Documenting ice in the Bay of Fundy Canada

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CR-2006-01

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R. Saunders and R. E. Baddour

March 2006

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DOCUMENTING ICE IN THE BAY OF FUNDY CANADA

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SUMMARY

Sea ice capable of impacting marine operations occurs periodically in the most favourable sites for energy harvest from the tidal currents of the Bay of Fundy in Nova Scotia and New Brunswick.

In-stream tidal current harvesting devices deployed at these sites will need to be engineered to tolerate at least 30% cover of sea ice 15 cm thick in floes of at least 100 metres in length. Propelled by tidal currents and prevailing winds, these floes may achieve velocities in excess of 8 knots in some locations.

In very severe winters, in-stream tidal current harvesting devices may be subjected to periods of 70% cover of 15-30 cm rapidly moving or packed sea ice.

Additional research is necessary to characterize tidal currents in the presence of ice and to design devices which can tolerate the sea ice conditions in the headwaters of the Bay of Fundy, one of North America's greatest tidal power resources.

Once ice-tolerant tidal current harvesting devices are developed, they may be deployable in other jurisdictions with energetic tidal flows which experience more severe conditions of sea ice than the headwaters of the Bay of Fundy.

In North America, these locations might include Northumberland Strait (between Prince Edward Island and New Brunswick), the Gulf of St. Lawrence (Quebec), the Strait of Belle Isle (Newfoundland and Labrador), Cook Inlet (Alaska), and Ungava Bay (Quebec).

Beyond the North American Continent, a market for ice-tolerant tidal current harvesting technology may exist in other circumpolar jurisdictions with energetic tidal flows.

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DOCUMENTING ICE IN THE BAY OF FUNDY CANADA

CR-2006-01

Richard Sanders and Emile Baddour

March 2006

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As a Preliminary to Developing Ice-Tolerant In-Stream Tidal Current Harvesting Devices

by

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We would also like to thank Environment Canada and the Canadian Ice Service for their assistance in preparing this report.

We wish to express our gratitude to the Electric Power Research Institute for making preliminary drafts of the Institute's tidal energy studies publicly available.

The authors would also like to thank Mr. George C. Baker, former Vice-President of the [Nova Scotia] Tidal Power Corporation, for informal discussion with us and for his contributions to the development of tidal power in the Bay of Fundy over the last four decades.

The first author would like to express his gratitude to the many individuals who shared their knowledge of ice conditions in the Bay of Fundy with him during the preparation of this report.

SUMMARY

Sea ice capable of impacting marine operations occurs periodically in the most favourable sites for energy harvest from the tidal currents of the Bay of Fundy in Nova Scotia and New Brunswick.

In-stream tidal current harvesting devices deployed at these sites will need to be engineered to tolerate at least 30% cover of sea ice 15 cm thick in floes of at least 100 metres in length. Propelled by tidal currents and prevailing winds, these floes may achieve velocities in excess of 8 knots in some locations.

In very severe winters, in-stream tidal current harvesting devices may be subjected to periods of 70% cover of 15-30 cm rapidly moving or packed sea ice.

Additional research is necessary to characterize tidal currents in the presence of ice and to design devices which can tolerate the sea ice conditions in the headwaters of the Bay of Fundy, one of North America's greatest tidal power resources.

Once ice-tolerant tidal current harvesting devices are developed, they may be deployable in other jurisdictions with energetic tidal flows which experience more severe conditions of sea ice than the headwaters of the Bay of Fundy.

In North America, these locations might include Northumberland Strait (between Prince Edward Island and New Brunswick) , the Gulf of St. Lawrence (Quebec), the Strait of Belle Isle (Newfoundland and Labrador), Cook Inlet (Alaska), and Ungava Bay (Quebec).

Beyond the North American Continent, a market for ice-tolerant tidal current harvesting technology may exist in other circumpolar jurisdictions with energetic tidal flows.

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Abbreviations

cm	**centimetre**
EPRI	**Electric Power Research Institute**
MW	**Megawatt**
MPH	**Miles per hour**
NB	**New Brunswick**
NL	**Newfoundland and Labrador**
NS	**Nova Scotia**
NSPI	**Nova Scotia Power Incorporated**
PEI	**Prince Edward Island**
PQ	**Province of Quebec**
USA	**United States of America**

I. Introduction

Abundant energy is the foundation of modern civilization. In this century, new sources of energy must be found to replace oil and gas, which are increasingly problematic to extract from the earth's crust, to transport to affluent consumers and to utilize without untoward environmental consequences.

A portion of the energy we obtain from burning oil and gas could be replaced by emerging technologies which convert the kinetic energy of moving water into electricity. Some of these devices convert the movement of waves into electricity (1,2). Others convert the flow of tidal currents, rivers and other natural and artificial waterways into electricity (3,4,18,20,22).

It is theoretically possible that electricity harvested from moving water could significantly reduce dependence on oil and gas for electricity generation, transportation and, possibly, space heating. For example, part or all of the electricity generated by burning gas (or oil) might be replaced by electricity generated by moving water in jurisdictions with appropriate water resources. In addition, the dependence of transportation on oil could be diminished if vehicles are powered by electricity generated by moving water or by hydrogen made from the electricity harvested from moving water. Finally, under certain economic conditions, oil or gas space heating might be replaced by electric space heating using electricity generated by moving water.

In Atlantic Canada (see Satellite Image One, p. 3) the most obvious undeveloped resource of moving water is the tidal flow in the headwaters of the Bay of Fundy (see Satellite Image Two, p. 4). For example, every six hours a volume of water traverses the Minas Passage (see Photograph One, p.5) that is equivalent to the five-day flow of the St. Lawrence River at Cornwall, Ontario (reference 5, Volume One, page 8). In addition, the Electric Power Research Institute (EPRI), under contract to the Provinces of Nova Scotia and New Brunswick to inventory the tidal current resources in these two jurisdictions, found that the tidal currents in the Minas region of the head waters of the Bay of Fundy are among the most promising sites in North America for tidal energy harvest (6,7).

Interest in converting energy from the Fundy tides into electricity is not new. Over the last century, plans to harvest both the potential energy and the kinetic energy of the Fundy tides have been advanced.

From the early 1900's to the 1980's numerous schemes were proposed, both in Canada and the United States, to capture the potential energy of the Fundy high tides using barrages, or dams (14). In the early 1980's, a 20 MW pilot barrage project was completed at Annapolis Royal, Nova Scotia (13,14). Today the Annapolis Royal Tidal Generating Station remains the second largest grid-

connected tidal power installation in the world. However, both the capital cost and environmental impact of this tidal power station have deterred the construction of larger facilities based on similar technology.

One very positive result of the historical interest in barrage technology is a feasibility study done in the late 1960's by the governments of New Brunswick, Nova Scotia and Canada. The report of this study, entitled *Report to Atlantic Tidal Power Programming Board on Feasibility of Tidal Power Development in the Bay of Fundy* (5), contains approximately 1500 pages of information on the Fundy region, including the most comprehensive descriptions of the sea ice conditions in the Bay of Fundy headwaters available (see reference 5, Satellite Image Two (p. 4), Figures One-Five and Appendix Two).

A device to convert the kinetic energy of the tidal currents in the Bay of Fundy into electricity was developed about 90 years ago.* Between 1915 and the early 1920's, Ralph P. Clarkson, a physics professor at Acadia University in Wolfville, Nova Scotia, and several colleagues designed, patented and tested what was perhaps the world's first in-stream tidal current device, the Clarkson Current Turbine (23). This device was to be installed in the Minas Passage (see Photograph One ,p. 5, and Satellite Image One, p. 3) to produce electricity for the Nova Scotia power grid at Cape Split. Unfortunately, the wooden prototype, which had been successfully tested, caught fire in 1920, and there was insufficient venture capital to replace it.

Professor Clarkson was certainly prescient in his proposal to harvest electricity from the tidal flow in the Minas Passage some 90 years ago. Today's emerging technologies (3,4,18,20,22) are in principle similar to the Clarkson Current Turbine (24). These modular technologies are designed to convert the kinetic energy of flowing water into electricity with relatively minor environmental impacts and at much lower capital costs than barrages. However, to harvest the huge tidal energy resource in the headwaters of the Bay of Fundy, including the Minas Passage, these in-stream tidal current harvesting devices must be able to tolerate the seasonal presence of sea ice (see below, sections II and III).

We document here the occurrence of sea ice in the sites on the Bay of Fundy in New Brunswick and Nova Scotia most suitable for tidal energy harvest. We recommend the development of sea-ice tolerant in-stream tidal current devices for deployment in the Bay of Fundy and, subsequently, in tidal-rich jurisdictions with more severe conditions of sea ice, in order to harvest the global resources of this alternative energy source.

*****

Underflow water wheels harvesting kinetic energy from the in-coming Fundy tide probably operated prior to 1900. This technology was used to generate mechanical energy, rather than electricity, and is not discussed here.

