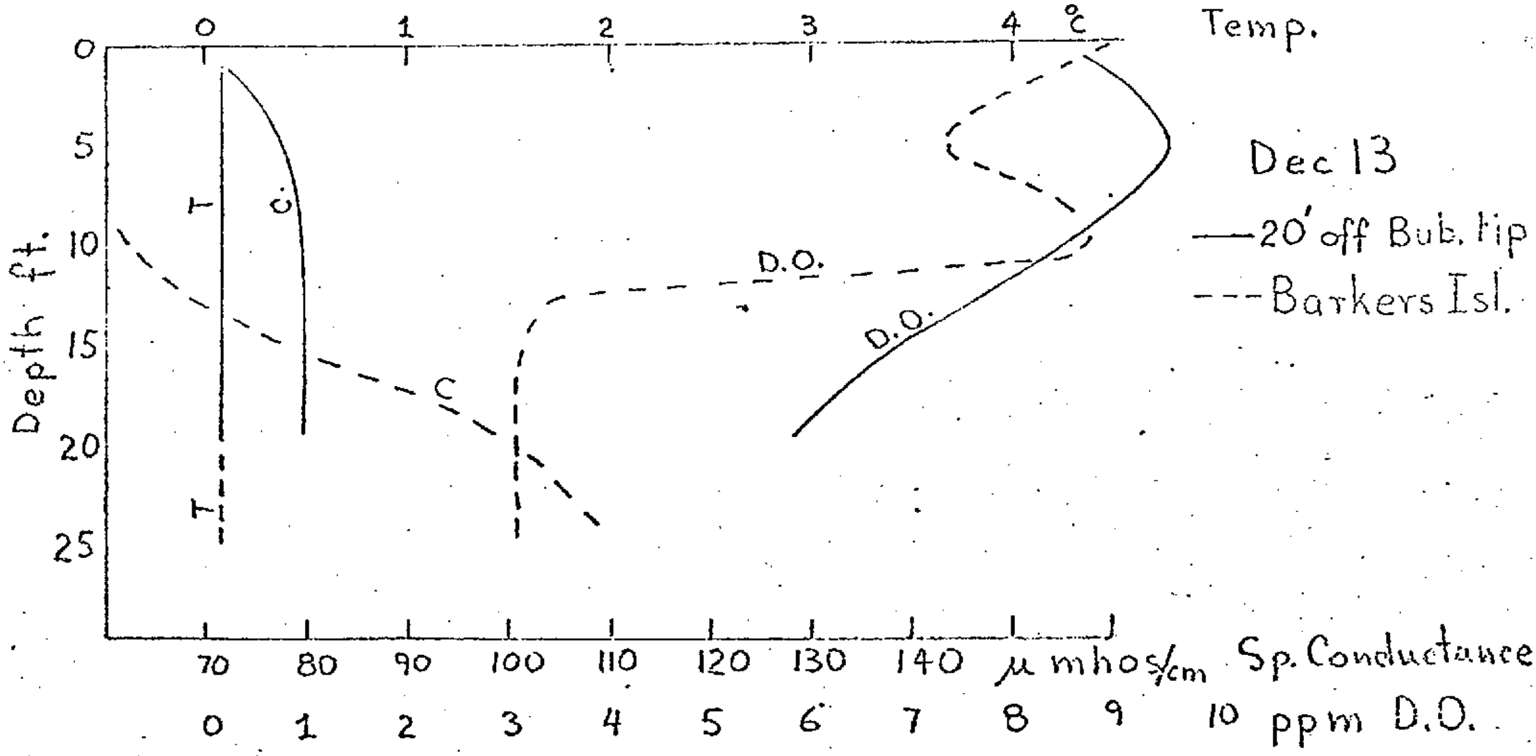

Superior Harbor
Barkers Island
ORE DOCKS
NEMADJI RIVER
OLD ORE DOCK
Channel
Superior Bay (St Louis River)
2
3
5
1
Bubbler
Minnesota Point
Superior Entry
Lake Superior
⊗ Aux. stations

Fig. 30

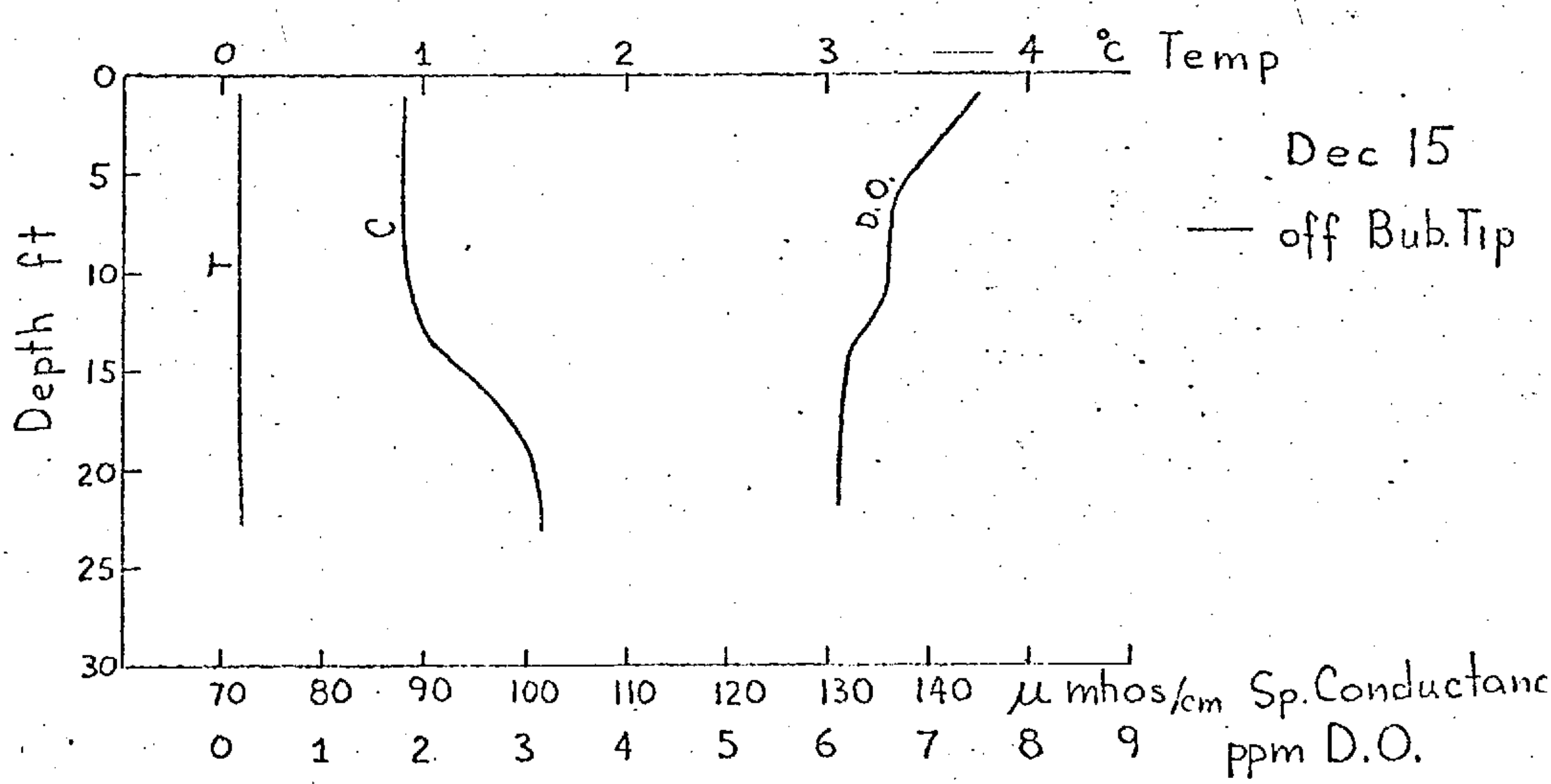


1 Ice curve for station (5)
2 Projected growth over Bubbler
3. Ice growth over Bubbler Area
Max. thickn.
Lake ice perm.
Mild weather
Jan 1-3 Storm
Artificial breakup
(Acc. Deg. Freezing days)^½
Ice inches
40
35
30
25
20
15
10
5
5
10
15
20
25
1
2
3

Fig. 31



Temp.
0 1 2 3 4 °C
Dec 13
—20' off Bub. tip
---Barkers Isl.
Depth ft.
0 5 10 15 20 25
T
C
D.O.
70 80 90 100 110 120 130 140 μ mhos/cm Sp. Conductance
0 1 2 3 4 5 6 7 8 9 10 ppm D.O.



0 1 2 3 4 °C Temp
Dec 15
— off Bub.Tip
Depth ft
0 5 10 15 20 25 30
T
C
D.O.
70 80 90 100 110 120 130 140 μ mhos/cm Sp. Conductanc
0 1 2 3 4 5 6 7 8 9 ppm D.O.

