FIRST JAMES BAY OCEANOGRAPHIC WORKSHOP

Canada Centre for Inland Waters

June 26, 1974

N.G. Freeman
Co-ordinator

November, 1974

FOREWORD

This report represents a compilation of the material presented during a one-day workshop on James Bay Oceanography held at C.C.I.W., Burlington, on June 26, 1974. Most speakers have provided a brief summary of about five pages, which have been retyped for consistency of presentation. No attempt has been made to have the submissions refereed. Since this publication contains only summaries of the papers, it is expected that the final work will be published in the scientific journals.

LIST OF ATTENDEES

1.	Mr. F.G. Barber	Oceanographic Branch, Marine Sciences, Department of the Environment, Ottawa, Ontario.
2.	Mr. D.A. Bondy	Atmospheric Environment Service, Applications & Consultation Division, Downsview, Ontario.
3.	Dr. R.G. Brown	Bedford Institute of Oceanography, Dartmouth, Nova Scotia.
4.	Mr. J.P. Croal	Consultant, Arctic Operations, 1239 Evans Blvd., Ottawa, Ontario.
5.	Dr. M.J. Dunbar	McGill University, Montreal, Quebec.
6.	Dr. M.I. El-Sabh	Oceanographic Section, University of Quebec at Rimouski, Rimouski, Quebec.
7.	Mr. N.G. Freeman	Marine Sciences, Central Region, Department of the Environment, Burlington, Ontario.
8.	Dr. G. Gantcheff	James Bay Development Corporation, Environment, Montreal, Quebec.
9.	Mr. P. Glaude	Lands Directorate, Department of the Environment, Hull, Quebec.
10.	Dr. G. Godin	Marine Sciences, Department of the Environment, Ottawa, Ontario.
11.	Dr. E.H. Grainger	Fisheries and Marine Service, Ste. Anne de Bellevue, Quebec.
12.	Dr. E.M. Hassan	Bedford Institute of Oceanography, Dartmouth, Nova Scotia.
13.	Dr. J.G. Hunter	Biological Station, Ste. Anne de Bellevue, Quebec.
14.	Mr. V. Koutitonsky	INRS, Oceanology, University of Quebec at Rimouski, Rimouski, Quebec.

15. Dr. K. Krank - Bedford Institute of Oceanography, Dartmouth, Nova Scotia.

16. Mr. T.D.W. McCulloch - Marine Sciences, Central Region, Department of the Environment, Burlington, Ontario.

17. Dr. T.S. Murty - Oceanographic Branch, Marine Sciences, Department of the Environment, Ottawa, Ontario.

18. Mr. T. Pullen - Marine Sciences, Central Region, Department of the Environment, Burlington, Ontario.

19. Dr. J. Raudsepp - Geologist, James Bay Development Corporation, Montreal, Quebec.

20. Dr. P.G. Sly - Lakes Research Division, Department of the Environment, Burlington, Ontario.

21. Dr. R. Thomas - Geophysical Limnology, Department of the Environment, Burlington, Ontario.

22. Dr. R.W. Trites - Bedford Institute of Oceanography, Dartmouth, Nova Scotia.

23. Dr. N. Watson - Great Lakes Biolimnology, Department of the Environment, Burlington, Ontario.

JAMES BAY WORKSHOP - JUNE 26, 1974

Presentations

Page No.

INTRODUCTION

by

N.G. Freeman

Objectives:

The main objective of the Workshop is to bring together scientists, working since 1971 on the physical, biological, geological and chemical oceanography of James Bay, to present their data, analyses and interpretations as completed to date. It is hoped that during the Workshop, not only the present projects will be delineated, but that future programs and other areas requiring further study will be brought out.

Throughout the presentations, it is anticipated that the discussion periods will expand the specific topics of the individual talks, such that more general questions can be evolved and scientific programs illuminated. Dr. Godin, as the Marine Sciences representative on the James Bay Cross Mission Project, has already done much to delineate a number of the specific questions that we must address ourselves in the planning of long-term goals; for example:

1. In what way does the freshwater mix with the more saline water of the Bay and what changes will occur in the mixing process after the completion of the Hydro works?

2. How does the ice cover affect the mixing process and what are the differences between summer and winter conditions?

3. Will the heat content of the Bay be significantly increased and will the ice growth be enhanced or diminished?

4. How much does the dissolved and suspended nutrients from the rivers contribute to the growth and maintenance of life in the Bay and will the local

marine fauna be affected by change in the regime and by how much?

5. What is the actual biological content of the estuaries and near-shore zones, what is their productivity and their sensitivity to external factors?

While this Workshop does not attempt to provide specific answers, nor to raise all the questions concerning the oceanic impact of the James Bay hydroelectric power project, nevertheless, it is a necessary first step to start a dialogue among the various agencies working on this problem.

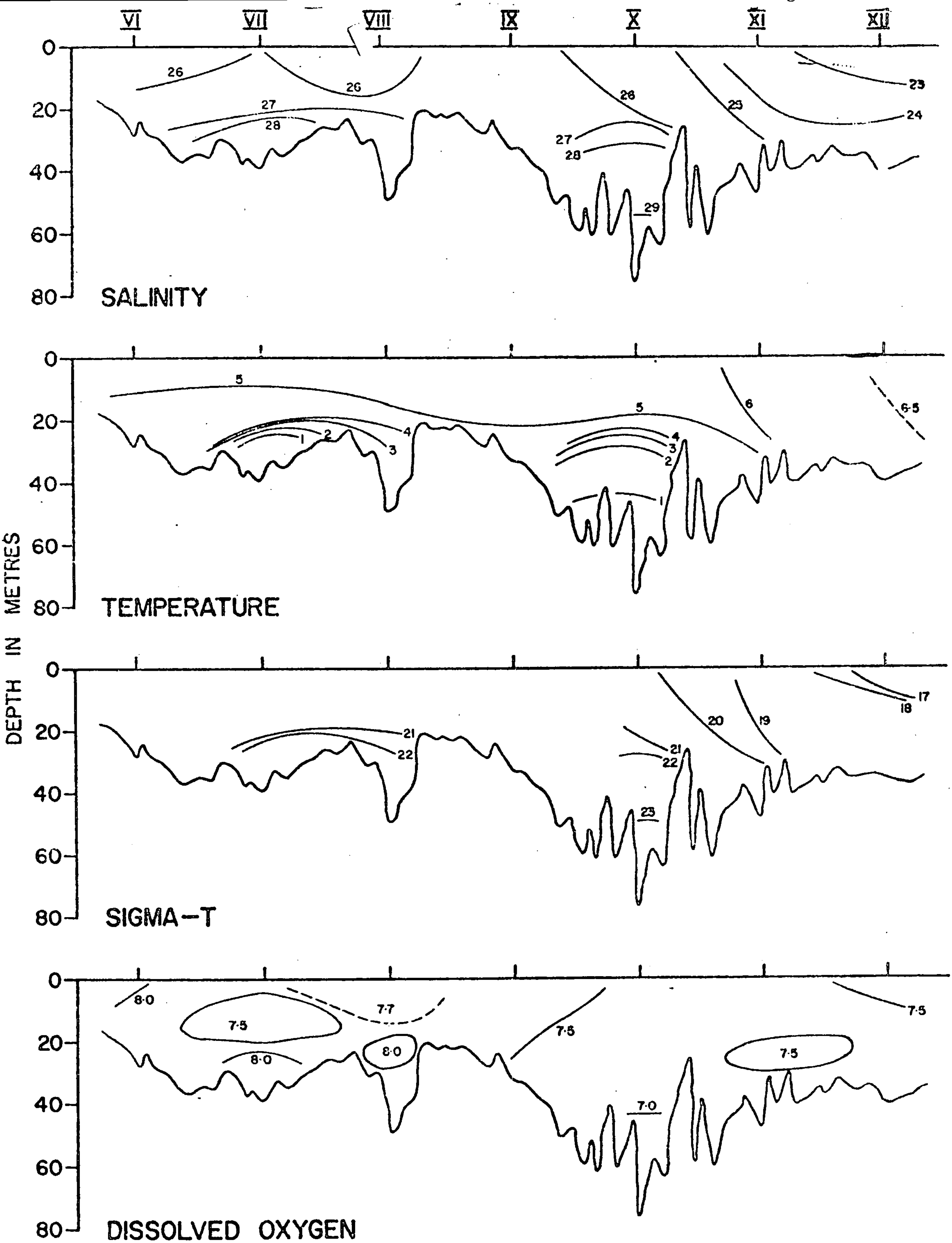


Figure 1 (cont'd.) Salinity, temperature, sigma-t and oxygen for Section of 14-17 September, 1972.

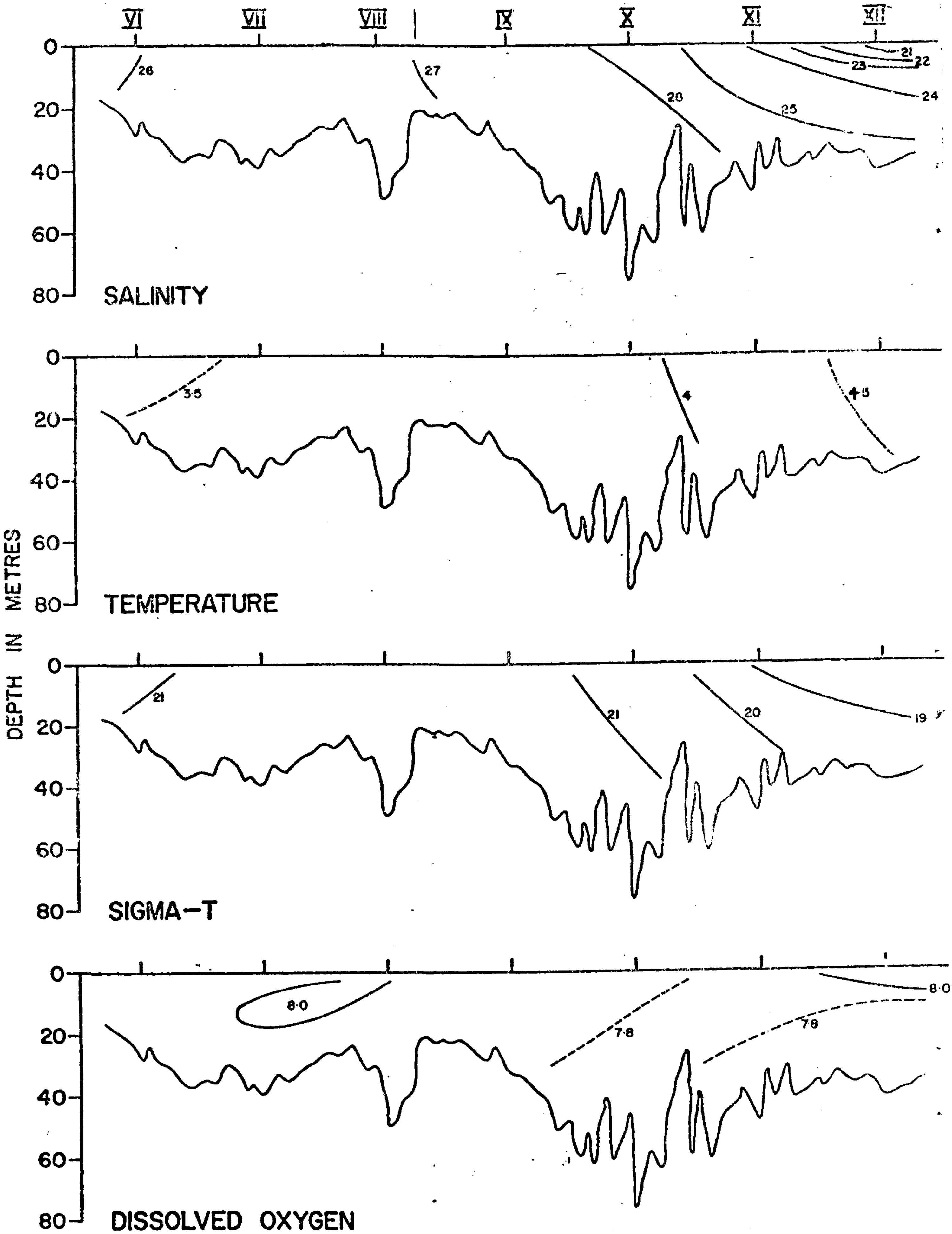


Figure 1 (cont'd.) Salinity, temperature, sigma-t and oxygen for Section of 11-13 October, 1972.

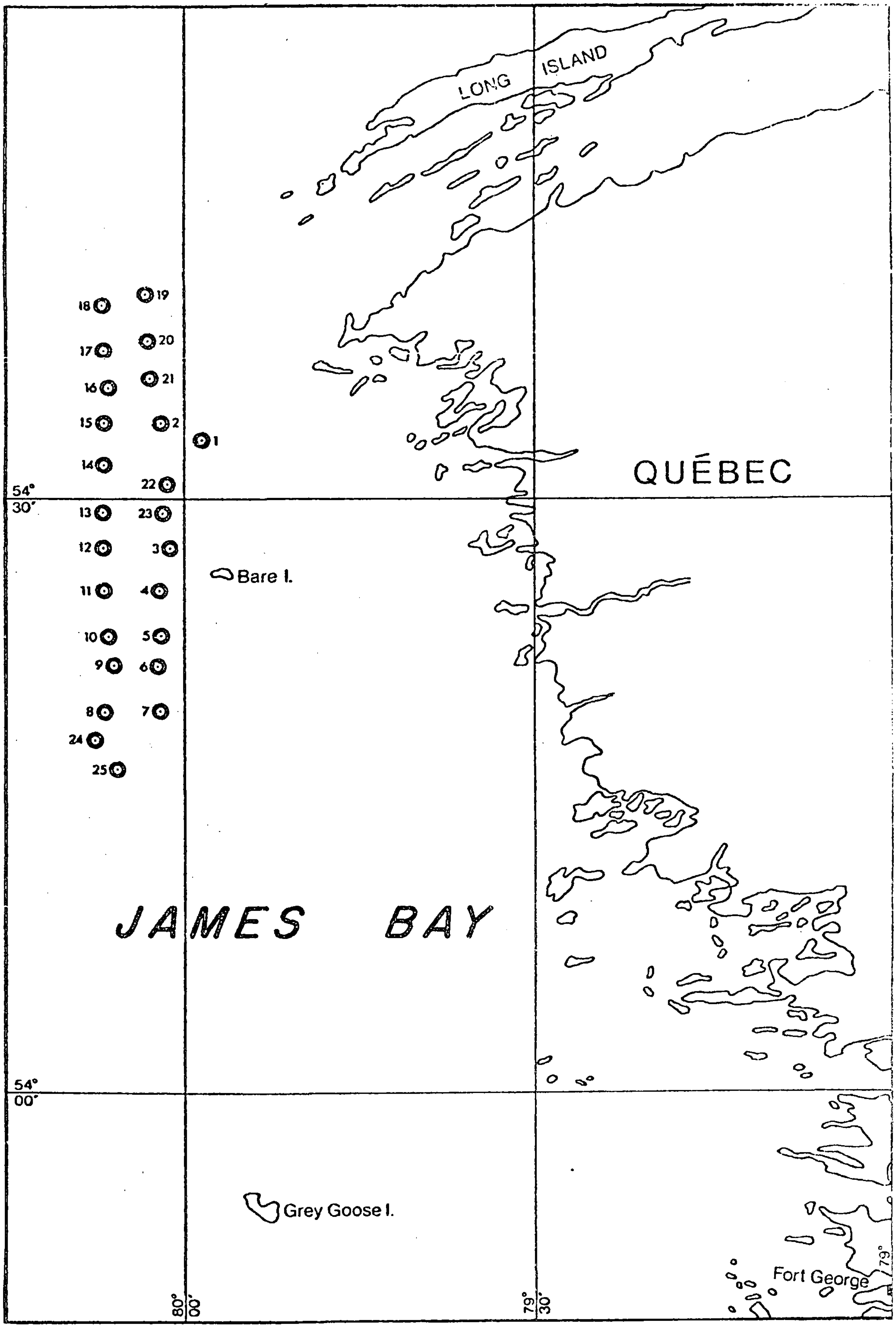


Figure 2: Position of Bottom Sample Stations

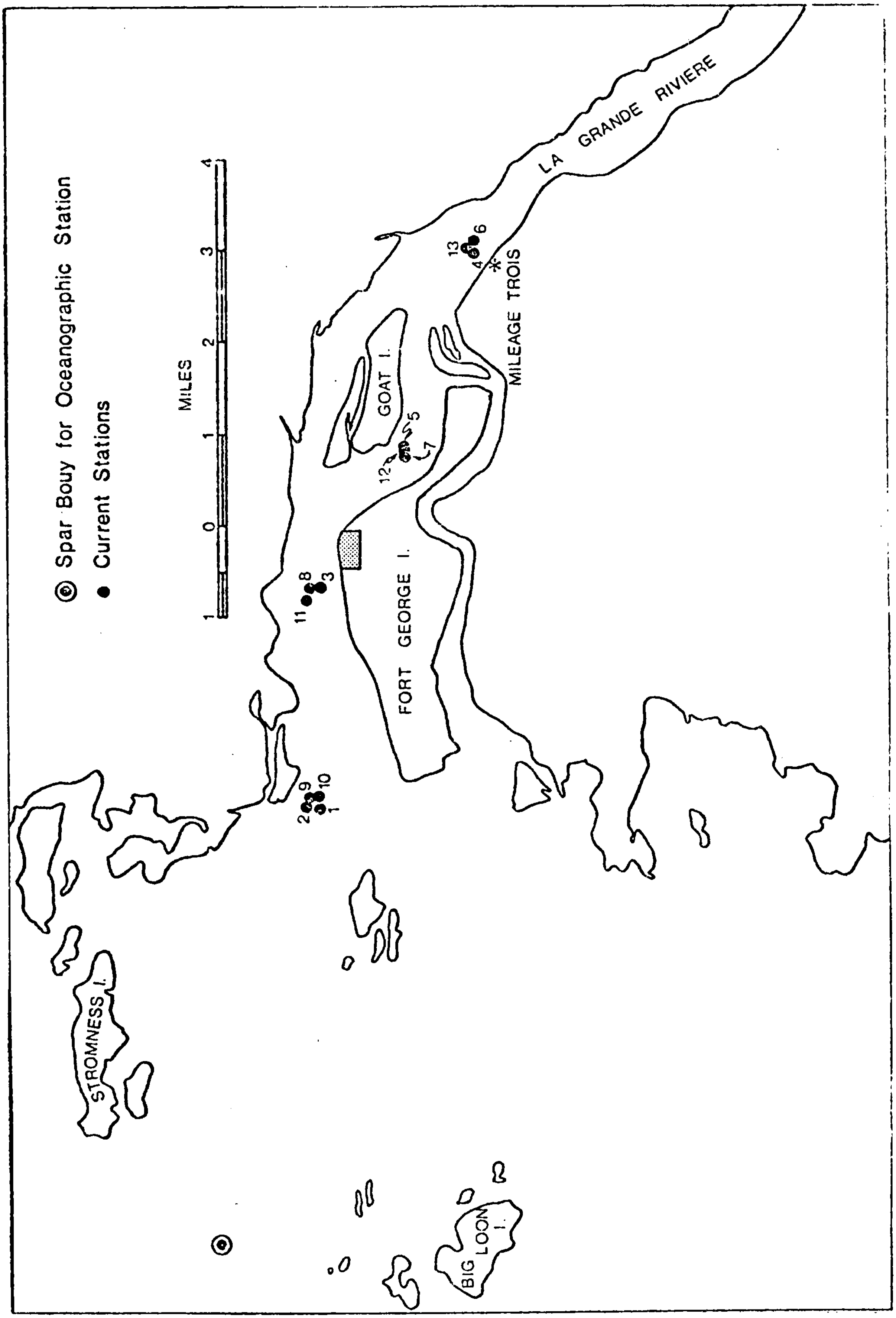


Figure 3: Position of Current Stations

JAMES BAY 1972, 1973, AND 1974 SUMMER OCEANOGRAPHIC DATA

by

T. PULLEN

This paper describes the oceanographic programs carried out in James Bay during the summers of 1972 and 1973, and will also mention the proposals for 1974. The oceanographic program was initiated to monitor the oceanography of James Bay before changes are made to the watershed on the eastern side of the Bay. This will allow assessments to be made, and the changes observed, studied and related to a baseline of prior observations.

In 1972 the main program consisted of sixteen oceanographic station positions over the northern half of the Bay. The five northern stations across the mouth of the Bay were chosen to recapture positions occupied by the Calanus in 1959 and twice by the Theta in 1961. The southern eleven stations were chosen to monitor the effect of La Grande Riviere on the Bay, the six in the rectangle being the most important.

During the summer of 1972, each of these 16 stations was occupied at the beginning, the middle and the end of the field season. In addition to this, the rectangle of stations was occupied on a fortnightly basis.

At all of these stations, bottle casts for salinity, temperature, and dissolved oxygen samples were taken. As well, a Bissett Berman S.T.D. was used to provide a profile. At each station, weather permitting, a vertical plankton tow was taken. For the geologists, a core was taken at each oceanic station occupied in October. Also, some of the bottom samples collected for the Hydrographic charting were retained and analysed at the Bedford Institute.

Figure 1 shows the three sets of profiles for the southern line of seven stations across the Bay. From these profiles one can see the downward progression of the thermoline, and the freshwater effects of the river on the Bay as the season progresses.

During the summer of 1973, the oceanographic program was very similar in design to that of the previous year, although not as extensive in scope. The same sixteen station positions were occupied, although only once at the beginning and once at the end of the season. The same parameters, salinity, temperature and dissolved oxygen were measured and as well a plankton tow was taken at each of the stations. These latter samples were forwarded to Fisheries Research Board at Ste. Anne de Bellevue.

Figure 2 shows the position of the 25 bottom sample stations. Each of these samples was retained and analysed for type and percentage of composition by the Geolimnologists at the Centre. A mechanical B.T. cast was taken at the 16 oceanographic stations occupied in October, making a total of 41 bottom samples and B.T. casts.

During 1973, some hydrodynamical observations were made in the estuary of La Grande Riviere. Figure 3 shows the position of the thirteen hour tidal cycle station occupied in the fall, at which salinity, temperature and speed were measured. Also marked on this map are the current stations occupied in the river. The equipment available was old and the results are limited to speed only, but it does give us a basis for planning future work.

The physical oceanographic data for 1972 is archived at C.O.D.C., that for 1973 is undergoing final corrections to the tapes before archival. Other data such as geological or biological results are kept in our own files here in Burlington, along with the B.T. slides and hydrodynamical data.

For the 1974 season the Narwhal will reoccupy the northern five stations in October. The program is limited as the ship will be in Chesterfield Inlet all summer, and no other large vessel will be available. There is a good chance that the southern eleven stations will also be occupied as this will give us a more consistent record of the Bay.

The extent of this project will depend on the ice and weather in October. Finally, a contract for current meter survey in the La Grande estuary has been planned for September, 1974.

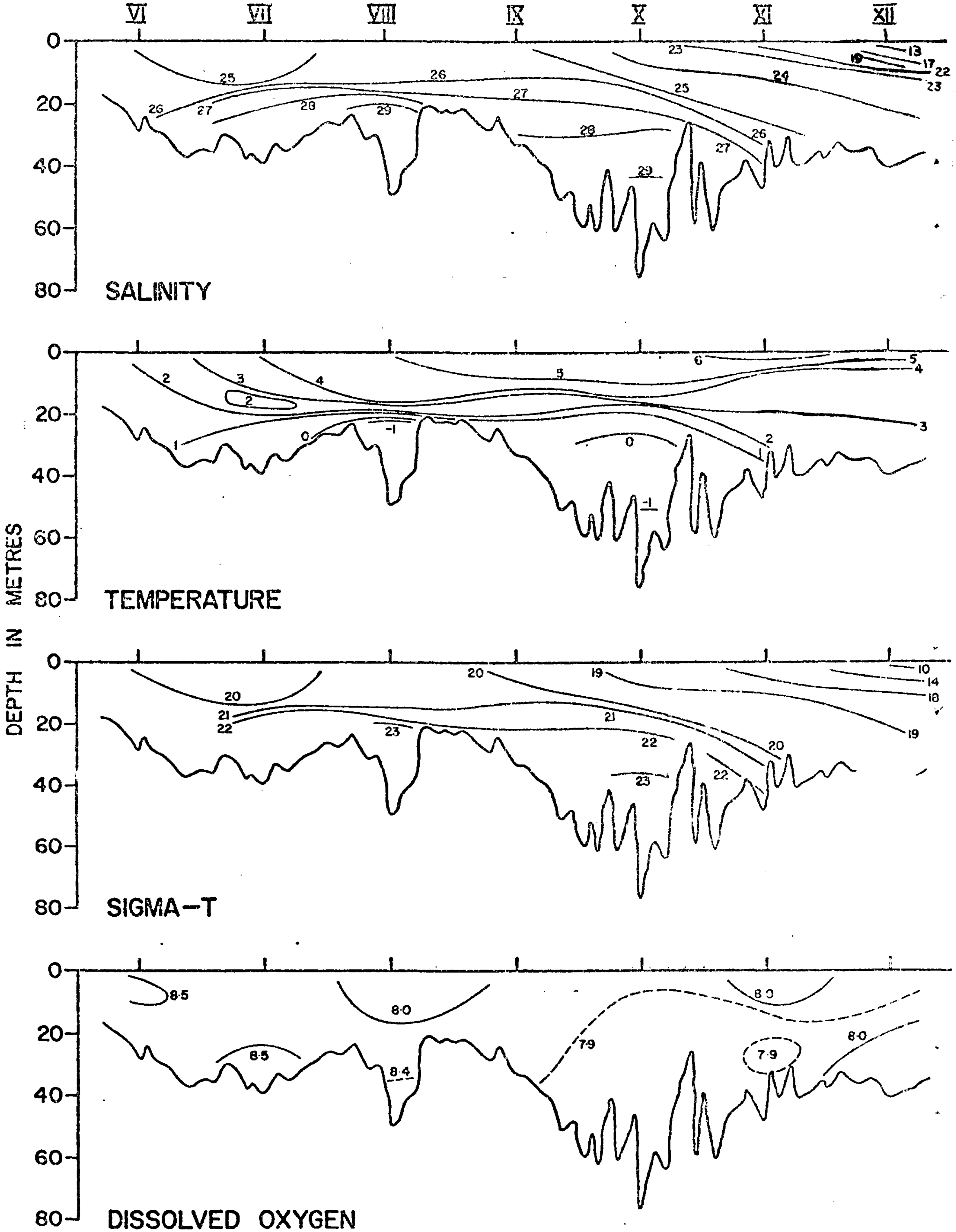


Figure 1 Salinity, temperature, sigma-t and oxygen for Section of 9-10 August, 1972

ON THE PHYSICAL OCEANOGRAPHY OF JAMES BAY

by

M.I. El-Sabh

and

V.G. Koutitonsky

Summary

The objective of this study is to analyze and interpret the physical oceanographic data collected in James Bay field surveys in 1972 and 1973, in order to extend the study of Barter (1972) and Murty on the effect of river inflow modification on the marine and estuarine circulation in James Bay.

An attempt was made to determine the total freshwater input to James Bay. The total freshwater run-off from all rivers around the Bay has a mean annual value of 6.96 x 10^3 m^3/sec; 23% of which comes from rivers along the western side of the Bay, while La Grande Rivière supplies approximately 28% of the total run-off input. It was found that the net total freshwater input varies from month to month, from a mean monthly minimum of 4.04 x 10^3 m^3/sec in March to a maximum of 18.45 x 10^3 m^3/sec in June. The mean annual total freshwater input to James Bay is 11.38 x 10^3 m^3/sec; about 39% of which is made up of net precipitation (precipitation minus evaporation). By applying a two-layer model to the Bay, a value of 10 months was estimated as the flushing time for James Bay.

Using the network of 16 oceanographic stations, the isotherms, isohalines, isopycnals and isopleths of dissolved oxygen were drawn for each cruise at horizontal surfaces of 0, 10, 30 and 50 meters. Vertical distributions of these properties were also drawn at two latitudinal sections in the Bay. Comparison between the distribution of properties

in 1972 and those in 1973 (Figures 1 and 2) indicates that considerable variations can occur from one year to the next. Examination of the horizontal and vertical distribution of properties at each cruise and the corresponding surface circulation pattern and vertical distribution of currents at the same cruise reveals that such variations depend mainly on the exchange of waters between Hudson Bay and James Bay. The existence of a freshwater layer below ice in the vicinity of the La Grande Estuary, suggested by Barber (1972), was confirmed and the seasonal variations of the different water masses were examined.