Satellite Image One

Atlantic Canada

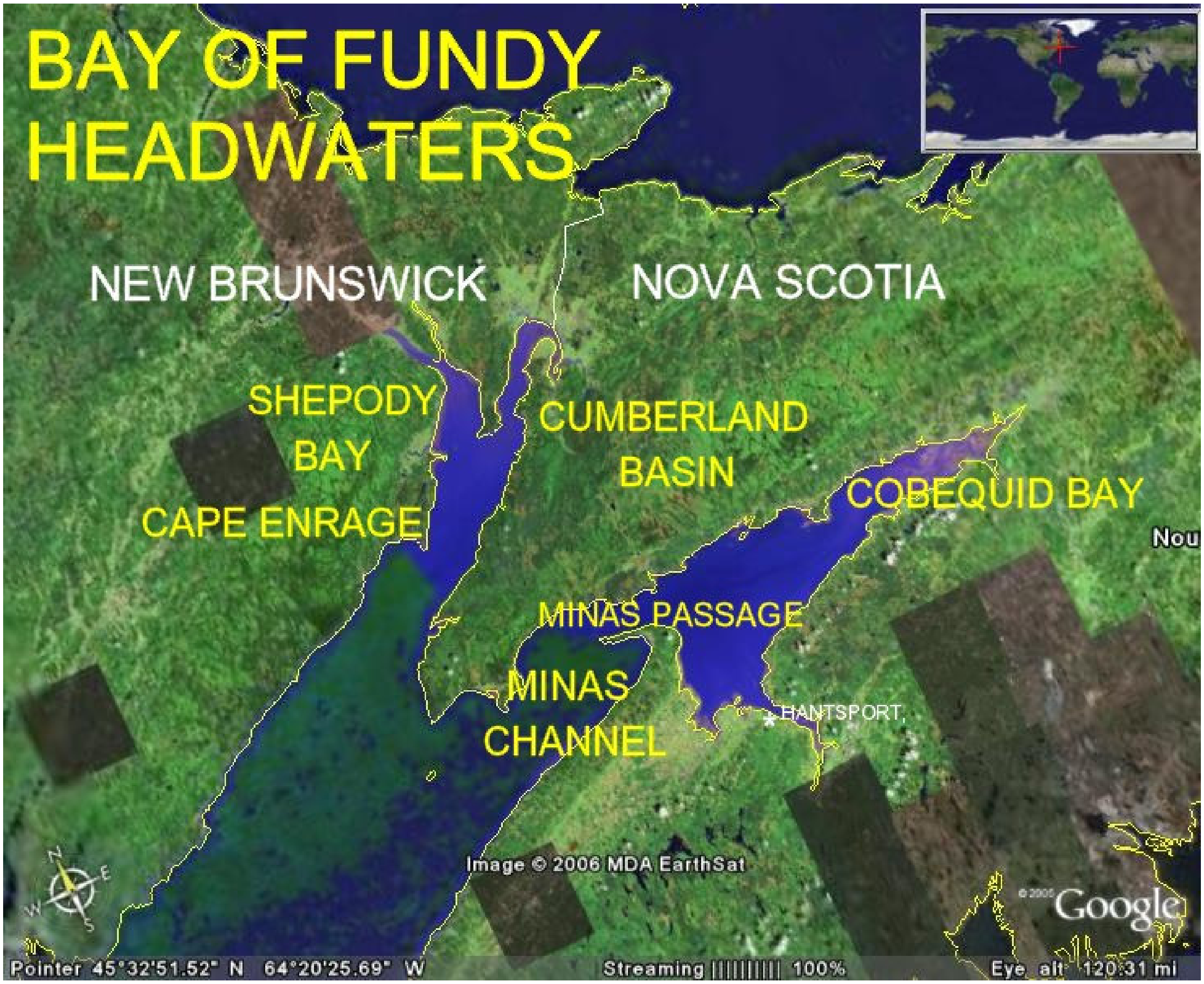
<u>Legend to Satellite Image One</u>

A view of Atlantic Canada. Provincial jurisdictions and several locations having potential for tidal energy harvest are indicated.

NB= New Brunswick; NL= Newfoundland and Labrador; NS= Nova Scotia; PEI= Prince Edward Island; PQ= Province of Quebec.
Modified from Google Earth (17).

Satellite Image Two

Bay of Fundy Headwaters



<u>**Legend to Satellite Image Two**</u>

A view of the headwaters of the Bay of Fundy with the major tidal power sites included. Shepody Bay and Cape Enrage are located in the province of New Brunswick. Cobequid Bay, the minas Passage and the Minas Channel are located in the province of Nova Scotia. The Cumberland Basin is shared by both New Brunswick and Nova Scotia. The location of the town of Hantsport, Nova Scotia, is indicated for reference in section III.,D., this report. Modified from Google Earth (17).

Photograph One

THE MINAS PASSAGE

(See Table One)

Legend to Photograph One
The region between Cape Sharp and Cape Split is known as the Minas Passage.

Every 6 hours and 12 ½ minutes an estimated 105 billion cubic feet of water traverses the Minas Passage. This is equal to the 5 day flow of the St. Lawrence River at Cornwall, Ontario (ref. 5, Volume 1, page 8).

The Electric Power Research Institute (EPRI) has described the Minas Passage as the most energetic tidal power site in the Bay of Fundy, and perhaps the most energetic site in North America (Table One and reference 6 pages 3 and 14; reference 7, page 11).

Photo: Ron Garnett – AirScapes www.airscapes.ca ; used with permission.

Table One
SEA ICE IN THE BAY OF FUNDY
AT SITES WITH HARVESTABLE TIDAL CURRENTS

Site*	Energy Harvest*	Sea Ice** 1968-2005
Minas Passage Nova Scotia	333 MW	Yes
Minas Channel Nova Scotia	262 MW	Yes
Cape Enrage New Brunswick	30 MW	Yes
Petit Passage Nova Scotia	18 MW	No
Head Harbour Passage New Brunswick	14 MW	No
Shepody Bay New Brunswick	13 MW	Yes
Cumberland Basin NS/NB	13 MW	Yes
Cobequid Bay Nova Scotia	13 MW	Yes
Grand Passage Nova Scotia	13 MW	No
Western Passage New Brunswick	10.8 MW	No
Digby Gut Nova Scotia	9.8 MW	No
Letete Passage New Brunswick	4.2 MW	No
Lubec Narrows New Brunswick	1.2 MW	No
St. John River, NB	[Not Reported by EPRI]	No

*

The Electric Power Research Institute (EPRI), under contract to the governments of New Brunswick and Nova Scotia, has identified the fourteen sites listed in Table One in New Brunswick and Nova Scotia on the Bay of Fundy as having harvestable tidal currents (6,7).
The Energy Harvest data presented in column two are also from EPRI (6,7) and are used here only to indicate the energy resource size at the various sites relative to one another (see below, 'Legend to Table One', subsection entitled 'Energy Harvest'.

**

Data from The Canadian Ice Service, Ice Archive (reference 12 and Appendix One, this document) and *Report to Atlantic Tidal Power Programming Board on Feasibility of Tidal Power Development in the Bay of Fundy,* Appendix 3, Ice and Sediment, by the Atlantic Tidal Power Programming Board, October, 1969 (reference 5 and Appendix Two, this document).

Legend to Table One

The most promising sites for tidal current harvest in the Bay of Fundy in New Brunswick and Nova Scotia are presented in column one of Table One. These sites are listed from the most energetic to least energetic. The sites presented in red periodically experience sea ice capable of impacting marine activities.

Sea Ice

The Minas Passage, the Minas Channel, Cape Enrage, Shepody Bay, the Cumberland Basin and Cobequid Bay all periodically experience 30% cover of sea ice 15 cm thick in floes of at least 100 metres in length (see Appendix One and section II.,E.,1., p. 14, this document). These ice floes may move under the influence of tidal currents which can exceed 7 knots and sustained winds which can exceed 50 MPH (reference 5, Appendix 4).

During very severe winters, the red sites in Table One may experience 70% cover with ice greater than 30 cm in thickness (reference 5 and Appendix Two, pages A3-4 and A3-17).

Inspection of the red sites in Table One reveals that approximately ninety percent of the harvestable tidal current energy in the Bay of Fundy in Nova Scotia and New Brunswick occurs at sites which experience sea ice capable of impacting marine operations.

In-stream tidal current harvesting devices in the Minas Channel and the Minas Passage, as well as those at Cape Enrage and in Cobequid Bay, Shepody Bay and the Cumberland Basin should be designed to tolerate the conditions of sea ice occurring at these sites during January, February and March of some years.

> ***Please note that Table One is a minimal statement of the winter ice conditions in the Bay of Fundy. The word "No" in column three of Table One means that sea ice has not been reported at a site in the references used to prepare Table One. However, ice in the Bay of Fundy has historically been under-reported to the Canadian Ice Service (see below, section II., C. Data from 1969-2000, p. 11, this document), and it is possible that ice occasionally occurs at the sites represented in Table One as having no sea ice.***

(Legend to Table One, cont.)

Energy Harvest

The work by EPRI to calculate the size of tidal current resources (6,7) is pioneering, but should be confirmed in field studies. For this reason, the energy harvest data presented in column two are used only to indicate the approximate energy resource size at the various sites relative to one another.

> ***Uncertainty in EPRI's energy harvest numbers is suggested by the variety of assumptions used in their calculation. Some of these assumptions underlie the calculation of the size of the tidal current resource at each site. Other assumptions are used in the calculation of the percentage of the tidal current energy which can be harvested without untoward environmental or ecological impacts. Additional assumptions are based on the performance of the latest generation of tidal current harvesting devices, most of which have not been deployed in full scale and none of which has been installed at the device densities used in EPRI's energy harvest calculations. For additional discussion of the assumptions used in EPRI's pioneering calculations of tidal energy, please see reference 21.***

We would, of course, like to know the potential contribution of tidal current power to society's electrical requirements (see Introduction, paragraph three, p. 1, this document). Consider, for example, the jurisdiction of Nova Scotia, where Nova Scotia Power Incorporated (NSPI) provides more than 97% of the province's electric generation, using 2,293 MW of installed capacity (13). Twenty seven percent of this generating capacity utilizes oil and gas (13).

It is not inconceivable that in Nova Scotia the electricity generated from the two most energetic sites in the Bay of Fundy, the Minas Channel and the Minas Passage, could replace the electricity presently obtained from oil and gas, supplies of which are likely to be exhausted in this century (see Introduction, paragraph one, p. 1, this document).

In this regard it is worth noting that the use of supplemental electricity generated from the tidal currents at the Minas Channel and the Minas Passage would be facilitated by employing pumped storage to re-time tidal generation so that the supply of electricity to the provincial grid could respond to consumer demand.

II. Documenting Ice in the Bay of Fundy

A. Data for 2001-2005 (The Canadian Ice Service *on line* and Appendix One)

Data from the Ice Archives of the Canadian Ice Service for the Bay of Fundy for the years 2002-5 are presented in Appendix One.

In 2001 there were no reports of ice in the headwaters of the Bay of Fundy.

During February, 2002, Cobequid Bay, Shepody Bay and the Cumberland Basin experienced greater than 90% ice cover with 30% of this ice 10-15 cm thick in 20-100 metre floes (see Appendix One).

In 2003 Cobequid Bay, the Minas Passage, the Minas Channel, Cape Enrage, Shepody Bay and the Cumberland Basin (i.e., all the red items in Table One) experienced at least a 30% cover of 15 cm ice in floes at least 100 metres in the longest horizontal dimension.

In 2004 the Minas Passage, Cobequid Bay and the Cumberland Basin experienced 30% cover of 15 cm thick ice in 100metre floes.