Fig. 33

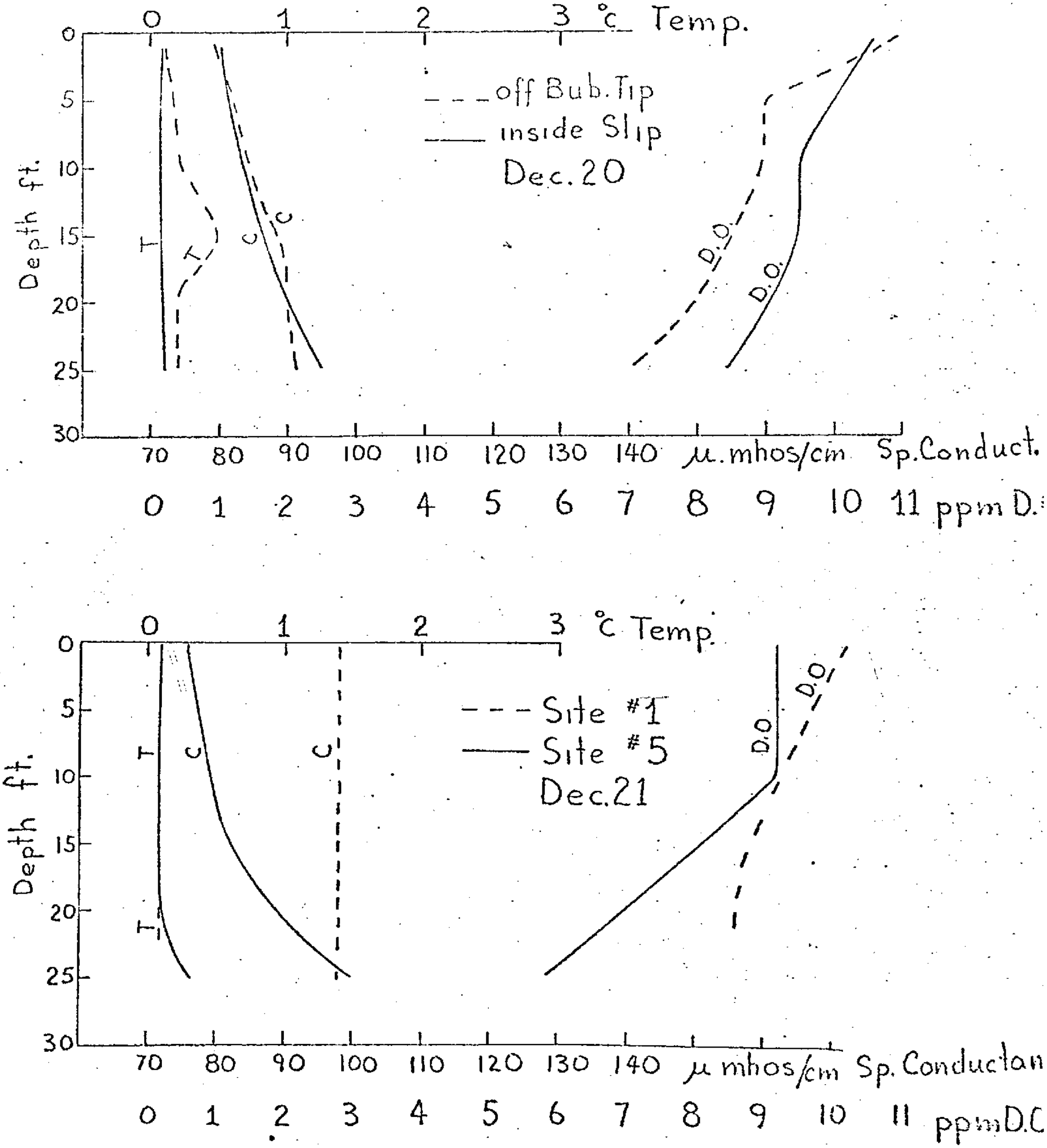
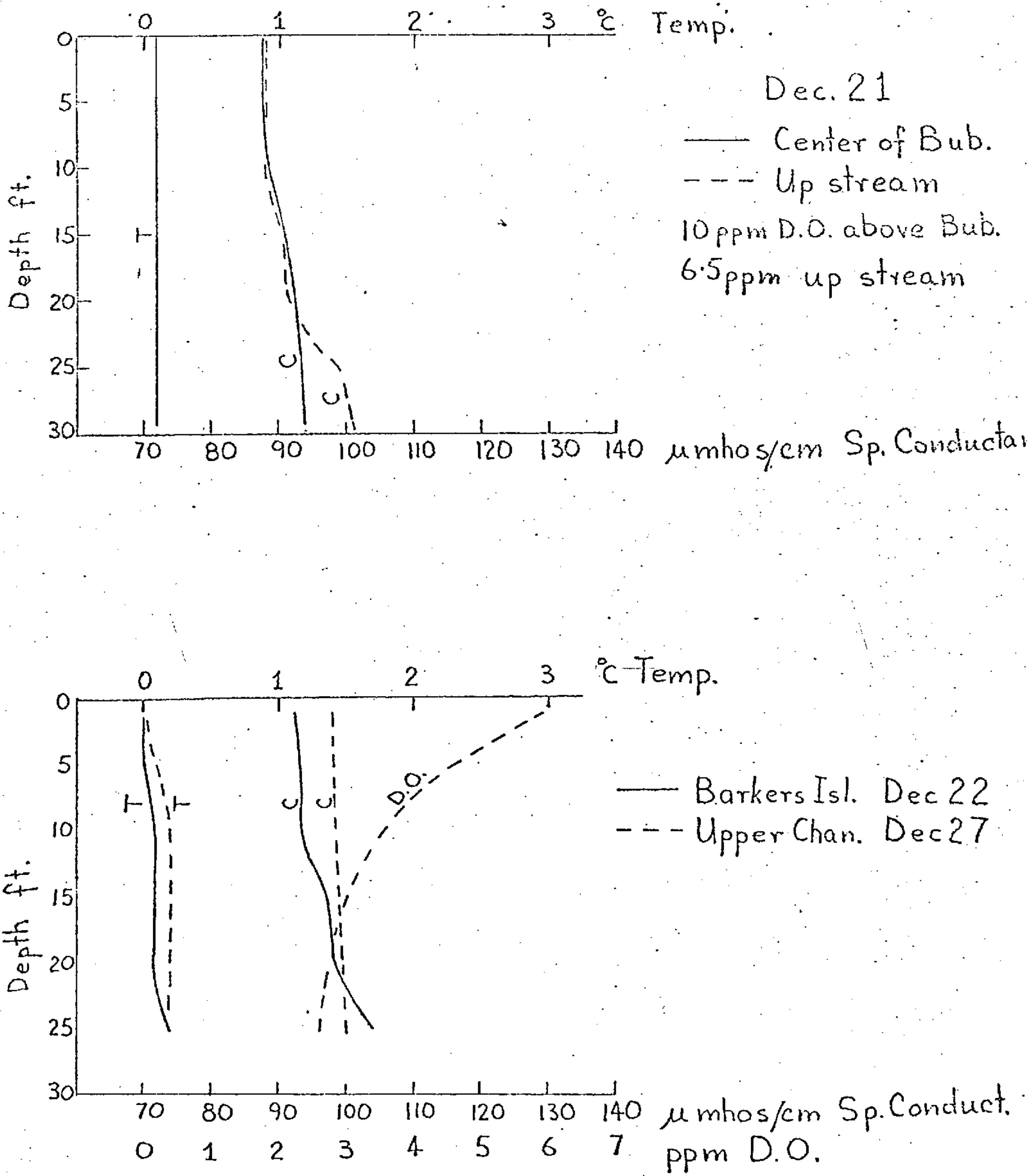
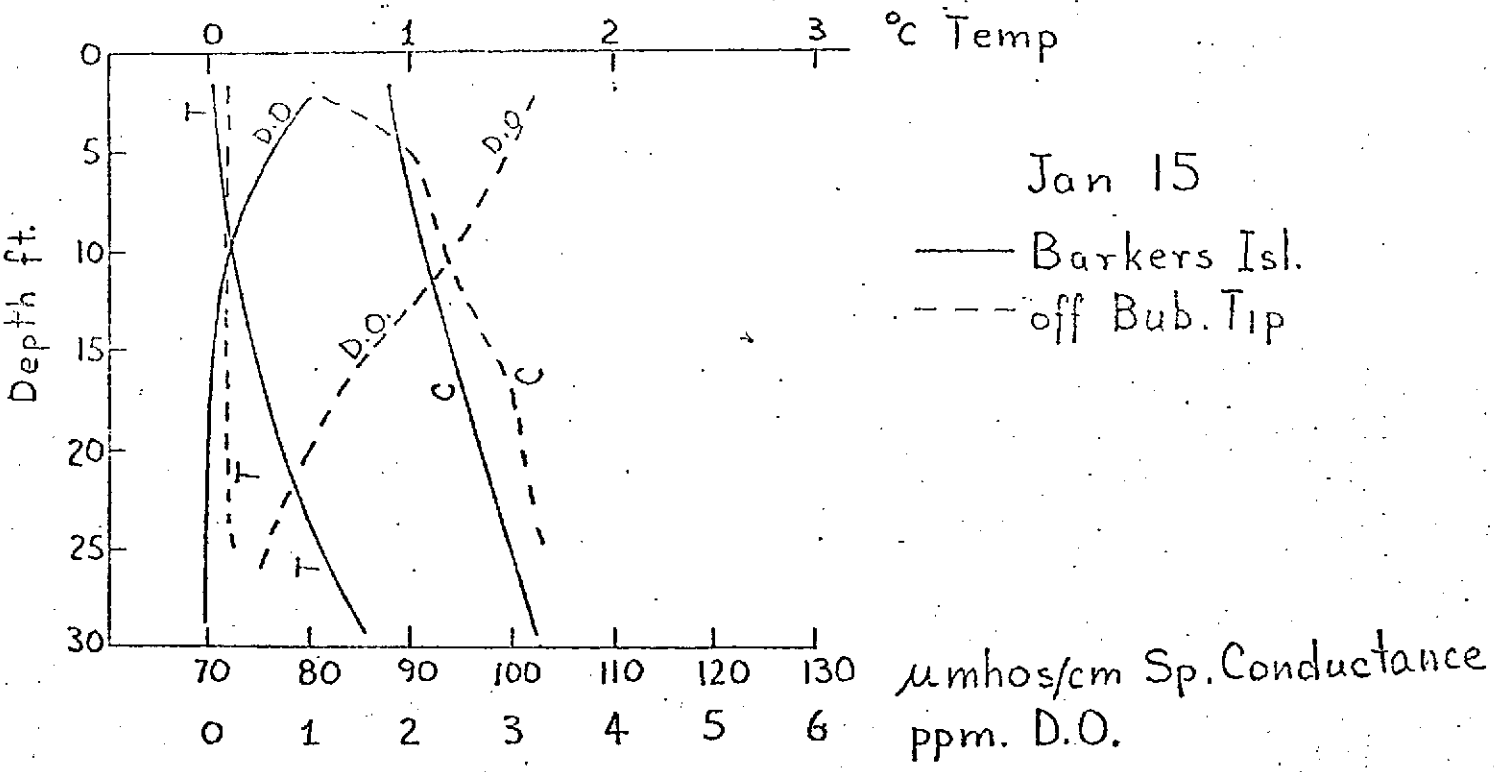

0
1
2
3 °c Temp.
off Bub. Tip
inside Slip
Dec. 20
Depth ft.
0
5
10
15
20
25
30
T
T
C
C
D.O.
D.O.
70 80 90 100 110 120 130 140 μ.mhos/cm Sp. Conduct.
0 1 2 3 4 5 6 7 8 9 10 11 ppm D.
0
1
2
3 °C Temp.
Site #1
Site #5
Dec. 21
Depth ft.
0
5
10
15
20
25
30
T
T
C
C
D.O
D.O
70 80 90 100 110 120 130 140 μ mhos/cm Sp. Conductan
0 1 2 3 4 5 6 7 8 9 10 11 ppm D.C

Fig. 34



°C Temp.
Dec. 21
Center of Bub.
Up stream
10 ppm D.O. above Bub.
6.5ppm up stream
Depth ft.
μmhos/cm Sp. Conductan
°C Temp.
Barkers Isl. Dec 22
Upper Chan. Dec 27
D.O.
Depth ft.
μmhos/cm Sp. Conduct.
ppm D.O.

Fig. 35


0 1 2 3 °C Temp
Depth ft.
0 5 10 15 20 25 30
T
D.O
D.O.
D.O.
C
C
T
T
Jan 15
Barkers Isl.
off Bub. Tip
70 80 90 100 110 120 130 μmhos/cm Sp. Conductance
0 1 2 3 4 5 6 ppm. D.O.

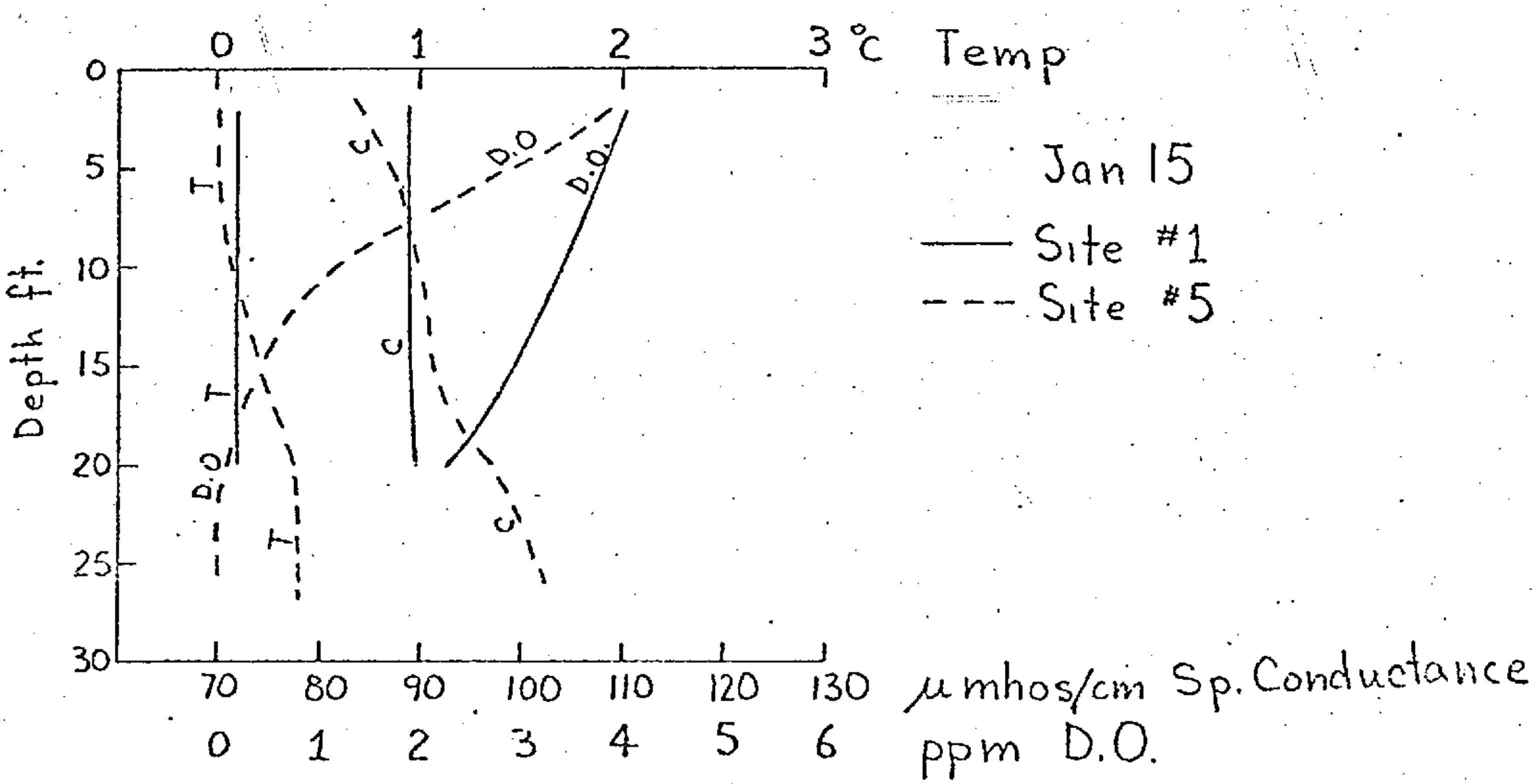

0 1 2 3 °C Temp
Depth ft.
0 5 10 15 20 25 30
T
C
D.O
D.O.
C
T
D.O
T
C
Jan 15
Site #1
Site #5
70 80 90 100 110 120 130 μmhos/cm Sp. Conductance
0 1 2 3 4 5 6 ppm D.O.