Using an average network of oceanographic stations, the geostrophic surface circulation pattern in James Bay was calculated for the months of August and October. Because of the complex bottom topography of the Bay, a variable reference layer for converting the relative velocities into absolute velocities was obtained for each month using Defant's method (Figures 3 and 4). A fairly consistent feature observed in the outflow from all rivers along the eastern side of James Bay is the existence of a strong narrow current in the surface layer flowing northward along the eastern side of the Bay. This current, which begins to develop near La Grande River area is subject to wide variations in strength with time. On some occasions, it moves northward with two branches; one continues to flow northward towards the east coast of Hudson Bay, while the other turns to the southwest and joins the inflow from Hudson Bay which takes place in the central part of the main entrance. Along the western side of James Bay, a tendency for a weak inflow from Hudson Bay takes place; part of which continues to move southward, while the other is deflected to the east and northeast direction to flow back to Hudson Bay either on the western side or by joining and reinforcing the outflowing current along the eastern side of the Bay. In order to investigate to what degree the water circulation in James Bay is coupled to Hudson Bay, the vertical distributions of the water transport through the cross-section connecting the two Bays were calculated for every 10 m. interval for the months of August and October. It was found that the coupling between the two Bays varies with time. The seawater discharge from Hudson Bay to James Bay is in August four times and in October about 10 times the freshwater discharge.

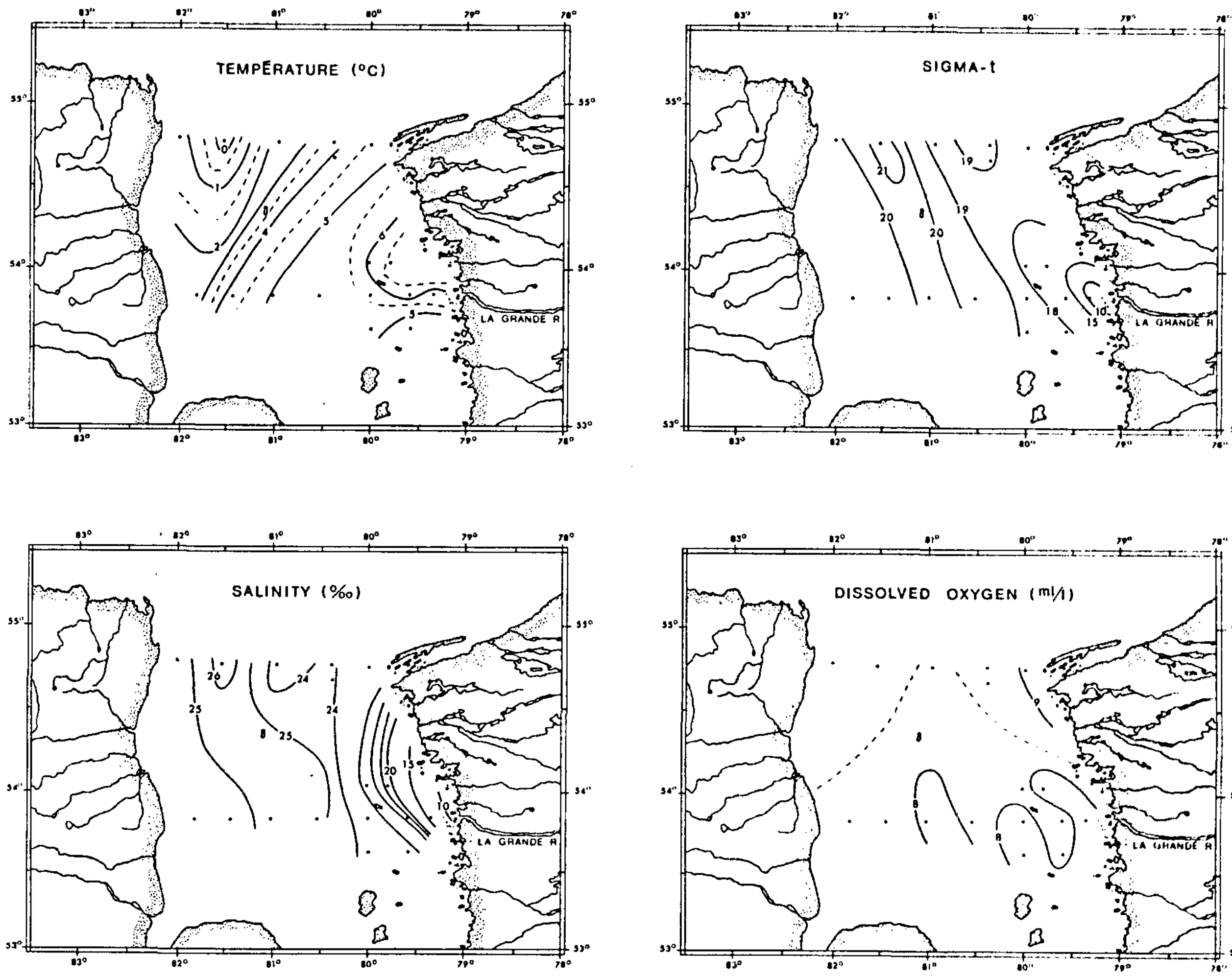
Wind and ice conditions and their seasonal variations in James Bay, together with the effect of the river modifications on the heat budget were also studied. The circulation pattern in James Bay and the transport sediments and possible changes in bottom topography in the La Grande Estuary are dealt with as well. Finally, recommendations are made for the planning of future studies in James Bay.

References

Barber, F.G., 1972 — On the Oceanography of James Bay
Canada Department of the Environment
Manuscript Report Series No. 24
pp. 1 - 96

El-Sabh & Koutitonsky, 1974 — Physical Oceanographic Studies in James Bay
(in preparation)

Murty, T.S., 1972 — Circulation in James Bay
Canada Department of the Environment
Manuscript Report Series No. 24
pp. 143 - 193



DEPTH: SURFACE

DATE : AUGUST 7-11, 1972

Figure 1 (a) Surface distribution of temperature, salinity and sigma-t and dissolved oxygen in James Bay, August 1972.

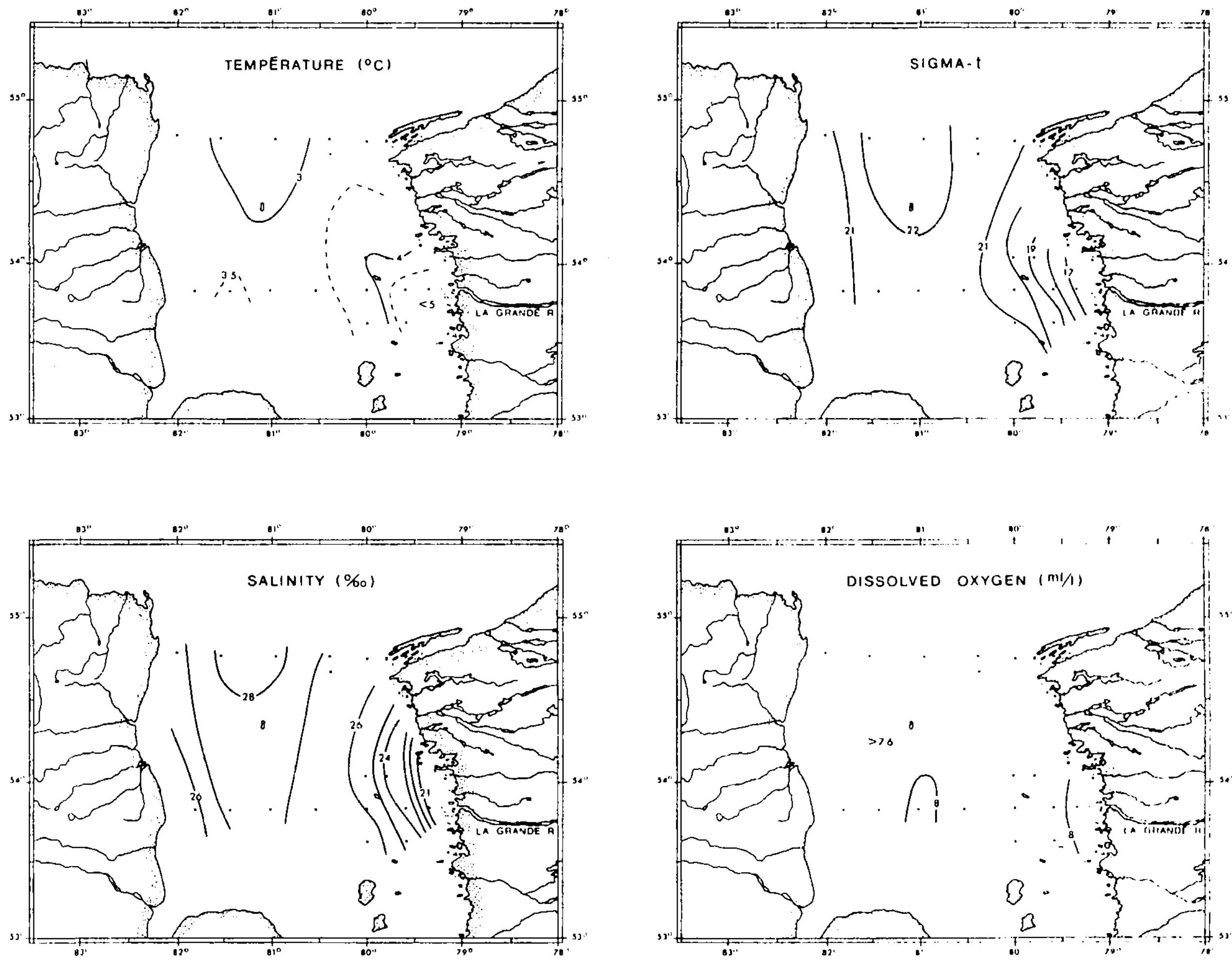
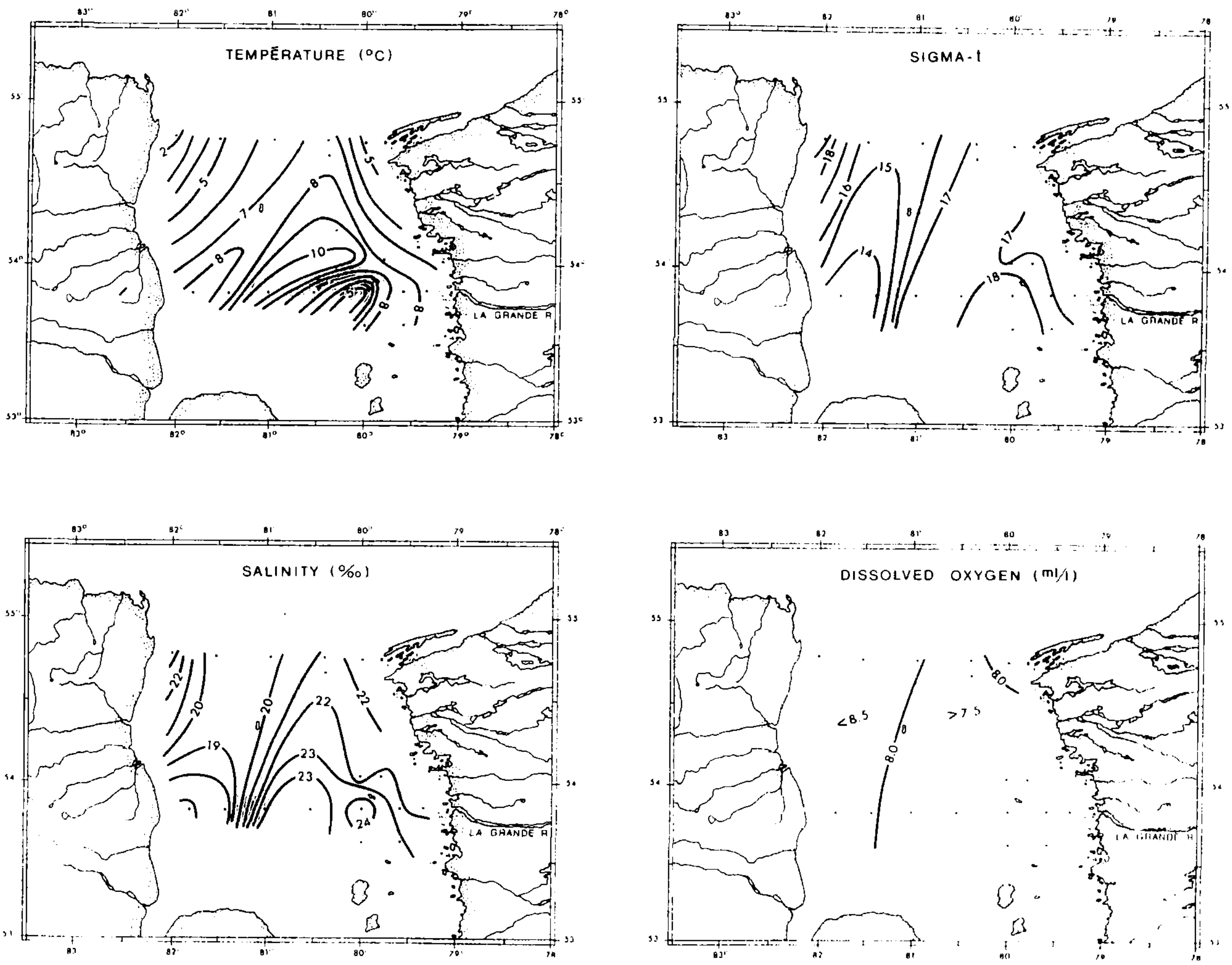


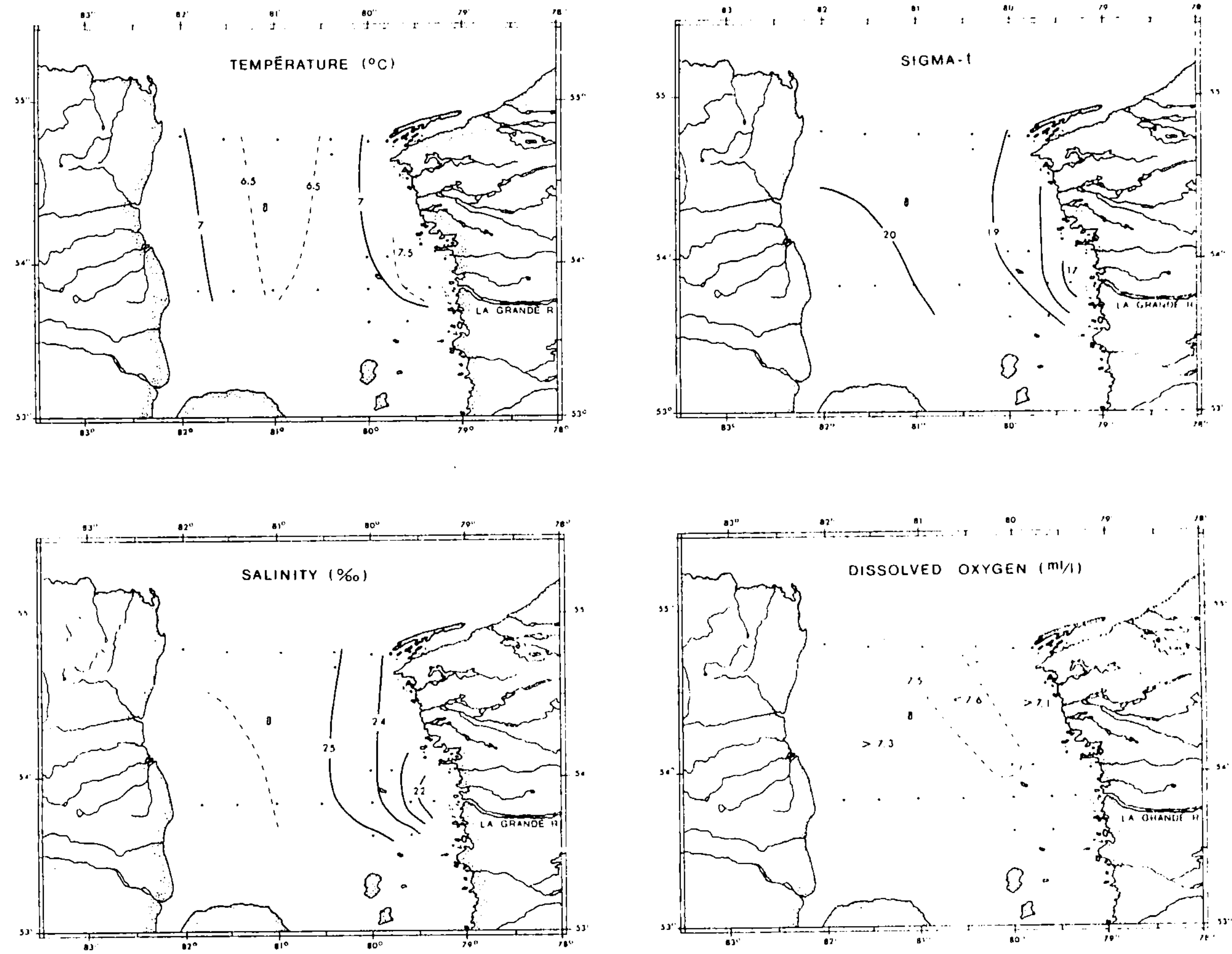
Figure 1 (b) Surface distribution of temperature, salinity, sigma-t and dissolved oxygen in James Bay. October 1972.



DEPTH: SURFACE

DATE : AUGUST 1-2 , 1973

Figure 2 (a) Surface distribution of temperature, salinity, sigma-t and dissolved oxygen in James Bay, August 1973.



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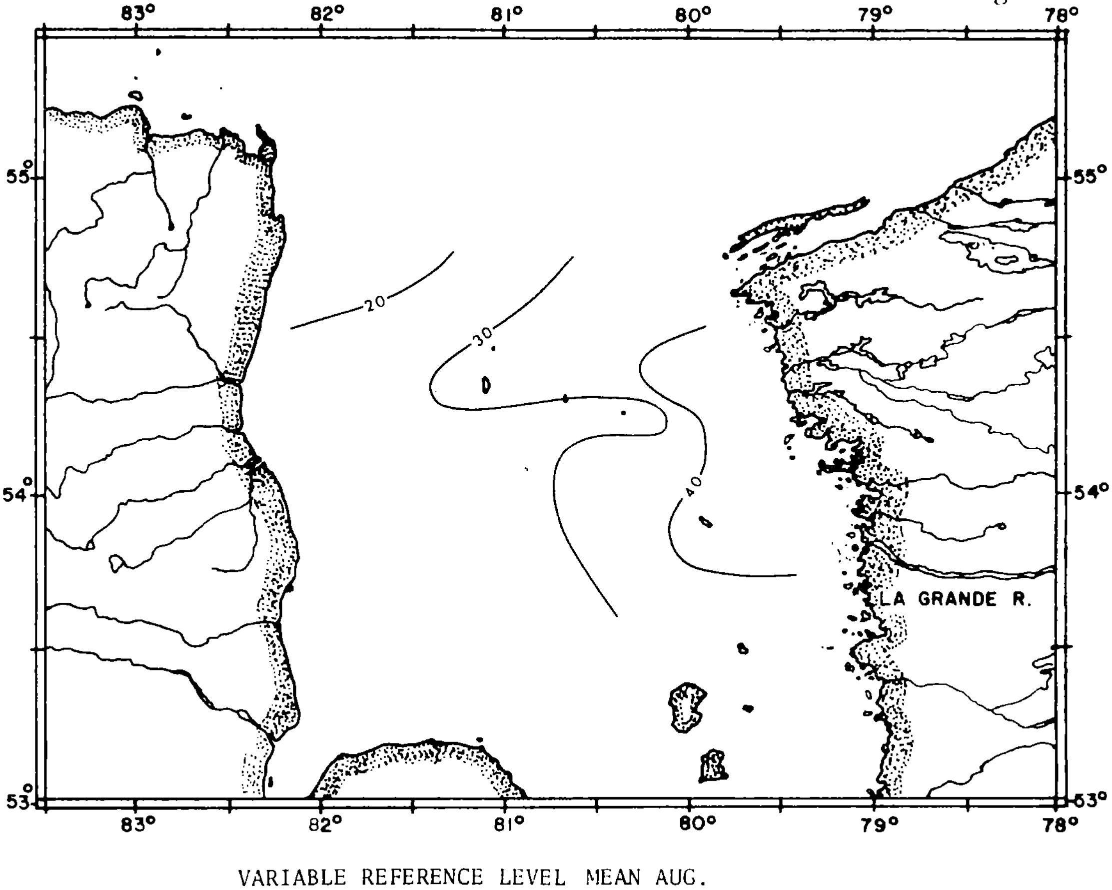
DATE : SEPT.30-OCT.1 , 1973

Figure 2 (b) Surface distribution of temperature, salinity, sigma-t and dissolved oxygen in James Bay, October 1973.



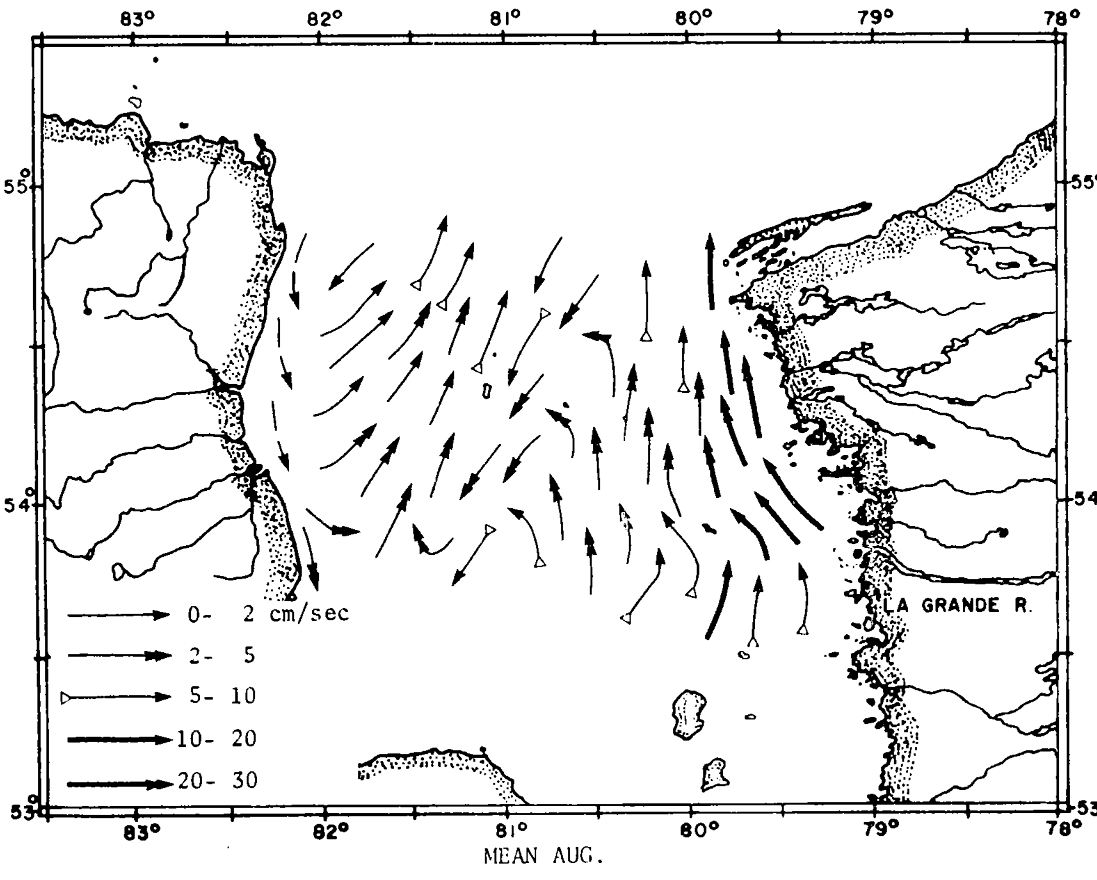


Figure 3 Field of the surface geostrophic currents in James Bay during August using the variable reference layer shown above.

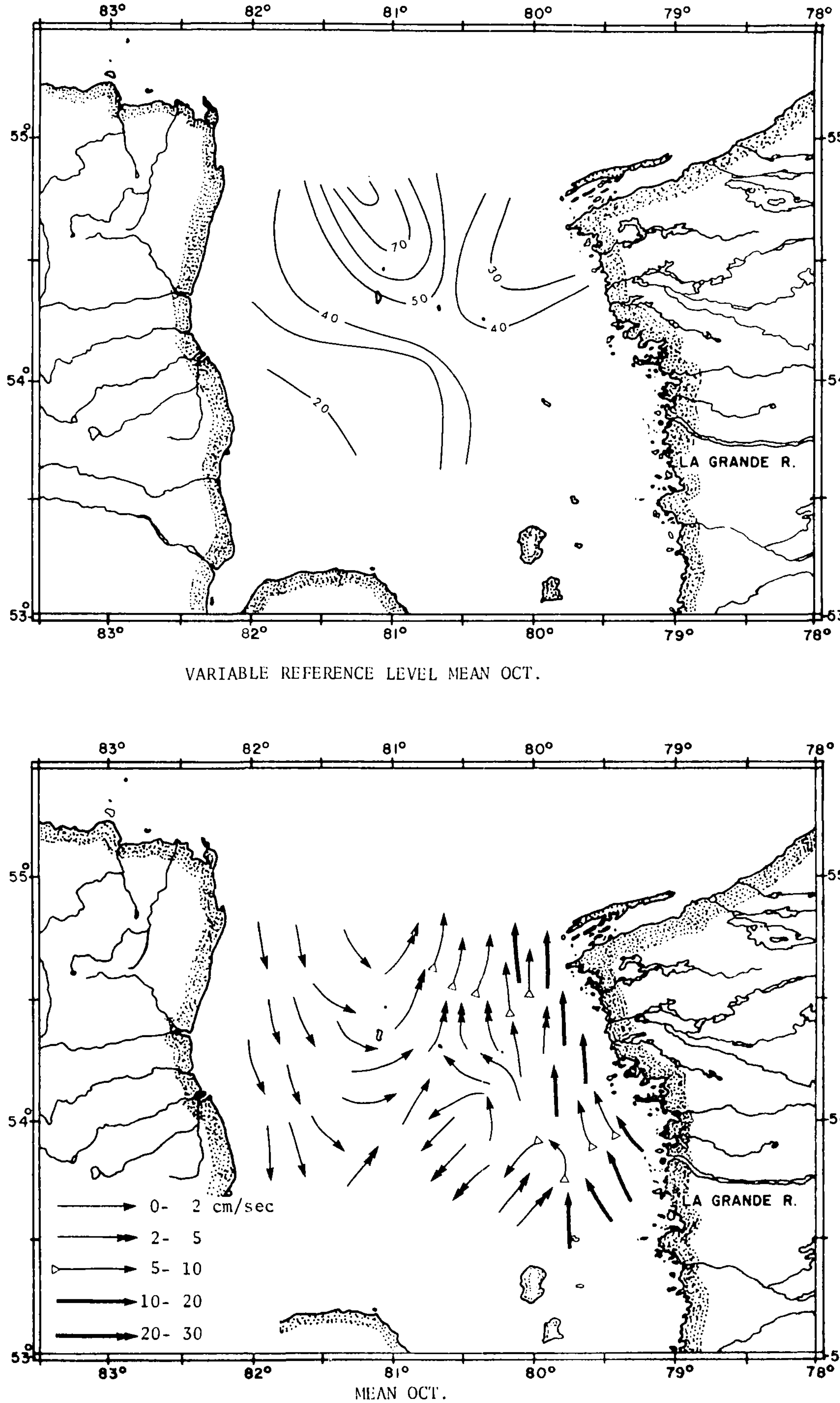


Figure 4 Field of the surface geostrophic currents in James Bay during October using the variable reference layer shown above.

OCEANOGRAPHIC OBSERVATIONS IN THE ESTUARY OF LA GRANDE RIVIERE, JAMES BAY

by

V.G. Koutitonsky

and

M.I. El-Sabh

Summary

The Hydroelectric Power Development now under construction on the eastern side of James Bay proposes to regulate the discharge of La Grande Rivière to a constant year round rate of 3970 m^3/sec. Actually the fresh water discharge varies seasonally, reaching a maximum rate of 3960 m^3/sec in June and a minimum rate of 460 m^3/sec in March, with a yearly mean rate of 1900 m^3/sec, see Figure (1). After completion of La Grande Complex, it is expected that an additional 3.2 x 10^{10} m^3 of fresh water will pour into James Bay through La Grande Rivière discharge region; part of this fresh water will originate from Eastmain River which is the only river naturally flowing into James Bay that is to be deviated into La Grande Rivière. It is intended in this brief summary to describe the physical parameters studied in La Grande Rivière estuary before any modification to the discharge occurs in order to assess and predict the impact that such modifications will have on the physical oceanography of James Bay.

La Grande Rivière estuary is of a coastal plain nature, as indicated by Figure (2) showing its bottom topography. Also on Figure (2), the extent to which fast ice covers the estuary from December to May is indicated; it spreads some 15 to 25 Km seaward of Fort George, and at the fast ice seaward limit an open lead is frequently observed during winter. In May mean air temperatures at Fort George increase above 0°C, see Figure (1), and ice starts to break in the river and the estuary. High run-off from upland melting quickly clears the estuary from ice by June and it remains ice free until November when new ice forms.

From June to October, mean monthly discharges in La Grande Rivière exceed 2400 m^3/sec, Figure (1). In August 1973, current measurements were performed in La Grande Rivière at three locations during different tidal phases. The current meter positions are shown on Figure (3). Although the current meters did not record directions, it was noticed that the current would always flow downstream regardless of the tidal phase. However, current magnitudes were tide dependent and ranged between 0.5 knots and 2 knots, see Figure (4). The average during the periods of observation was 1.2 knots.