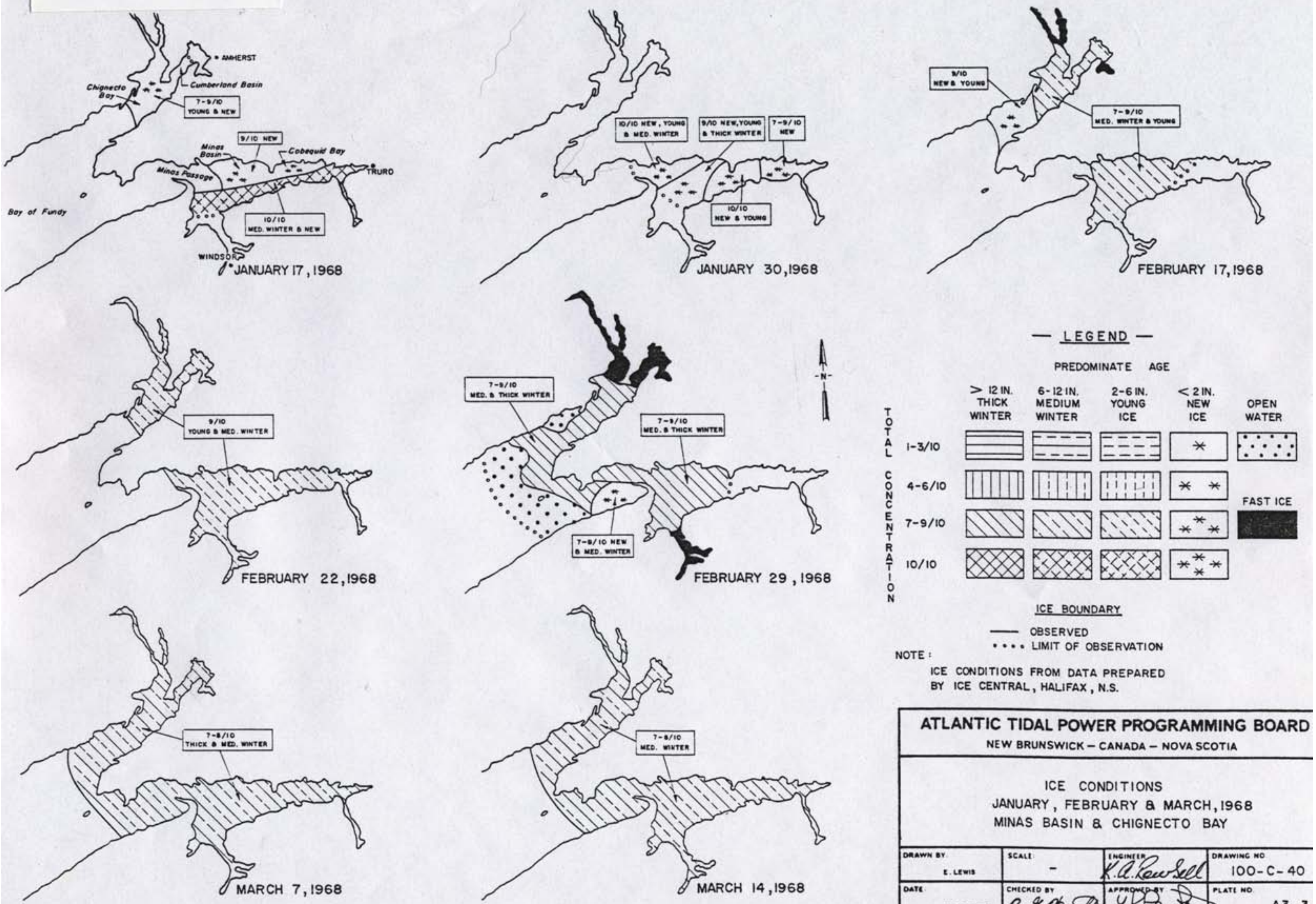
In addition, at various times during 2003 and 2004, a 20% cover of ice at least 15 cm thick in 100 metre floes was present at all six of the sites in red in Table One (see Appendix One).

In 2005, almost all sites listed in Table One (p. 6) experienced "open water" in February. "open water" is defined as less than 10% ice cover and is distinct from "ice free" (reference 19, p. I-9). We assume that the expression "open water" does not denote ice infestation sufficient to impact marine activities. Therefore, 2005 is not registered here as having a significant (see section II.,E.,1., p. 14 for definition of significance) ice infestation in the Bay of Fundy headwaters.

In summary, examination of the data in the Ice Archives of the Canadian Ice Service indicates that in three of the last five years (2002, 2003 and 2004) significant (p. 14) ice has been reported in the head waters of the Bay of Fundy. The reader is directed to Appendix One for a more complete picture of the occurrence of sea ice in the headwaters of the Bay of Fundy between 2002 and 2005 (inclusive).

B. Data from 1968 (Figures 1-5 (below), Appendix Two (this document) and reference 5)

FIGURE ONE



NOTE:

ICE CONDITIONS FROM DATA PREPARED BY ICE CENTRAL, HALIFAX, N.S.

ATLANTIC TIDAL POWER PROGRAMMING BOARD

NEW BRUNSWICK – CANADA – NOVA SCOTIA

ICE CONDITIONS
JANUARY, FEBRUARY & MARCH, 1968
MINAS BASIN & CHIGNECTO BAY

DRAWN BY: E. LEWIS	SCALE: –	ENGINEER: K.A. Rowsell	DRAWING NO: 100-C-40
DATE: AUG. 7, 1969	CHECKED BY: B. G. Knight	APPROVED BY: [signature]	PLATE NO: A3-3

FIGURE TWO

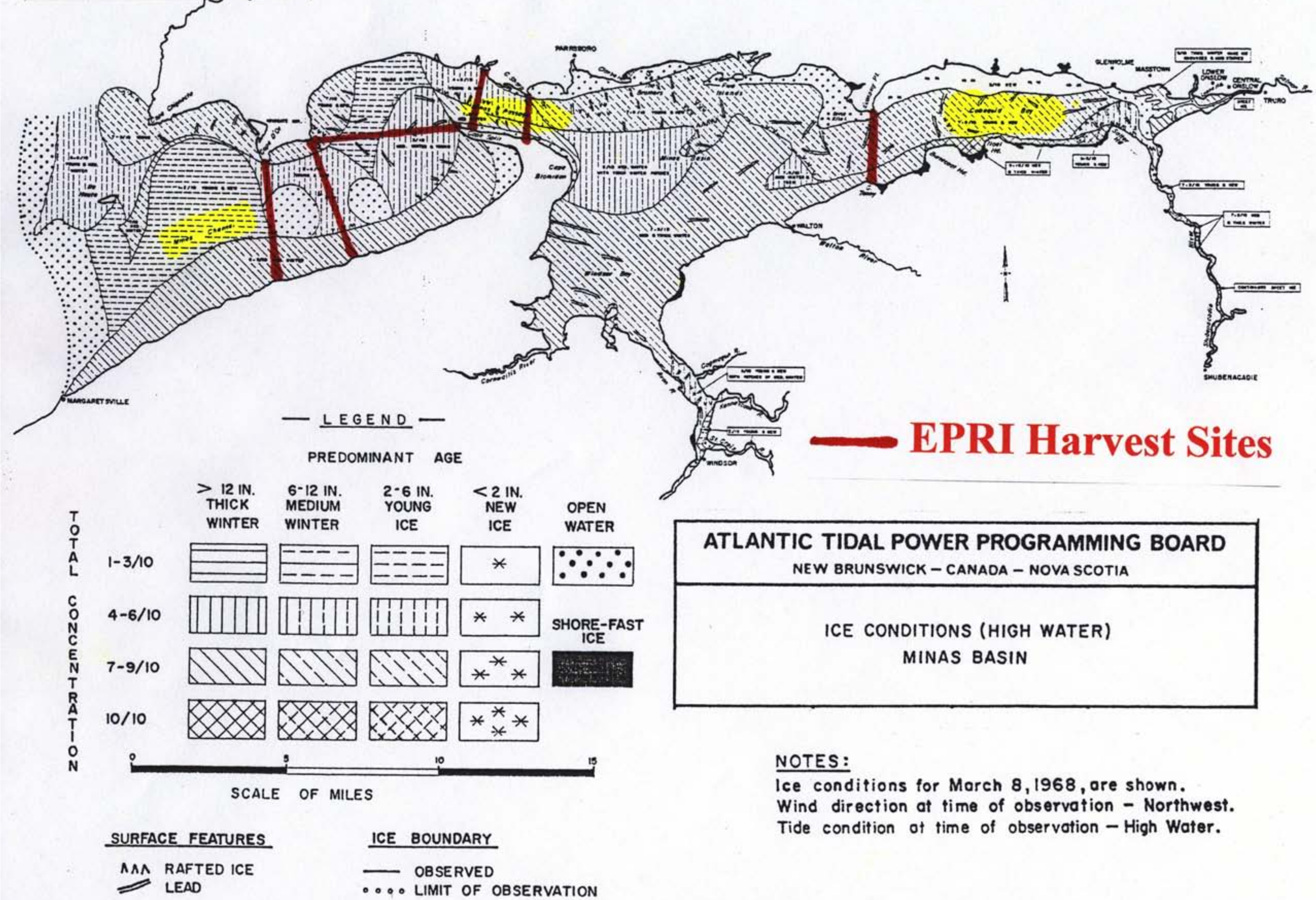

PARRSBORO
GLENHOLME
MASSTOWN
LOWER ONSLOW
CENTRAL ONSLOW
TRURO
WALTON
SHUBENACADIE
WINDSOR
MARGARETSVILLE
Cape Blomidon
EPRI Harvest Sites
LEGEND
PREDOMINANT AGE
> 12 IN. THICK WINTER
6-12 IN. MEDIUM WINTER
2-6 IN. YOUNG ICE
< 2 IN. NEW ICE
OPEN WATER
SHORE-FAST ICE
TOTAL CONCENTRATION
1-3/10
4-6/10
7-9/10
10/10
0
5
10
15
SCALE OF MILES
SURFACE FEATURES
RAFTED ICE
LEAD
ICE BOUNDARY
OBSERVED
LIMIT OF OBSERVATION
ATLANTIC TIDAL POWER PROGRAMMING BOARD
NEW BRUNSWICK – CANADA – NOVA SCOTIA
ICE CONDITIONS (HIGH WATER)
MINAS BASIN
NOTES:
Ice conditions for March 8, 1968, are shown.
Wind direction at time of observation – Northwest.
Tide condition at time of observation – High Water.