Fig. 36

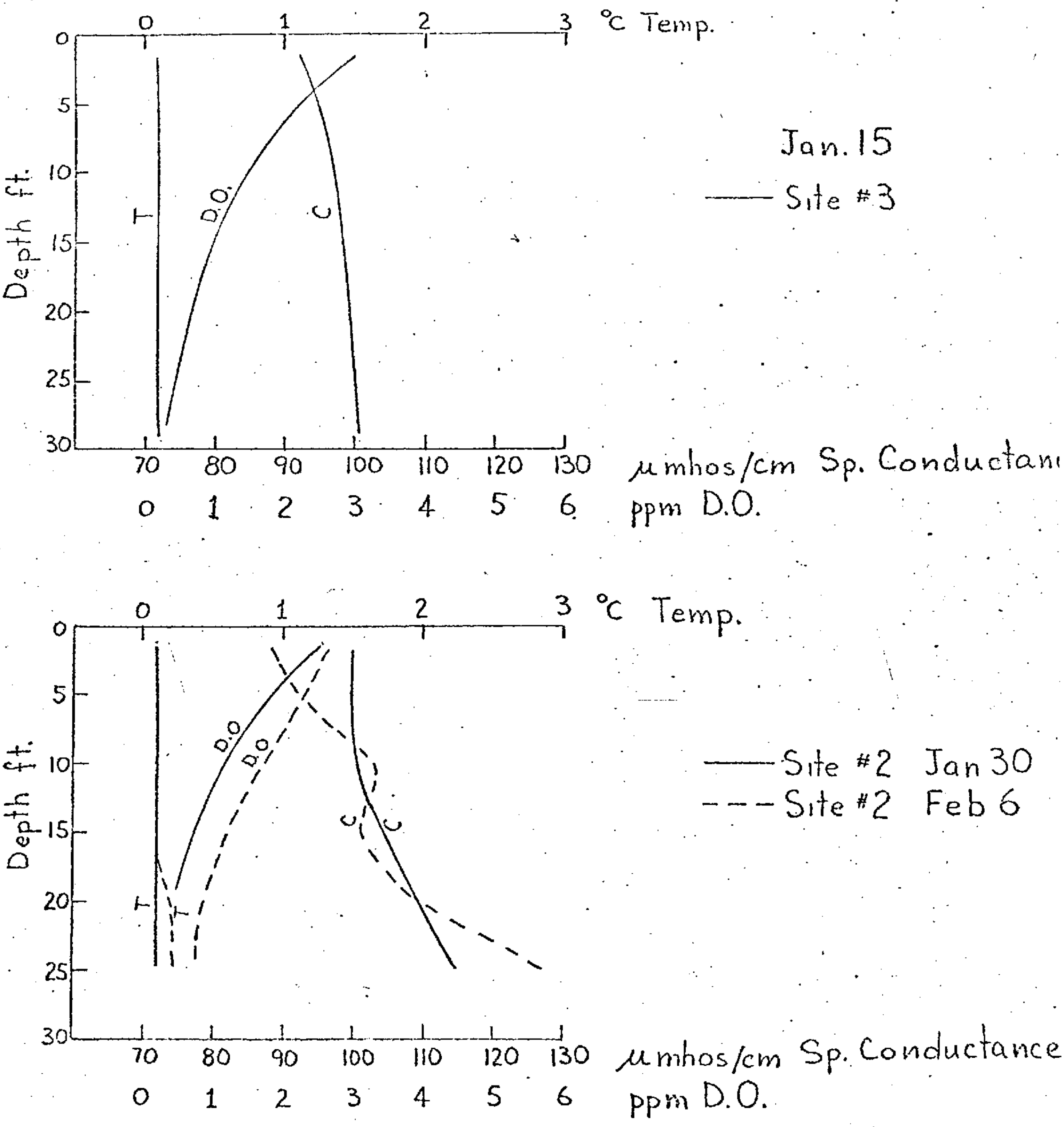
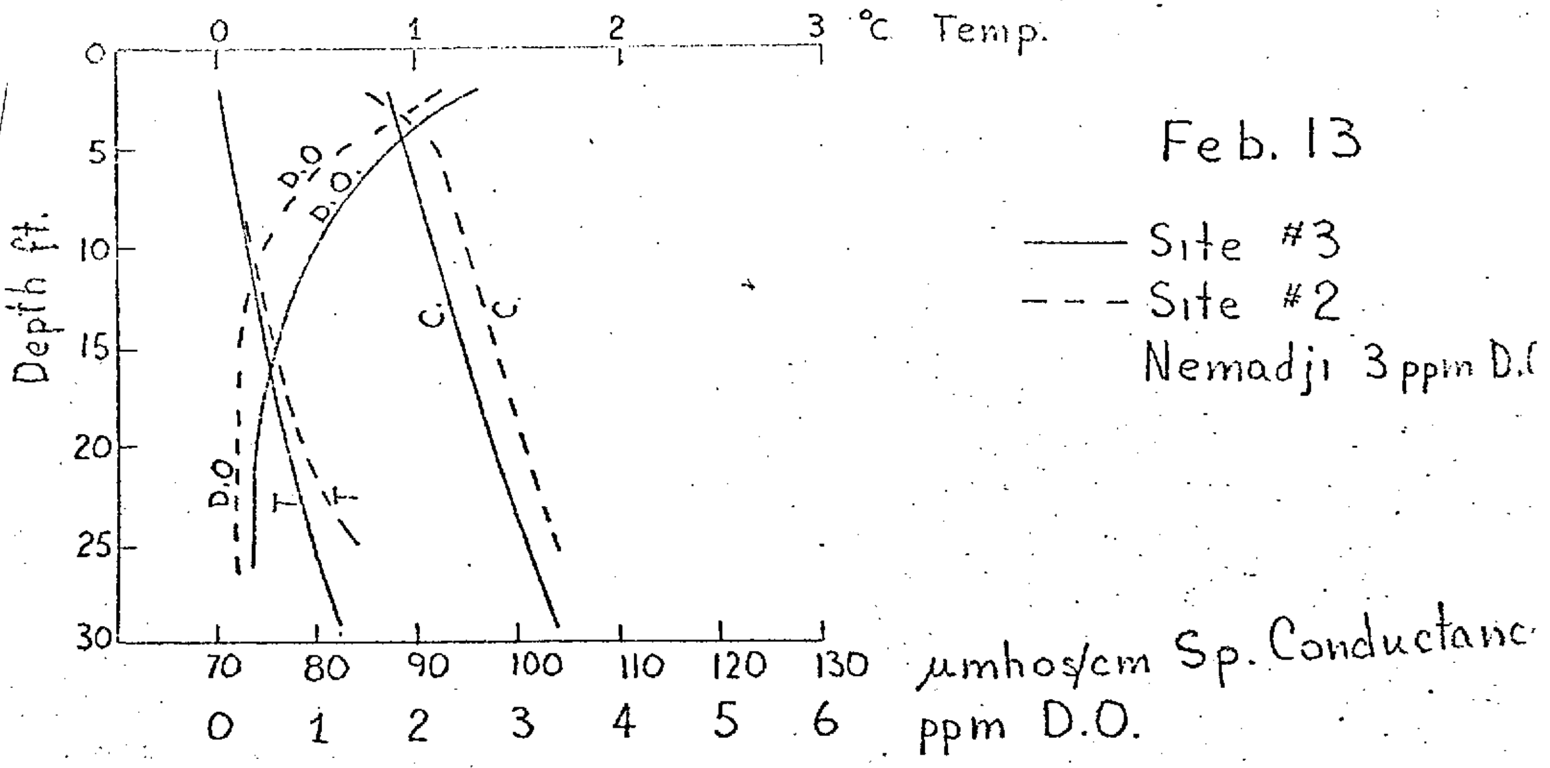

0
1
2
3
°C Temp.
0
5
10
15
20
25
30
Depth ft.
T
D.O.
C
70
80
90
100
110
120
130
μ mhos/cm Sp. Conductanc
0
1
2
3
4
5
6
ppm D.O.
Jan. 15
Site #3
0
1
2
3
°C Temp.
D.O
D.O
C
C
T
T
μ mhos/cm Sp. Conductance
ppm D.O.
Site #2 Jan 30
Site #2 Feb 6

Fig. 37


0 1 2 3 °C Temp.
Feb. 13
Site #3
Site #2
Nemadji 3 ppm D.O.
Depth ft.
0 5 10 15 20 25 30
D.O.
T
C
70 80 90 100 110 120 130 μmhos/cm Sp. Conductance
0 1 2 3 4 5 6 ppm D.O.

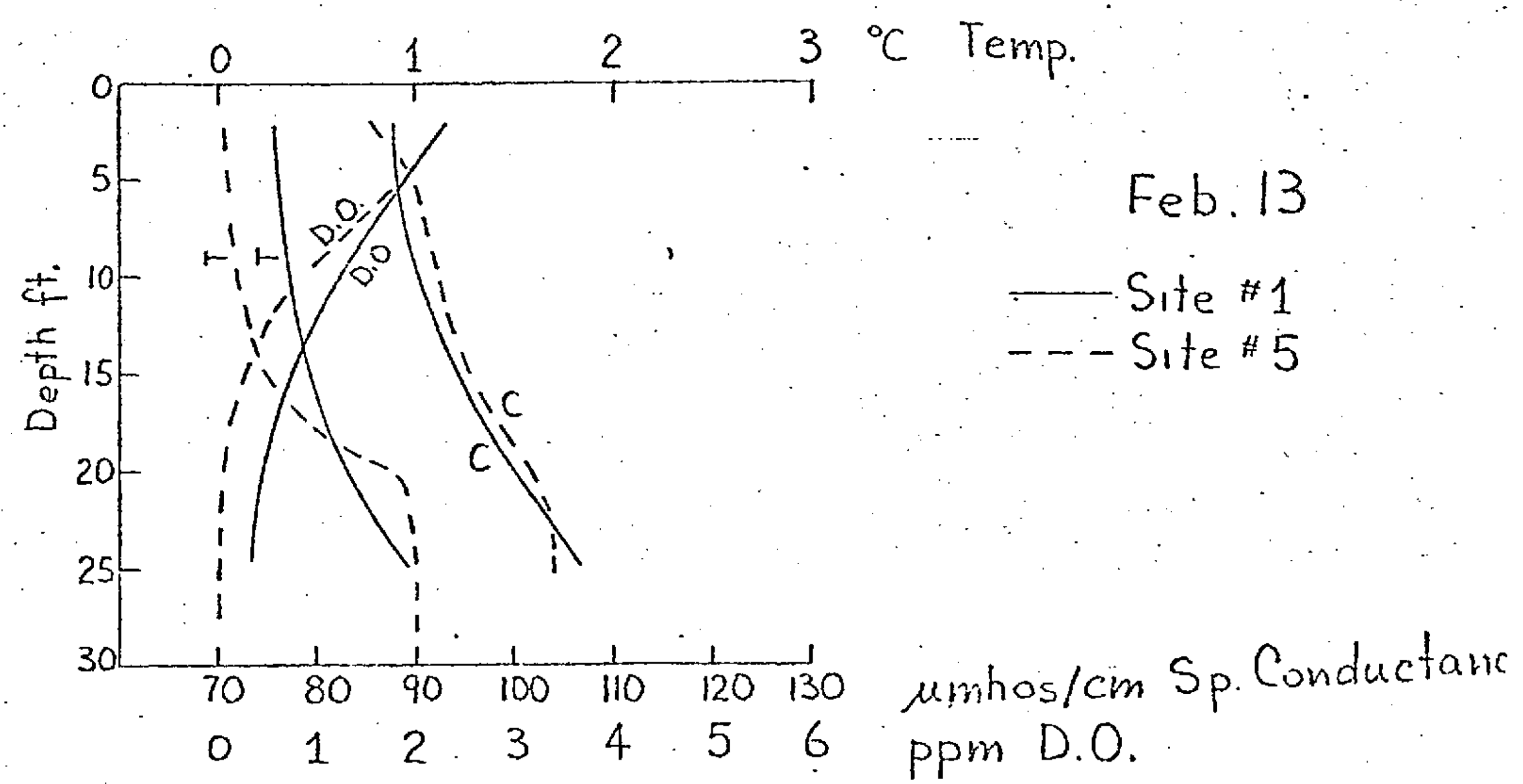

0 1 2 3 °C Temp.
Feb. 13
Site #1
Site #5
Depth ft.
0 5 10 15 20 25 30
D.O.
T
C
70 80 90 100 110 120 130 μmhos/cm Sp. Conductance
0 1 2 3 4 5 6 ppm D.O.