Salinity and temperature measurements were also performed in the river during September 1973. The location of the stations appear on Figure (3), and the results on Figure (5). It can be seen that the salinity at all stations remained below $2\,^{o}/oo$ with no definite vertical profile. Also, the temperature results showed no variation between stations, and with depth. It remained at $12.0 \pm 0.5°C$. Although these results only apply to the months of August and September, they can be extrapolated to the whole period of June to October during which the mean monthly discharge rate remains above 2400 m^3/sec. In other words, it seems that down to the river mouth, the water remains fresh, homogeneous in nature and it flows downstream; fresh water is thought to mix with salt water somewhere near the 5 m depth contour line during this period of the year.

Tidal cycle observations performed in the estuary at station "X", see Figure (3) during ice free (Sept. '73) and ice covered (Mar. '74) periods gave some evidence about the type of mixing involved in the estuary, its spatial variation, and the difference between summer and winter mixing. In summer, a fresh water surface layer ($< 5\,^{o}/oo$ salinity) about 1 m. thick reached station "X" just after the ebb tide, see Figure (6). At that moment the $20\,^{o}/oo$ isohaline was at 5 m. below water level, while the rest of the column remained around $21\,^{o}/oo$. During incoming tide, the fresh water layer was squeezed at the surface such that with tidal mixing and wind stress momentum transfer, surface waters reached a salinity of $19\,^{o}/oo$ three hours after HW. Then, bottom salinity was $23\,^{o}/oo$. Magnitudes of surface currents (at 1 m depth) reached 2 knots at 1 hour before LW and decreased to 0.2 knots at 1 hour before HW.

In winter, mixing is much reduced by the presence of motionless fast ice at the surface. Without the wind stress applied at the water surface, and without the turbulent boundary layer under ice produced by ice drift, one can expect the low river discharge to extend as a fresh water layer under the ice, at least to the seaward limit of fast ice. In fact, from the tidal salinity and temperature observations performed in March 1974 at station "X", a very strong density gradient can be noticed just below the 2 m fresh water surface layer, see Figure (7); this seems to indicate that no eddy mixing occurs at the fresh-salt water interface. Some tidal mixing can be depicted below the fresh water layer, but its intensity is much reduced as compared to summer. The fresh water (S = 2 ^{o}/oo) thickness remained at 2 m. throughout the tidal cycle, indicating that its high stability is not affected by tides, that run-off alone does not produce mixing, and that the underside of fast ice in that region has a small roughness parameter. At the floe edge, it is expected that the freshwater layer will mix more readily with its underlying salt water (25 ^{o}/oo, - 1.3°C) because of ice drift and because of wind stress (when an open lead exists). It is strongly suggested here that temperature and salinity vertical profiling should also be performed beyond the fast ice edge in winter.

The proposed yearly constant discharge at La Grande Rivière mouth may lead to an earlier ice break-up in the estuary, a later fast-ice formation there, and a shortening of the melting period. Also, it was found that, from November to April, James Bay will gain heat as a result of the exchange processes with Hudson Bay due to the increase in fresh water input. The gained heat will either shorten the melting period over the whole Bay, or increase the evaporation which may produce a thicker snow cover on the eastern inlands (downwind areas). Moreover, a thicker fast-ice cover is expected from La Grande estuary towards Cape Jones where an increase in ice export can be anticipated. From May to July, the discharge modifications will reduce the freshwater input in James Bay; it was shown that James Bay heat storage will be increased.

The result would be an increase in precipitation (from increased evaporation) in the downwind areas, and for an increase in the tendency towards homogeneity in the water column, actually observed by late summer in James Bay. Sediment transport, bed load and suspended load, will definitely increase in La Grande Rivière, leaving a 5 mm. gravel river bed after modifications, not to forget side erosion and a possible change in the actual La Grande Rivière estuary bottom topography. From July to October, no change in the fresh water input in James Bay is anticipated from the discharge modifications except the year round feature and results of the spatial relocation of Eastmain water from Eastmain estuary to La Grande estuary, the effects of which should be carefully studied before the Hydro Electric Project is completed.

Reference

El-Sabh, M.I., and V.G. Koutitonsky. Physical Oceanographic Studies In James Bay
I.N.R.S. - Océanologie, Rapport No. 1,
I.N.R.S. - Océanologie, Rimouski, 1974. (in press)

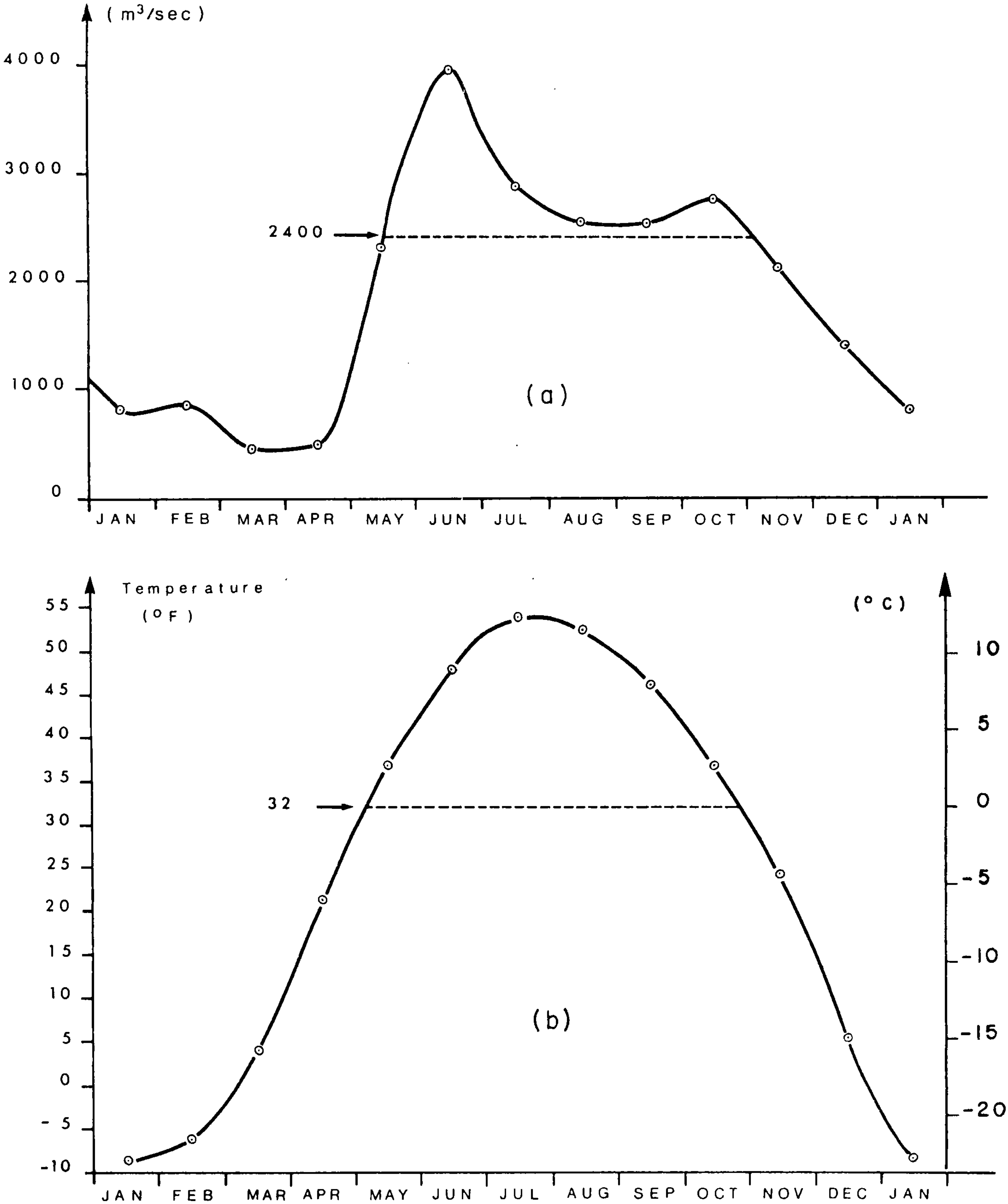


FIGURE 1: (a) La Grande Rivière mean monthly discharge rate.
(b) Mean monthly air temperatures at Fort George.

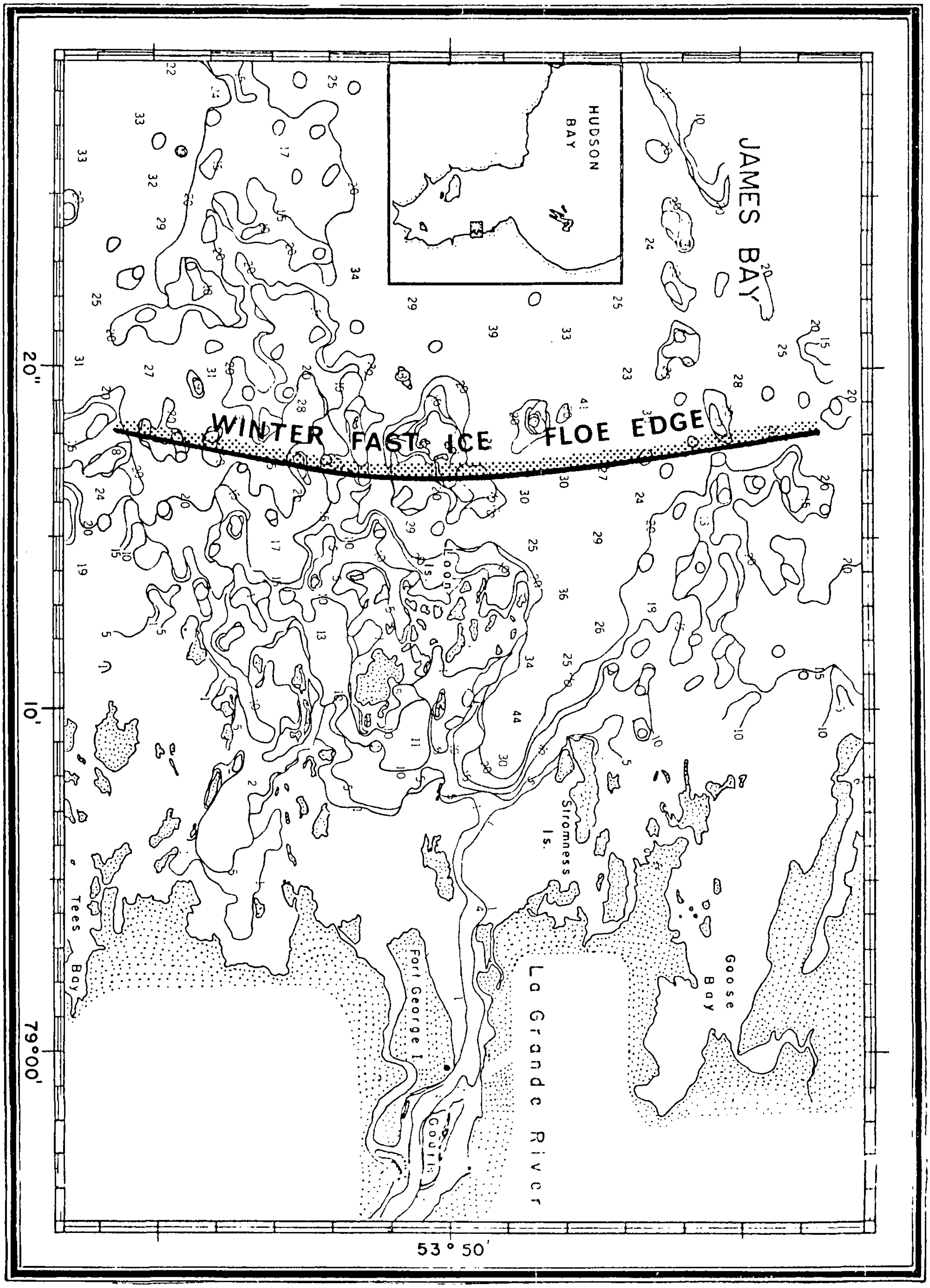


FIGURE 2: Bottom topography and Winter Fast Ice in the estuary of La Grande Rivière, James-Bay.

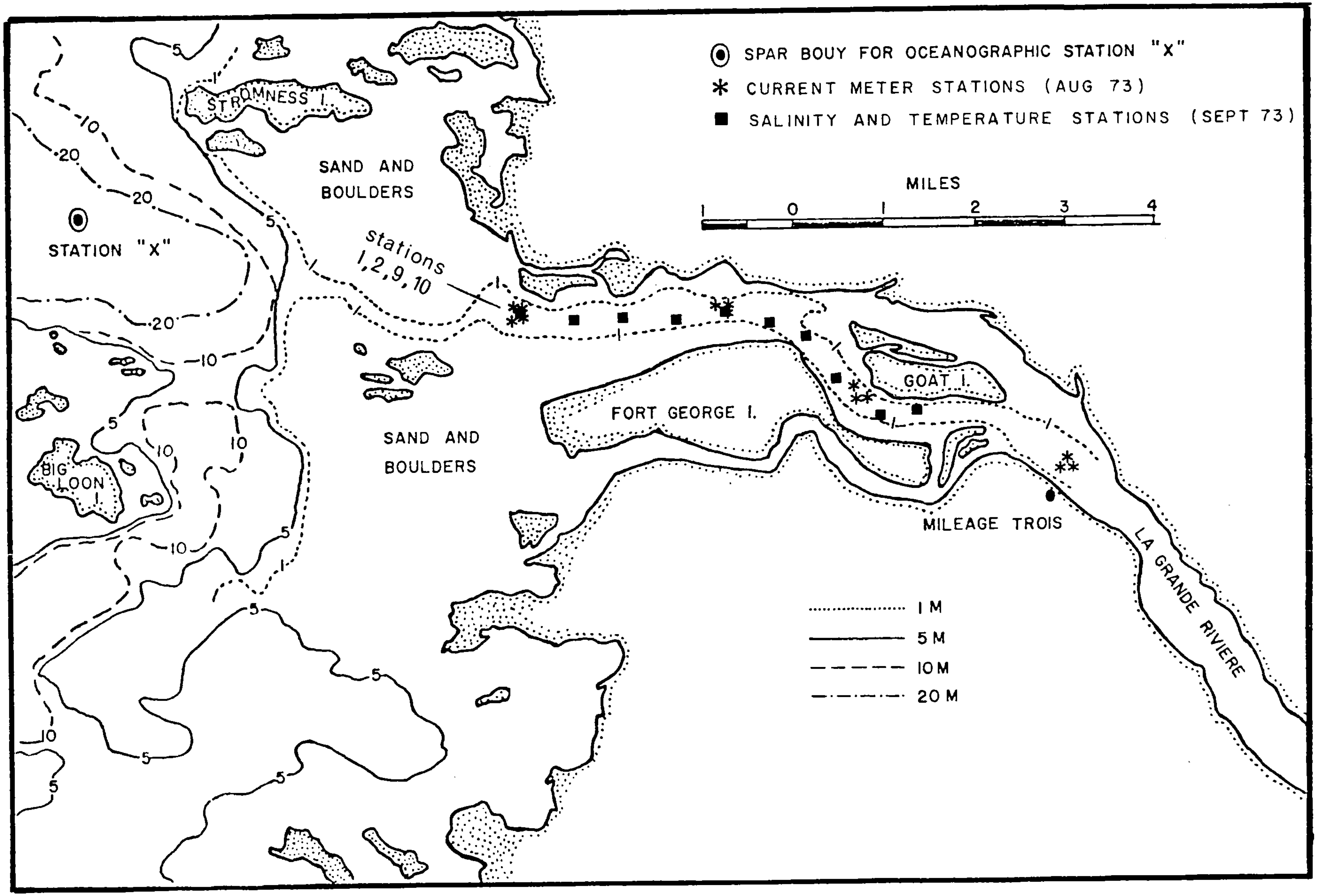


FIGURE 3: Locations of Oceanographic Stations in La Grande Rivière and Estuary.

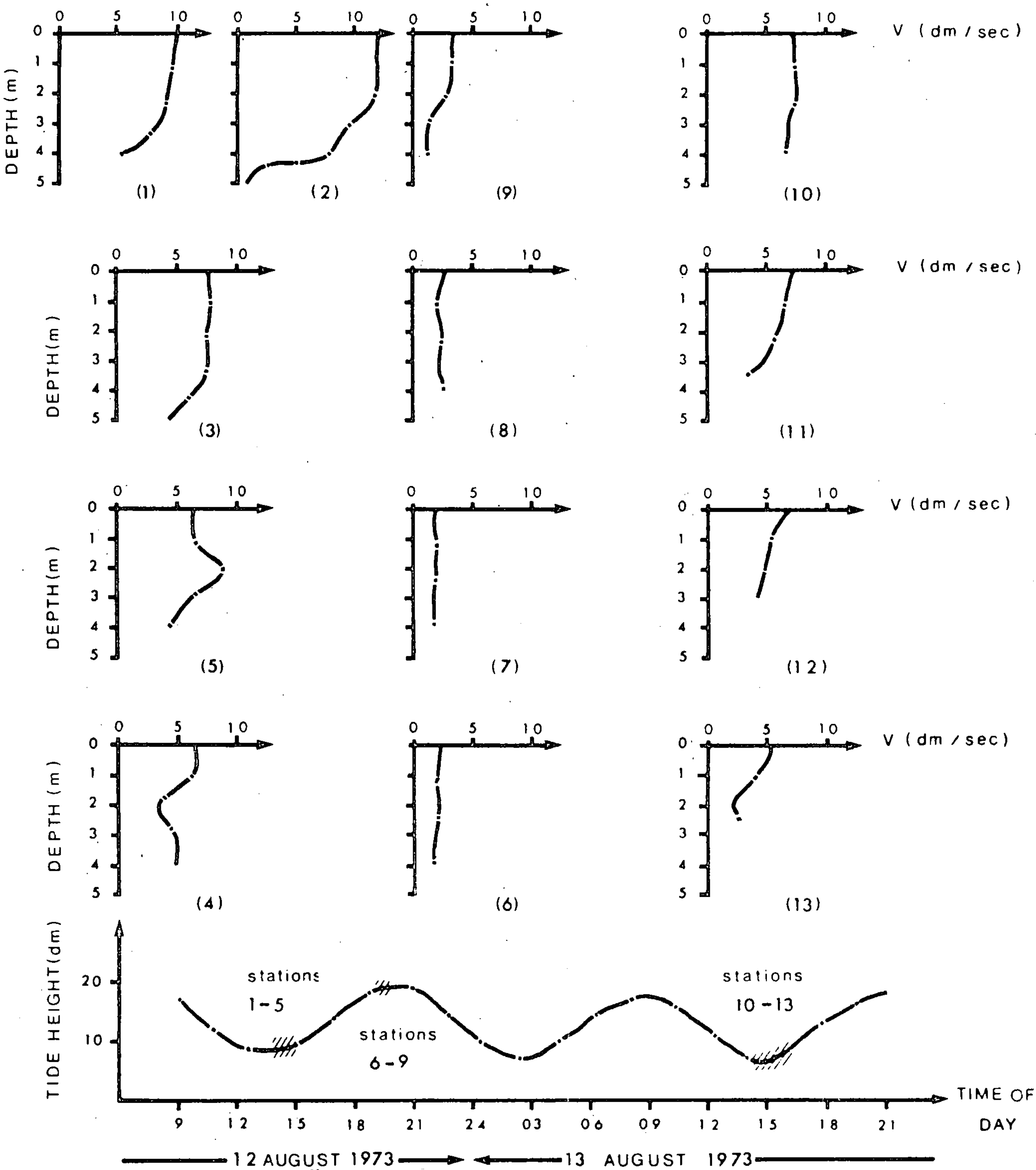


FIGURE 4: Results of current measurements and corresponding tidal information in the Estuary of La Grande Rivière, August 1973.

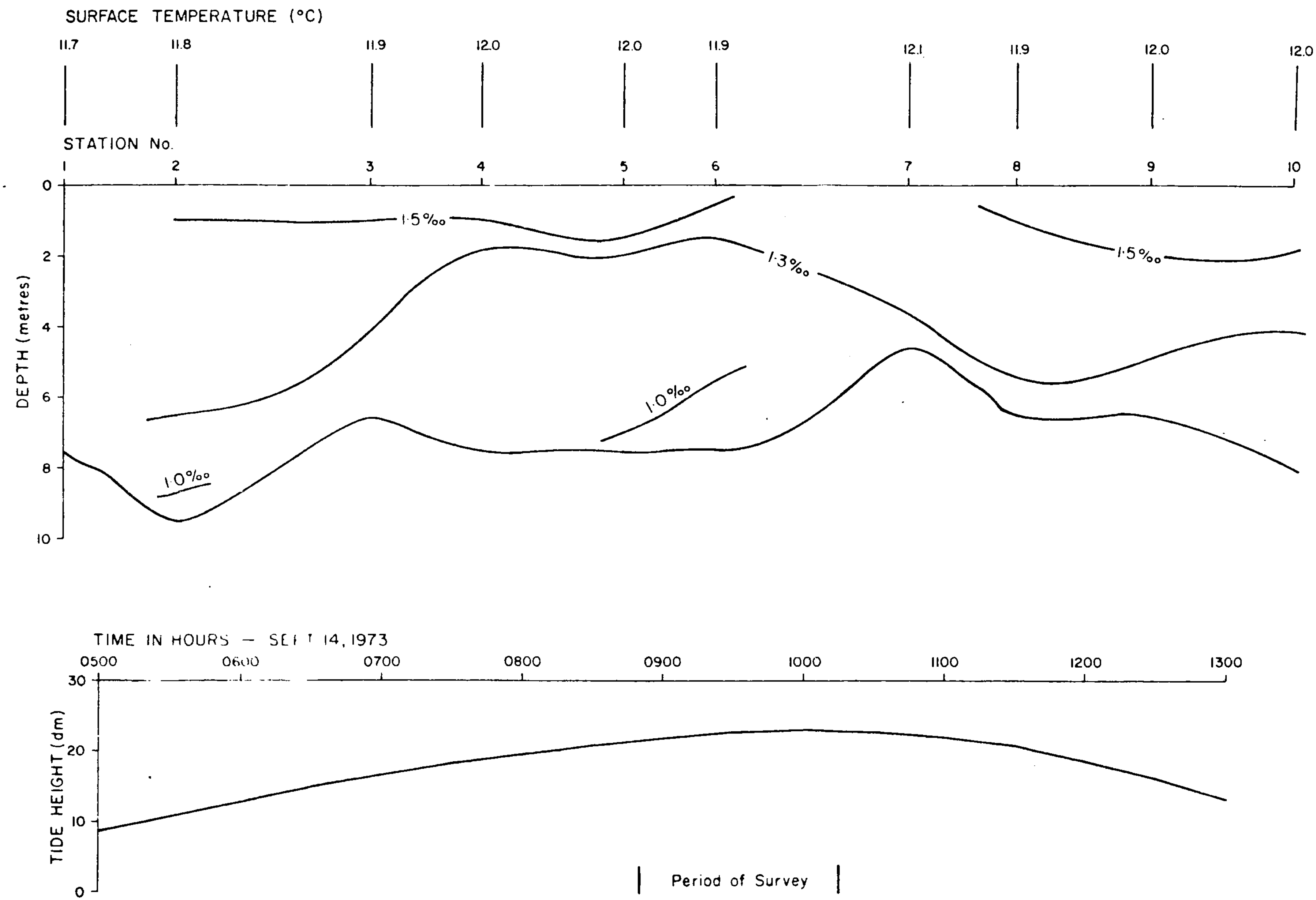


FIGURE 5: Salinity and Temperature distribution in La Grande Rivière downstream end, September 1973

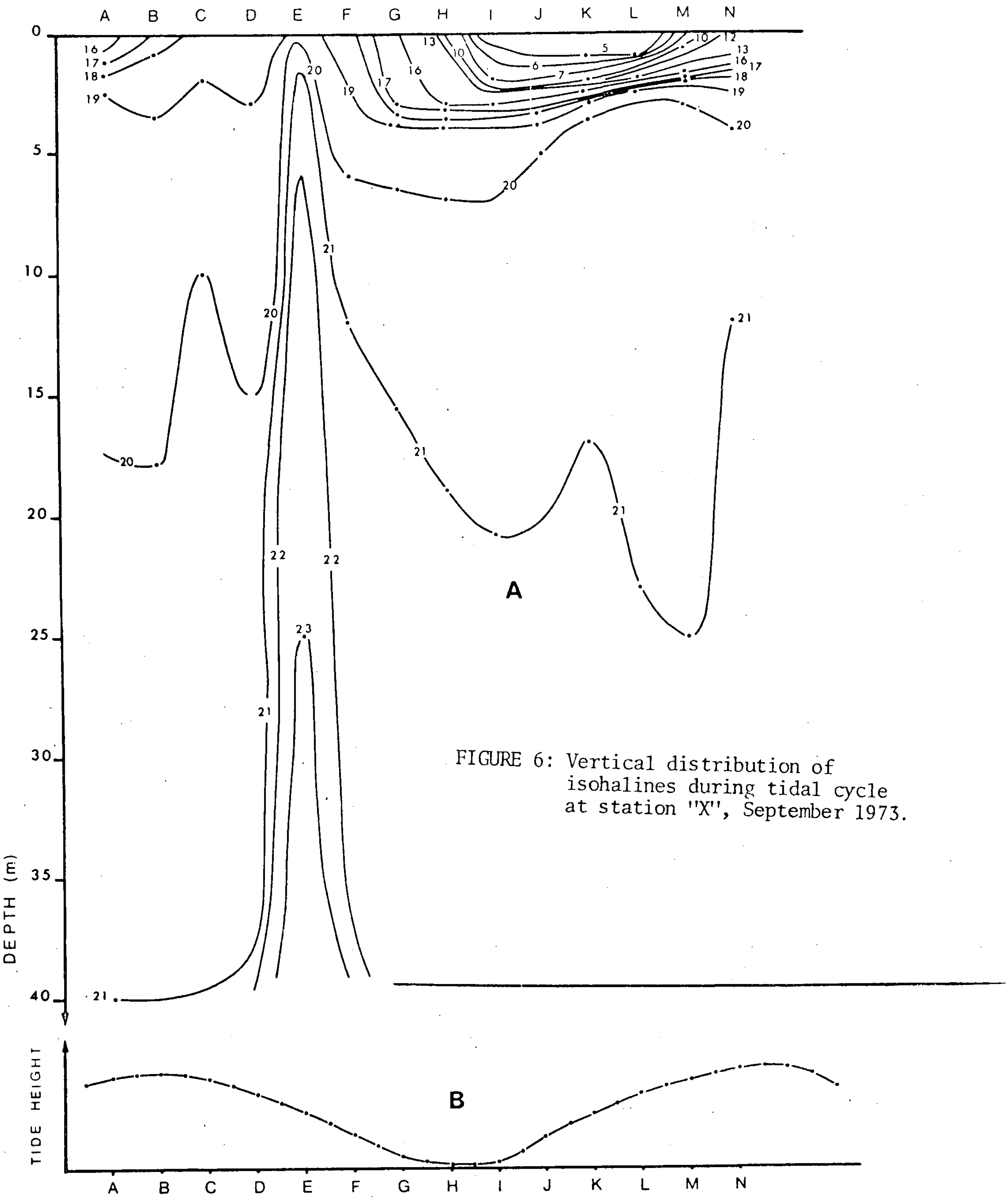


FIGURE 6: Vertical distribution of isohalines during tidal cycle at station "X", September 1973.