FIGURE THREE

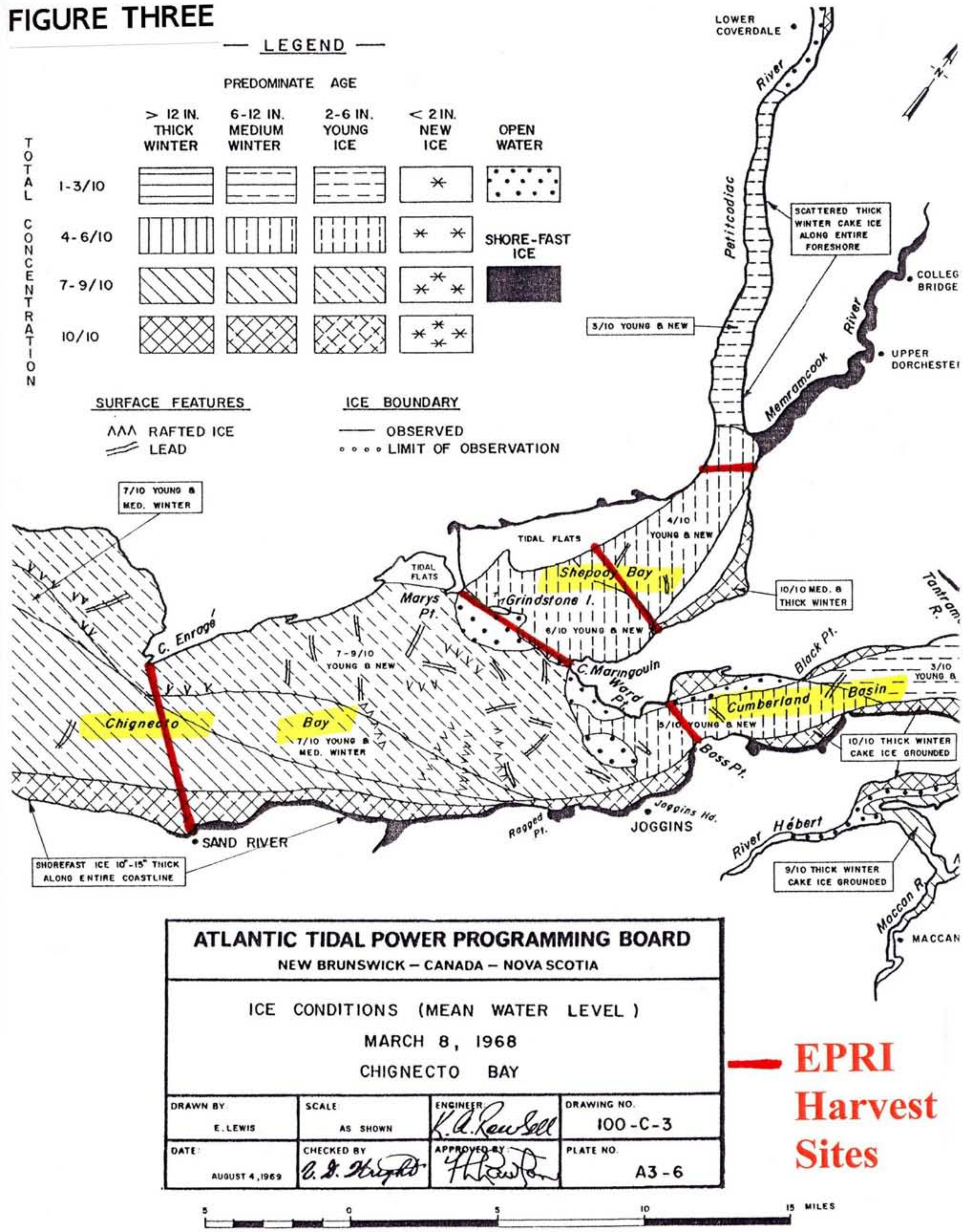


FIGURE FOUR

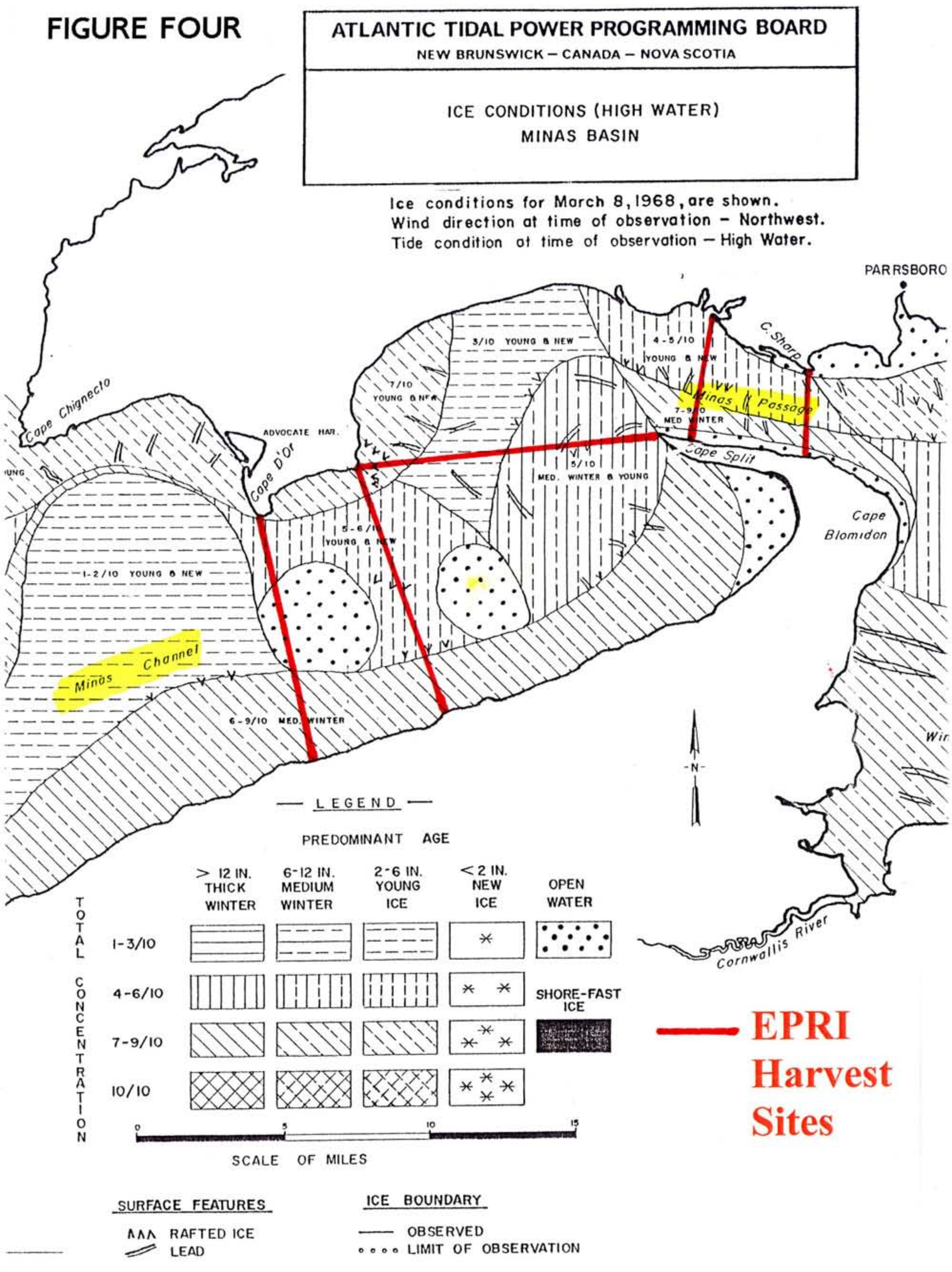

ATLANTIC TIDAL POWER PROGRAMMING BOARD
NEW BRUNSWICK – CANADA – NOVA SCOTIA
ICE CONDITIONS (HIGH WATER)
MINAS BASIN
Ice conditions for March 8, 1968, are shown.
Wind direction at time of observation – Northwest.
Tide condition at time of observation – High Water.
PARRSBORO
C. Sharp
Cape Chignecto
ADVOCATE HAR.
Cape D'Or
Cape Split
Cape Blomidon
Minas Passage
Minas Channel
3/10 YOUNG & NEW
4-5/10 YOUNG & NEW
7/10 YOUNG & NEW
7-9/10 MED. WINTER
5/10 MED. WINTER & YOUNG
5-6/10 YOUNG & NEW
1-2/10 YOUNG & NEW
6-9/10 MED. WINTER
Cornwallis River
-N-
LEGEND
PREDOMINANT AGE
> 12 IN. THICK WINTER
6-12 IN. MEDIUM WINTER
2-6 IN. YOUNG ICE
< 2 IN. NEW ICE
OPEN WATER
SHORE-FAST ICE
TOTAL CONCENTRATION
1-3/10
4-6/10
7-9/10
10/10
0
5
10
15
SCALE OF MILES
SURFACE FEATURES
RAFTED ICE
LEAD
ICE BOUNDARY
OBSERVED
LIMIT OF OBSERVATION
EPRI Harvest Sites

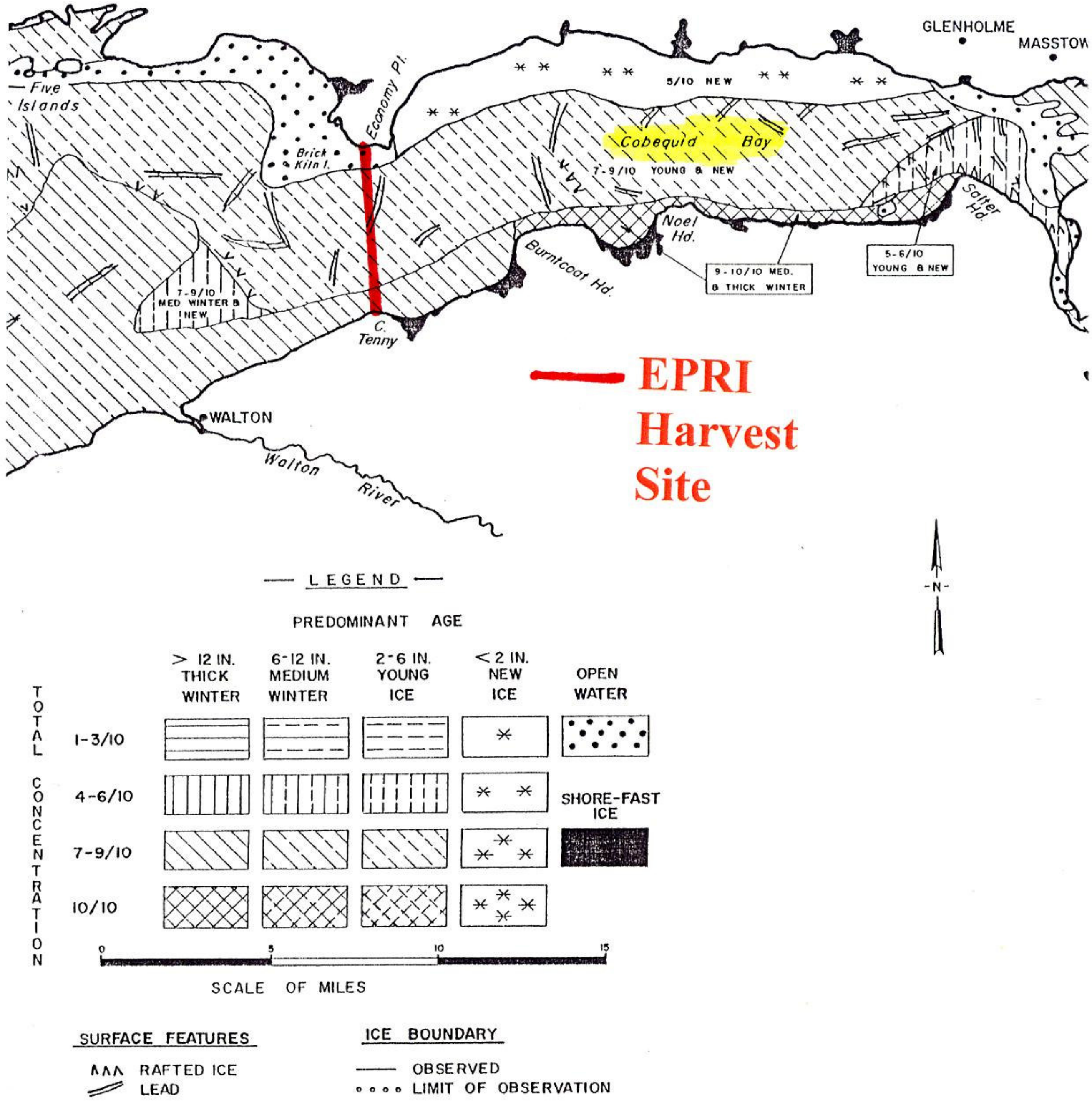
FIGURE FIVE

ATLANTIC TIDAL POWER PROGRAMMING BOARD

NEW BRUNSWICK – CANADA – NOVA SCOTIA

ICE CONDITIONS (HIGH WATER)
MINAS BASIN

Ice conditions for March 8, 1968, are shown.
Wind direction at time of observation – Northwest.
Tide condition at time of observation – High Water.