Fig. 38

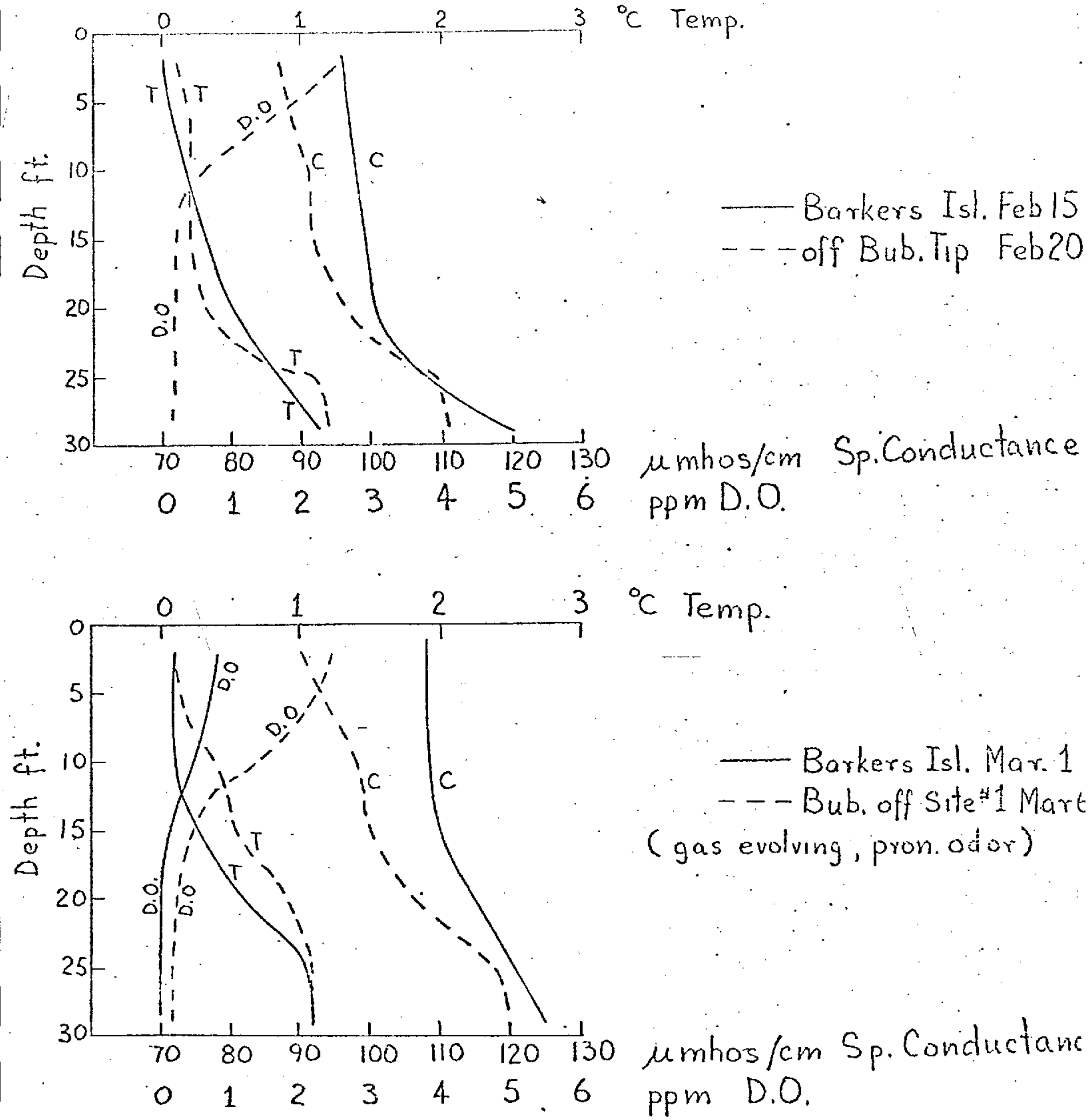

0
1
2
3
°C Temp.
0
5
10
15
20
25
30
Depth ft.
T
T
D.O
C
C
D.O
T
T
70
80
90
100
110
120
130
μmhos/cm Sp. Conductance
0
1
2
3
4
5
6
ppm D.O.
Barkers Isl. Feb 15
off Bub. Tip Feb 20
0
1
2
3
°C Temp.
0
5
10
15
20
25
30
Depth ft.
D.O
D.O
C
C
T
T
D.O.
D.O
70
80
90
100
110
120
130
μmhos/cm Sp. Conductanc
0
1
2
3
4
5
6
ppm D.O.
Barkers Isl. Mar. 1
Bub. off Site #1 Mart
(gas evolving, pron. odor)

Fig. 39

Summary of progress:

The studies for the past nine months have established the type of measurements which should be pursued in subsequent investigation of the year-round water transport in the western tip of Lake Superior and the St. Louis River bays.

Following is our plan for future studies.

Objectives:

Summer-Fall

1. Continuation of studies of the upwelling along the N.E. shore and the eddy currents at the tip of the lake with aid of ERTS images showing the turbidity plumes and patterns at the tip of the lake.

2. Continued investigation of water quality in the bays and investigation of the transport of effluents out of the harbor area into the lake and how these pertain to the water quality at the tip of the lake.

3. Investigation of the mixing processes in the Superior bay using the established parameters suitable in detecting mixing and the water current measurements at the entries. A new instrument for current measurements will be set up by the U. S. Army Corps of Engineers at both entries.

Winter

1. Study of winter currents in the lake through physical and chemical tracing of the effluents.

2. Study of ice growth, cover and ice packing in the lake tip area using ERTS images; and continuation of harbor ice studies together with the environmental effect of bubbler, should these be in operation again.

Plan of operation:

Summer-Fall

To establish further the nature of the upwelling along the North Shore for westerly winds, horizontal temperature gradient, and accompanying water velocity profile with depth will be monitored at Knife River site and a site in the vicinity of the Cloquet water intake.

To obtain quantitative data on the eddy current depth profiles for temperature, turbidity, water velocity, and the thermocline activities will be made at a site near the Cloquet intake and a point 6 miles directly N.E. from the station where the ERTS images show a northerly turnaround in the currents. The data will be then correlated with the ERTS data on turbidity plumes.

To produce quantitative data sufficient for analytical study of the eddy current, at least five continuously monitoring stations should be established at the tip of the lake. If our application to other agencies for the support of more extensive ground truth data collection is accepted, such station will be established. Under present conditions of manpower and instrumentation, however, only two regularly visited sites can be maintained.

During the times of rough sea conditions on the lake, the work on monitoring of water quality in the Superior bay and the St. Louis bay will be continued on the same basis as in the past. The data will be examined for influence of effluents on the water quality at the Cloquet intake, which will be continuously monitored by the city of Cloquet.

Two intensive 3 day studies consisting of continuous monitoring of water quality in the Superior bay and the water currents at the entries will be made to evaluate the mixing process in the bay. This material together with other measurements in the bays will serve the purposes of masters thesis for Mr. Kirby Stortz. A detailed operation plan is available should NASA require it.

Winter

Winter studies will be maintained at the 1972-73 level. The chemistry department at UMD will have complete their operational setup of the experiment this year so that the tracing of effluents by chemical means will add to our information of wintertime water transport in the lake and will identify further the cause of odor at the Cloquet intake. The local U. S. Army Corps of Engineers in going to install a year-round system for water current measurements at the entries. This should substantially aid us in studies of mixing processes in Superior bay. We had requested support for our wintertime studies from the EPA as we felt that the studies were germane to their interests, since three municipal water intakes are located at the tip of the lake. The agency has rejected our request.

Studies of the onset of ice cover and its growth in the western arm of Lake Superior will be pursued further. ERTS data for the ice cover will be used in relating the ice cover to the spring packing of ice at the tip of the lake.

As a part of our understanding of NASA's practice to serve the community, we enumerate the possible application of our work for the benefit of the community:

1. Work on water transport in the winter and summer is necessary to water users of the area. Currently all intakes experience some difficulty with water quality, though it is intolerable only at the Cloquet intake. That intake must either be relocated or a filtration must be provided designed with sufficient knowledge of water quality parameters for any further degredation in water quality at their intake. Such could for instance arise, should extensive bubbler systems be installed in the Superior bay for purposes of extension of shipping season.
2. The knowledge of water transport is also essential for purposes of determination of the effects of dumping of harbor dredging in the lake. In the past dredgings were disposed of at the tip of the lake. Such practice will resume in the future when the on land disposal sites are unavailable or too costly. It is anticipated that this will happen within the next 10 years because of limitations of the on land sites, and likely much sooner for economic reasons. By that time the ongoing program in pollution control should remove the dangerous pollutants from the harbor. However, there will always be considerable amounts of organic, fibrous material which could degrade the water at the intake if proper dumping sites are not selected. Dr. Keith Larson of the U. S. Army Corps of Engineers at Minneapolis is well aware of this problem and is considering our work as a part of the Corps long range program.

3. The winter studies on the bubbler operation and the work on ice conditions in the bay and the lake are useful to the shippers. Excellent program for monitoring overall ice cover on the lake exists and will improve with ERTS program. However, quantitative data on ice growth at the tip of the lake is sparce. The study of ice conditions in the harbor and ice growth and packing at the tip of the lake is important to the proposed extension of the shipping season.

Involvement in community:

1. We have had close cooperation from the Cloquet City Engineer, Mr. Bruce Boyer, in use of their facility and exchange of information on their problem with water quality at their intake.
2. This year we will be involved to a limited extent with the harbor dredging program through the National Biocentrics Corporation and the U. S. Army Corps of Engineers.
3. Our winter studies on bubbler have been made in cooperation with the Biocentric Corporation and the local U. S. Army Corps of Engineers, the local office under Mr. Clarence Wang.
4. The monitoring of water quality on St. Louis River and its bays is a cooperative program with Mr. A. Biele, the chemist at the Lakewood Pumping Station for Duluth. He is responsible for most of the chemical analysis of the samples.

I wish to thank Mr. Clarence Wang; Mr. Bruce Boyer, and Mr. Art Biele, and their personnel, for their advice and cooperation on this project. I would also like to thank Dr. Ted Odlaug and Dr. Ted Olson for their discussions, guidance, encouragement, and the use of their research facilities. Finally, I would also like to thank my students, Kirby Stortz and James Rohlf for helping me out in the task of data collection.

CONTENT PAGE

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JOURNAL OF ECONOMIC ENTOMOLOGY

Aerial Photography: Use in Detecting Simulated Insect Defoliation in Corn[1]

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ABSTRACT

Artificial defoliation in corn was used to explore the usefulness of aerial photography in detecting crop-insect infestations. Defoliation on top of plant was easily detected, while that on the base was less so. Aero infrared film with Wratten 89B filter gave the best results, and morning flights at the scale of 1:15840 are recommended. Row direction, plant growth stage, and time elapse since defoliation were not important factors.