(a) SALINITY

(b) TEMPERATURE

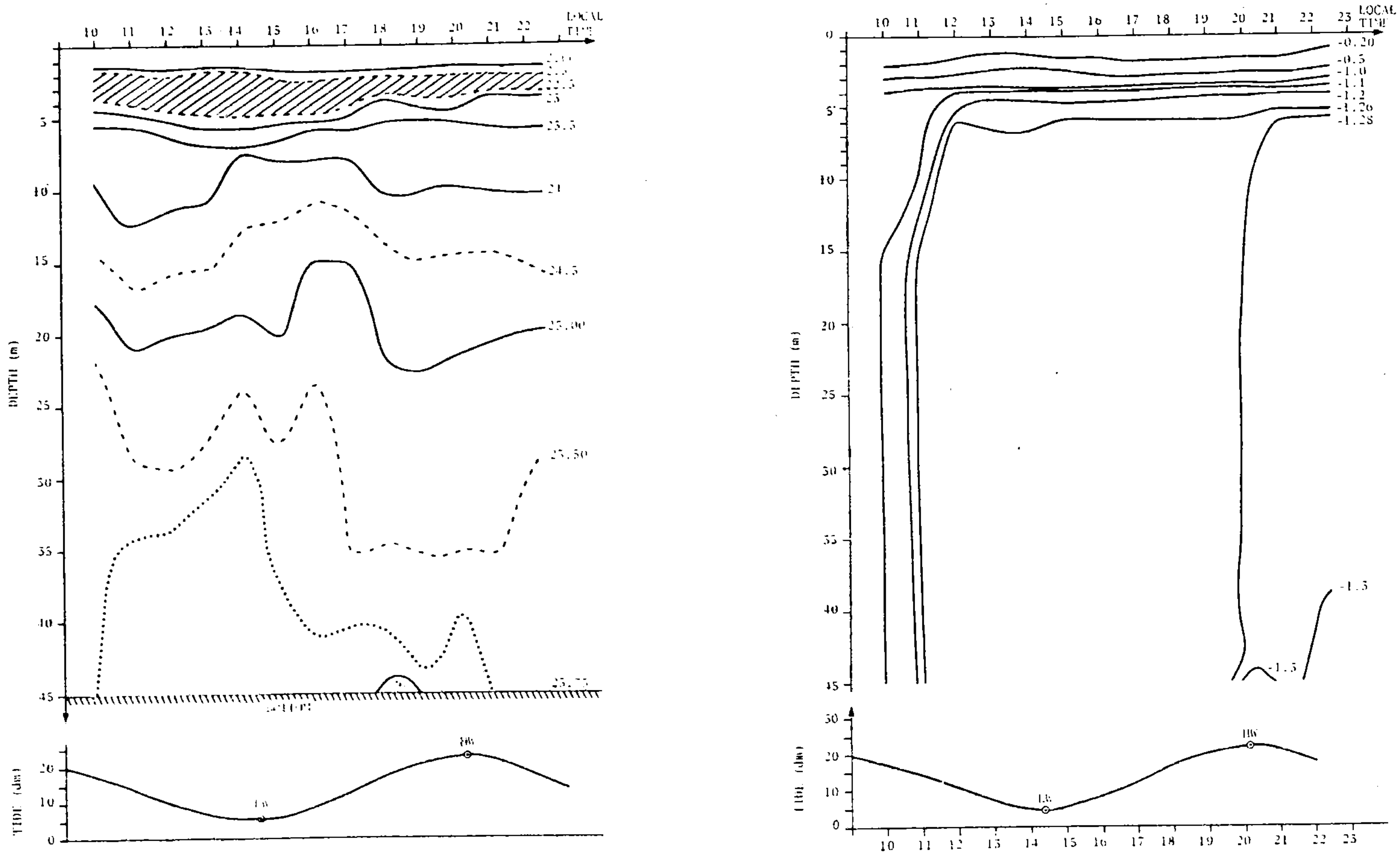


FIGURE 7: Vertical distribution of salinity and temperature during tidal cycle at station "X", March 1974.

WATER MASSES AT THE MOUTH OF JAMES BAY DURING THE SUMMER OF 1972

by

E.M. Hassan

The present paper deals with water masses as inferred from the 1972 observations in James Bay (Pullen, 1974). Both the northern section - at the mouth of the Bay - and the southern section - opposite Fort George - are considered. The volume of water masses represented by these sections was calculated according to the thickness of water layer with uniform characteristics, the distance between the stations, and the assumption that the section represents a strip of uniform width around it. This is a weak assumption, but in absence of a dense network of stations, it is the safest that could be made. Temperatures were divided into intervals of 0.5°C and salinities into intervals of $1^{o}/oo$.

The temperature-salinity volume composition for the northern section appears in Figures 1, 3, and 5, while that for the southern section appears in Figures 7, 9, and 11. The TS diagrams for the individual stations of the sections appear in the Figures 2, 4, 6, 8, 10, and 12. By comparing the two sections occupied at the same month, the difference of water masses in space could be inferred and by comparing the different occupations of the same section, the seasonal variation could be inferred (Table 1). The northern section always exhibited colder, more saline water than the southern section, as it is affected by Hudson Bay water. The spread of the salinity in the northern section was equal or smaller than the spread at the south, due to the proximity of the southern section to the source of fresh water. The temperature spread was similar in the two sections except in October, when the cooling reduced the temperature range in the south to half of that in the north. Mixing increased in both sections from August to October, but the mean salinity of the sections remained essentially the same. The increasing mixing as fall approaches indicates also that for this method, a fewer number of stations during fall and winter might supply information equivalent to a larger number in summer.

None of the results is qualitatively surprising, but their value is that they enable us to speak quantitatively about the water masses. It is of interest to extend these results at both ends, towards the summer at the beginning and towards the winter at the end. It is also important to repeat them to find the year to year natural variation.

Table 1

Some Statistical Characteristics of Water Masses in the Two James Bay Sections

	Mean Salinity			Salinity Spread			Mean Temperature			Temperature Spread		
	August	September	October	Aug.	Sept.	Oct.	Aug.	Sept.	Oct.	Aug.	Sept.	Oct.
Northern Section	28.78‰	28.74‰	28.84‰	10‰	10‰	6‰	-0.26°C	+1.76°C	+1.73°C	7°C	8.5°C	5°C
Southern Section	26.33‰	26.04‰	26.13‰	10‰	10‰	8‰	+2.14°C	+4.29°C	+3.71°C	8.5°C	7°C	2°C

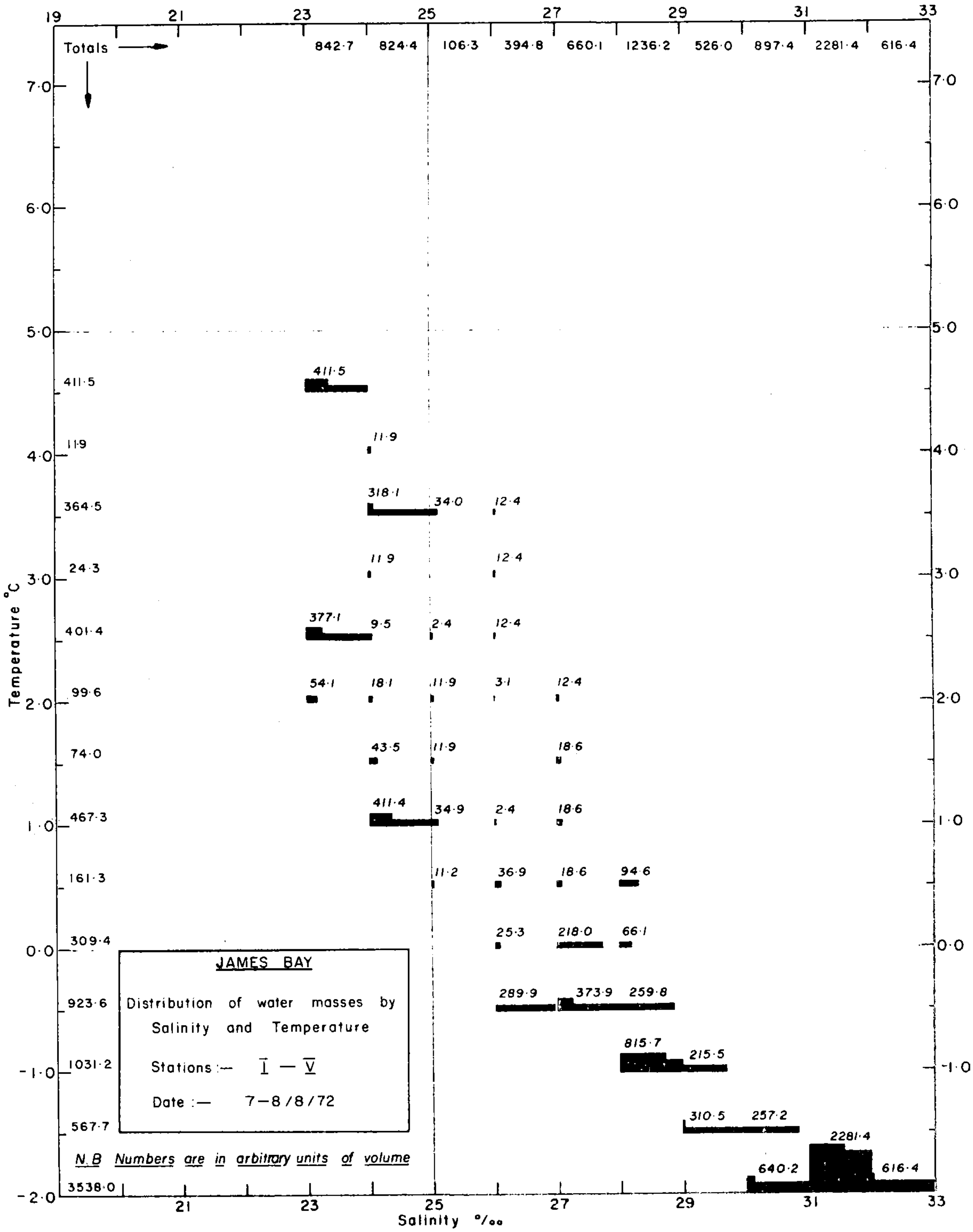


FIGURE 1: Water volumes at characteristic temperature and salinity at the mouth of James Bay August 7-8, 1972.

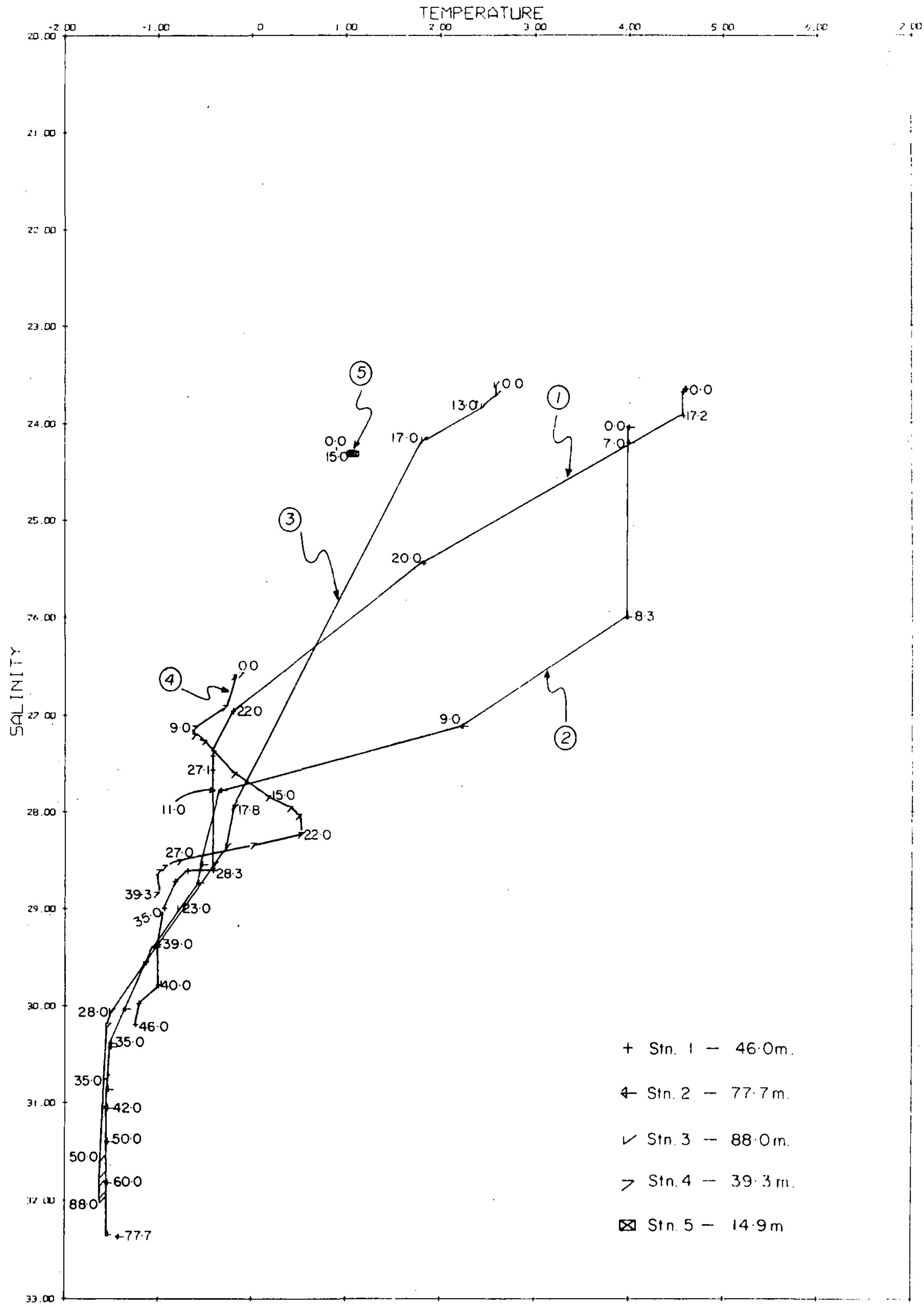


FIGURE 2: T-S relations at Stations I to V at the mouth of James Bay, August 7-8, 1972.

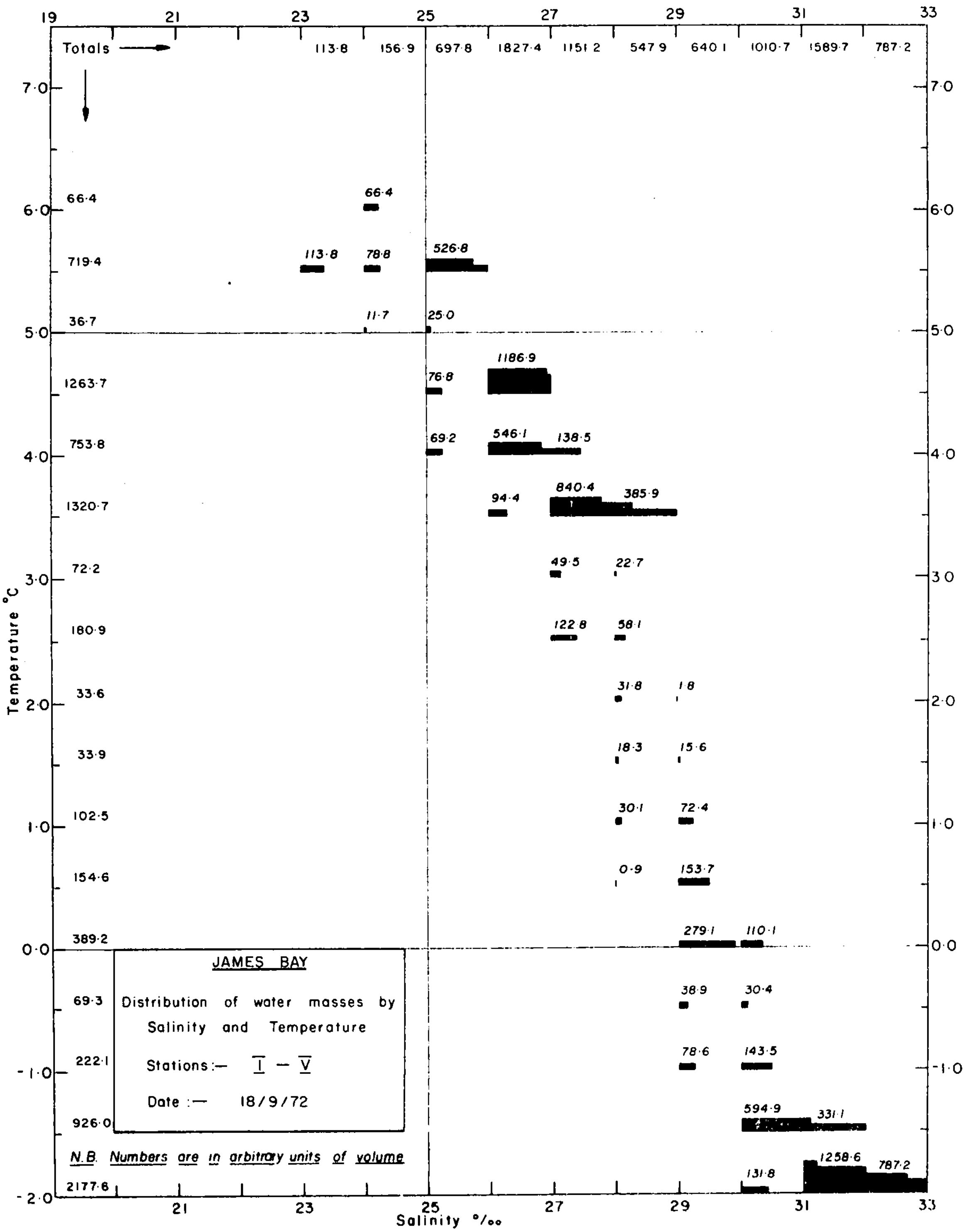


FIGURE 3: Water volumes at characteristic temperature and salinity at the mouth of James Bay, September 18, 1972

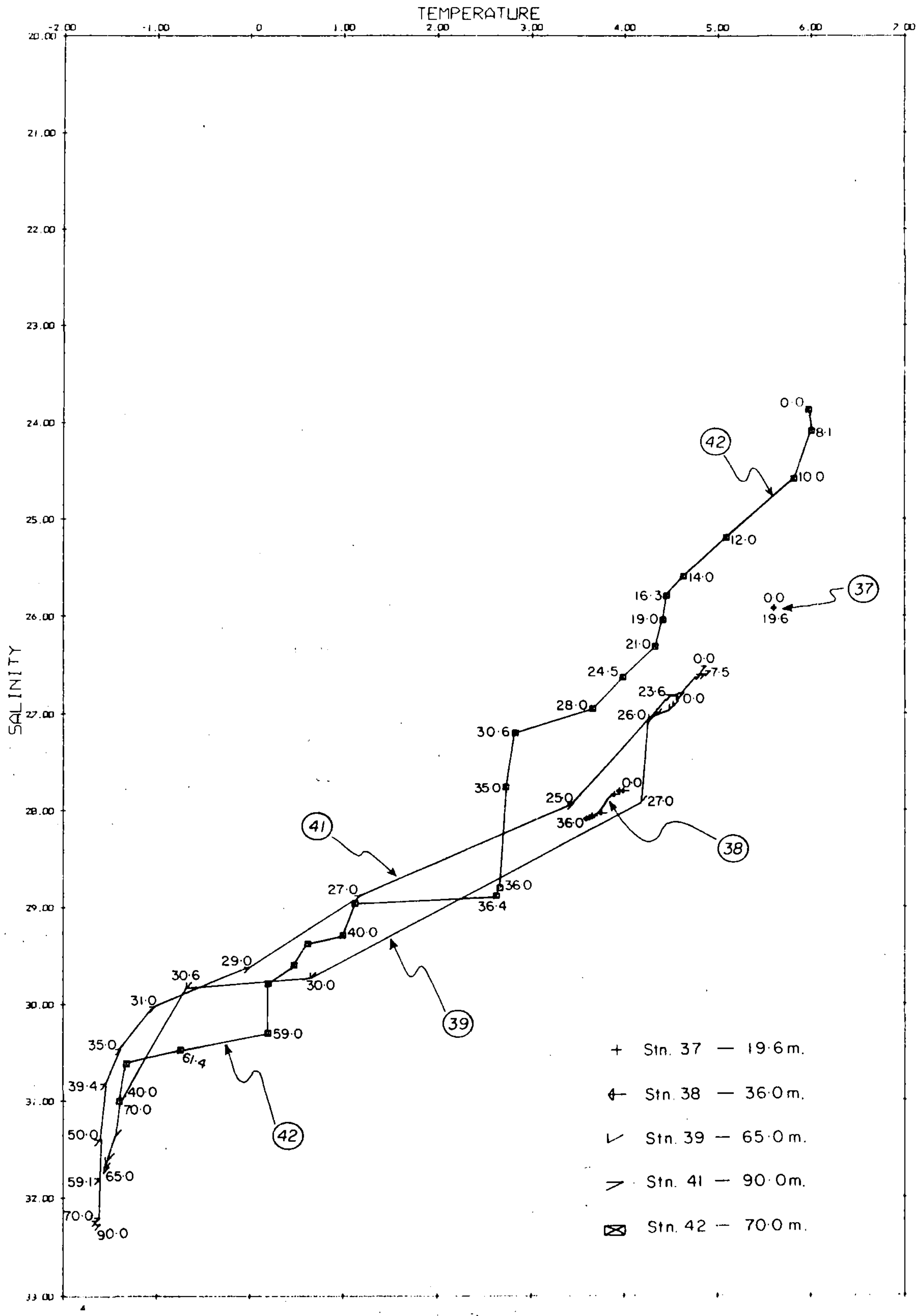


FIGURE 4: T-S relations at Stations I to V at the mouth of James Bay, September 18, 1972.

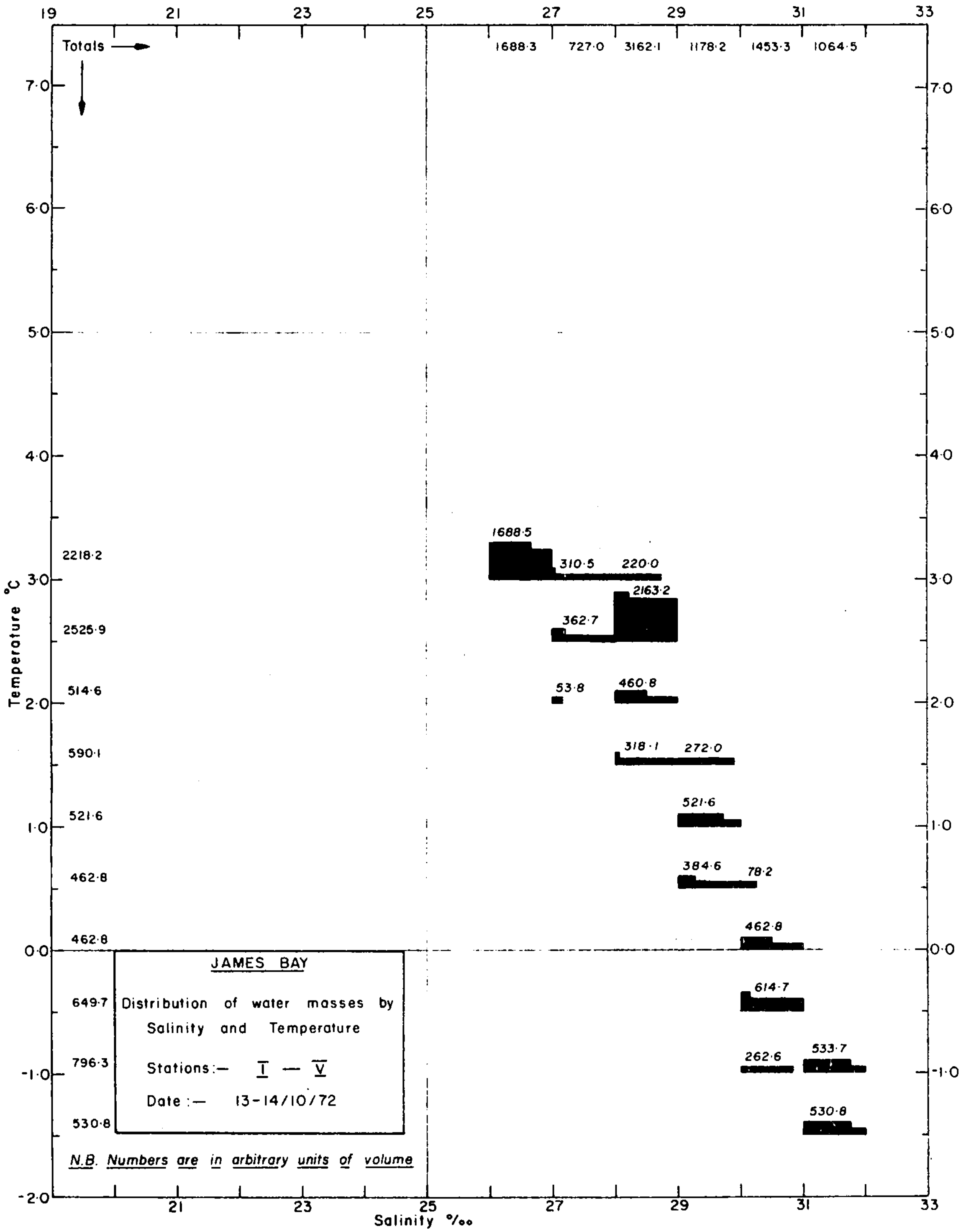


FIGURE 5: Water volumes at characteristic temperature and salinity at the mouth of James Bay, October 13-14, 1972

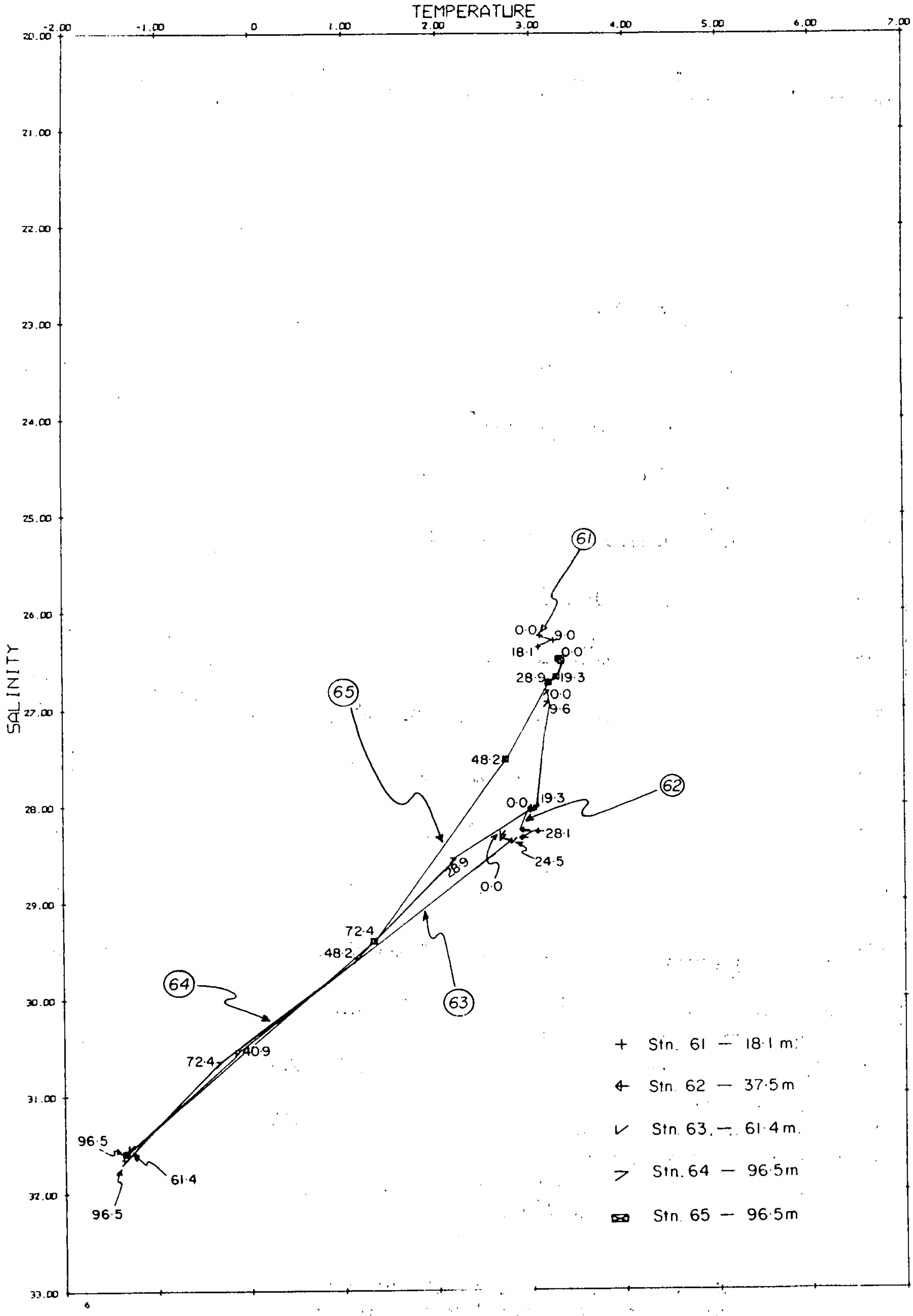


FIGURE 6: T-S relations at Stations I to V at the mouth of James Bay, October 13-14, 1972.