Figures One-Five are adapted from reference 5, *Report to Atlantic Tidal Power Programming Board on Feasibility of Tidal Power Development in the Bay of Fundy*. This study, funded by the Government of Canada, the Province of New Brunswick and the Province of Nova Scotia, documents in great detail the ice conditions in the Chignecto and Minas branches of the Bay of Fundy in the winter of 1968. Data collection was by both aerial surveillance and ground reconnaissance. The winter of 1968 was one of the coldest on record.

Figure One shows the ice conditions in the upper Bay of Fundy on seven days in January, February and March of 1968. The diagrams indicate that ice over six inches (15 cm) thick covered 70% of Shepody Bay, Cape Enrage, the Cumberland Basin, the Minas Channel, the Minas Passage and Cobequid Bay during February and March. The most extensive ice cover occurred during the week of February 29, 1968, "when Chignecto Bay, Minas Basin, Passage and Channel were 70 to 90% covered with medium and thick winter ice" (Appendix Two, p. A3-4, this report), and may not be reflected on the diagram of that date in Figure One. *(N.B. The expression "Chignecto Bay" subsumes Shepody Bay, Cape Enrage and the Cumberland Basin.)*

Figures Two thru Five show the EPRI harvest sites superimposed on ice maps of the headwaters of the Bay of Fundy on March 8, 1968.

Figure Two shows the ice conditions in the Minas branch of the Bay of Fundy on March 8, 1968. The EPRI harvest sites (6) in the Cobequid Bay, the Minas Passage and the Minas Channel are superimposed on this ice map. Figures Four and Five are enlarged (and hopefully somewhat more readable) versions of this ice map for the Minas region and the Cobequid Bay.

Figure Three is an ice map of the Chignecto branch of the Bay of Fundy on March 8, 1968. This figure has the EPRI harvest sites (7) superimposed in Shepody Bay, Cumberland Basin and Cape Enrage.

By inspection of Figures One-Five, it is obvious that significant accumulations of ice were present at all the sites proposed by EPRI for tidal current energy harvest in the upper reaches of the Bay of Fundy during January, February and March of 1968.

As noted above, these six sites—three in the Minas Branch and three in the Chignecto Branch of the Bay of Fundy—constitute over 90% of the energy EPRI feels is extractable from the Bay of Fundy in New Brunswick and Nova Scotia (Table One (p. 6) and references 6,7).

By way of comparison with the data from the Canadian Ice Service for 2001-2005 (discussed above section II., A., p. 9 this report), the accumulations of ice in 1968, as documented in the 1969 feasibility study, seem to exceed those of 2003 and 2004. This might be due to the exceptionally cold winter in 1968 or, perhaps, to the occurrence of global warming in the years since 1968.

C. Data from 1969-2000 (The Canadian Sea Ice Climate Atlas)

The Canadian Ice Service did not consistently receive reports of ice in the Bay of Fundy between 1970 and 2000 (11) . These incomplete reports were used to produce *The Canadian Sea Ice Climate Atlas*.+ Hence, this document is a minimal statement of ice in the Bay of Fundy for the period 1970-2000.

With the understanding that the following six charts from the Canadian Ice Atlas under-represent both the frequency and the extent of ice in the Bay of Fundy, the following interpretations of Figures Six thru Eleven are presented.

+ Erratum for *Sea Ice Climate Atlas – East Coast of Canada 1971-2000*: "Please note that ice in the Bay of Fundy area has not been reported consistently in the period 1971-2000. Consequently, the atlas products are not reliable in that area" (11).