Larvae of both armyworms, *Pseudaletia unipuncta* (Haworth), and grasshoppers defoliate corn plants. Information on the amount of leaves destroyed is useful in assessing potential crop losses, and assists in estimating the levels of pest populations involved. To obtain such information by ground checking requires considerable labor and time. Time is particularly crucial because early availability of this information is essential for preparing plant-protection measures.

Aerial photography has been used in various aspects of agriculture (Brenchley 1968). Work has been done on forest insects (Heller et al. 1959, Bajzak 1966, Wert and Roettgering 1968, Harris 1971); range insects (Meyer and Woolfolk 1967); and fruit insects (Hart and Myers 1968). No information is available on detecting cereal-crop-insect infestations.

We explored the usefulness of aerial photography in this latter respect. The work was done on the Rosemount Experiment Station of the University of Minnesota in Rosemount in 1970 and 1971.

GENERAL METHODS.—*Aerial Photography and Image Analysis.*—Multiband reconnaissance equipment of the University of Minnesota, College of Forestry, in the form of a 70-mm quadricamera unit and a photo aircraft, were used. The film-filter combinations, photo scales, overflight times, and film enhancement procedures used in 1970 and 1971 follow.

	1970	1971
Film/filter combination		
Ektachrome MS/Wratten 2A		×
Ektachrome Infrared/Wratten 12	×	×
Ektacolor/Wratten 2A		×
Panchromatic Plus-X/Wratten 8		×
Panchromatic Plus-X/Wratten 58	×	
Panchromatic Plus-X/Wratten 25A	×	
Aero Infrared/Wratten 89B	×	×
Photo scale		
1:4000	×	
1:6336		×
1:12000	×	
1:15840		×
1:31680		×
Time of flight (CST)		
0900–1000	×	×
1100–1200	×	
1300–1400	×	
Film enhancement procedures		
I^2S Mini-Addcol	×	×
I^2S Digicol Viewer	×	
Photo-optical Density Slicing	×	
ISI VP-8 Image Analyzer		×

To insure that all possible photographic characteristics were considered, both multiband and Ektachrome infrared transparencies were subjected to various types of enhancement (Meyer and Chiang 1971): (1) the 1970 70-mm multispectral (three) positive transparencies were optically combined through component filters by means of the engineering prototype of the I^2S (International Imaging System) Additive Color (Addcol) viewer; the current model 6030 Mini-Addcol combiner was used for analysis of the 1971 multispectral imagery; (2) the 1970 Ektachrome infrared transparencies were enhanced through a process of color separation using a photo-optical density-slicing technique; the resulting isodensity image (10 levels) was then reproduced in 3M Color Key, registered, and mounted; (3) one of the better Plus-X/Wratten 25A 1970 season transparencies was evaluated with the I^2S 4000 Digicol viewer; (4) the Jul. 31, 1971, Aero Infrared/Wratten 89B transparency was enhanced on the ISI VP-8 Image Analyzer.

Field Plots.—Two fields, P-10 and A-15, were used in 1970, and one, P-10, was used in 1971 (Fig. 1). The general area has Waukegon silt loam type of soil. Some characteristics of the crop and planting, and information on defoliation follow.

	1970	1971
Row direction in the field		
E–W (field P-10)	×	×
N–S (field A-15)	×	
Row width	30 in.	30 in.
Plant population (no. plants per acre)		
Field P-10	19,250	20,666
Field A-15	21,000	
Corn variety		
Field P-10	Pfister SX-3935	Pioneer 3784
Field A-15	Funks 4222	
Defoliation levels		
(a) 0 leaves removed (control)	×	×
(b) 2 basal leaves removed		×
(c) 4 basal leaves removed	×	×
(d) 6 basal leaves removed		×
(e) 8 basal leaves removed	×	
(f) 2 top leaves removed		×

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[2] Professor, Department of Entomology, Fisheries, and Wildlife; formerly Research Fellow; and Professor, College of Forestry, University of Minnesota, respectively.

(g) 4 top leaves removed		X
(h) 6 top leaves removed		X
(i) 4 basal leaves removed on alternate plants		X
(j) 4 alternate leaves removed		X
Number of replicates in each field	6	2
Plot size	24 rows X 75 ft.	24 rows X 75 ft.
Subplot size	8 rows X 25 ft.	8 rows X 25 ft.
Dates of defoliation/no. extended leaves at that time	Aug. 14/16 Aug. 21/16	July 10/11 July 26/13 Aug. 3/16
Dates of flights/days after defoliation	Aug. 24/13 Aug. 24/10	July 20/1 July 27/1 and 8 July 31/5 and 12 Aug. 4/1, 9 and 16

PROCEDURES AND RESULTS.—*1970 Study*.—Artificial defoliation was to be done late in July, the usual time when armyworm larvae invade corn fields under Minnesota conditions, but it was delayed until Aug. 14 and 21 because of weather problems and aircraft availability. Flights were made Aug. 24. The plants had reached their maximum height with approximately 16 leaves, and the silk was in the drying stage. Two levels of defoliation were made, 4 and 8 basal leaves were removed, both simulating armyworm larval feeding. The 2 levels and a control were each replicated 3 times within a plot. All leaves removed from the plants were hauled off the plots. Flights were made in the forenoon, at noon, and in the early afternoon.

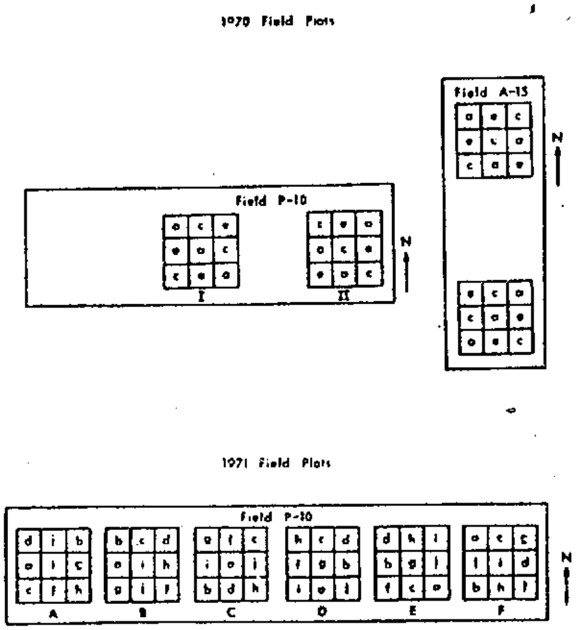

FIG. 1.—Fields in 1970 and 1971, showing types of defoliation (a–j, see text).

The transparencies were examined both with unaided vision and under magnification. On all film-filter combinations, and at both scales, defoliation level e was clearly visible with or without magnification (Fig. 2). This high degree of visibility was due to 2 factors: (a) stress caused by removal of approximately ½ of the leaves on each plant, and (b) somewhat increased vertical exposure of the soil. In no case was defoliation level c visible on the original photographs. This was not particularly surprising in view of the probable lack of effect of this relatively light defoliation upon plants so near maturity.

The 3 enhancement procedures described earlier were applied to the transparencies. None made defoliation level c visible. However, with the I²S Addcol viewer, the visibility of defoliation level c was improved, and other features such as crop maturity differentials, drainage patterns, compaction due to past animal trailing, were realized. With the I²S 4000 Digicol viewer, details discernible on the original imagery became much more visible to the unaided eye.

The results showed several points of methodological importance: (1) row direction, E-W or N-S, did not influence over-all pictoral quality and rendition; (2) the quality of forenoon photography was the best, afternoon the next, and noon the poorest; (3) the 8-row plots were large enough for experimentation; (4) replications within a block were not necessary.

1971 Study.—Since 1970 results showed that E-W and N-S row directions did not make any difference, only 1 field (P-10) was used in 1971. We photographed only in the forenoon and replications were reduced to 2. But more types of defoliation below the level of 8 leaves removed were studied: 2, 4, and 6 basal leaves were removed, simulating armyworm larval feeding; 2, 4, and 6 top leaves were removed, simulating grasshopper feeding; and 4 basal leaves were removed on alternate plants, and every other leaf on the plant (4 leaves in total) was removed. The last 2 types are to simulate lighter levels of insect infestation.

Defoliations were done July 19, July 26, and Aug. 3, when plants had 11, 13, and 16 leaves, respectively. Tassels were out Aug. 3. Flights were made July 20, 27, 30, and Aug. 4. Thus photographs were taken at 3 stages of plant maturity, and from 1 to 16 days after defoliation.

Transparencies were viewed under stereomagnification. As shown in Fig. 1, there were 9 subplots with 8 different types of defoliation and a control. The subplots showing colorations lighter than the field in general were noted. The lightest was assigned a rating of 1, the next lightest 2, and so on. A subplot did not have a rating if it was not distinguishable from the field in general. In a given plot, there might be 2 subplots showing the same degree of lightness, and they were assigned the same rating. Thus in a plot there could be more than one subplot rated 1, or 2, or 3. It should be noted that the subplot rated 1 in a given plot might not be of the same lightness as that in another plot.

During the process of evaluation, the levels of defoliation were not made known. Two persons viewed the transparencies and made evaluations independently, and produced similar results.

Table 1 includes data to compare the 4 film-filter combinations and three time lapses at the photo scale of 1:15840. The film-filter combination Aero Infrared/Wratten 89B gave the best quality. More subplots were distinguished (see figures in the right hand column) with that combination than with the others. There

Table 1.—Ratings of different types of defoliation with 3 time lapses, and 4 film/filter combinations (photo scale 1:15840).

Date of defoliation	Date of flight	No. days lapsed	Film/filter combination	Rep.	Plot	Subplots (defoliation levels) a	b	c	d	e	f	g	h	i	j	No. subplots rated lighter than general field
Aug. 3	Aug. 4	1	Aero Infrared/	I	B				1			3	2		3	8
			Wratten 89B	II	A				3			2	1		3	
			Ektachrome Infrared/	I	B						1					3
			Wratten 12	II	A							2	1			
			Ektachrome MS/	I	B						1					3
			Wratten 2A	II	A							2	1			
			Ektacolor/	I	B						1					3
			Wratten 2A	II	A							2	1			
July 26	Aug. 4	9	Aero Infrared/	I	E	3	4	4	3		4	2	1			10
			Wratten 89B	II	C						2	3	1			
			Ektachrome Infrared/	I	E	3					4	2	1			6
			Wratten 12	II	C							2	1			
			Ektachrome MS/	I	E	2									1	4
			Wratten 2A	II	C							1	1			
			Ektacolor/	I	E							2	1			4
			Wratten 2A	II	C							1	1			
July 19	Aug. 4	16	Aero Infrared/	I	F						3	2	1	3	3	9
			Wratten 89B	II	D						2	2	1		3	
			Ektachrome Infrared/	I	F					3	3	2	1			7
			Wratten 12	II	D						2	3	1			
			Ektachrome MS/	I	F								1			1
			Wratten 2A	II	D											
			Ektacolor/	I	F						2		1			3
			Wratten 2A	II	D								1			

were no consistent differences among the 3 time lapses of 1, 9, and 16 days.

Table 2 is organized to compare the effects of 3 factors on the photographic resolution of the different levels of defoliation. The 3 factors are: (1) degree of plant maturity as reflected by the date on which defoliation was made, (2) time lapse as reflected by the number of days between defoliation and flight, and (3) photo scale. The data include only the film-filter combination of Aero Infrared/Wratten 89B, since this gives the best photographic quality. Unfortunately, mechanical problems during the scale III flight on July 20 ruined the photography.

Comparisons can most readily be made by examining the number of times the subplots received ratings. The figures in the 1st and 3rd columns on the left reflect the effect of plant growth stage when defoliation was made (1st column) and the time lapse between defoliation and flight (3rd column). Figures in the last column on the right show no consistent differential result from these 2 factors.

The figures in the next to the bottom row reflect the effect of photo scale and type of defoliation. Scales 1:6336 and 1:15840 were about equal in clarity, while 1:31680 was less clear. The bottom row gives the overall detectability of the types of defoliation based on frequency of being rated and values of the ratings. The 3 types most consistently detected, in order of coloration contrast are h, g, and j. The next types are d and f. The least detected were b, c, i, and a. The differential among these was slight and accuracy of detection very low; as reflected by the fact that level a, which is the control with no leaves removed, was given a rating on 3 occasions, although all at low levels of lightness. It should be mentioned, however, that there was no such confusion at the scale of 1:6336.