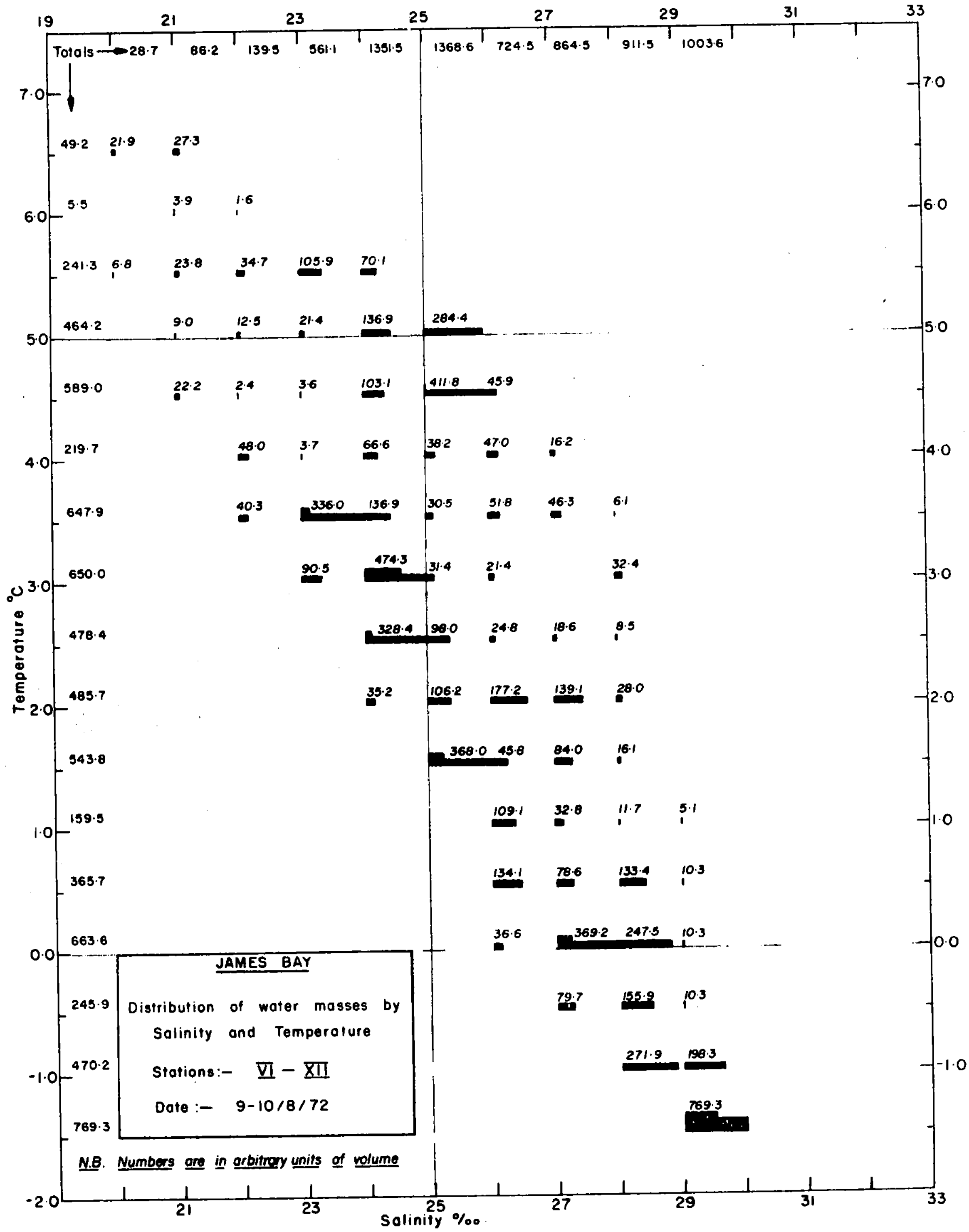


FIGURE 7: Water volumes at characteristic temperature and salinity at the section opposite Fort George, August 9-10, 1972

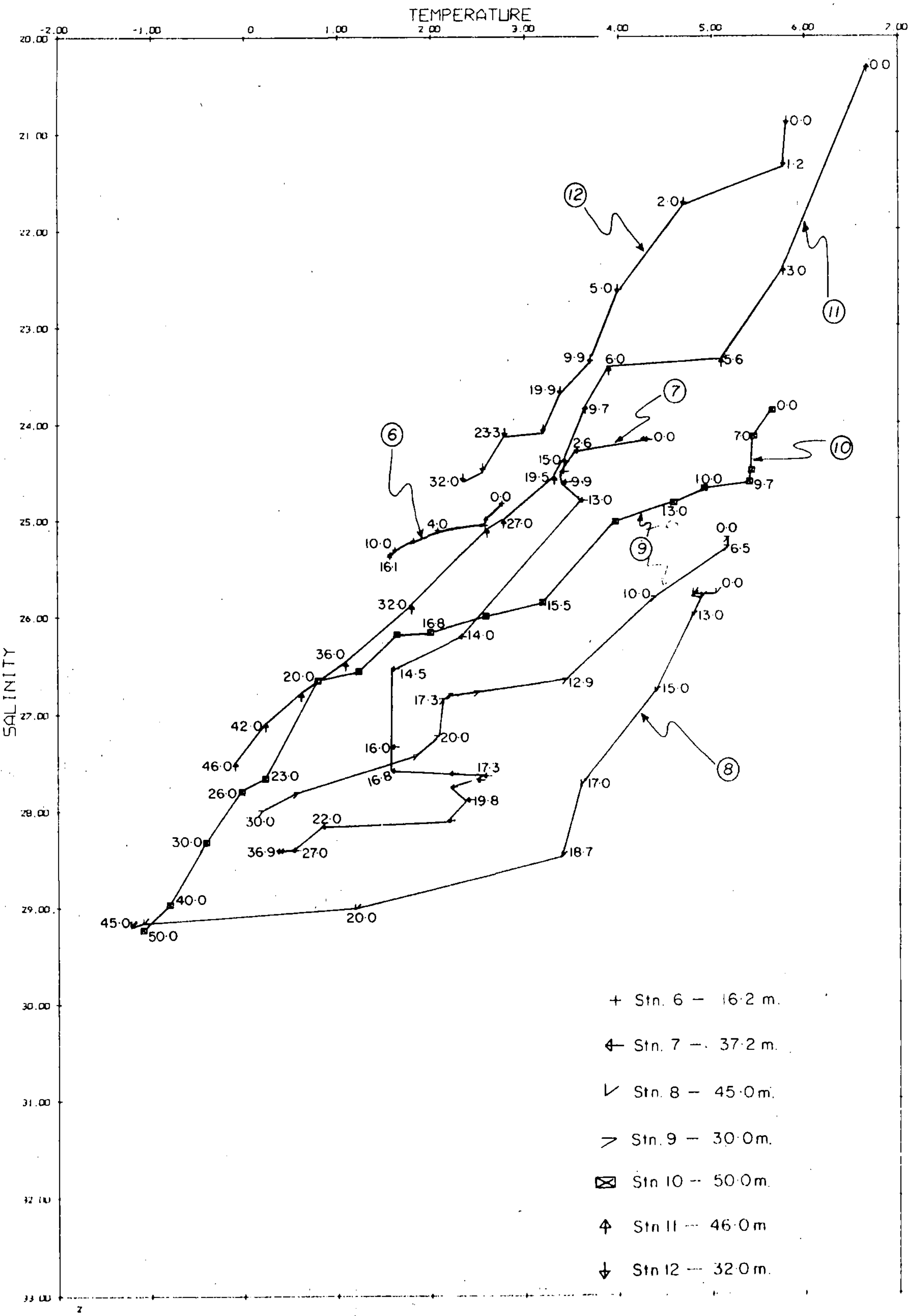


FIGURE 8: T-S relations at Stations VI to XII at the section opposite Fort George, August 9-10, 1972.

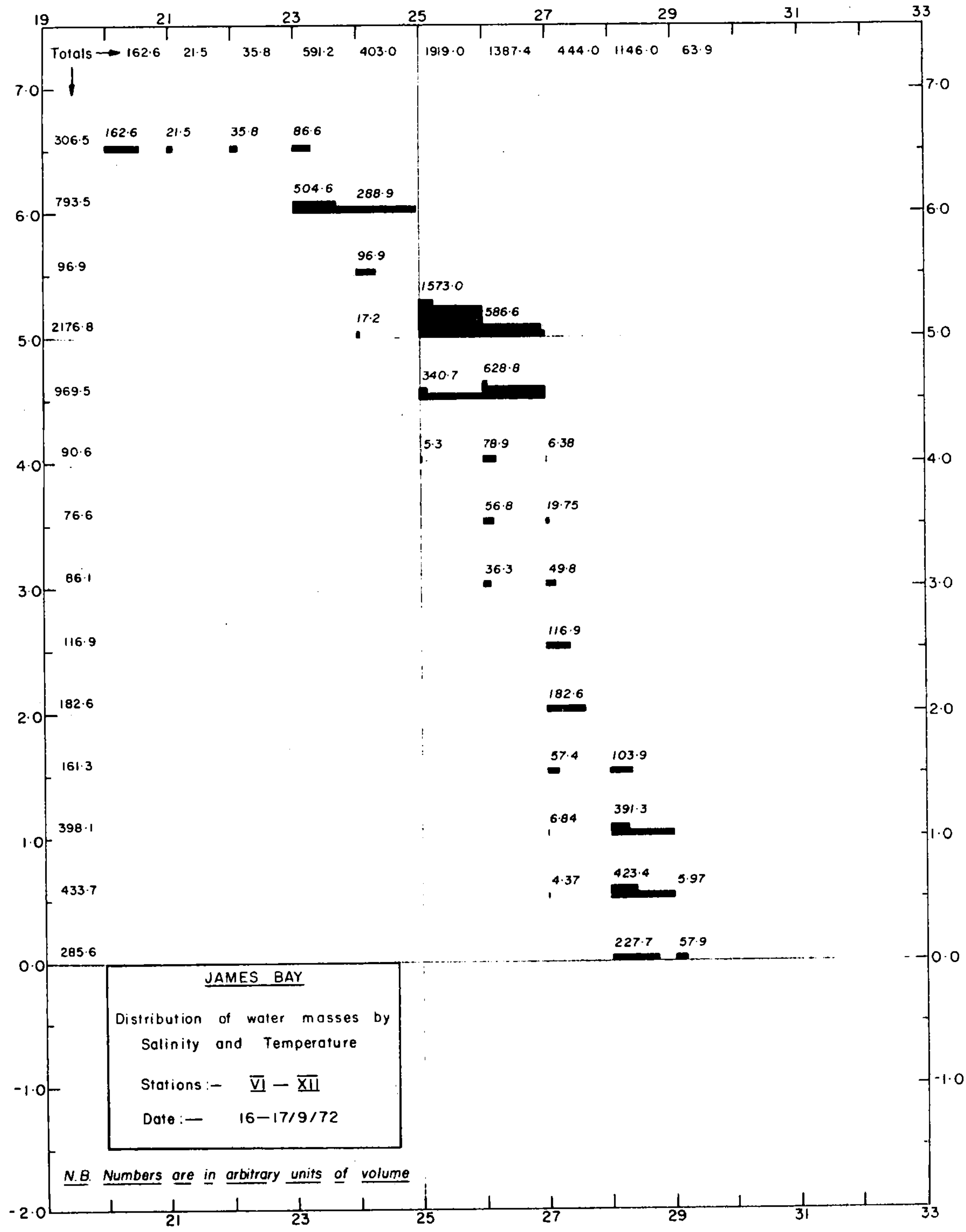


FIGURE 9: Water volumes at characteristic temperature and salinity at the section opposite Fort George, Sept. 16-17, 1972.

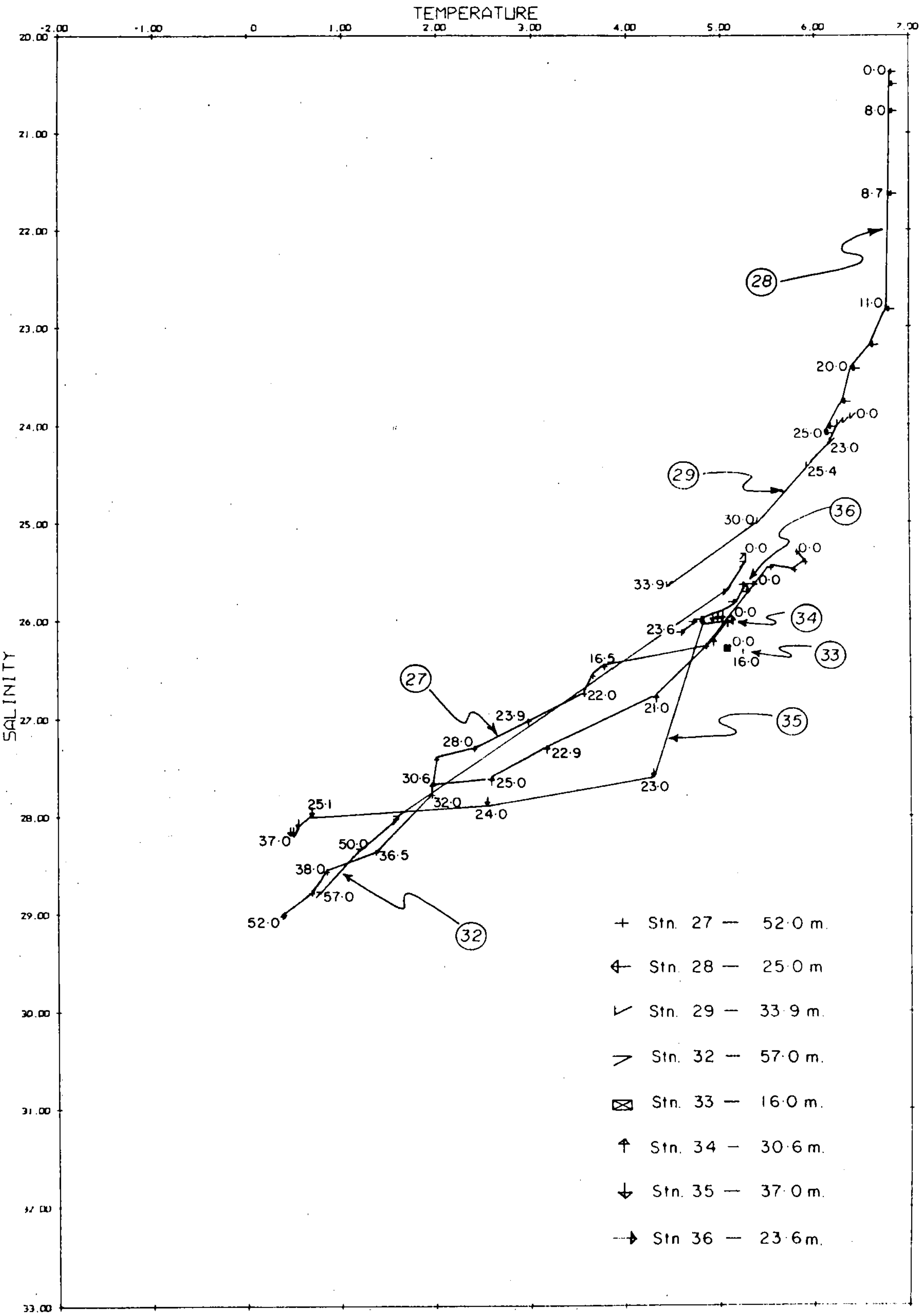


FIGURE 10: T-S relations at Stations VI to XII at the section opposite Fort George, September 16-17, 1972

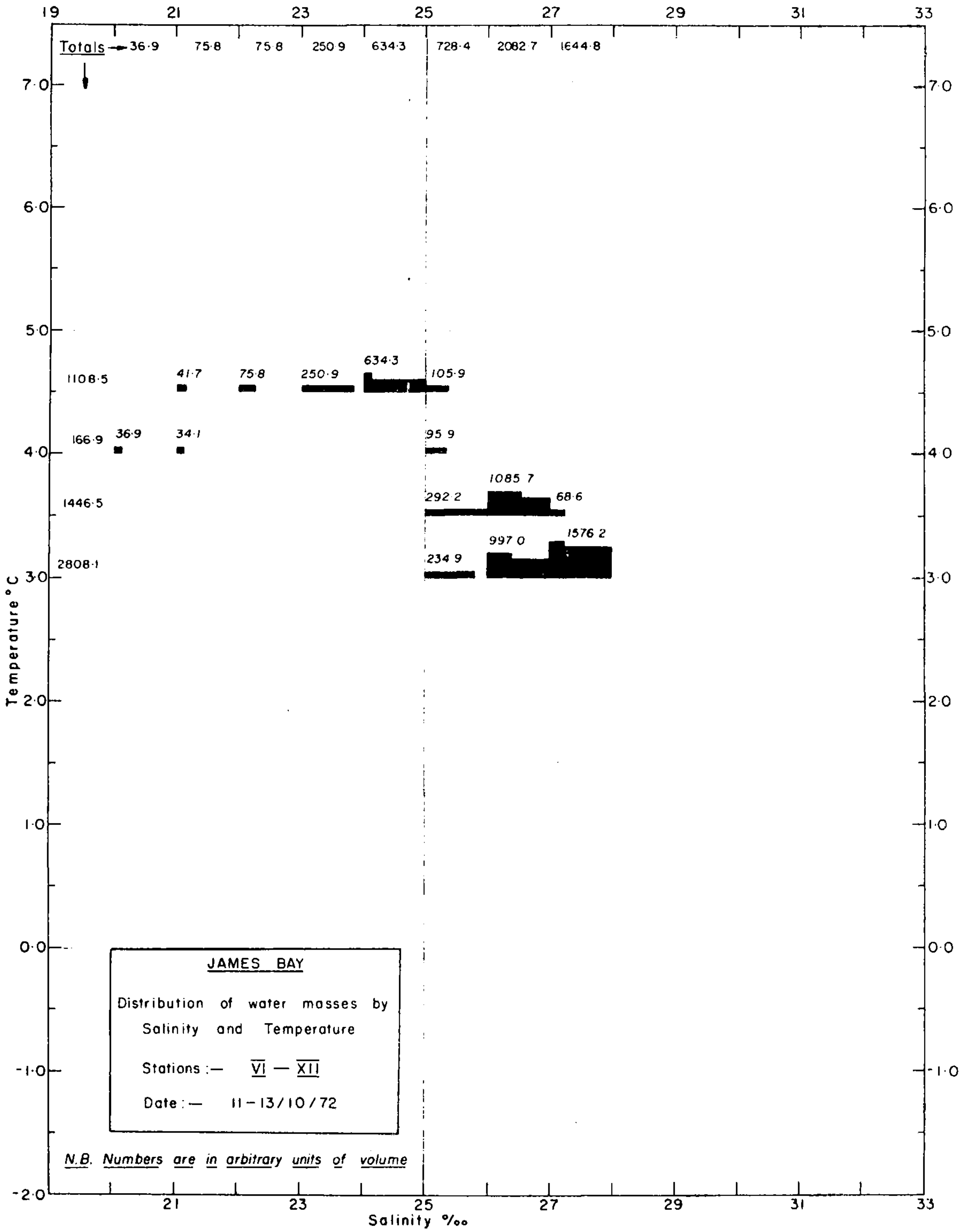


FIGURE 11: Water volumes at characteristic temperature and salinity at the section opposite Fort George, October 10-13, 1972

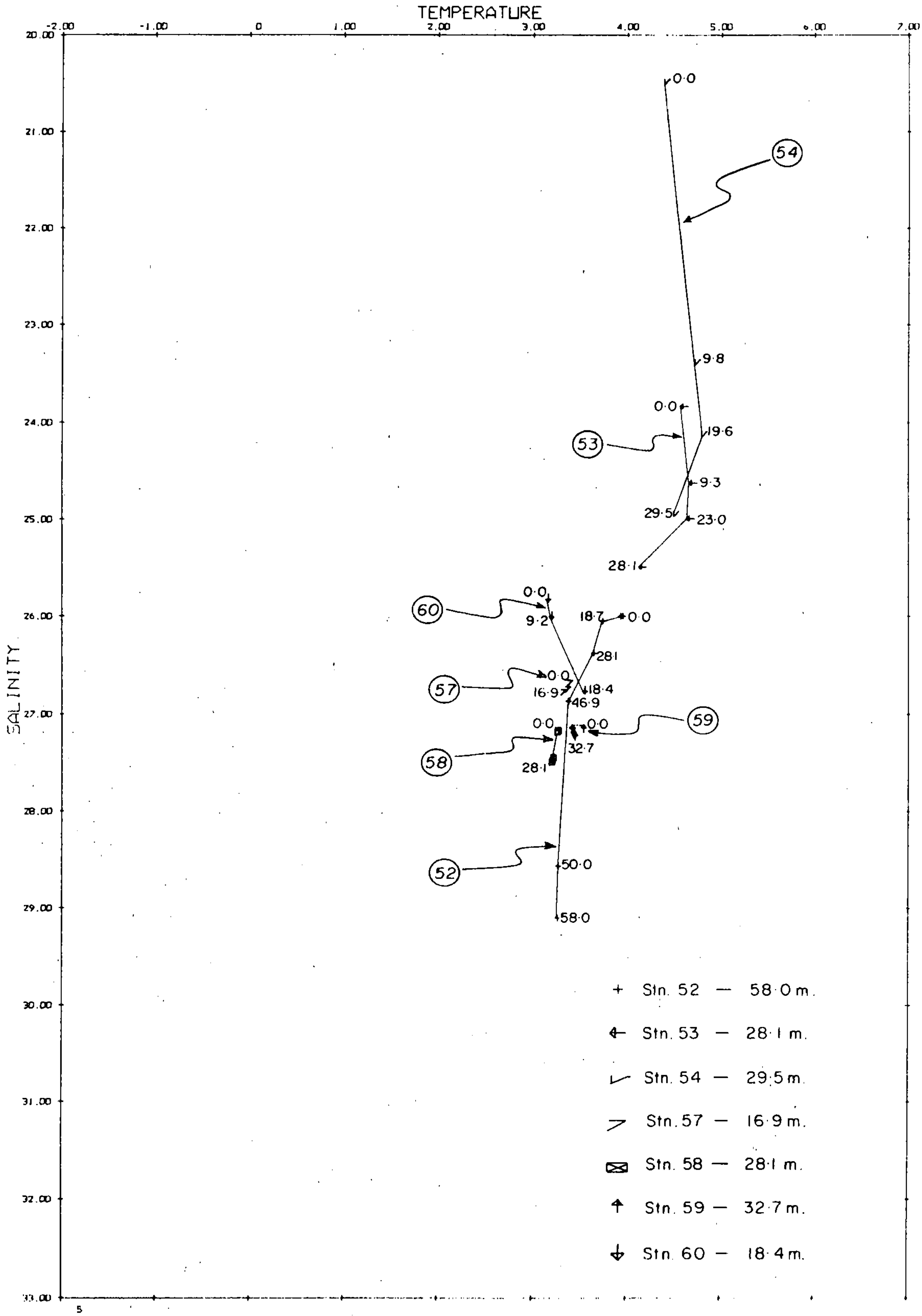


FIGURE 12: T-S relations at Stations VI to XII at the section opposite Fort George, October 10-13, 1972

SUMMARY
WINTER OCEANOGRAPHY JAMES BAY 1973-74

by

J.P. Croal

1.0 With the rapid development of Quebec's hydroelectric power projects in the James Bay area, it was considered advisable to establish oceanographic data of the waters of James Bay, using the sea and river ice in winter as a working platform.

In the spring of 1973 a contract was awarded to J.P. Croal to assess and report on the extent that simple oceanographic observations could be made from the winter ice cover of James Bay, and establish an oceanographic station in the deep water (45 M) about 7 miles west of Fort George, using local Indians as assistants.

J.P. Croal was in the field at Fort George from April 13 to April 20, 1973; based on conditions of the ice, it was considered practical to carry out some basic oceanography in the area prior to break-up of the river. A modified bathythermograph (less winch, cable and nose cone) and a Beckman RS-5 Salinometer were provided by the Atlantic Oceanographic Laboratory.

The period April 30 to May 11 was again spent at Fort George training a local Cree Indian, Mr. Samuel Tapiatic and in occupying a station 6.6 miles west of Fort George at a depth of 45 meters.

Two reports resulted from this early work:

(a) Preliminary oceanographic data of a station established near Fort George, James Bay in May, 1973, Field Report No. 1 by F.G. Barber, J.P. Croal, S. Tapiatic, Oceanographic Branch, Marine Sciences Directorate.

(b) MSD 6355-4-2, June 11, 1973- Report by J.P. Croal, Field Assessment of Winter Oceanography at Moosonee, Fort George and Great Whale. Marine Sciences Directorate, Oceanography Branch.

1.2 As a result of the work carried out in 1973 at Fort George, a six-month contract was awarded to J.P. Croal (December 10, 1973 to June 10, 1974) to establish and maintain a program of oceanographic observations from the winter ice cover of James Bay using simple oceanographic instruments in the hands of local Indians, based at Fort George, P.Q., to train the local people to a standard that will enable them to operate the main station near Fort George at appropriate intervals, and to occupy a series of stations in a section seaward of this site. The scientific authority for the operation is Mr. N.G. Freeman, Marine Sciences Directorate, C.C.I.W., Burlington, Ontario.

J.P. Croal was in the field at Fort George from December 28, 1973 to May 14, 1974.

Recordings commenced on January 11, 1974 and the project was terminated on May 10, 1974 due to unfavourable ice conditions and the pending break-up.

1.3 The oceanographic team at Fort George consisted of J.P. Croal, S. Tapiatic, first field assistant, D. Cox, Second field assistant (both assistants Cree Indians). During the course of the operation Mr. N. Freeman and F. Barber visited Fort George for short periods and added to the data with test work by helicopter, and a B.T. survey.

1.4 Stations occupied

Main Stations - Croal				Number of Recordings
No. 1	53°51.25'N	79°10.25'W	1973-1974	49
2	53°52.25'N	79°14.3'W	1974	13
3	53°53.2'N	79°16.55'W	1974	1
4	53°50.27'N	79°15.15'W	1974	1
10	53°50.75'N	79°07.6'W	1974	4

BT Stations - Barber				Number of Recordings
No. 5	53°54.0'N	79°09.0'W	1974	1
6	53°52.25'N	79°14.3'W	1974	1
7	53°42.4'N	79°11.0'W	1974	1
8	53°42.4'N	79°15.8'W	1974	1
9	Off Ft. George school water intake		1974	1

Test Stations - Freeman				
NF Test 1	53°51.25'N	79°10.25'W	1974	1
2	200' off Pt. Skidoo		1974	1
3	53°50'N	79°16'W	1974	1
4	53°51.89'N	79°15.4'W	1974	1

1.41 Method

Instruments used were B.T. less winch, wire and nose cone, Van Dorn water sampler, Beckman RS-5 salinometer. In addition, Mr. Freeman tried a C.T.S. Yellow Springs Instrument Co. Model #33 Serial No. 899.

Weather data, ice thickness and snow cover records were made throughout the winter at the main stations. Travel over the ice was by ski-doo towing a box sled.

Mr. Freeman conducted tests using a Hughes 500 helicopter as a method of transportation and from which the recordings were carried out.

Tents heated by wood burning box stoves were used at the main stations.

1.5 A report of the 1974 operation is now available, MSD 6355-4-2, June 10, 1974, Field Report, Winter Oceanography James Bay 1974. Contract serial No. OSR3-0455 by J.P. Croal assisted by S. Tapiatic.

A data report for the 1973-74 data is being worked up at Marine Sciences Directorate, CCIW, Burlington.

2.0 Conclusion

It is entirely feasible to conduct winter oceanography through the ice cover in the Fort George area.

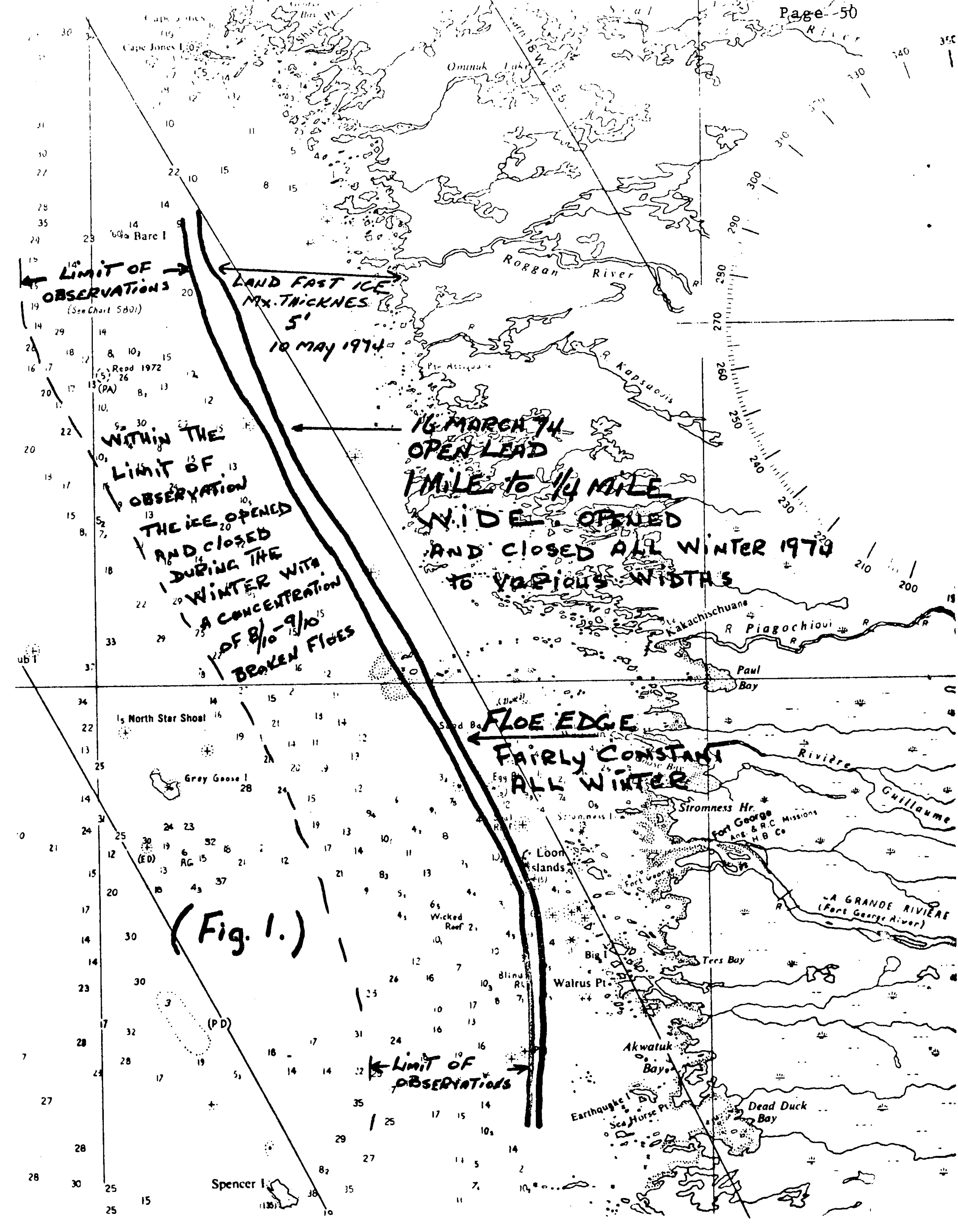
Heated shelters are required on the ice in cold weather and instruments must be protected from jarring during transit and also protected from cold soaking. Very careful consideration must be given to the calibration of the Beckman RS-5 salinometer prior to recording. The problems and solutions are outlined in the Field Report in detail.