FIGURE SIX

CANADIAN ICE SERVICE

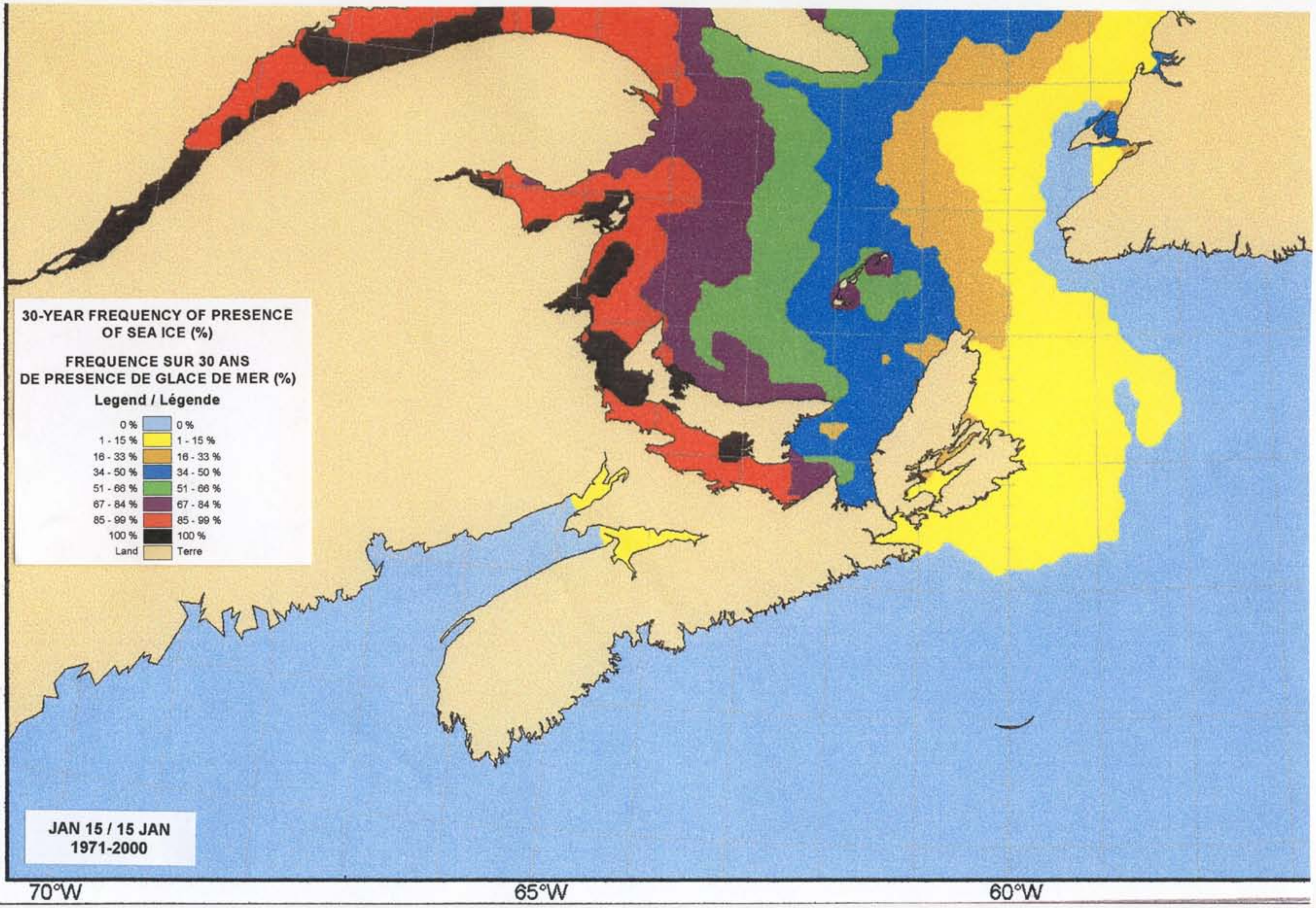


FIGURE SEVEN

CANADIAN ICE SERVICE

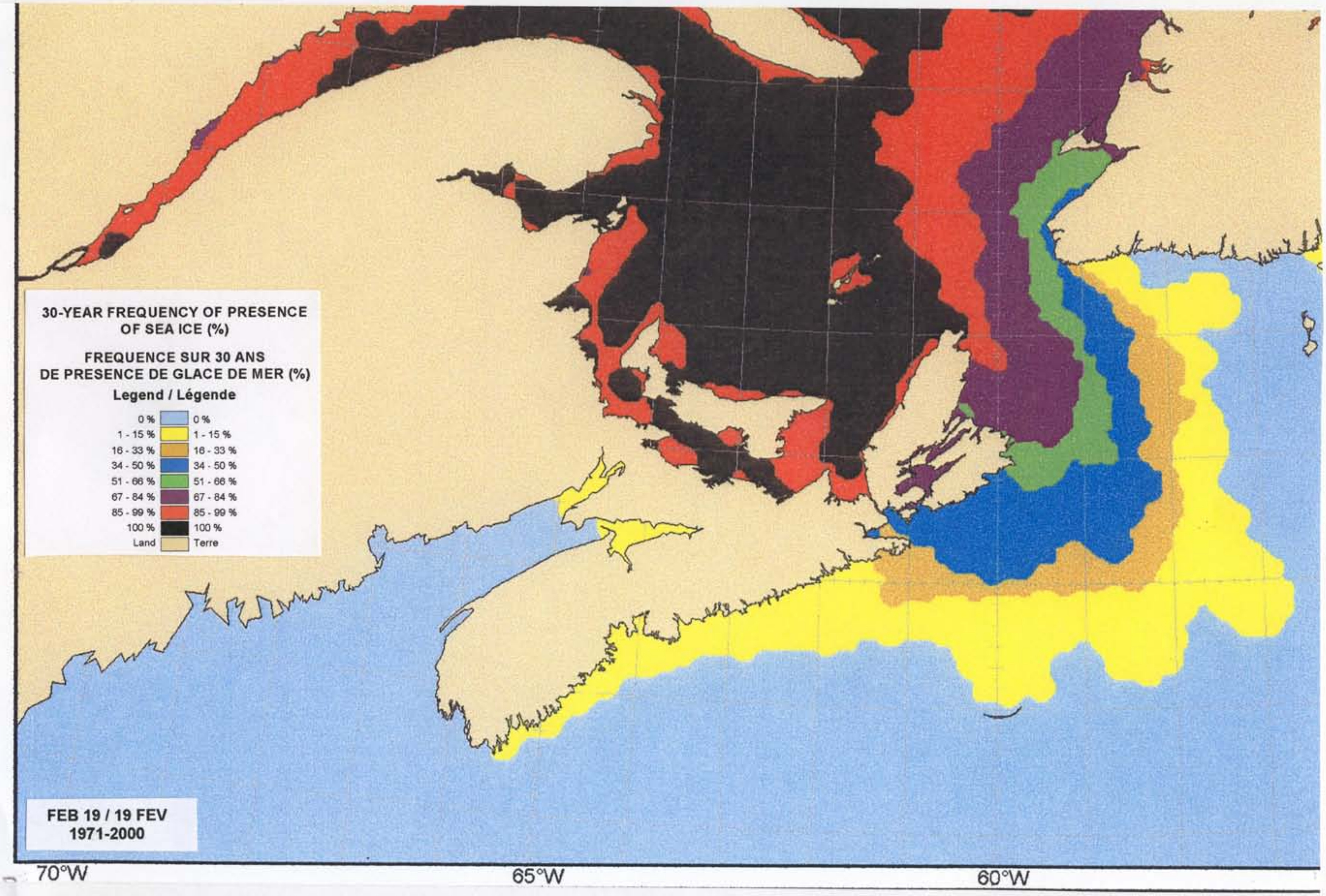
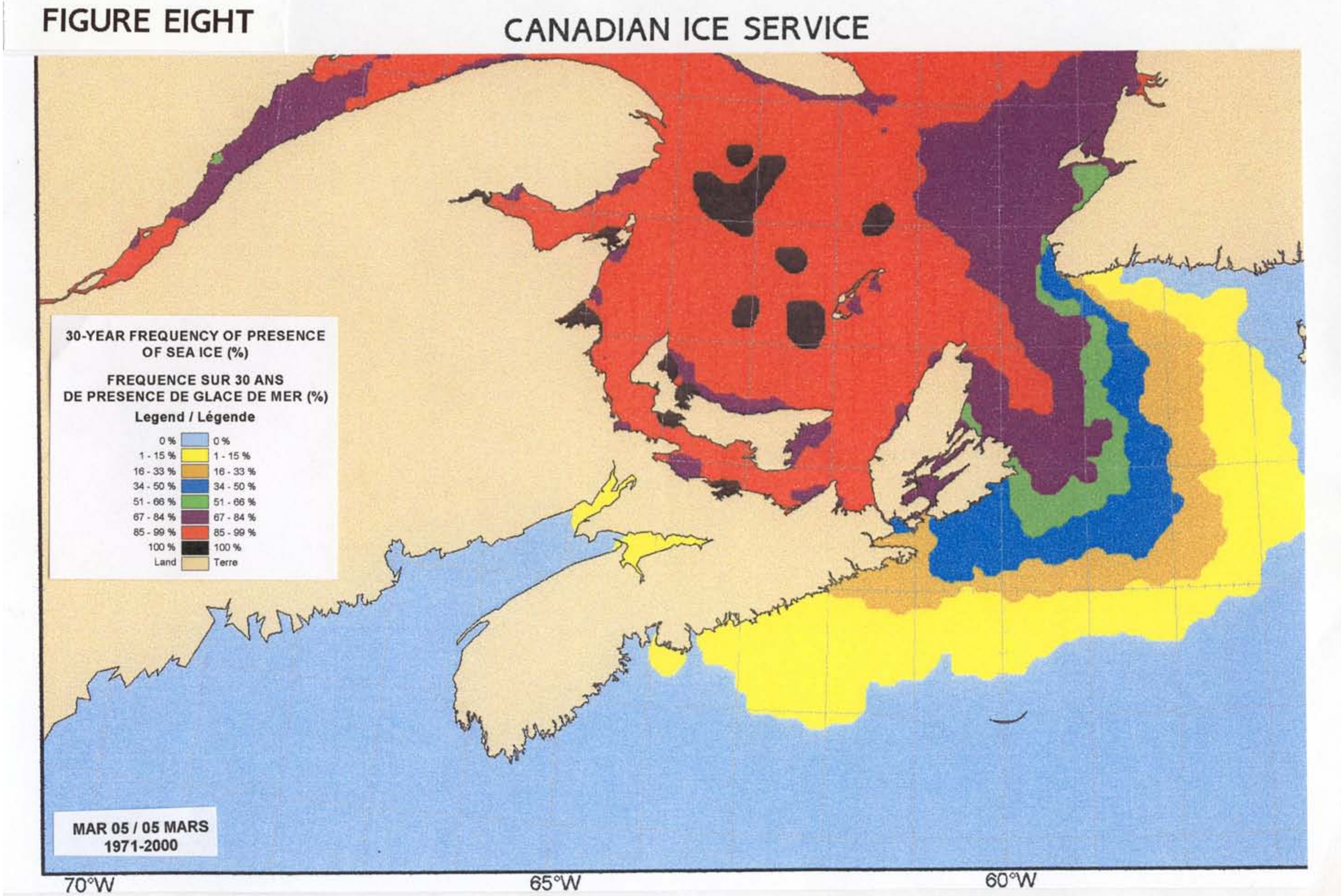


FIGURE EIGHT



Figures 6, 7 and 8 suggest that sea ice has been present in both the Chignecto and Minas branches of the Bay of Fundy during January, February and March in 1-15% of the years between 1971 and 2000. The actual occurrence is likely higher than 15% over this period, since ice in the Bay of Fundy area was reported inconsistently to the Canadian Ice Service (p. 11, this report). As noted above (section II.A., p. 9, this report), sea ice occurred in the headwaters of the Bay of Fundy in three of the last five years.