PRACTICAL IMPLICATIONS.—The 2 years' results have the following implications which are of practical significance in using aerial photography for detecting defoliation:

1. Defoliation in corn may be detected with reliability regardless of row-direction.
2. Detection is feasible within one day after defoliation; it is not necessary to wait for intensive plant stress.
3. Detection is feasible when plants are at the 11-leaf stage through tasseling.
4. The scale of 1:6336 gave most reliable detection, but considering the economics, the scale of 1:15840 is to be recommended.
5. Aero Infrared film with Wratten 89B filter gave the best results among the 7 combinations tested.
6. Morning flights are recommended.
7. Defoliation on top of plant is easier to detect than that on the basal part of the plant.

The artificial removal of corn leaves in square plots probably is easier to detect amid normally growing corn fields than natural infestations. It is probable that corn earworm or armyworm infestations would be more uniform over corn fields, and the contrast levels would be more difficult to define. One other factor which was not involved in this test, because leaves were artificially removed, is the likelihood that grasshoppers or armyworms would not consume entire corn leaves. Partially consumed leaves would probably change color and be better detected with normal color or color infrared film than by infrared film with an 89B filter.

Our next step will be to test the potential of the method in fields with real armyworm and/or grasshopper infestations. The information is published now with the hope that the method can be tested by entomologists elsewhere when the opportunity arises.

ACKNOWLEDGMENT.—Funding for the final image enhancement and analysis by NASA's Office of University Affairs (Proj. NGL-24-005-263) is gratefully acknowledged.

Table 2.—Ratings of different levels of defoliation with 3 scales, 3 plant stages, and 6 time lapses (film/filter combination—Aero Infrared/Wratten 89B).

Date of def.	Date of flight	No. days lapsed	Rep.	Plot	Scale I (1:6336) sub-plots (defoliation levels)									Scale II (1:15840) sub-plots (defoliation levels)									Scale III (1:31680) sub-plots (defoliation levels)									No. sub-plots rated lighter than general field
					a	b	c	d	f	g	h	i	j	a	b	c	d	f	g	h	i	j	a	b	c	d	f	g	h	i	j	
7/19	7/20	1	I	F				3		2	1		3				3		2	1		3	No photographs taken									18[a]
			II	D				2	3	2	1		2				3	3	2	1		3	No photographs taken									
7/26	7/27	1	I	E				3		2	1		3		3				2	1		3							1			
			II	C				2		3	1		3			3	2		2	1		2	2						1		2	21
8/3	8/4	1	I	B				2		3	1		3				1		3	2		3				2			1		3	
			II	A				3		2	1		3				3		2	1		3	2				2		1	2		23
7/26	7/31	5	I	E			3	3	3	2	1	4	3				4		2	1	3	4		3			3	2	1		3	
			II	C				2		2	1		3				2		2	1		3						2	1		2	28
7/19	7/27	8	I	F						2	1		3						2	1								2	1			
			II	D				3		2	1		3				2	2	1	1		1						2	1		2	19
7/26	8/4	9	I	E				3	3	2	1		3	3	4	4	3	4	2	1							3	2	1			
			II	C				3		2	1		3					2	3	1						3	3	2	1			26
7/19	7/31	12	I	F				4	4	2	1		3				4		2	1		3				3		2	1		3	
			II	D				3	4	2	-1		3		3		2	3	2	1		2					2	2	1			27
7/19	8/4	16	I	F						2	1		3					3	2	1	3	3						1	2			
			II	D						2	1		3					2	2	1		3					2	3	1			20
No. sub-plots rated lighter than general field[b]					0	0	1	13	5	16	16	1	16	1	3	2	11	7	16	16	2	13	2	1	0	3	6	10	14	1	6	
Overall rating					9	8	7	4	5	2	1	6	3	9	6	8	4	5	2	1	7	3	6	8	9	5	4	2	1	7	3	

[a] Only Scales I and II are included. Others include Scales I, II, and III.
[b] Scales I and II include 8 groups, Scale III includes 7 groups.

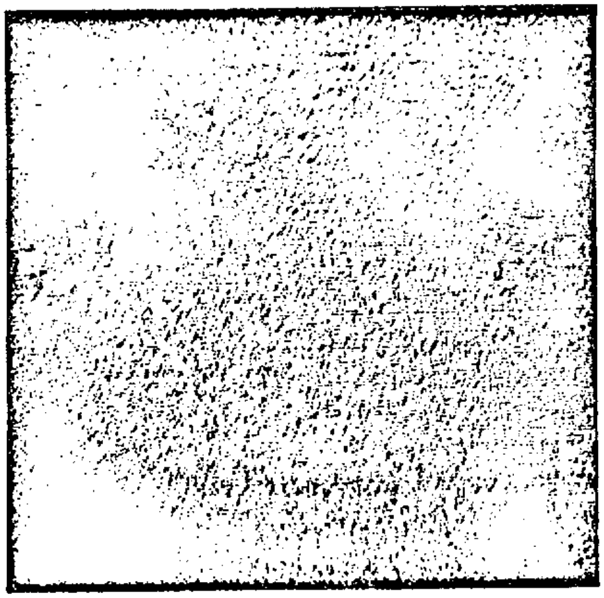

Plate A

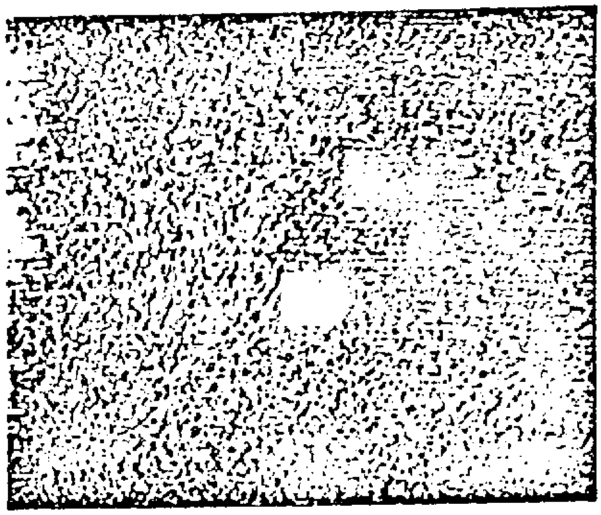

Plate B

FIG. 2.—*Plate A*, Optical combiner view of the 1970 Plus-X/Wratten 58, Plus-X/Wratten 25A and Aero Infrared/Wratten 89B transparencies of Plots I (left) and II. *Plate B*, Digicol Analyzer view of the portion of the Plus-X/Wratten 25A transparency showing Plot II. Original negative scale = 1:4,000; north is at top of page.

Plate A

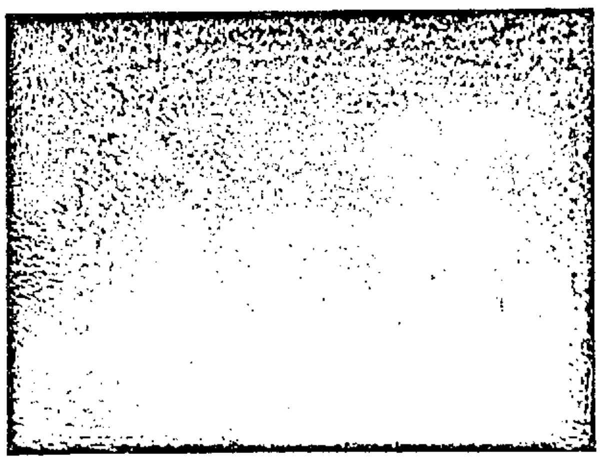

Plate B

FIG. 3.—*Plate A*, Optical combiner view of the July 31, 1971, Plus-X/Wratten 8 and Aero Infrared/Wratten 89B transparencies of Plots C, D, E and F (from left to right). Plot F is only partially shown. *Plate B*, VP-8 Image Analyzer view of the Aero Infrared/Wratten 89B transparency of Plots C, D, E and F (also from left to right). Plots C and D are being adversely affected by vignetting at the edge of the 70 mm transparency. Original negative scale = 1:6,336; north is at top of page.

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N73-32269

"Feasibility of Detecting Major Air Pollutants by Earth-Oriented Satellite-Borne Sensors."

Investigators: Dr. Harold J. Paulus, David W. Hoffman,
Department of Environmental Health

To further aid in the evaluation of air pollution in the Minnesota area, ERTS-1 MSS imagery are being sought for areas where enormous sources of air pollution are present. The identification and densitometric examination of air pollutants, especially suspended particulates, should help to evaluate the lesser sources of air pollution in Minnesota.

Contrast reductions over the metropolitan areas are being examined for possible construction of isopleths of particulate matter, and for correlation with air pollution index values from local measurements.

Data sources from which atmospheric parameters are directly available are the Minnesota Pollution Control Agency, Minneapolis Air Pollution Control Division, St. Paul Air Pollution Control Division and local meteorological stations.

The examination of pollution injury to vegetation (crops and forests) in the area of air pollution sources will be evaluated.

The capabilities of the ERTS-1 MSS imagery relative to air pollution will soon be presented to the Minnesota Pollution Control Agency and other local agencies concerned with air pollution.

N73-32270 [78]

USE OF REMOTE SENSING IN THE ANALYSIS OF SNOWMELT FLOODS

by

C. Edward Bowers

I Introduction

The objective of this study is the evaluation of remote sensing data and particularly ERTS Imagery as an aid to the determination of percent snow cover and possibly water content of snow on the ground. This information is of interest in the application of some mathematical simulation models to the forecasting of spring snowmelt floods.

The largest floods of record for most areas in Minnesota have usually occurred in the spring and consist in whole or in part of snow melt runoff. Thus, in attempts to predict the magnitude and timing of the spring floods it is necessary to obtain data on the snowpack during late winter and early spring. If small areas are of interest, it is relatively easy to make field measurements of water content and estimates of percent snow cover. However, the primary problems usually develop in the 16,200 square mile Minnesota River Basin, the 19,100 square mile area of the Mississippi River above Anoka or combinations of these two areas and a downstream segment for a total of 59,200 square miles. A similar problem exists for 40,000 square miles of the Red River of the North Basin. Thus, data collection for areas of this magnitude can be formidable.

Currently, field sampling of the water content of snow at 60 locations in Minnesota, North Dakota and Wisconsin provide some data on water content of snow. (This corresponds to 1 measurement for about 1500 square miles.) Information on percent snow cover is not generally available.

II - Current Research

Studies of snowmelt flood analysis in the upper midwest are currently underway at the St. Anthony Falls Hydraulic Laboratory, Department of Civil and Mineral Engineering, University of Minnesota. The studies sponsored by OWRR involve fitting of a mathematical simulation model to the Minnesota River Basin, using available hydrologic data for past years. The model, involving about 8,000 input statements, requires information on water content of snow and percent snow cover as well as river discharge, precipitation, temperature and related variables. Snow melt can be computed on a continuous basis either by a degree-day or temperature method, or an energy basis involving solar radiation as well as temperature. The model computes the melt and the balance of snow in storage but must be provided with a relationship between water content of snow and percent snow cover. Figure 2 illustrates one simple relationship; this assumes that if the snow water-content is greater than 1 inch, there is 100% snow cover, with a linear relationship between 0 and 1 inch. This has not been verified and is the area in which remote sensing, applied to the 16,200 square mile basin should be helpful. Figure 3, shows part of the print-out of the model and Figures 4 and 5 show computed or simulated discharge compared to observed discharge. The results for the Pomme de Terre River (1967) Figure 4, are good. The agreement for the Minnesota River at Jordan (Figure 4) and the Chippewa River (1969), Figure 5, indicate the need for improvement.

It is hoped that the ERTS Imagery for the Minnesota Basin in late winter and early spring will provide a sound basis for estimating percent snow cover over the large areas involved in the mathematical simulation study. However, there is no reason to limit the ERTS study to the Minnesota Basin. Since field data on water content are available for all of Minnesota and parts of Wisconsin and North Dakota, these additional areas will also be considered and possibly used in the study.

Flood damages in Minnesota amounted to $92,000,000 in 1965 and $77,000,000 in 1969, two of our worst flood years. Annual flood damages are on the order of 10 to 15 million dollars. Research studies plus flood plain management should help to reduce these figures.