Local natives can be trained to operate simple oceanographic equipment, but would require further training before they could conduct a complete winter oceanographic programme on their own. Their attention to detail, and care of equipment in the field is not yet acceptable.

3.0 Future Work

It is recommended that the work started in the Fort George area in 1973 be continued. Station No. 1 appears to be giving fairly representative data of the river mouth Loon Island area. This station has been occupied through the ice a total of 49 times since 1973 including a 13-hour recording period on March 8, 1974. Station No. 1 was occupied on a twice weekly schedule during the 1974 winter. This might be reduced to once every two weeks in 1975 with an expanded programme closer to the floe edge by helicopter during the latter part of April into May.

From observations made of ice conditions off Fort George during the winter of 1974, it is considered that there is more open water and ice movement in this area than has previously been reported, and in fact this might be true of the rest of James Bay. This is also worthy of study.


LIMIT OF OBSERVATIONS
(See Chart 5801)
LAND FAST ICE
Mx. THICKNES
5'
10 MAY 1974
16 MARCH 74
OPEN LEAD
1 MILE to 1/4 MILE
WIDE. OPENED
AND CLOSED ALL WINTER 1974
to VARIOUS WIDTHS
WITHIN THE
LIMIT OF
OBSERVATION
THE ICE OPENED
AND CLOSED
DURING THE
WINTER WITH
A CONCENTRATION
OF 8/10-9/10
BROKEN FLOES
FLOE EDGE
FAIRLY CONSTANT
ALL WINTER
LIMIT OF
OBSERVATIONS
(Fig. 1.)
Cape Jones I.
Ominuk Lake
Bare I
Roggan River
Kapsaouis
Kakachischuane
Piagochioui
Paul Bay
North Star Shoal
Grey Goose I
Rivière Guillaume
Stromness Hr.
Fort George
Ang. & R.C. Missions
H.B. Co
Loon Islands
LA GRANDE RIVIERE
(Fort George River)
Wicked Reef
Big I
Tees Bay
Walrus Pt
Akwatuk Bay
Earthquake I
Sea Horse Pt
Dead Duck Bay
Spencer I

SOME THOUGHTS ON THE WINTER OCEANOGRAPHY

by

F.G. Barber

The data and remarks of the previous participants confirm that James Bay is of interest to oceanography quite in addition to the problems associated with development of hydroelectric potential there. Nevertheless, the assessment of the impact on oceanographic conditions remains an interesting problem, noting that the modification to the run-off of the La Grande will also include a period when the flow is stopped. As well, the flow in the Eastmain River is to be very much reduced apparently.

From the time of our first assessment or review of the oceanography of James Bay my interest has been directed mainly to the conditions during the winter, or rather, during the period of ice cover. It was foreseen that a change of structure could occur under the ice adjacent to sources of freshwater, such that a freshwater layer would exist, and that away from such sources there would be little structure. As yet, we have no direct evidence concerning the latter feature, but it has been determined that a freshwater layer does exist close to the La Grande.

As already mentioned (JPC), we have noted that there is much more open water in winter in the Bay than has been reported. Initial evidence for this came out of our own experience, but casual examination of remote sensing data, including APT from 1967, suggest this to be the general condition. There are a number of other curious features of the ice cover there which might provide useful information. One is the distribution of snow on the ice which seemed to reflect the occurrence of relatively stronger winds from the northwest. Another is the occurrence of a clear ice, i.e. the so-called "black" ice, which contains "hollow inclusions". It is evident that the light level in the water below this ice cover is much above that normally experienced under sea ice, but how much higher is uncertain. One reference suggests that the light intensity is similar to that in the absence of ice. The amount and distribution of this ice was not determined.

It was anticipated that internal waves would be observable at the interface at the bottom of the low salinity layer, but as yet only indirect data on this aspect has been obtained. Similarly, it was anticipated that movement in this layer would be mainly tidal; some limited observations with a tethered drogue at position 1 indicated a movement to the south at about 20 cm sec^{-1}.

Assuming that the runoff in the La Grande was the same in 1974 and in 1970, then it seems likely that a significant fraction of this run-off, more than 50%, remains in a surface layer of low salinity. However, we still lack adequate data on the distribution of this layer and, therefore, about the degree of mixing which occurs. It may be significant that, as mentioned, the ice cover in mid-Bay appears much less consolidated than in Hudson Bay, for example. With this would be associated a relatively higher heat loss which, if sensible heat, suggests convection over the total depth.

Two conditions are visualized: in one, a layer of very low salinity exists under areas of fast ice (mainly around the periphery of the Bay); the other, a region of little structure, is associated with the pack or moving ice. It seems possible that the regime of the ice cover in the La Grande estuary could be significantly altered by the post-construction flow, e.g. the proportion of fast ice to pack ice off the estuary could be altered. There are, however, a number of aspects which require evaluation; one is the distribution of salinity and temperature in the water during the period of ice cover, another is knowledge of the distribution of the freshwater layer under the ice cover and its quantitative relation to the runoff.

OUTLINE OF GEOLOGICAL - CHEMICAL STUDIES FOR JAMES BAY

by

D.H. Loring

Marine and estuarine geological and geochemical studies are required to define the sedimentary and chemical evironments in James Bay and to assess the possible effects of natural and man-made changes on these environments by the James Bay Power Project.

In order of priority, these studies should be concerned with (1) the supply of dissolved and suspended matter from rivers draining into the east side of the Bay particularly from those rivers which will be developed first such as La Grande; (2) the sources and dispersal of material in the estuaries of these rivers; (3) the sedimentary and chemical environments in the shallow water (<10m) adjacent to the east side of the Bay and (4) the general sedimentary and chemical environment(s) of the Bay itself.

River Influx Studies: It seems essential that priority be given to the determination of the amount and nature of dissolved and suspended organic and inorganic material now entering the east side of the Bay, particularly from those rivers now being brought under control if changes in the sedimentary and chemical environment of the Bay are to be predicted.

To determine the influx from the rivers and the changes which might take place from them, it is necessary to arrange for (1) a network of monitoring stations to be set up at the mouths of the major rivers as well as from selected sites in their drainage basins; (2) collection of samples at the sites that would be representative of the whole flow of the water at the sampling point and changes which occur in the water with variations in discharge rates for its (a) dissolved load and (b) the suspended solids; (3) measurement of the major constituents of the dissolved load and the grain size, chemical and mineralogical composition of the suspended load, and (4) analysis and interpretation of the data. I understand monitoring stations now exist at the entrance of the La Grande River, as well as in the head waters of the Great Whale, Opinaca, Eastmain and Rupert Rivers. These stations would serve to initiate this program, but more are required. Although the analysis of the dissolved load is usually carried out routinely by the sampling agency, more specialized groups may be required to carry out mineralogical and chemical analysis of the suspended matter.

These studies will be required to answer such environmental questions as 1) the amount and nature of the material supplied by each of the rivers and the supply rate; 2) possible changes in the quality and amount of this material entering the Bay during the construction of roads and dams in the drainage basins of the rivers under development and after the river flows are nearly cut off or changed after completion; 3) the part this material plays as essential nutrients for the growth and maintenance of freshwater and marine life in the rivers, estuaries and bays; 4) the extent to which local marine fauna are dependent on river-derived material, etc., and 5) the effect of shutting off this supply for a short or long term on the biota and the physical environment of the affected drainage basins, rivers, and estuaries, etc.

Background information would also be required on the local geology and physiography of the drainage basins of the individual rivers.

Aside from environmental considerations and from a practical viewpoint, these studies should supply some answers to such geological engineering questions as 1) the rate at which the basins created by dams will fill up with sediments; 2) the changes in the erosional process at the construction sites; 3) the sites of potential land-slides of unconsolidated sediments which may be similar in origin, composition, and sensitivity to flow as those found in the St. Lawrence lowlands and in the vicinity of the Saguenay River near Chicoutimi; 4) the long term effect of differential crustal rebounce which is now taking place in this region at an estimated rate of 30 to 100 cm/century

(0.3 cm to 1 cm/yr) and to a height of 240 m above present levels (Innes and Weston, 1966, Andrews 1966) on such things as the dam design and safety factors, on the dam sites themselves as well as on the capacity and hydro-electrical potential of the dams, etc.

Estuarine Studies: It is likely the estuarine environments will be first to reflect the impact of changes in freshwater influxes of dissolved and suspended matter. To predict the effect of these changes, it will be necessary to (1) determine the present concentrations, composition, dispersal pattern, and transport mechanisms of suspended matter in the estuary and (2) to define the sedimentary and chemical environment of the estuary in relation to the present physical-chemical conditions.

A sampling program would be required in each estuary and would involve the collection and analysis of water and suspended matter samples throughout the estuary in relation to the geography, and physical oceanographic processes operating in the estuary. Supplementary measurements would include secchi disc readings, depth, temperature, salinity, currents, etc. Bottom grab samples and cores from selected sites, echo sounding profiles along with laboratory analysis of the samples for grain size, mineral composition, carbonate content, and organic carbon would be required to define the present sedimentary environments of the estuary. Since each estuary will vary in character, details of the program would have to be worked out on an individual basis.

A study of the geomorphology and sediments along the shores of the estuary would also be required to assess their contribution to the sedimentary environment of the Bay and the changes that might occur if nearshore erosion and depositional process are altered in the estuary.

These studies will provide some answers to such questions as to 1) extent to which the sediments and suspended matter of the estuary are in equilibrium with the present physical-chemical environments; 2) the possible changes in the nature and processes of sedimentation (erosion, transport and deposition) and circulation patterns in the estuaries;

3) the effect on the benthic and pelagic biota by any new erosional and depositional patterns in the estuaries; 4) the changes in the shorelines of the estuaries that might take place with alteration of the physical oceanographic environment.

Nearshore Studies: A reconnaissance study of the nearshore zone (water depths <10m) along the east side of James Bay will be required to outline the sedimentary environment of this zone and to evaluate the extent to which material from the individual rivers is contributed to this zone.

This study would involve a series of bottom sampling and echo sounding traces across this zone from the bottom to the top of the Bay at about 15-30 nautical miles intervals with sampling stations spaced not more than 2 nautical miles apart. It would also include sampling of the suspended and dissolved matter in the water column throughout this zone. Requirements for laboratory analysis of the samples would be similar to those outlined for the estuarine studies.

Offshore Studies: Very little is known about the marine geology of James Bay, although background information has been published* on the bedrock and glacial geology (Norris and Stanford, 1969) and the rivers (Cummings, 1969) as well as on the morphology, sediments and fauna of Hudson Bay (Pelletier, *et al* 1968, Pelletier 1969, Wagner 1969). A systematic bottom sampling and echo sounding program on a reconnaissance scale is required to delineate the sedimentary environments of the Bay and the effects that changes in the depositional concentrations, along the east coast might have on the Bay as a whole.

It will also be necessary to investigate the bedrock and surficial geography within the framework of this study because the potential mineral and oil deposits of the Bay and the long term effects of the natural rapid rebound of the crust in this region on the oceanographic, biological and geological process have yet to be fully evaluated (Pelletier *et al* 1968, Wagner 1969). This study will require bottom and core sampling, continuous sesmic profiling, underwater photography and some short rock cores to obtain the necessary information.

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*Earth Science Symposium on Hudson Bay, Geological Survey of Canada, Paper 68-53, 1969, Ed. P.J. Hood.

This program could be carried out in conjunction with other surveys such as biological or oceanographic, or bathymetric surveys. Sampling and analysis of the suspended matter would also be carried out throughout the Bay to complement the other studies. Many of the samples could be collected on an opportunity basis, but a separate systematic sampling program would probably yield the most useful results.

References

Andrews, J.T. 1969. The pattern and interpretation of restrained Post-Glacial and residual rebound in the area of Hudson Bay. In Earth Sciences Symposium on Hudson Bay. pp 49-61. Ed. P.J. Hood, Geological Survey of Canada Paper 68-53 Ottawa, Ontario.

Cumming, L.M. 1969. Rivers of the Hudson Bay Lowland, pp 144-169. Geological Survey of Canada Paper 68-53.

Innes, M.J.S., and Weston, A.A., 1966. Crustal uplift of the Canadian Shield and its relation to the gravity field; Ann. Acad. Sci. Fennicoe Ser. A. Vol. 111, pp 169-176.

Norris, A.W. and Sanford, B.V., 1969. Paleozoic and Mesozoic geology of the Hudson Bay Lowlands. Geological Survey of Canada, Paper 68-53, pp 169-205. Ottawa, Ontario.

Pelletier, B.R., 1969. Submarine physiography, bottom sediments, and models of sediment transport. Geological Survey of Canada, Paper 68-53. pp 100-135. Ottawa, Ontario.

Pelletier, B.R., Wagner, F.J.E. and Grant A.C., 1968. Marine Geological Investigations in Hudson Bay. In Science, History and Hudson Bay, Vol. II. Chapter 9, Pt III. Canada Department of Energy, Mines and Resources.

Wagner, Frances J.E., 1969. Faunal study, Hudson Bay and Tyrrell Sea. Geological Survey of Canada. Paper 68-53. pp 7-42. Ottawa, Ontario.

A SCRUTINY OF THE TIDE GAUGE INFORMATION COLLECTED DURING THE 1972 SURVEY OF JAMES BAY

by

G. Godin

The Geotechnological group of Burlington has carried out a general oceanographic survey in James Bay during the summer of 1972 and the report "James Bay Data Report 1972" (Pullen 1973) contains its preliminary results. We intend in this paper to study more closely the tidal information collected.

Figure 1 shows, on a common time scale, the recordings of all the tide gauges operating during the 1972 season. The tidal oscillations are evident but strong distortions in the mean level can be seen and mask in particular the intervals of spring and neap tides. We note the extreme levels recorded on September 22 and October 9, 1972.

Modification of the cotidal charts and reduction of the data to a common reference level

The analysis of the readings already published in Pullen (1973) and a new analysis of the discontinuous record for Loon Island indicate that the cotidal charts drawn in 1972 (Godin) should be slightly modified. The data are reduced to a common reference level by first removing the quantity Z_o in the published analyses. Then we eliminate the tide by the low pass filter $A_{24}^2 A_{25}$. Since we know nothing precise about the pattern of circulation in the domain covered by the gauge network, we assume that during the 102 days of observation at Loon Point, the net circulation was null: the 102 average level is, therefore, assumed to be horizontal in the area delineated by East Cub Island, Spencer Island, Roggan River and Hook Island. The low pass filtering in Figure 2 shows the filtered values at Loon Point from which the mean level was calculated. We notice in passing the great similarity of the low pass at the various stations, thus confirming our assumption that the 102-day mean level in that area was very nearly horizontal.

Using the Loon Point 102-day mean level, we reduce the levels observed at the other stations by comparing the mean level at Loon Point over the interval during which the second tide gauge operated: the difference between the short term mean level at Loon Point and the 102 mean level gives the quantity necessary to reduce the mean level at the secondary stations to a level common to that of Loon Point. Table 1 indicates the results of the adjustments. The low pass shown in Figure 2 incorporates these corrections.

Power Spectrum of the low pass

Once the data has been adjusted to a common level, the latter part of the low pass for Loon Island was joined to the low pass of Loon Point in order to obtain a longer interval of observation on the daily mean level; the joining was made smoothly probably because of our adjustment procedure. The power spectrum of the low pass is shown in Figure 3. The first peak covers the frequency interval of 1 cycle/50 days to 1 cycle/25 days; its origin is not known. The two following peaks at 1 cycle/8 days and 1 cycle/5 days can be safely assumed to reflect weather cycles. The fourth peak straddles a frequency interval of 1 cycle/72 hours and 1 cycle/86 hours. We find it intriguing because it corresponds to the periods of what appears as two damped free oscillations noticeable in the low pass in Figure 2 on days 231-235 and 241-245.

Damped Oscillations

These latter oscillations may be represented by the function

$$Ae^{-kt}\cos\sigma t + pt + q$$

Figures 4 and 5 illustrate the fit. The periods of 73 and 98 hours are far larger than the natural periods of James Bay or Hudson Bay, but may correspond to a Helmholtz mode of the James Bay - Hudson Bay - Hudson Strait system. The damping parameter which corresponds to k = .003 hour^{-1} in both cases implies a maximum current velocity of the order of 10 cm/hour.

Storm Surges

Four storm surges were noted in the observation of 1972, on day 183 (July 3), 241 (August 28), 266 (September 22) and 283 (October 9). Figure 6 shows the residues (difference between the observed and predicted levels) and the low pass of the hourly observations over these intervals.

The surge of the 9th of October caused the death of one person and sent two to the hospital as noted in an article published in the Ottawa Citizen on Thursday, October 12, 1972.

We have tried to build a statistical model to represent the surge using as input parameters:

- P the pressure as measured from the synoptic charts at the centre of James Bay
- E the easterly component of the geostrophic wind
- S the southerly component of the geostrophic wind.

Table 2 shows the degrees of representation by the function

$$d = P(2) + E(3)E(3) + |E(2)| + |S(1)|$$

where the integer denotes the number of lags of 6 hours before the displacement d. The contribution of $|E(2)|$ and $|S(1)|$ have no physical significance and should really be eliminated from a realistic physical prediction model.

Tidal streams implied by the gauge observations

Newton's equations in the x and y direction imply the components of u and v of the current (for periodic motion) and the surface gradients $\partial\zeta/\partial x$ and $\partial\zeta/\partial y$. The linearized friction parameter can be estimated assuming a depth of about 20 m, the Chezy coefficient $C \sim 48\, m^{\frac{1}{2}}/\text{sec}$,

$g = 9.81$ m/sec^2 and $v_{max} \sim 50$ cm/sec. The gradients $\partial\zeta/\partial x$ and $\partial\zeta/\partial y$ can be deduced from the observations and the cotidal charts (keeping in mind that they are complex quantities because of the presence of friction). As a consequence, we can calculate the tidal streams prevailing at 53°50'N 79°30'W and these values are given in Table 3. We notice that the current rotates clockwise and has an extreme value of about 45 cm/sec. The major axis of the current ellipse tends to lie along a northerly direction and the currents follow the high water by 15 to 45 minutes.

Tidal Streams and flows inside the La Grande River

The equation of hydrodynamics can be solved in one dimension and estimates of the currents and discharges due to the tide can be made using the gauge observations at Loon Point and at La Grande River tidal stations. Table 4 summarizes the results of such calculations with tidal flows of the order of 200-2500 m^3/sec at the mouth of La Grande and of the order of 1600-2000 m^3/sec, three miles upstream with about 40 minutes delay.

Table 1

REDUCTION OF DATA TO A COMMON LEVEL

Location	Period Of Observation Day Hr → Day Hr	Mean Sea Level x_1 metres	Mean Sea Level Observed at Adjoining Station x_2 metres	Mean Sea Level at Pte au Huard x_3 metres	Temporary Mean Sea Level Compared to Absolute Mean Sea Level $x_o=x_3-x_1$ metres	Correction (Raised) To Local Values $\Delta=x_2-x_o$ metres
Pte au Huard	180 12 → 282 13	.0043	.0043	.0043	.0000	.0043
R. Roggan	248 12 → 277 13		-.0044	.0667	.0624	-.0668
R. La Grande	260 12 → 282 13		-.0465	.0332	.0289	-.0754
I. au Huard	190 12 → 195 13					
	200 1 → 209 20					
	215 19 → 216 17					
	221 22 → 248 24					
	255 20 → 269 6					
	272 19 → 282 13		.0526	-.0008	-.0051	.0577
I. Turning	181 12 → 211 13		.0008	.0110	.0067	-.0060
I. Crochet	251 12 → 277 13		-.0048	.0771	.0728	-.0776
I. Ourson (East)	228 12 → 232 13		-.0917	-.1173	-.1216	.0299

Table 2

Statistical model of the four storm surges observed in the mouth of La Grande River during the 1972 season.

ANALYSIS OF VARIANCE

	Degrees of Freedom	Sum of Squares	Average by Degrees	Sum of Averages
Regression	4	3.374	.843	F
Residual	51	.504	.010	84

COEFFICIENTS

Variables	Value	Probable Error	Multiple Correlation R	R^2	ΔR^2
Constant	18.2712				
P(2)	-.0182	.0014	.7134	.5089	.5089
E(3)|E(3)|	.0010	.0002	.8483	.7196	.2107
|E(2)|	.0172	.0036	.8973	.8051	.0855
|S(1)|	.0124	.0017	.9328	.8701	.0650

Table 3

Solution of the system of equations (13) off the mouth of La Grande River.

Tidal Constituent	σ/g sec/cm	Semi-Major Axis M cm/sec	Semi-Minor Axis m cm/sec	Inclination θ degrees	Phase α degrees
M_2	1.4324×10^{-5}	23	-6	87	75
S_2	1.4826×10^{-5}	6	-1	57	328
N_2	1.4055×10^{-5}	9	-4	111	48
K_1	$.7433 \times 10^{-5}$	3	0	61	169
O_1	$.6891 \times 10^{-5}$	2	0	37	121

$r/g = .9485 \times 10^{-5}$ sec/cm $\qquad$ $\Omega/g = 1.1998 \times 10^{-5}$ sec/cm

Table 4

Tidal Constituents

Quantity	Units	M_2	S_2	N_2	Location
		Constants			
σ	$10^{-4}sec^{-1}$	1.4052	1.4544	1.3788	
r/σ		3.6568	3.5331	3.7268	
$\sigma/(gD_o)^{1/2}$	$10^{-4}m^{-1}$	.2339	.2482	.2354	
k_1	$10^{-4}m^{-1}$	.2834+.3713i	.2869+.3793i	.2814+.3669i	
		Observed Values			
H_o, h_o	m,deg	.594,243.8	.172,335.3	.089,209.5	Pte au Huard
H_1, h_1	m,deg	.371,267.0	.121,345.2	.056,232.7	La Grande River
		Calculated Values			
A	m	-.027-.032i	.007+.012i	.000-.006i	
B	m	-.104+.298i	.071+.024i	-.039+.028i	
$Q(0,t)$	m^3/sec	$1839\cos(\sigma t-219.5)$	$358\cos(\sigma t-312.5)$	$280\cos(\sigma t-183.3)$	Pte au Huard
$u(0)$	m/sec	.584	.114	.089	
Phase Lag between the current and the tide		24°	23°	26°	
$Q(x_o,t)$	m^3/sec	$1579\cos(\sigma t-237.9)$	$320\cos(\sigma t-344.5)$	$234\cos(\sigma t-203.0)$	La Grande River
$u(x_o)$	m/sec	.501	.101	.074	
Phase Lag		29°	1°	30°	