FIGURE NINE

CANADIAN ICE SERVICE

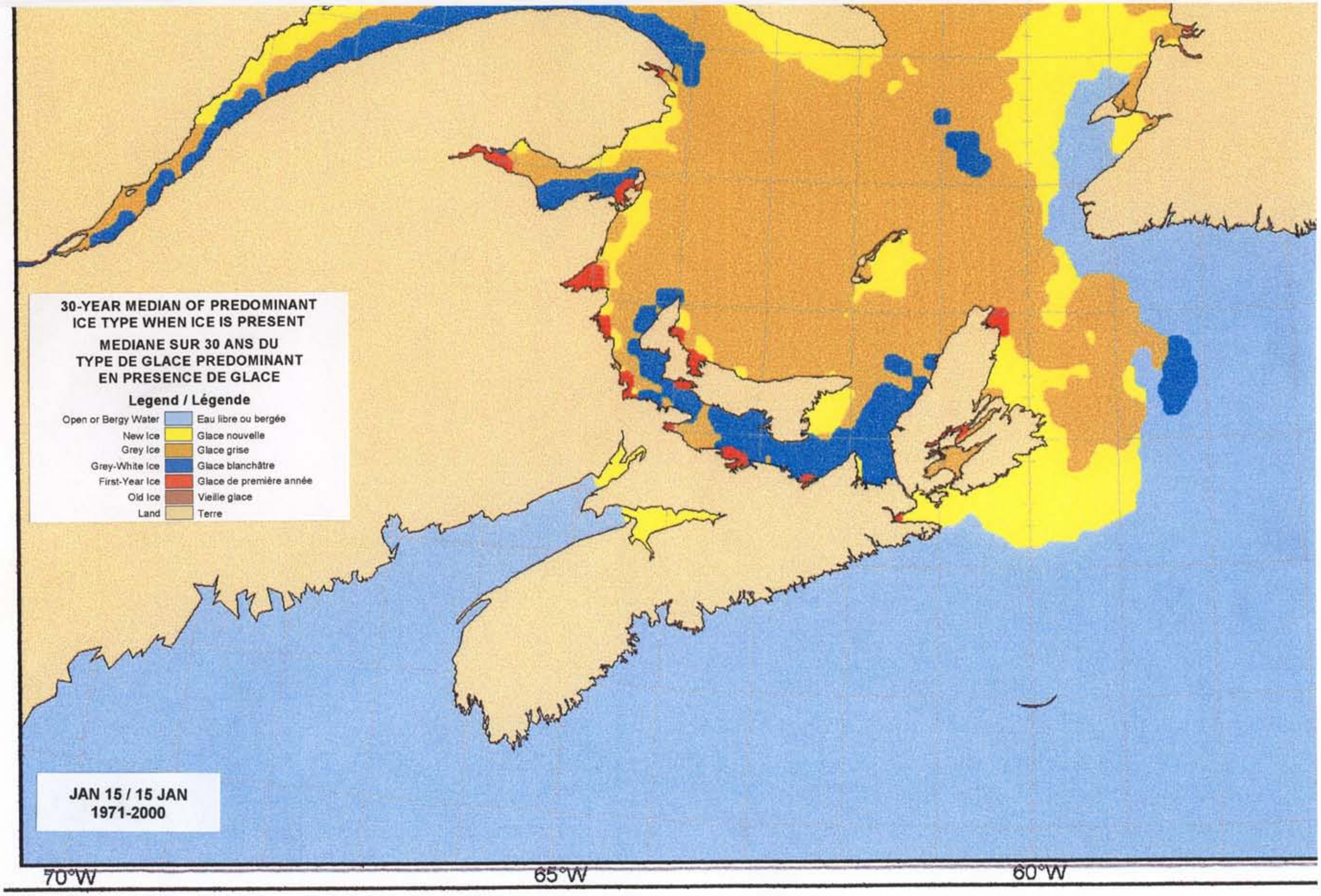


FIGURE TEN

CANADIAN ICE SERVICE

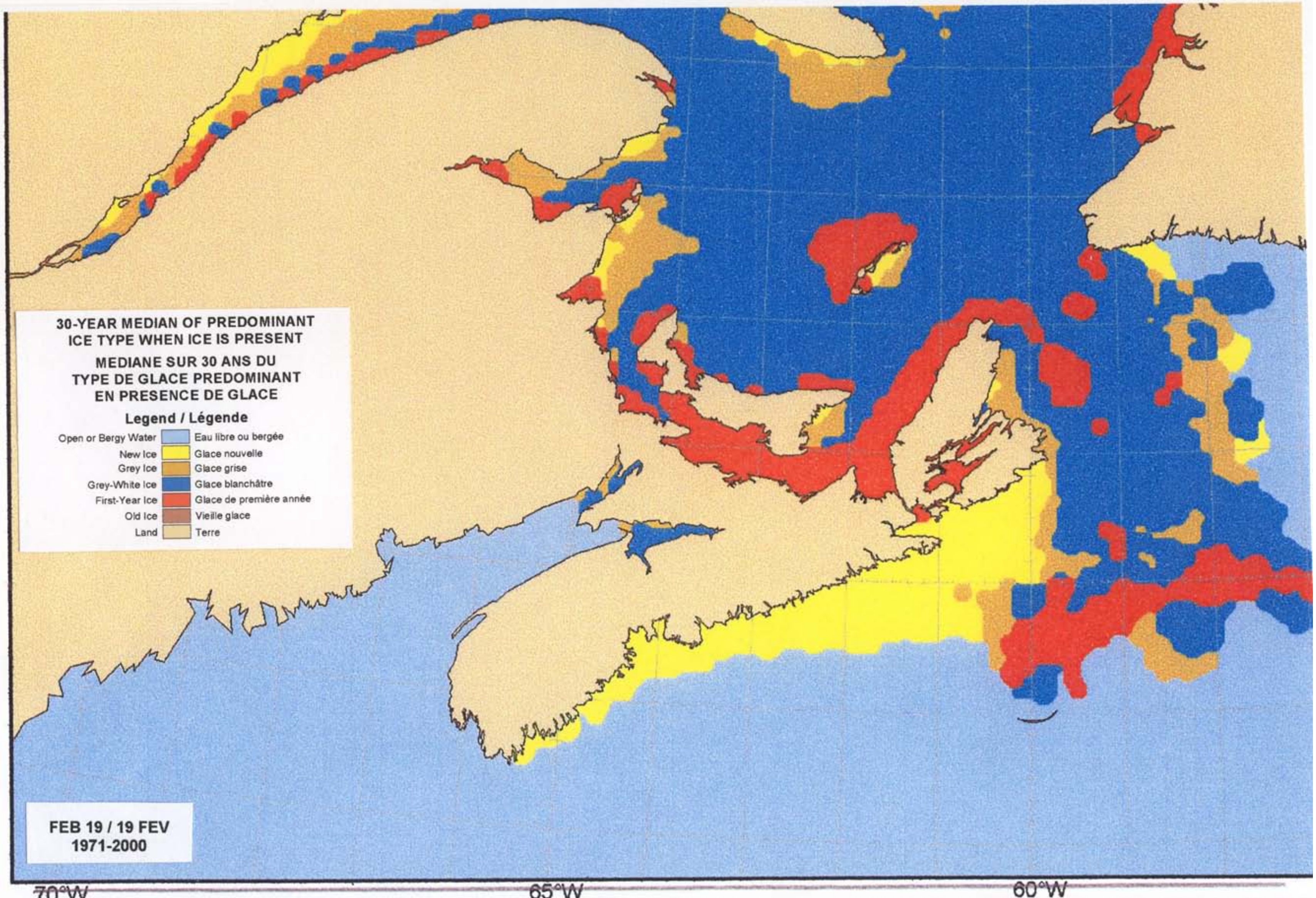
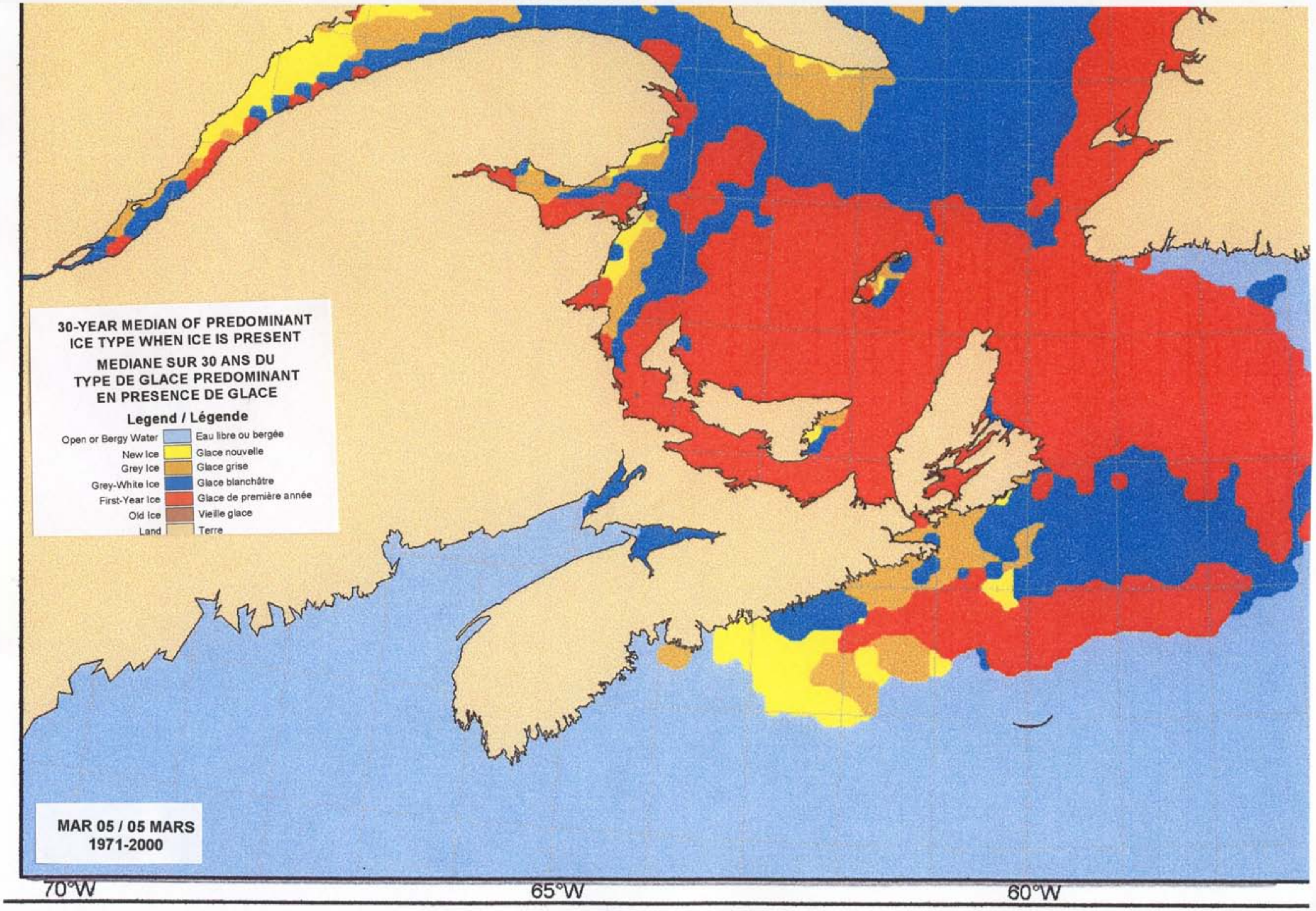


FIGURE ELEVEN

CANADIAN ICE SERVICE



Figures 9, 10 and 11 provide information about the nature of the ice which occurred in the headwaters of the Bay of Fundy between 1971 and 2000. During January, February and March, the ice was either *New Ice*, *Grey Ice* or *Grey-White Ice*. According to Environment Canada's Fact Sheet on Sea Ice Symbols (see Appendix One, 1., this document), *New Ice* is less than 10 cm thick, *Grey Ice* is 10-15 cm thick and *Grey-White* Ice is 15-30 cm thick.

Inspection of Figures 9-11 suggests that *New Ice, Grey Ice* or *Grey White Ice* were reported in the Cobequid Bay, the Minas Passage, Cape Enrage, Shepody Bay and the Cumberland Basin at some time during January, February or March in the period from 1971 to 2000.

By way of comparison with the data in Figures 9-11, note that some of the ice in the Bay of Fundy headwaters during the winter of 1968 was thicker than 30 cm (12 inches). (See Figures One thru Five, this document, where ice thicker than 30 cm is called *Thick Winter Ice*. See also the discussion of the 1968 ice in Appendix Two, this document, pages A3-4 and A3-17, first complete paragraph.) As noted above (section II.,B., p. 11, this report), the winter of 1968 may have been exceptionally cold or there may now be a trend to less ice formation due to global warming.

D. Impressions of an Eye Witness

1. Captain Lloyd McLellan (15)

In December, 2005, Captain Lloyd McLellan retired as Captain of the *Spanish Mist*, a tug boat owned by Fundy Gypsum Company in Hantsport, Nova Scotia, after 37 years of service.

Hantsport is located in the Minas Basin (see Satellite Image Two, p. 4), and cargo ships must pass through the Minas Channel and the Minas Passage to reach Fundy Gypsum's loading dock (see Satellite Image Two (p. 4), Photograph One (p. 5) and Table One (p. 6)). Fundy Gypsum ships rock from its facility in Hantsport and uses the *Spanish Mist* to assist cargo vessels as they traverse the Minas region of the Bay of Fundy to approach its dock. Cargo ships dock on the rising tide and sail at high tide. Approximately 40,000 tons of gypsum is loaded in less than three hours (16).

Captain McLellan's report is that the approach of cargo ships to Fundy Gypsum's docking facility is obstructed by ice approximately one year in three. Some years cargo ships have had to wait two or more weeks for the ice to clear so they could reach the dock in Hantsport.

However, in Captain McLellan's experience, the Minas Passage is only obstructed with ice for days—not weeks---as is the case with the approach to Fundy Gypsum's dock in Hantsport. Under certain conditions, winds can blow ice into the Minas Passage, perhaps even overcoming the force of the incoming tide to temporarily obstruct this waterway. His feeling is that the strong tidal currents in the Minas Passage will often rapidly clear out the obstructing ice. The ice being cleared is sometimes "moving pretty fast" as it exits the Minas Passage. The velocity of ice movement has obvious implications for the design of tidal current devices (see below, section II.,E.,1.,b., p. 15 and section III.,D., p. 16).

E. Findings

1. Significant sea ice occurs periodically in the tidal power-rich sites of the Bay of Fundy

Both the records of the Canadian Ice Service (see Figures Six—Eleven and Appendix One) and the ice survey done in 1968 by the Tidal Power Board (see Figures One—Five and Appendix Two) suggest that significant sea ice has occurred in the head waters of the Bay of Fundy during some winters between 1967 and 2006. This conclusion is supported by the eyewitness report of Captain McLellan (section III.,D, above).