Fig. 1 - Shaded area shows location of the Minnesota River watershed relative to Minnesota and surrounding states

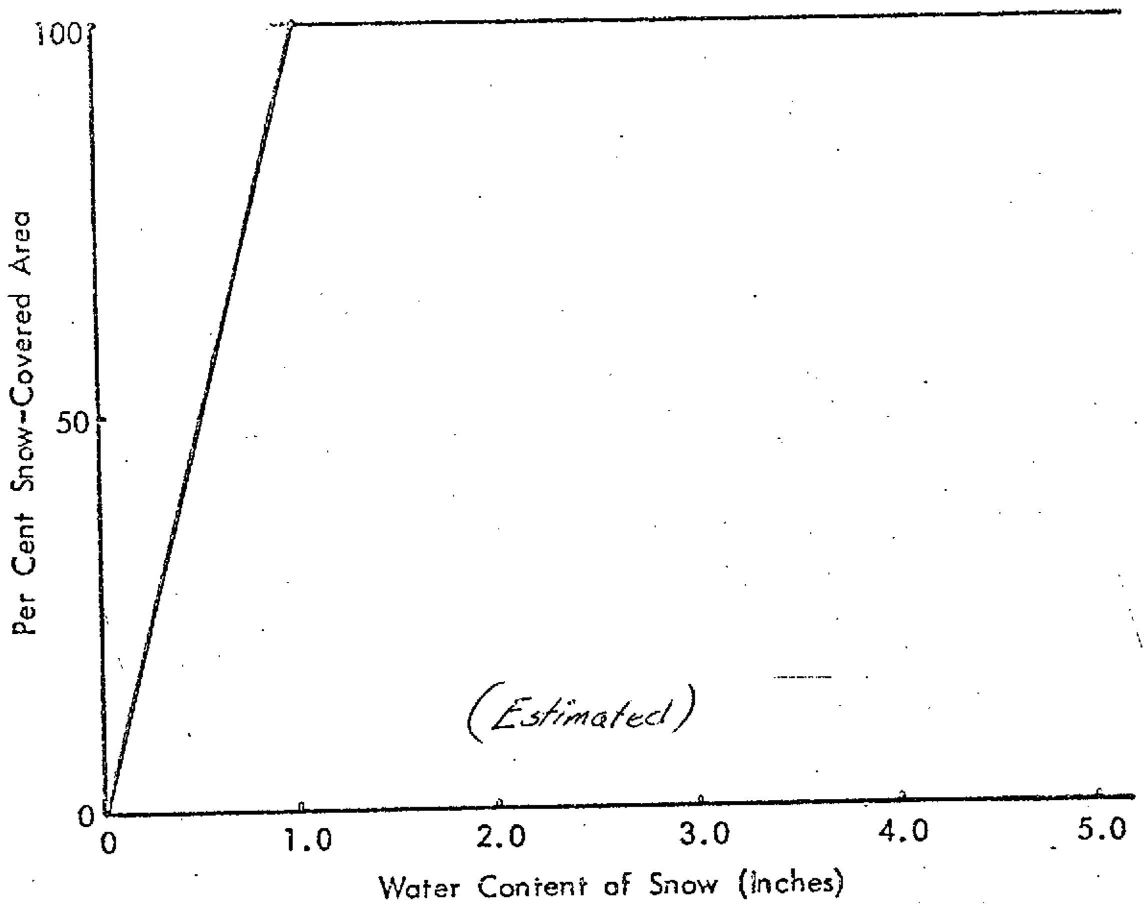

Fig. 2. Snow-Covered Area as a function of Water Equivalent in Snowpack

BASIN RESULTS - STATION [illegible] CHIPPEWA RIVER SNOW

135454 RUN DATE RUN NO. INITIAL DATE, HOUR JOB DESCRIPTION N.P.D., CORPS OF ENGINEERS
-0 10 MAR 1969 00 -MINNESOTA RIVER WATERSHED 1969

ETI = .10 IN./DAY, MELT RATE = .010 IN./DEGREE-DAY, AREA = 1870.0 SQ. MI.

April!

DAY	HOUR	PCPN	IRA	RN-AR	ML-AR	IAR	ELEV	SCA	D-DY	IMA	MELT	MI	SMI	ROP	RGP	BII	BFP	BASEF	SUBSF	SURF	DISCH	HOUR	DAY
APR 1969																					APR 1969		
1	00	.01	0	.05	.05	1	990	100	0.0	0	0.00	0.00	0.00	35	0.00	.10	22	18	77	156	256	00	1
2	00	0.00	100	.05	.10	1	990	100	5.0	100	.05	.05	0.00	35	.02	.10	22	19	75	153	249	00	2
3	00	0.00	0	.05	.10	1	990	100	0.0	0	0.00	0.00	0.00	35	0.00	.09	23	21	78	160	260	00	3
4	00	0.00	100	.05	.15	2	990	100	5.0	100	.05	.05	0.00	35	.02	.09	23	22	83	170	275	00	4
5	00	0.00	100	.05	.21	3	990	100	6.0	100	.05	.05	0.00	35	.02	.09	23	24	103	212	340	00	5
6	00	0.00	100	.05	.23	3	990	100	2.5	100	.02	.07	0.00	35	.01	.09	23	26	120	247	395	00	6
7	00	0.00	100	.05	.29	4	990	100	5.0	100	.05	.05	0.00	35	.02	.09	23	29	132	271	433	00	7
8	00	.20	100	.12	.44	6	990	100	16.0	100	.16	.35	0.00	35	.13	.09	23	33	224	450	717	00	8
9	00	.67	100	.35	.63	8	990	100	19.0	100	.19	.86	.13	35	.30	.09	23	46	541	1160	1696	00	9
10	00	.35	100	.42	.78	10	990	100	15.0	100	.15	.51	.59	35	.18	.10	23	66	960	1900	2995	00	10
11	00	.01	100	.42	.88	12	990	100	10.0	100	.10	.11	.82	35	.04	.09	23	88	1194	2447	3731	00	11
12	00	.02	100	.45	1.03	14	990	100	13.0	100	.15	.17	.80	35	.06	.09	23	109	1234	2534	3880	00	12
13	00	.03	100	.50	1.35	18	990	100	23.0	100	.32	.35	.81	35	.12	.09	23	131	1246	2554	3933	00	13
14	00	.07	100	.52	1.85	25	990	100	29.0	100	.50	.57	.93	35	.20	.10	23	156	1340	2746	4243	00	14
15	00	.09	100	.55	2.70	36	990	100	22.0	100	.85	.94	1.21	35	.33	.10	23	188	1607	3297	5093	00	15
16	00	.04	100	.57	4.38	58	990	100	21.0	100	1.68	1.72	1.72	35	.61	.12	22	233	2183	4553	6971	00	16
17	00	0.00	100	.57	5.98	80	990	100	20.0	100	1.60	1.60	2.73	35	.56	.13	22	295	2981	6342	9619	00	17
18	00	0.00	33	.57	7.17	96	990	34	15.0	100	1.25	1.20	3.67	35	.42	.17	22	367	3676	7876	11945	00	18
19	00	0.00	0	.57	7.52	100	1003	0	13.0	33	1.04	.35	5.89	35	.12	.16	21	439	3955	8515	12912	00	19
20	00	.01	0	.57	7.52	100*0000		0	0.0	0	0.00	0.00	5.79	35	0.00	.16	21	504	3726	8027	12258	00	20
21	00	.02	0	.57	7.52	100*0000		0	0.0	0	0.00	0.00	5.69	35	0.00	.15	21	559	3210	6910	10689	00	21
22	00	0.00	0	.57	7.52	100*0000		0	0.0	0	0.00	0.00	5.59	35	0.00	.15	21	607	2624	5656	8869	00	22
23	00	0.00	0	.57	7.52	100*0000		0	0.0	0	0.00	0.00	5.49	35	0.00	.14	21	647	2072	4467	7187	00	23
24	00	0.00	0	.57	7.52	100*0000		0	0.0	0	0.00	0.00	5.39	35	0.00	.14	21	680	1596	3442	5720	00	24
25	00	.02	0	.57	7.52	100*0000		0	0.0	0	0.00	0.00	5.29	35	0.00	.14	22	708	1207	2604	4521	00	25
26	00	.03	0	.57	7.52	100*0000		0	0.0	0	0.00	0.00	5.19	35	0.00	.13	22	729	900	1942	3574	00	26
27	00	.58	0	.57	7.52	100*0000		0	0.0	0	0.00	0.00	5.09	35	0.00	.13	22	746	664	1432	2844	00	27
28	00	.56	0	.57	7.52	100*0000		0	0.0	0	0.00	0.00	4.99	35	0.00	.12	22	759	486	1046	2291	00	28
29	00	0.00	0	.57	7.52	100*0000		0	0.0	0	0.00	0.00	4.89	35	0.00	.12	22	767	351	759	1679	00	29
30	00	0.00	0	.57	7.52	100*0000		0	0.0	0	0.00	0.00	4.79	35	0.00	.12	22	772	253	546	1573	00	30

Melt

Percent of snow covered area (computed).

Computed stream discharge

BASIN RESULTS - STATION 5700.0 CHIPPEWA RIVER RAIN

135460 RUN DATE RUN NO. INITIAL DATE, HOUR JOB DESCRIPTION N.P.D., CORPS OF ENGINEERS
-0 10 MAR 1969 00 -MINNESOTA RIVER WATERSHED 1969

ETI = .10 IN./DAY, MELT RATE = 0.000 IN./DEGREE-DAY, AREA = 1870.0 SQ. MI.

DAY	HOUR	PCPN	IRA	RN-AR	ML-AR	IAR	ELEV	SCA	D-DY	IMA	MELT	MI	SMI	ROP	RGP	BII	BFP	BASEF	SUBSF	SURF	DISCH	HOUR	DAY
APR 1969																					APR 1969		
1	00	.01	0	0.00	0.00	0	0	0	0.0	0	0.00	0.00	5.16	85	0.00	.10	45	8	0	0	9	00	1
2	00	0.00	0	0.00	0.00	0	0	0	0.0	0	0.00	0.00	5.12	85	0.00	.10	45	8	0	0	9	00	2
3	00	0.00	0	0.00	0.00	0	0	0	0.0	0	0.00	0.00	5.02	85	0.00	.09	45	8	0	0	9	00	3
4	00	0.00	0	0.00	0.00	0	0	0	0.0	0	0.00	0.00	4.92	83	0.00	.09	45	8	0	0	8	00	4
5	00	0.00	0	0.00	0.00	0	0	0	0.0	0	0.00	0.00	4.82	80	0.00	.09	46	8	0	0	8	00	5
6	00	0.00	0	0.00	0.00	0	0	0	0.0	0	0.00	0.00	4.72	78	0.00	.08	46	8	0	0	8	00	6
7	00	0.00	0	0.00	0.00	0	0	0	0.0	0	0.00	0.00	4.62	75	0.00	.08	46	8	0	0	8	00	7
8	00	.20	0	0.00	0.00	0	0	0	0.0	0	0.00	0.00	4.52	73	0.00	.08	46	7	0	0	8	00	8
9	00	.67	0	0.00	0.07	0	0	0	0.0	0	0.00	0.00	4.42	70	0.00	.08	46	7	0	0	8	00	9
10	00	.36	0	0.00	0.00	0	0	0	0.0	0	0.00	0.00	4.32	68	0.00	.07	46	7	0	0	8	00	10
11	00	.01	0	0.00	0.00	0	0	0	0.0	0	0.00	0.00	4.22	65	0.00	.07	46	7	0	0	7	00	11
12	00	.02	0	0.00	0.00	0	0	0	0.0	0	0.00	0.00	4.12	63	0.00	.07	46	7	0	0	7	00	12
13	00	.03	0	0.00	0.00	0	0	0	0.0	0	0.00	0.00	4.02	60	0.00	.07	47	7	0	0	7	00	13
14	00	.07	0	0.00	0.00	0	0	0	0.0	0	0.00	0.00	3.92	58	0.00	.07	47	6	0	0	7	00	14
15	00	.09	0	0.00	0.00	0	0	0	0.0	0	0.00	0.00	3.82	55	0.00	.05	47	6	0	0	7	00	15
16	00	.04	0	0.00	0.00	0	0	0	0.0	0	0.00	0.00	3.72	53	0.00	.04	47	6	0	0	7	00	16
17	00	0.00	0	0.00	0.00	0	0	0	0.0	0	0.00	0.00	3.62	50	0.00	.04	47	6	0	0	6	00	17
18	00	0.00	65	0.00	0.00	0	0	0	0.0	0	0.00	0.00	3.52	48	0.00	.04	47	6	0	0	6	00	18
19	00	0.00	100	0.00	0.00	0	0	0	0.0	0	0.00	0.00	3.42	45	0.00	.04	47	6	0	0	6	00	19
20	00	.01	100	.00	0.00	0	0	0	0.0	0	0.00	.01	3.32	43	.00	.05	47	6	2	4	12	00	20
21	00	.02	100	.01	0.00	0	0	0	0.0	0	0.00	.02	3.23	41	.01	.05	47	6	8	17	33	00	21
22	00	0.00	100	.01	0.00	0	0	0	0.0	0	0.00	0.00	3.14	38	0.00	.05	47	6	14	30	52	00	22
23	00	0.00	100	.01	0.00	0	0	0	0.0	0	0.00	0.00	3.04	36	0.00	.05	47	7	15	32	55	00	23
24	00	0.00	100	.01	0.00	0	0	0	0.0	0	0.00	0.00	2.94	34	0.00	.05	48	7	14	29	52	00	24
25	00	.02	100	.02	0.00	0	0	0	0.0	0	0.00	.07	2.84	34	.01	.05	48	8	15	31	55	00	25
26	00	.03	100	.03	0.00	0	0	0	0.0	0	0.03	.03	2.75	33	.01	.05	48	9	22	45	77	00	26
27	00	.59	100	.21	0.00	0	0	0	0.0	0	0.00	.58	2.67	32	.19	.05	48	16	116	237	371	00	27
28	00	.56	100	.41	0.00	0	0	0	0.0	0	0.00	.56	2.97	35	.19	.05	48	35	327	670	1032	00	28
29	00	0.00	100	.41	0.00	0	0	0	0.0	0	0.00	0.00	3.23	41	0.00	.05	47	58	477	976	1515	00	29
30	00	0.00	100	.41	0.00	0	0	0	0.0	0	0.00	0.00	3.13	38	0.00	.05	47	78	491	1007	1577	00	30