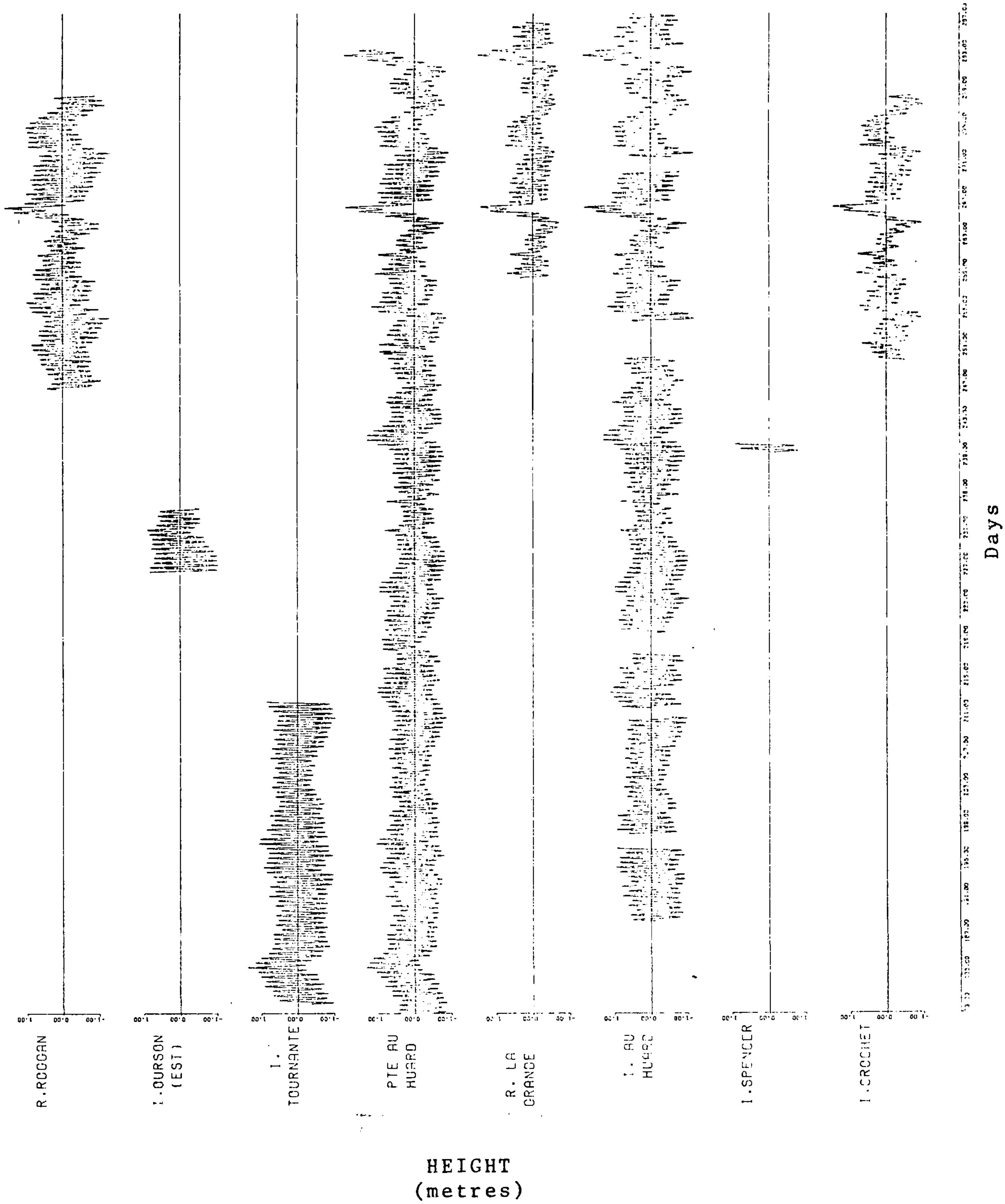


FIGURE 1 Tide Gauge Records - Summer 1972
Plotted on Common Time Scale

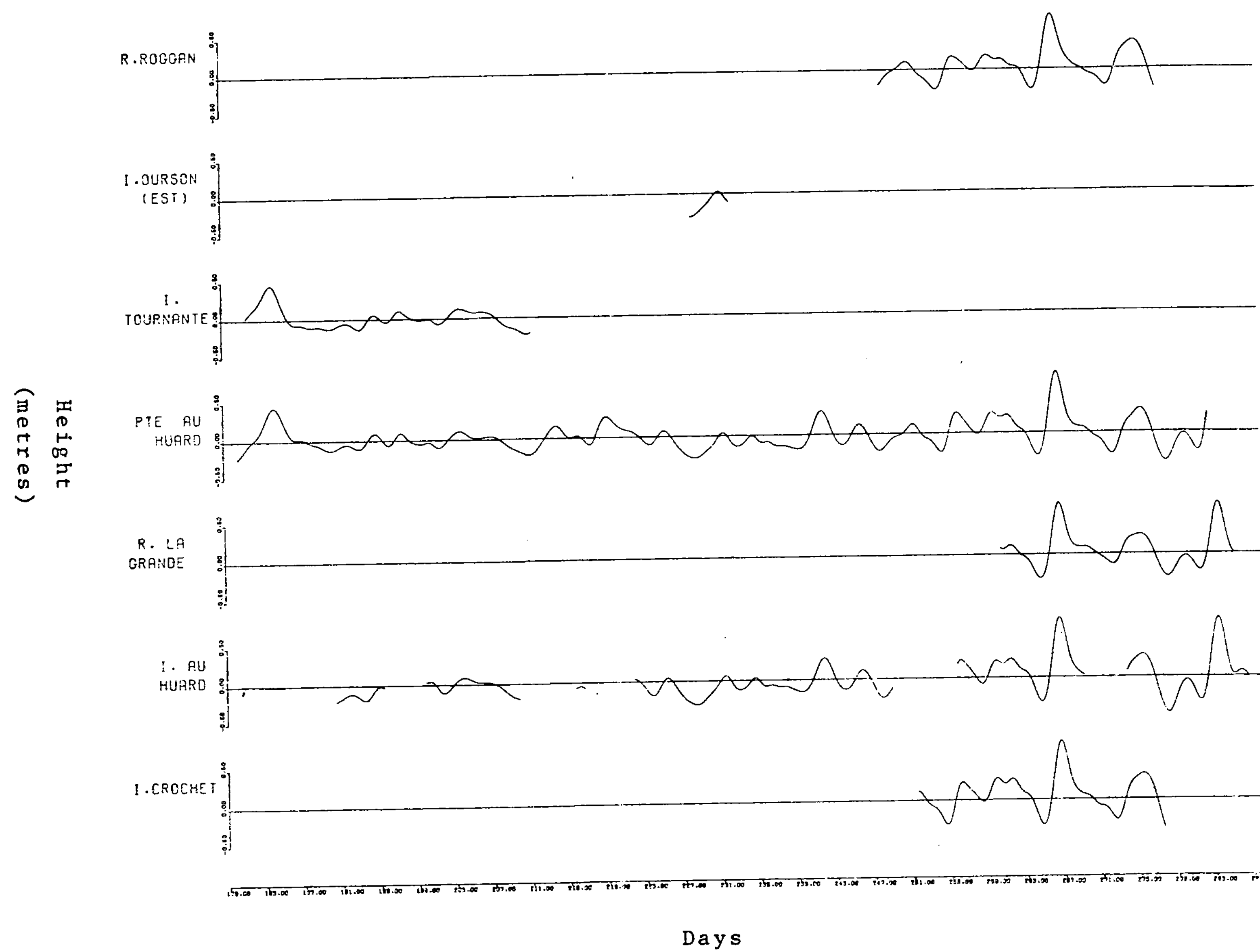


FIGURE 2 Low Pass of Hourly Recordings

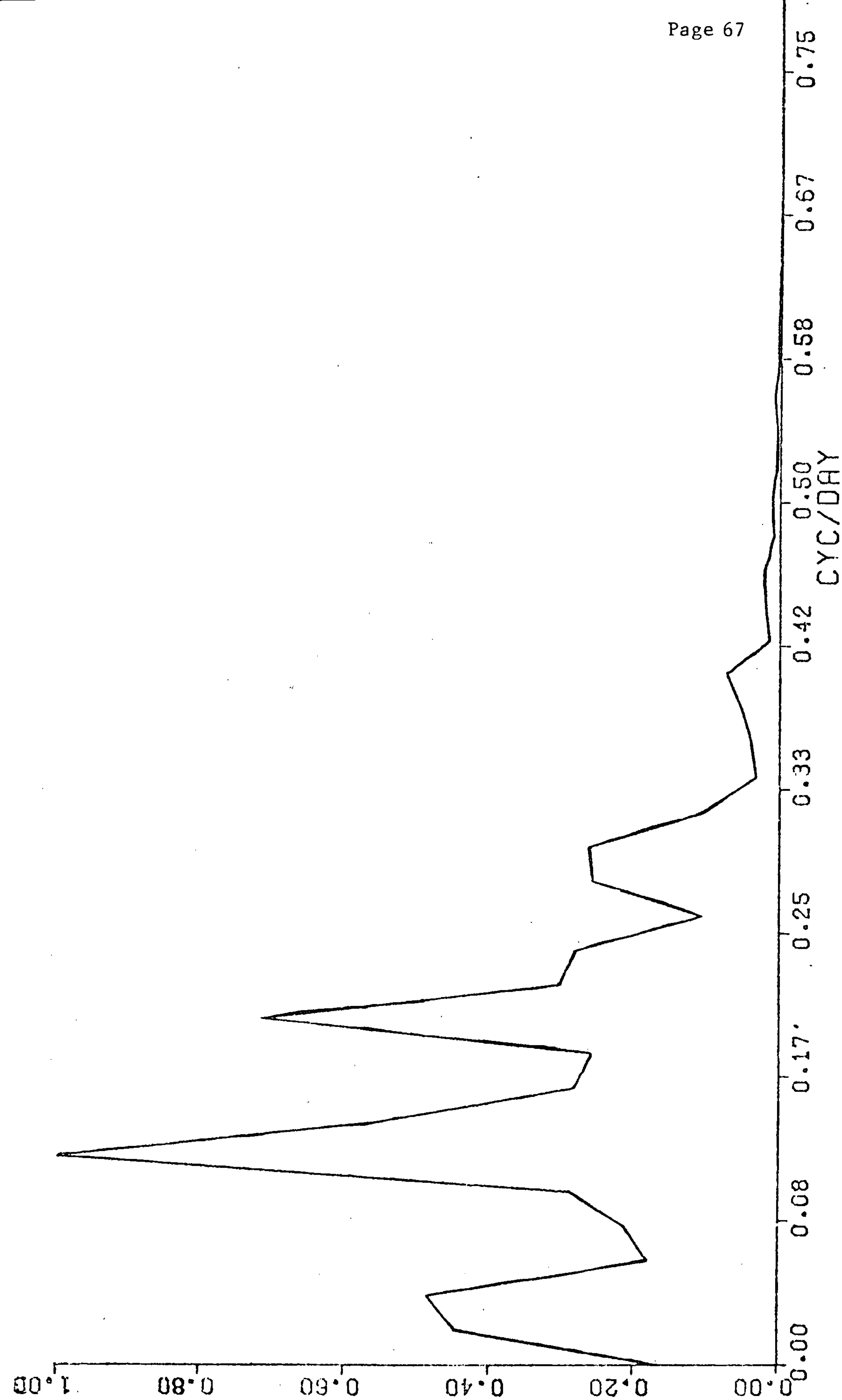


FIGURE 3 Power Spectrum of the low pass for Loon Island

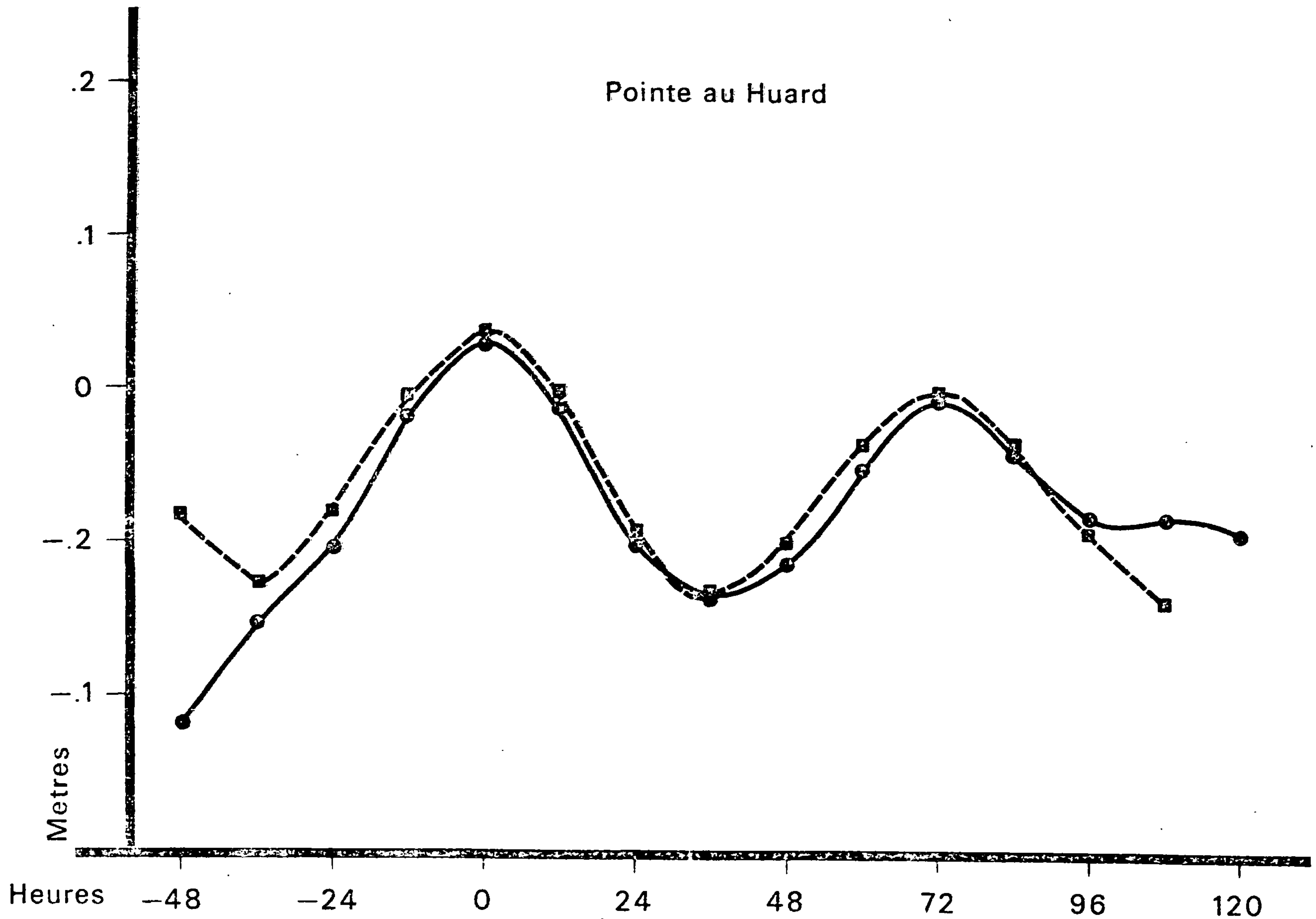


FIGURE 4 Free Damped Oscillation Fitted to the Observations - CASE 1

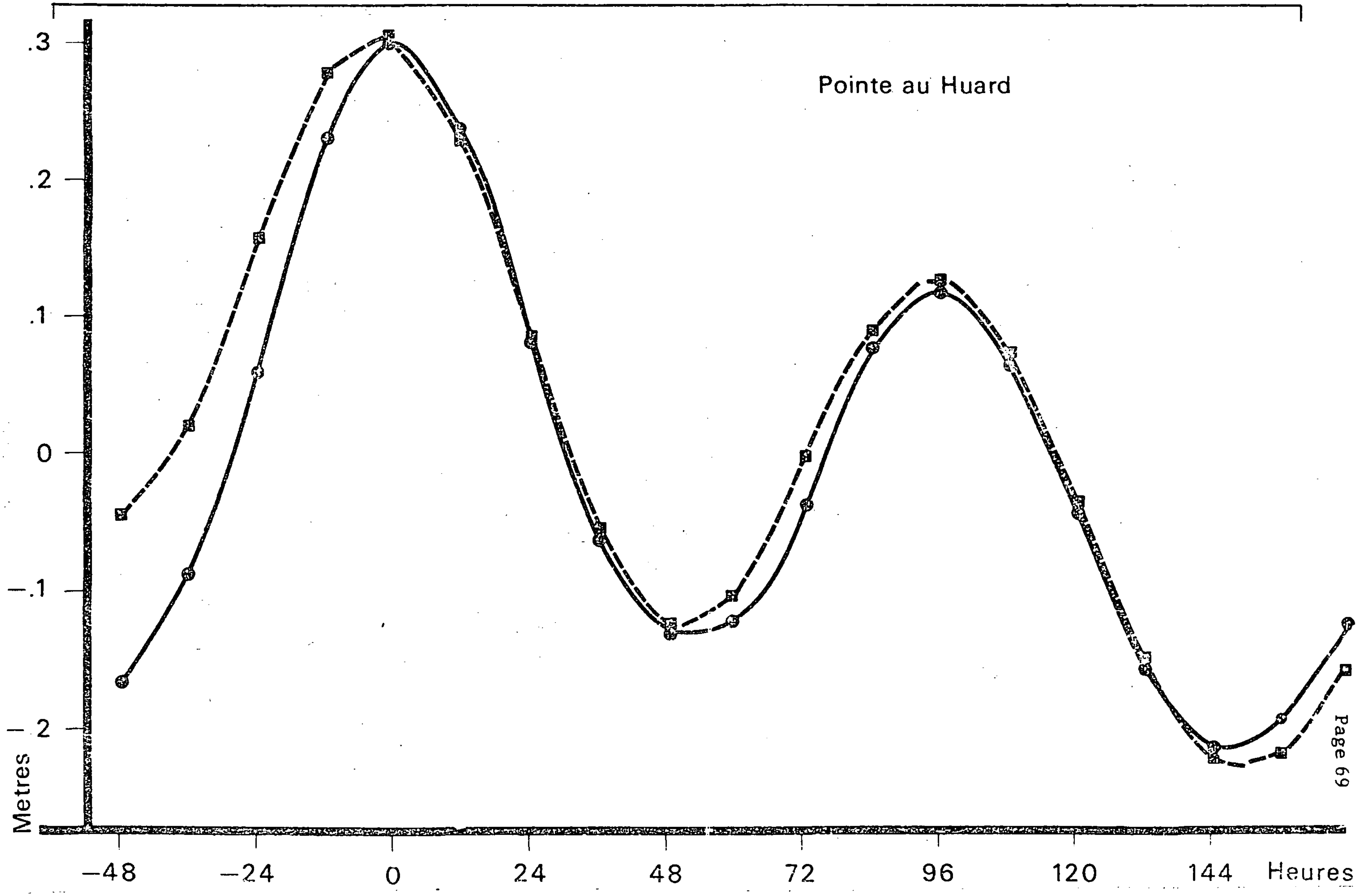


FIGURE 5 Free Damped Oscillation Fitted to the Observations - CASE 2

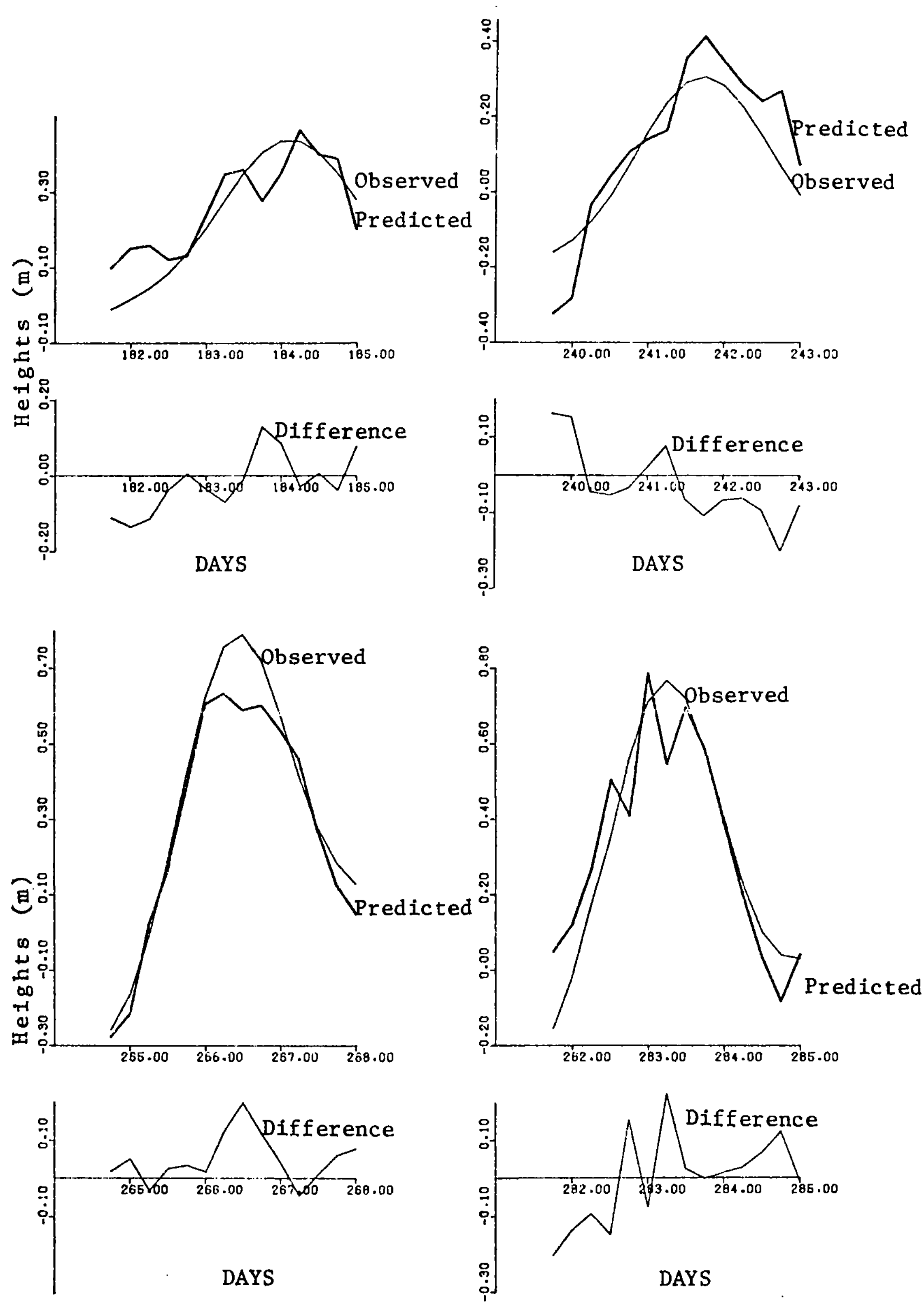


FIGURE 6 Predicted and Observed Surge and Differences

TWO-DIMENSIONAL NUMERICAL TIDAL MODEL FOR THE HUDSON AND JAMES BAY SYSTEM

by

N.G. Freeman

and

T.S. Murty

and

E. Ter Heijden

INTRODUCTION

A number of pragmetic considerations led to the development of a tidal propagation model for the Hudson - James Bay system. An experimental program is being undertaken by the Canadian Department of the Environment in co-operation with NASA to measure the variations in sea level using satellite altimetry and this is being applied to three specific water bodies, one of them being the Hudson - James Bay system. In order to validate these measurements, it was requested that a complete and and up-to-date picture be provided of the tidal regime in this system. Also, the hydroelectric power development in the rivers and estuaries emptying into northeast James Bay has renewed interest in the oceanography of this water body. In addition, the Hydrographic Service is planning a bathymetric survey of the complete Hudson - James Bay system and an accurate co-tidal chart is required for reduction of the soundings to a common datum. As a part of this program, in situ tide gauges will be used to locate the amphidromic points and to verify the onshore tidal observations.

MATHEMATICAL MODEL

The dynamical equations used in this model are the vertically integrated forms of the equations of motion and continuity in spherical polar co-ordinates as given in Heaps (1969):

$$\frac{\partial M}{\partial t} = 2\Omega N \sin\phi - \frac{gh}{a\cos\phi}\frac{\partial \eta}{\partial X} - \frac{T_{BX}}{\rho}$$

$$\frac{\partial N}{\partial t} = -2\Omega M \sin\phi - \frac{gh}{a}\frac{\partial \eta}{\partial \phi} - \frac{T_{B\phi}}{\rho}$$

$$\frac{\partial \eta}{\partial t} = \frac{-1}{a\cos\phi}\left[\frac{\partial M}{\partial X} + \frac{\partial}{\partial \phi}(N\cos\phi)\right]$$

where X is east longitude, ϕ is north latitude, M and N are the X and ϕ components of the flow, and T_B is bottom stress.

A linearized form of bottom friction is used:

$$T_{BX} = \frac{\rho R}{h} M, \quad T_{B\phi} = \frac{\rho R}{h} N$$

Since there is no absolute way of choosing the friction coefficient, R was varied over a range of 0.1 to 1.0 cm. $sec.^{-1}$. Heaps (1969) used 0.24 in his study of North Sea storm surges.

The grid was drawn such that M, N points fall on closed boundary locations while η points fall on open boundary locations (at the mouth of Hudson Bay). The computations were made for two different tidal constituents, M_2 and K_1. The co-phase and co-range lines near the mouth for these two constituents were prepared from observed tide gauge records. The M_2 co-tidal chart prepared by Easton (1972) was also taken into consideration. Since M_2 and K_1 are the major constituents in each of the two species, especially near the mouth, the study was confined to these two constituents only.

RESULTS

Table 1 gives a comparison of the amplitude and phase of the numerical results versus the analysed gauge station data. It can be seen that for the M_2 tide the phase agreement is good, but the amplitude appears consistently about 40% too low. This problem we are presently investigating by running some numerical experiments in which bottom topography and boundary conditions are altered. For the K_1 tide the amplitudes are very well reproduced while the phase is somewhat less accurately simulated, with approximately 30° loss in phase observable at all stations. Again, the above numerical experiments should help to explore this discrepancy.

Figure 1 shows the co-phase and co-amplitude lines for the M_2 tide using a friction co-efficient of R = 0.1. The numerical results are in good qualitative agreement with the previous work of Dohler (1966) and Godin (1972), particularly in the reproduction of the amphidromic points. Comparison with Dohler's results, shows that the locations of the western amphidromic point (61°N, 87°W) and the eastern amphidromic point (58°20'N, 79°W) are within a degree of latitude and longitude of the numerical results. Dohler's diagram has no south-eastern amphidromic point, while the model produces one at 57°30'N, 77°W.

Table 1 Comparison of Model and Observed Results

	M_2 (Z+5)				K_1 (Z+5)			
	Model		Observed		Model		Observed	
Station Name	$\bar{H}$(cm)	g(°)	$\bar{H}$(cm)	g(°)	$\bar{H}$(cm)	g(°)	$\bar{H}$(cm)	g(°)
Chesterfield Inlet	91	117	131	115	6.9	233	9.1	187
Churchill	117	238	152	225	8.4	265	8.7	234
Winisk	72	82	109	83	6.6	350	5.0	322
Fort George	16	250	66	238	3.5	188	5.7	116
Port Harrison	8	312	11	330	2.8	77	2.3	23

This additional amphidromic point could be due to a lack of tidal data which could alter Dohler's curve, a lack of depth data to the east of Belcher Islands which could alter the numerical results, or the fact that the amplitudes are small and hence the errors could be large. The degenerate node in James Bay located on the eastern shore is slightly north of the position given by Godin (1972). However, Godin (1974) shifted this northward after using more recent data, and thus our results are in good agreement with his.

Figure 2 gives the co-phase and co-amplitude lines for K_1 using a friction co-efficient of R = 0.1. The co-tidal chart for K_1 for Hudson Bay could not be compared with Dohler's work because he has given only a chart for the mean tide. For the K_1 tide, we expect fewer amphidromic points than for the M_2 tide, and we expect the single amphidromic point to be located near the center of the system due to the fact that Hudson Bay is almost square. A significant result of the computation is the ability of the numerical model to reproduce the degenerate node in the northeastern corner of James Bay, as described by Godin (1974). Not only the position, but also the amplitudes and phases are in good agreement.

A few experiments using the M_2 constituent were made on variation of lateral boundary in order to test the effect of the uncertainties in the discrete representation of the topography. In the first experiment the representation for the Belcher Islands was varied, and in the second experiment the representation of the west coast of James Bay was varied. In the case of the island size diminution, there was only slight change in the position of the south-eastern amphidromic point. When the west coast of James Bay was stretched westward there was no noticeable change in the tidal propagation.

A number of experiments, in which friction was varied, were also conducted to ascertain the effect of arbitrary choice of a friction co-efficient on propagation and amplitude. In the case of the M_2, the higher value of R = 1.0 moved the western amphidromic point by 150 km. and the amplitude was reduced by a factor of 4, while the eastern and southern amphidromic points disappeared altogether. In the case of the K_1 constituent, a slight reduction in friction (R = 0.075) caused very little change in location of the amphidromic point. A significant reduction in friction (R = .01) produced generally irregular co-phase and co-amplitude lines; specifically very rapid changes in amplitude in the northern part of James Bay and very little change in the southern part occurred. When friction is increased significantly (R = 1.0), the main Hudson Bay amphidromic point is shifted south-south-east by 100 km. and the James Bay degenerate node becomes an amphidromic point located approximately 10 km. offshore.

Current ellipses are not shown, but they have been constructed for a number of locations in the system. As would be expected, across the mouth of Hudson Bay the streams are strongly rotary, becoming more rectilinear near the shores. The maximum M_2 amplitudes are on the order of 1 1/2 knots, which is in good agreement with the sparse current observations given in Dohler (1967). Off Churchill the M_2 current is elliptical with major and minor amplitudes of 40 cm/sec and 15 cm/sec respectively. The major axis is directed northeast-southwest. At the mouth of James Bay the currents are significantly reduced, with the maximum current being just over 15 cm/sec. This is about 1/2 the speed Godin (1972) obtained from his one-dimensional model of James Bay. The discrepancy can be explained again by the lower tidal amplitudes in the numerical model.

CONCLUSIONS

The simple two-dimensional numerical model qualitatively reproduces the M_2 and K_1 tidal propagation in Hudson and James Bays. While at this stage, precise station agreement is not achieved, the model results can be used to construct appropriate co-tidal charts and to analyse tidal propagation in the system.

REFERENCES

Anonymous, 1972 — Harmonic Constants and Associated Data for Canadian Tidal Waters. Volume 4 - Arctic and Hudson Bay, Tides and Water Levels, Marine Sciences Branch, Department of the Environment, Ottawa.

Dohler, G.C., 1966 — Tides in Canadian Waters, Canadian Hydrographic Service, Marine Sciences Branch, Department of Mines and Technical Surveys, Ottawa. Cat. No. M54-966

Dohler, G.C., 1967 — Tides and Tidal Currents in Hudson Bay, Science and History of Hudson Bay. Published by Department of Energy, Mines and Resources, Ottawa, Reprint No. 105

Easton, A.K., 1972 — Tides of Hudson Strait, Bedford Institute of Oceanography, Report Series BI-R-72-6, Dartmouth, N.S.

Godin, G., 1972 — The Tides of James Bay. Canada Department of the Environment, Marine Sciences Branch, M.S. Report No. 24, Ottawa, Canada.

Godin, G., 1974 — A Scrutiny of the Tide Gauge Information Collected During the 1972 Survey of James Bay. To be published in the Marine Sciences Manuscript Report Series (a summary is presented in the First James Bay Workshop proceedings).

Heaps, N.S., 1969 — A Two-Dimensional Numerical Sea Model. Proceedings of the Royal Society, Vol. 265, A.1160, p.p. 93-137.