Fig. 3. Typical Output from SSARR model, Chippewa River Watershed

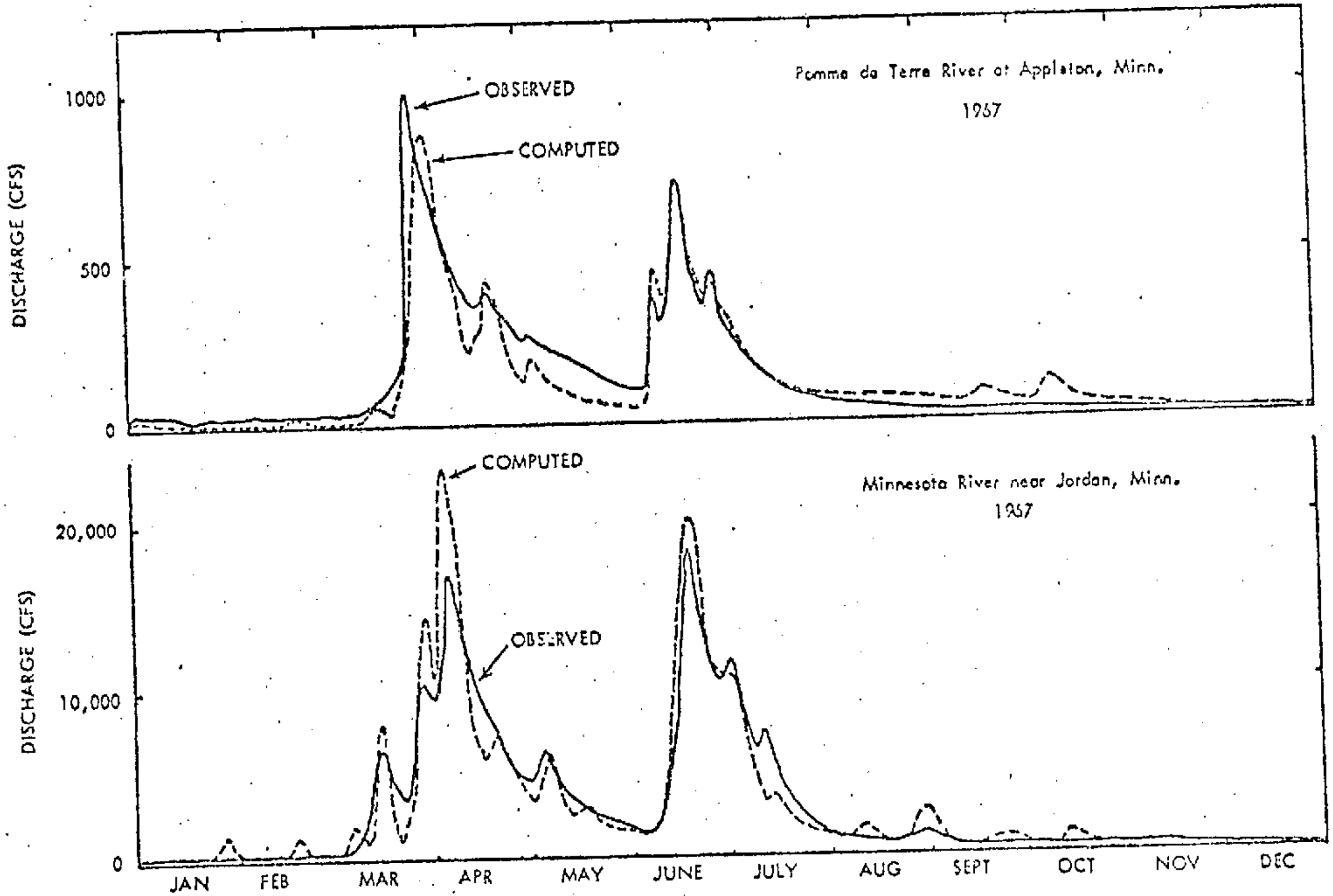

Fig. 4. Simulated and Observed Flow at Two Stations in Minnesota River Basin in 1967.

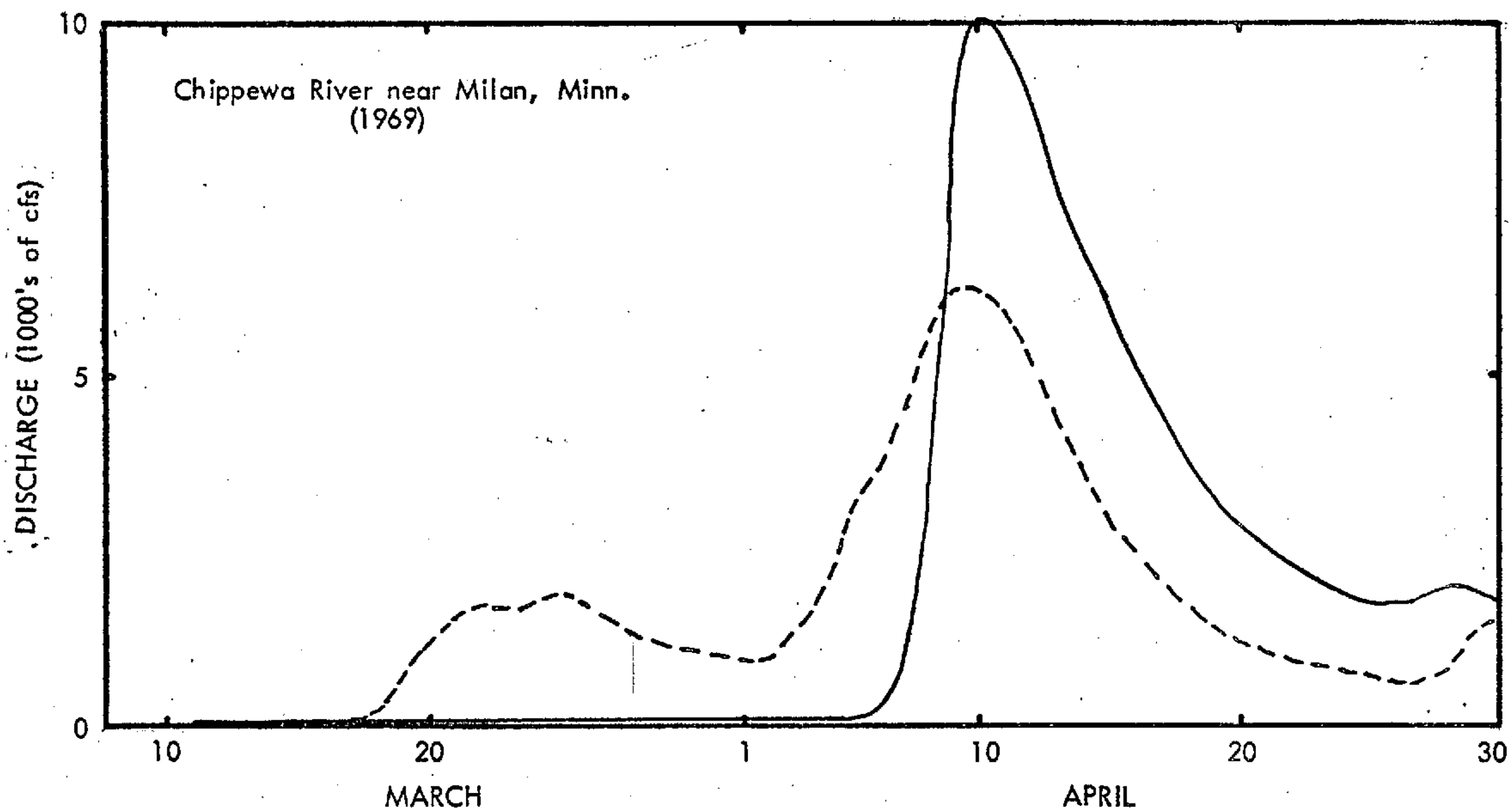

Fig. 5. Simulated Discharge of Chippewa River near Milan for 1969.

N73-32271

"A Proposal for Precambrian Mineral Resource Evaluation in Minnesota Utilizing ERTS Imagery."

Investigator: Dr. Donald Davidson, Jr.
Department of Geology

I propose an investigation of the discriminatory ability of ERTS imagery to geological relationships in Precambrian rocks of Minnesota. These rock units hold promise for potential mineral resources as do important ore deposits found in similar rocks to the north in Canada.

Two major Precambrian rock units are proposed for examination using ERTS imagery. The research planned involves the discrimination of rock types to show their aerial extent and an interpretation of the structural relationships between and within the various rock units. A considerable amount of ground truth information developed by the bedrock mapping program done in the past 10 years by the Minnesota Geological Survey is available for both units proposed.

The two major rock units to be examined are:

1. Archean Greenstone Belts

Greenstone belts throughout Canada are the most important sources of Cu-Ni-Zn-Ag-An ores in that country. Several greenstone belts are known to occur in Northern Minnesota. The best studied belt, the Vermilion belt, has proven to be essentially barren. Moreover, geologic mapping and exploration work has been conducted in most known greenstone belts. However, adequate study and evaluation of these belts has been hampered by the lack of regional as well as detailed information concerning distribution, structural relationships and other geological data. Regional structural and lithologic analysis in and near the several belts may hold the key to either why a belt is barren or where more favorable areas of mineralization are to be found.

2. The Troctolite Series of the Duluth Gabbro Complex

Known Cu-Ni mineralization is found in the lower, western part of the Duluth Gabbro Complex in rocks of troctolitic composition. To date Cu-Ni ore bodies are found in the basal contact zones of within the Troctolite Series. The total extent of the boundaries of the troctolitic units have not been determined primarily because of their extensive occurrence. Since the basal contact of the units is where known ore deposits have been found, regional patterns, structural studies and even a broad delineation of the major rock units could be of great value to continued exploration. Additional information of regional scope could greatly enhance the chance for further success in discovery of Cu-Ni deposits.

This proposed program, while having considerable scientific value, merits consideration because the scientific results can be expected to have considerable value in determining the metal resource potential of the Duluth Gabbro Complex.