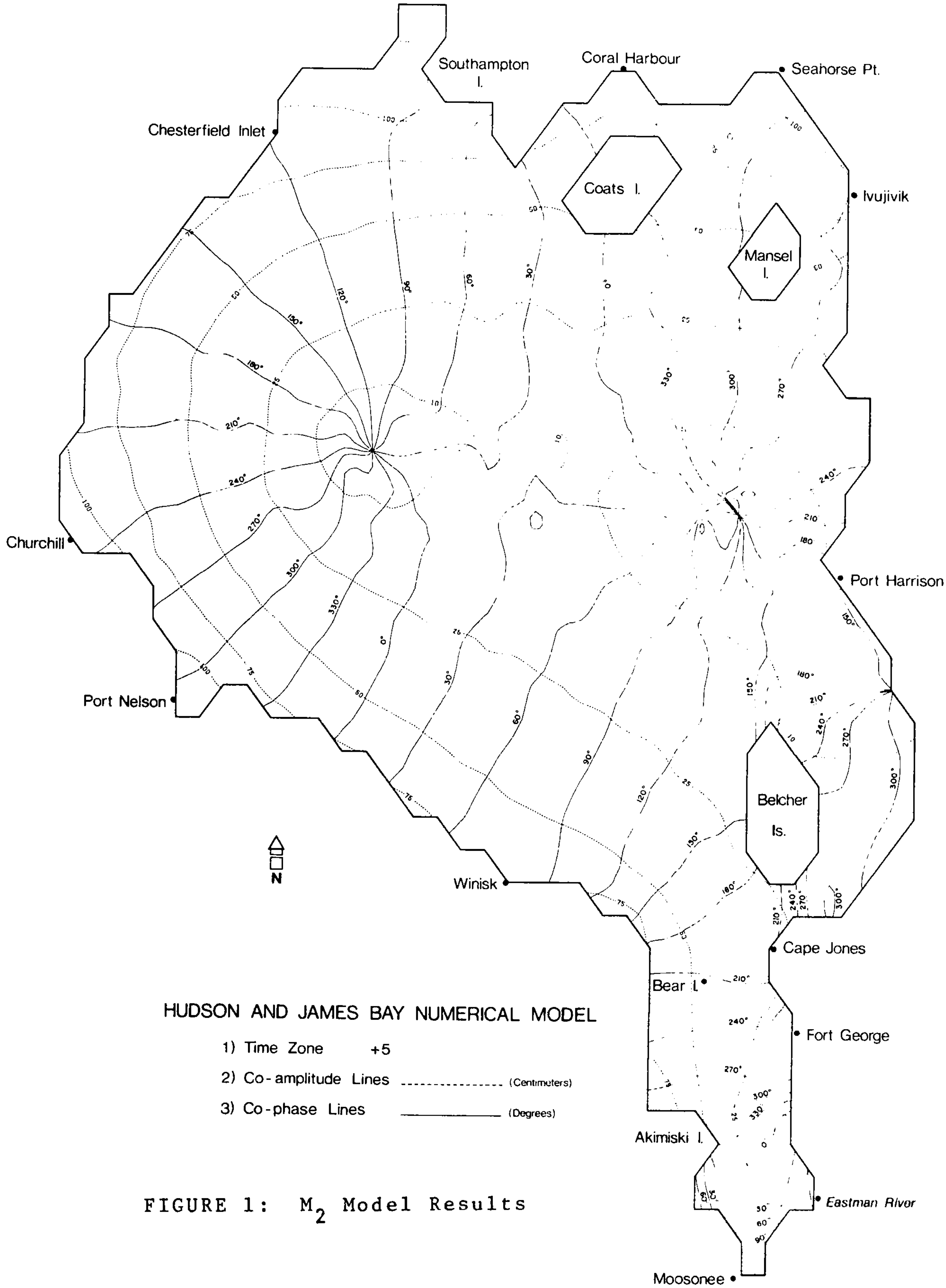


FIGURE 1: M_2 Model Results

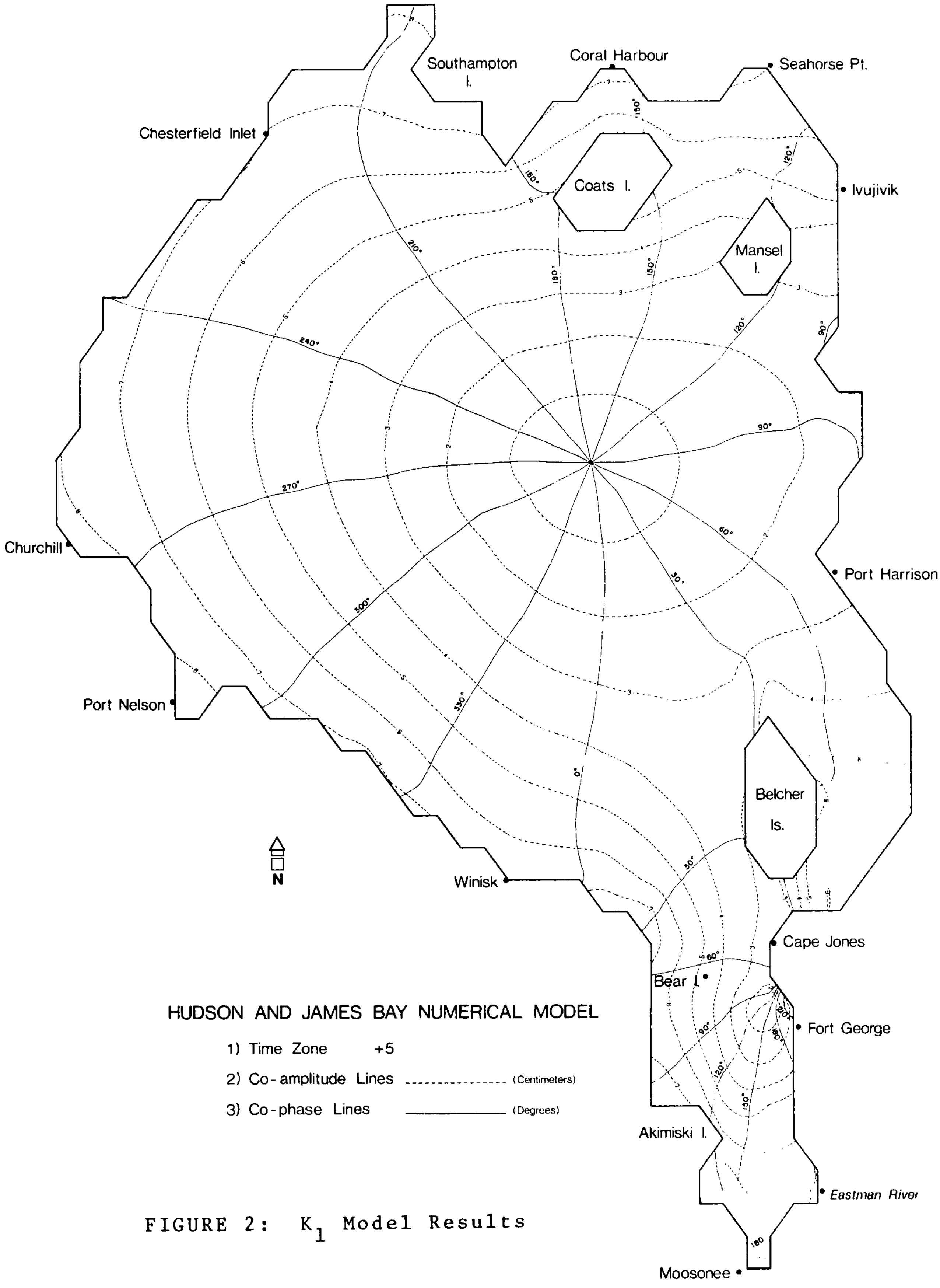


FIGURE 2: K_1 Model Results

AIR-SEA INTERACTION MODEL FOR JAMES BAY

by

T.S. Murty

and

M.L. Khandekar

Abstract

The various models available in the literature on air-sea interaction for determining the effect of water bodies such as the Great Lakes on winter cyclones are briefly reviewed. It is proposed that the meso-scale model developed by Lavoie and successfully used by him to study the effects of Lake Erie on the atmosphere could be used for understanding the influence of James Bay on the atmosphere. Two separate computer models with different boundary conditions at the ground level (i.e. surface of James Bay), one with present circulation regime and the second with estimated (from estuarine models) of altered circulation in James Bay, will help to estimate the possible modification of the atmosphere in the James Bay region following the hydroelectric power project construction.

1. Introduction

The possible meso-scale modifications of the atmosphere associated with the proposed hydroelectric power project of rivers draining into James Bay can be approximately determined through an air-sea interactional model in which the surface boundary conditions of James Bay are included in some detail. Before one can deduce the meso-scale changes in the atmosphere that could occur following the power project, it is necessary to understand the influence of James Bay on the present weather. To this end, one can benefit from the experience gained through the numerical models that have examined the effect of the Great Lakes on the weather regime. Some of the notable works are the following: Peterssen and Calabrese (1959) examined the role of Great Lakes in warming the air in winter. Danard and Rao (1972) studied the effects of the Great Lakes on a winter cyclone and this study was extended by Danard and McMillan (1974).

The study of Peterssen and Calabrese is an analysis of observed data and this technique could be used for James Bay. The other two studies referred to, are numerical models with a grid size 190 km (at 60°N). Although the grid is relatively crude, nevertheless, the study of Danard and Rao showed that the effects of Great Lakes on a winter cyclone during an interval of 36 hours are significant.

(a) the temperature at 850 mb is raised by 5°C
(b) the surface pressure is reduced by 5 mb
(c) The large scale precipitation is increased by 3 mm (Note that if all the water vapour in the atmosphere suddenly falls as rain, it will cover the entire earth by a layer of thickness of 1 inch or 25.4 mm)
(d) modifies the Ekman layer winds by 3 $m.sec^{-1}$
(e) increases the vorticity and convergence of the Ekman layer winds by 2×10^{-5} sec^{-1}.

The model of Danard and Rao could be used to study the effects of Hudson Bay system (which includes Hudson Bay, James Bay, Hudson Strait, Ungava Bay and Foxe Basin (Figure 1)) on the atmosphere. For examining the influence of James Bay alone, one might make use of a model developed by Lavoie (1972) who simulated the influence of Lake Erie on the atmosphere making use of a 6 km grid. He was able to use a fine mesh (and yet keep within the computer memory size) through using a much simpler model than that of Danard and Rao. In spite of its simplicity, this model quite successfully simulated the local, but often very heavy snowfalls that occur on the lee shores of the Great Lakes during cold air outbreaks in early winter. Thus, it appears feasible to examine the influence of James Bay on the atmosphere, especially precipitation, through this relatively simple model.

2. Lavoie's meso-scale model

The atmosphere is modelled as consisting of three layers (Fig. 2) each of which has a different lapse rate of potential temperature. The lower layer which is in contact with the surface of the water body has a superadiabatic lapse rate which represents a boundary condition of upward heat flux. This layer also contains most of the frictional wind shear. Lavoie set the upper boundary of this layer arbitrarily at 50 m. The middle layer is assumed to be effectively homogeneous in its vertical distribution of potential temperature, moisture and momentum. Note that the horizontal inhomogeneities in the middle layer are the main forcing mechanisms (e.g. variable surface heat and momentum fluxes, sloping terrain, release of latent heat from precipitation within the layer). The middle layer terminates at its upper boundary by an inversion or a first-order discontinuity in temperature which separates it from the top layer considered to be deep and having a constant and stable lapse rate. Thus, it is assumed here that the atmospheric response on the meso-scale is determined mainly by the behaviour of the mixed layer (middle layer) as a whole with only secondary dependence upon the detailed vertical structure of this layer or upon the vertical structure of the top stable layer.

The meso-scale phenomenon we are concerned with has characteristic wavelengths of the order of tens of km in the horizontal and less than 5 km in the vertical. Time-dependent calculations are limited to the well-mixed middle layer and interactions with the other two layers are parameterized. For the meso-scale considered here, it has been customary to assume that the pressure field is determined by density distribution alone without reference to the field of motion which means that the atmosphere is always in hydrostatic balance. This assumption rules out the possibility of resolving individual convective clouds. Since buoyancy effects are ignored, the strong and narrow bands typical of intense lake-effect storms might not be reproducable by this model. However, the basis for this model is the assumption that the location and intensity of such a convective band is determined by the larger meso-scale disturbance. If this assumption is true, then the meso-scale variables could be used to parameterize convection and thus allow some feedback between the scales of motion.

Thus, in essence, we are saying that the convective clouds are assumed to be constrained to the mixed layer. Using this model to calculate the horizontal meso-scale disturbance due to inhomogeneities in heating, evaporation, friction and topography associated with Lake Erie, Lavoie showed that, all the above assumptions are justified a posteori. He also showed that the details in the vertical structure of the planetary boundary layer are relatively unimportant in determining the meso-scale disturbance.

The final set of equations used in the computation are summarized here. The four prognostic variables are

V horizontal velocity vector

θ potential temperature for dry air

h height of inversion; also used as subscript referring to value at top of inversion

q specific humidity

The equations for these four variables are:

$$\frac{\partial V}{\partial t} = -V\nabla V - K \times fV - F_i - (h_i - h)\, f\Psi + \frac{g}{\theta_h}\left[\theta - \theta_h - \frac{\Gamma}{4}(h_m - h_i)\right]\nabla h + \frac{g}{\theta}(h - Z_s)\nabla\theta - \frac{C_D}{(h - Z_s)}|V|V \qquad (1)$$

$$\frac{\partial \theta}{\partial t} = -V\nabla\theta + \frac{C_D^1}{(h - Z_s)}|V|(\theta_o - \theta) + \frac{L\theta\bar{\alpha}M}{C_p\bar{T}(h - Z_s)} \qquad (2)$$

$$\frac{\partial h}{\partial t} = V\nabla h + W_h + \left(\frac{1}{\Gamma}\frac{\partial\theta}{\partial t}\right)_{\theta=\theta_h} \qquad (3)$$

$$\frac{\partial q}{\partial t} = V\nabla q + \frac{C_D^{II}|V|(q_o - q)}{(h - Z_s)} - \frac{B|W_h|(q - q_h)}{(h - Z_s)} \qquad (4)$$

where

t	time
∇	horizontal vector gradient operator
K	unit vector along Z axis
f	coriolis parameter
F_i	value (vector) of F (defined below) at the initial height of the inversion $F_H \equiv \frac{\theta}{\theta_H} (\alpha \nabla P)_H$
H	height of surface assumed unaffected by the meso-scale disturbance; also used as subscript referred to this surface.
α	specific volume
P	atmospheric pressure
h_i	initial (undisturbed) height of the inversion
Ψ	rotated vertical shear vector of the geostrophic wind in the upper, stable layer
g	gravity
Γ	vertical gradient of potential temperature characteristic of the upper, stable layer
h_m	maximum disturbed height of the inversion.
Z_s	top of the lower layer
C_D	drag coefficient for momentum
C^1_D	drag coefficient for heat
θ_o	potential temperature for dry air at ground surface.
L	latent heat of sublimation.
C_p	specific heat of air at constant pressure
M	net precipitation rate (cm.hour^{-1})
T	temperature in degrees Kelvin
Bar	denotes a mean value in the middle layer
W	vertical velocity.
C^{II}_D	drag coefficient for moisture

q_o specific humidity at ground level

β coefficient weighting mixing of moisture through inversion.

These four equations (1) to (4) are obtained from the following basic equations for the mixed layer (i.e. middle layer).

$$\frac{dV}{dt} = - K \times fV - \alpha \nabla P + \alpha \frac{\partial T}{\partial Z} \tag{5}$$

$$\frac{d\theta}{dt} = \frac{-\alpha\theta}{C_p T} \frac{\partial Q}{\partial Z} + \frac{\alpha L \theta}{C_p T} M^1 \tag{6}$$

$$\frac{1}{\alpha}\frac{d\alpha}{dt} = \nabla V + \frac{\partial W}{\partial Z} \tag{7}$$

$$\frac{dq}{dt} = -\alpha\frac{\partial E}{\partial Z} - \alpha M^1 \tag{8}$$

$$\alpha\frac{\partial P}{\partial Z} = - g \tag{9}$$

$$\theta = \frac{\alpha}{R} \frac{P_*^k}{P^{k-1}} \tag{10}$$

where

T eddy stress vector

Z vertical coordinate

M^1 net condensation rate per unit volume

E vertical moisture flux

R specific gas constant of dry air

P_* constant reference pressure of 1000 mb.

$k = \frac{R}{C_p} = 0.286$

Lavoie (1972) discussed the development of the model leading to equations (1) to (4). More details on the computational procedure are given by Davis, Lavoie, Kelley and Hosler (1968).

References

1. Danard, M.B. and G.V. Rao (1972)

Numerical study of the effects of the Great Lakes on a winter cyclone, Monthly Weather Review, Volume 100, p. 374-382.

2. Danard, M.B. and McMillan, A.C. (1974)

Further numerical studies of the effects of the Great Lakes on winter cyclones, Monthly Weather Review, Volume 102, p. 166-175.

3. Davis, L.G., Lavoie, R.L., Kelley, J.I., and Hosler, C.L. (1968) Lake effect studies, Technical Report, Department of Meteorology, The Pennsylvania State University, May, 1968, p. 108.

4. Lavoie, R.L. (1972) A meso-scale numerical model of lake-effect storms, Journal of Atmospheric Sciences, Volume 29, p. 1025-1040.

5. Petterssen, S. and Calabrese, P.A. (1959)

On some weather influences due to warming of the air by the Great Lakes, Journal of Meteorology, Volume 16, p. 646-652.

FIGURE 1: Geography of the Hudson Bay region.

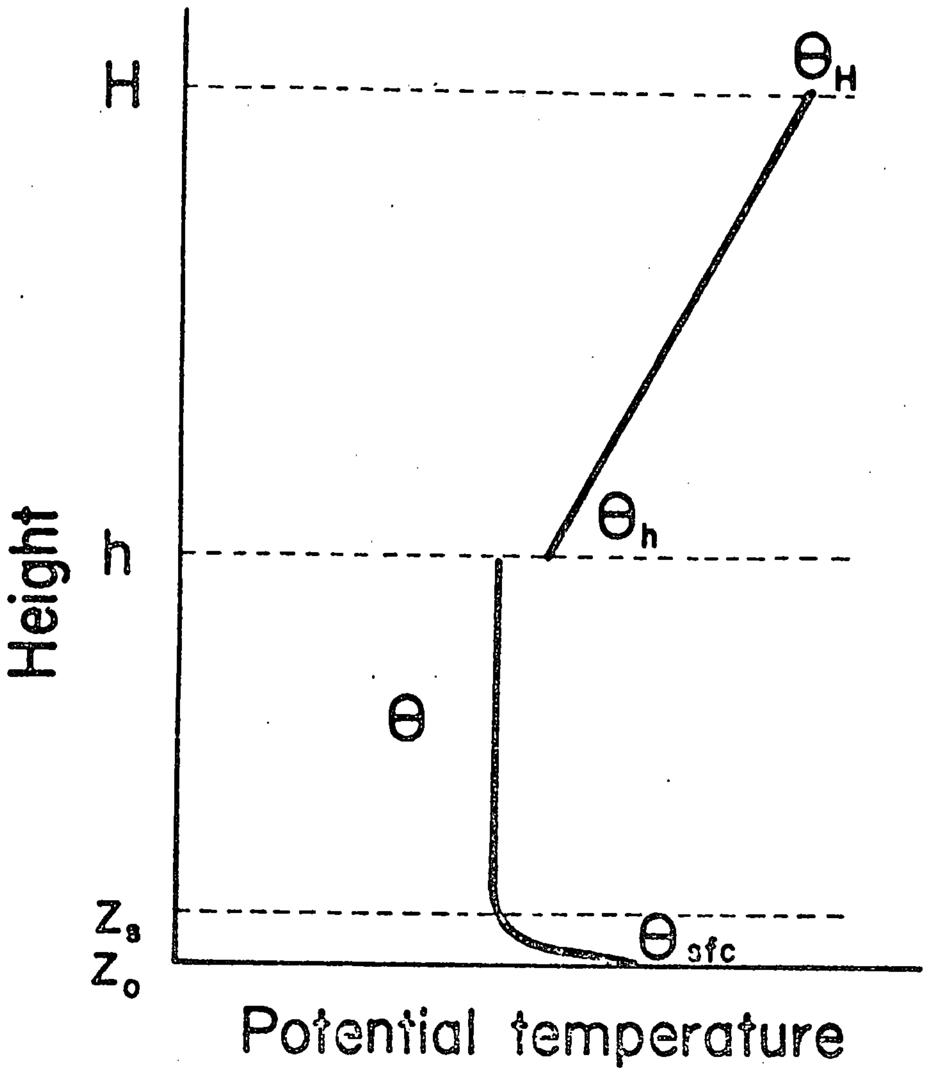


FIGURE 2: The thermal structure of the 3-layer model.
(from Lavoie, 1972)

ATMOSPHERIC ENVIRONMENT SERVICE
JAMES BAY PROGRAM OF CLIMATIC STUDIES

by

D.A. Bondy

The purpose of this report is to inform on the A.E.S. James Bay Program both as an aid in the planning of a major multi-disciplinary survey of Hudson - James Bays and to assist in the review and preliminary evaluation of the present knowledge of the region. The objectives of the A.E.S. James Bay Program are to:

1) determine the nature of the climatic changes which may result from altered land use,
2) establish procedures which could be used for the prediction of the climatic impact of land modifications around James Bay and elsewhere, and
3) provide support for other departmental programs as well as for the overall projects.

As a result of consolidation, the A.E.S. program now consists of the following studies and activities:

1) Impact Assessment
2) Sea, river and lake ice
3) Surface climatological network for climatic and water balance studies
4) Development climatology
5) Water balance
6) Weather Services.

1. Impact Assessment

The objectives of this study are to define the climate prior to and following construction, and thereby identify the climatic changes. It is hoped that through this study procedures will evolve that could be used in other such development projects.

Since the definition of the pre- and post-construction climates must await the actual measurements from the climatic network, a predictive study was initiated to put the magnitude of the possible climatic changes into perspective. To do this, a "Climatic Impact Assessment Team" was assembled and assigned the task of predicting the climatic effects of the first phase of the James Bay Hydroelectric Project (at that time LG-1, LG-2 and Opinaca reservoirs). Relying extensively on precedents observed at other reservoirs and known topoclimatological relationships, the "Impact Team" predicted a post-reservoir climate. Much of the work was based on the fact that the reservoirs would have a low albedo when ice-free and a high albedo when frozen and snow covered. Thus, both the amount and the seasonal distribution of absorbed solar heat would be altered. The capacity of water to store heat or cold that may be released at a later time and the effect on the wind regime of the reduced surface roughness factor were then the key changes investigated by the team.

Past studies and actual measurements of the climatic effects that hydroelectric projects and their reservoirs produce have been carried out. They have all concluded that only local climatic effects are produced in the form of slight maritime influences. The results of the climatic impact forecast do not differ from these. In the case of James Bay, however, more caution or foresight is being exercised because there are those who fear the possibility of large-scale climatic changes if the Bay ice regime is upset. Early findings indicate that the effects of the river diversions on James Bay ice will be limited to local areas near the estuaries of the affected rivers. Wind and solar insolation are the primary factors dictating the ice regime, the fresh water outflow playing only a minor role of estuarine ice "flushing".

Concurrently with this study, a report on the meteorological consequences of changes in the surface environment is being prepared by McGill University. Additionally, the climatic impact forecast is being updated to cope with changing engineering plans and to include other phases of development.

2. Sea, River and Lake Ice

Considerable ice data is presently available from the A.E.S. ice program which has been developed to support Canadian shipping interests. A.E.S. "Ice Circulars" began reporting on ice conditions in 1959 with Ice Forecasting Central adding to the documentation of ice observations in 1964. A variety of means are utilized to obtain the information: Photographs are taken by earth satellites to give broad overviews and Electra turboprop aircraft report by visual observation, radar maps, infrared imagery, laser trances and photographic mosaics.

During the 1972-73 ice season, the coverage of James Bay was intensified to include 14 detailed ice reconnaissance flights over James Bay. These along with more casual passovers resulted in a coverage of 23 flights for one season. Since then, however, the flights have been cut back to 8 per year. There has also been an expansion of the ice thickness measurement network in the New Quebec region.

3. Surface Climatological Network for Climatic and Water Balance Studies

In 1967, there was only a handful of climatological stations in the James Bay region proper. Through collaboration with the Quebec Meteorological Service, over 30 stations have been added resulting in a network of more than 50 stations (see map). Plans call for 7 of these stations to be Principal stations (i.e. manned and measured wind, precipitation, temperature, sunshine, evaporation, depth of snow and water equivalent and humidity); 15 Secondary (i.e. unmanned and recording precipitation, temperature, sunshine, humidity and snow depth and water equivalent) and 20 Tertiary (i.e. unmanned and measuring precipitation and snow depth and water equivalent). Unfortunately, plans to establish stations on some of the Bay islands have not yet been implemented. The enhanced climatic network will provide other studies with more representative climatic data.

4. Water Balance

Intensive work on the water balance must await field measurements from the climatic network. As a consequence, this study is mainly in its conceptual stage. The objectives are to define the principal hydro-climatic features of the water balance, and estimate changes therein during and following development.

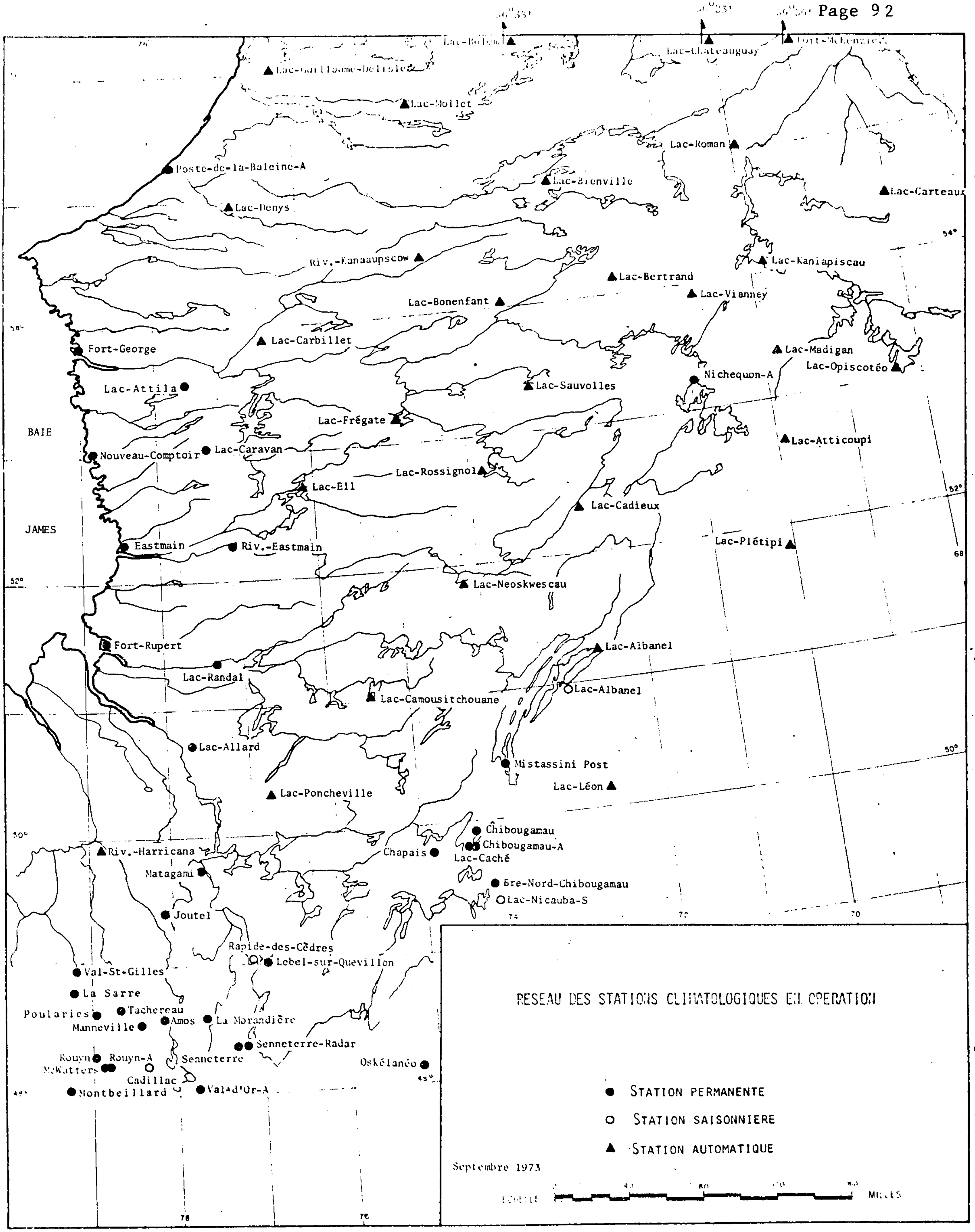
5. Development Climatology

This involves the synthesis of climatic data as required for the selection of sites for harbours, towns, industrial areas, for the placement of transmission lines and support towers and also to provide design information for engineering and conservation purposes.

Two of the four ice accretion studies have been completed. A preliminary report has also been prepared on the climate and sea ice conditions for the James Bay Seaport area (near Fort George). Similar estuarine climate studies are planned for the Quebec coast.

6. Weather Services

This relates to the provision of weather services in support of current operations and in particular, air operations. A Weather Office, staffed by three presentation technicians, was established at Matagami airport during 1973. Arrangements are in progress for the establishment of a similar weather service outlet at Radisson in 1975.



Lac-Bohem
Lac-Chateauguay
Fort-McKenzie
Lac-Guillaume-Delisle
Lac-Mollet
Lac-Roman
Poste-de-la-Baleine-A
Lac-Bienville
Lac-Carteaux
Lac-Denys
Riv.-Kanaaupscow
Lac-Kaniapiscau
Lac-Bertrand
Lac-Vianney
Lac-Bonenfant
Lac-Carbillet
Fort-George
Lac-Madigan
Lac-Opiscotéo
Nichequon-A
Lac-Sauvolles
Lac-Attila
Lac-Frégate
BAIE
Lac-Atticoupi
Nouveau-Comptoir
Lac-Caravan
Lac-Rossignol
Lac-Ell
Lac-Cadieux
JAMES
Lac-Plétipi
Eastmain
Riv.-Eastmain
Lac-Neoskwescau
Lac-Albanel
Fort-Rupert
Lac-Randal
Lac-Albanel
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Mistassini Post
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Chibougamau
Chibougamau-A
Riv.-Harricana
Chapais
Lac-Caché
Matagami
Bre-Nord-Chibougamau
Lac-Nicauba-S
Joutel
Rapide-des-Cèdres
Lebel-sur-Quevillon
Val-St-Gilles
La Sarre
Poularies
Tachereau
Manneville
Amos
La Morandière
Senneterre-Radar
Rouyn
Rouyn-A
Senneterre
Oskélanéo
Cadillac
Montbeillard
Val-d'Or-A
RESEAU DES STATIONS CLIMATOLOGIQUES EN OPERATION
STATION PERMANENTE
STATION SAISONNIERE
STATION AUTOMATIQUE
Septembre 1973
MILES