"Significant" sea ice is defined [here as sea ice present in floes which are at least 15 cm thick and which are at least 100 metres in their longest surface dimension and which cover at least 30% of the total water surface. Ice floes of these dimensions would be likely to impact many marine activities, including the shipping of gypsum rock and the harvest of tidal energy.

The precise frequency of significant sea ice in the Bay of Fundy headwaters from 1967 to 2005 remains uncertain. Consistent records of ice in the Bay of Fundy are only available for 2001-2005 (11,12 and section II., A. and II., C. above) and for 1968 (reference 5, Figures One thru Five and Appendix One, this document). However, there is both systematic and anecdotal evidence that in three of the last five winters "significant" sea ice infestations occurred at some of the most promising sites for tidal power harvest in the headwaters of the Bay of Fundy.

In one of the last five years, 2003, significant ice infestations occurred at all six of the most promising sites (Minas Passage, Minas Channel, Cape Enrage, Shepody Bay, Cumberland Basin, and Cobequid Bay—see Table One) for tidal power harvest in the headwaters of the Bay of Fundy (see Appendix One), as it did in the winter of 1968 (see Figure One).

And in 2004 three sites, Cobequid Bay, Minas Passage and Cumberland Basin met the criteria for significant sea ice infestation.

In addition, 2002 experienced ice conditions at some sites (Shepody Bay, Cumberland Basin and Cobequid Bay) which would probably impact tidal current harvesting activities [i.e., 30% cover with 10 cm ice in 20 metre floes (see Appendix One)], although this infestation does not reach the definition of significance given on the preceding page.

Moreover, it is conceivable that ice from the three sites infested in 2003 and the three sites infested in 2002 could impact tidal current energy harvest at the other tidal current sites in the Bay of Fundy headwaters, if the ice were to move to (or through) the other sites under the force of tidal currents or prevailing winds.

a. Tidal power devices deployed at these sites would have to tolerate these ice conditions periodically

As illustrated in Table One (p. 6), the headwaters of the Bay of Fundy contain some of the most promising sites to harvest tidal energy in North America. Any devices installed in these sites would minimally have to tolerate conditions similar to the 30% cover by 15 cm thick sea ice in 100 metre floes that occurred in 2003. To ensure longer operational life, tidal current devices should be capable of withstanding the thicker sea ice, the more extensive cover and the larger floes which occurred in 1968 (see figures One-Five and Appendix Two, pages A3-4 and A3-17).

b. Tidal power devices deployed in the headwaters of the Bay of Fundy would also have to tolerate the movement of significant sea ice

The velocity of sea ice movement would be an additional engineering consideration in the design and deployment of in-stream tidal current devices in the headwaters of the Bay of Fundy. The floes of ice in the Bay of Fundy are carried by tidal currents and driven by wind. When these forces worked in unison, ice velocities in excess of 8 knots might be attained. Tidal current devices for deployment in these sites should be designed to tolerate the presence of rapidly moving sea ice and/or the pressure of ice packed by winds and tidal currents.

Additionally, circular tidal currents, particularly acting in highly energetic but spatially constricted regions such as the Minas Passage (Photograph One, p. 5; Table One, p. 6, line one), might cause sea ice floes to exert grinding forces on objects they contact, including components of tidal current harvesting devices.

In summary, tidal current devices should be designed to tolerate the presence of rapidly moving sea ice and ice packed by wind and tidal currents, if they are to be deployed in the headwaters of the Bay of Fundy.

III. Harvesting Tidal Current Energy in the Presence of Sea Ice.

A. Introduction

There are several obvious ways the presence of sea ice could impact the harvest of in-stream tidal energy. First, the presence of ice floes could alter the kinetic energy available for harvest by in-stream devices. Second, the presence of ice could reduce the weather windows for installation, maintenance, repair and overhaul of in-stream tidal current devices. Third, ice could make physical contact with the tidal current harvesting device.

B. Impact of sea ice on the tidal current resource

It is important to characterize the impact of ice floes on the tidal current resource in the headwaters of the Bay of Fundy. This characterization should begin with experiments to measure the tidal current resource as a function of depth—i.e., from the water's surface to the sea floor—in the absence of sea ice. This information would be particularly important in the Minas Passage, parts of which exceed 100 metres in depth (5,6).

Similar depth-experiments can then be performed in the presence of ice. The impact of ice on the tidal current resource can be determined by comparing the size of the resource in the presence and absence of ice.

C. Impact of sea ice on access to the tidal current resource

The seasonal presence of sea ice will make the installation, repair, maintenance and overhaul of tidal current devices more challenging. Installation and routine maintenance could be scheduled during spring, summer and fall. Repairs during January, February and March might be minimized by the use of proven technology with high redundancy and low maintenance requirements.

D. Physical contact between the harvesting device and sea ice

The sea ice conditions at the most promising sites need to be characterized by further research. These sites would include, but perhaps not be restricted to, the Minas Passage and the Minas Channel in Nova Scotia and Cape Enrage in New Brunswick.

Damage to tidal power harvesting devices, and/or their appendages, could occur from physical contact with sea ice. The extent of damage would depend on the design of the device and the momentum of the sea ice.

It is important to note that both the mass and the velocity of sea ice must be determined. This report has emphasized the mass of ice present in the headwaters of the Bay of Fundy. However, as noted above, the tidal currents in the headwaters of the Bay of Fundy can exceed 7 knots (5,6,23) and produce non-linear flow patterns (Photograph One, p.5, and reference 5), which could grind sea ice against tidal energy devices.

In addition, wind may affect both the velocity and direction of ice floes both during tidal ebb and flow and at slack tide. Research on the consequences of collisions of sea ice with tidal harvesting devices and/or their appendages would need to include studies of prevailing winter winds.

Perhaps the most obvious method of avoiding physical contact between ice floes and in-stream tidal current harvesting devices would be to install the devices underwater, below the draught of sea ice (and any recreational or commercial vessels, if the tidal harvest area is also used for these purposes).

Theoretically, such devices could either rest on the sea floor or be tethered at an appropriate depth below the sea surface. In either case, access to the device for servicing and maintenance will be increasingly restricted the further from the water's surface it is positioned. On the other hand, the further the device is from the water's surface, the less likely contact with sea ice will be.

The inverse relationship between accessibility and protection has obvious design implications. For example, if accessibility is the paramount concern, in-stream tidal current devices which breech the water's surface would be a logical choice. However, in circumpolar climates, these devices will need to be engineered to tolerate ambient surface ice conditions. This type of arctic engineering project has succeeded both in Atlantic Canada and elsewhere in North America.

The Confederation Bridge, which spans Northumberland Strait (see satellite Image Two, p. 4) between New Brunswick and Prince Edward Island, is an example of a structure engineered to tolerate more severe ice conditions than those in the headwaters of the Bay of Fundy in New Brunswick and Nova Scotia (see Figures One thru Eleven, Appendix Two (this document) and reference 8). The engineering principles developed for the Confederation Bridge could be applied to the design of ice-tolerant tidal current devices which breech the water's surface.

Another example of successful arctic engineering is provided by the off shore oil and gas platforms in Cook Inlet, Alaska. These structures were designed to withstand the forces imposed by moving ice packs more formidable than those found in the Bay of Fundy, and "*The fact that there are now hundreds of platform-years of performance experience without a major failure testifies to the competence of the structural design*s." (ref. 9, p. 17 [emphasis added]).

On the other hand, if the major consideration is protection from contact with sea ice, this may be achieved by reducing device accessibility. However, location below the water's surface requires that tidal current devices be designed using proven technology and with adequate redundancy to obviate the need for service during periods of ice infestation (see section III., C., p. 16).

It is quite possible that both surface (3,4) and submerged (18, 20,22) designs will find applications in harvesting tidal energy from ice-infested waters. For example, the physical characteristics of some micro-environments may favour installation of surface designs, while other microenvironments are better suited to the deployment of submerged devices.

Satellite Image Three

SOME NORTH AMERICAN TIDAL CURRENT SITES WITH SEA ICE

Legend to Satellite Image Three

A view of northern North America with some tidal current sites which experience seasonal sea ice.

Modified from Google Earth (17).

E. Conclusion

Developing techniques to harvest tidal current power in the Bay of Fundy in the presence of sea ice could serve as a preliminary to the harvest of tidal current energy under more severe conditions of sea ice. Arctic engineering might eventually access the more challenging tidal currents in other jurisdictions such as Cook Inlet (Alaska) (9), Ungava Bay (Quebec) (10), the Straits of Belle Isle (Newfoundland and Labrador), the Gulf of St. Lawrence (Quebec) and Northumberland Strait (Prince Edward Island/New Brunswick) (8) (see Satellite Image Three, p. 19).

Beyond the North American Continent, other circumpolar jurisdictions with energetic tidal flows may also become markets for ice-tolerant tidal current harvesting technology. In these jurisdictions it is possible that tidal power can replace the energy now obtained from non-renewable resources such as oil and gas.

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V. Appendices

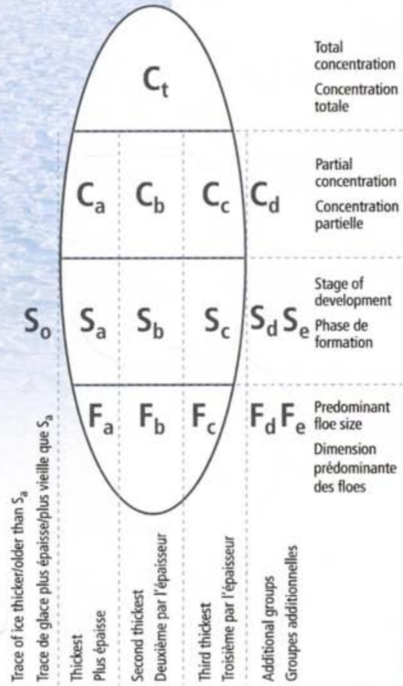
A. Appendix One

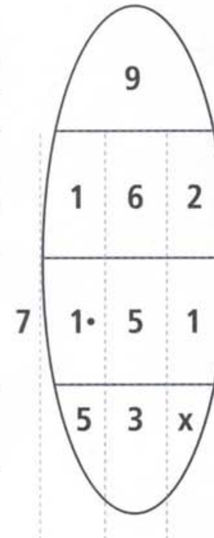
1. **Environment Canada Fact Sheet: Sea Ice Symbols**
2. **Canadian Ice Service Regional Ice Analyses: Eastern Coast**
    a. **Selected data 2001-2005**

Environment Canada / Environnement Canada

FACT SHEET / FICHE D'INFORMATION

SEA ICE SYMBOLS
SYMBOLES DE LA GLACE DE MER
2004





Total concentration: the ice coverage of an area determined by its concentration and expressed in tenths (in this example, 9/10).
Concentration totale : l'étendue de la couverture de glace, exprimée en dixièmes de la superficie du secteur (dans cet exemple, 9/10).

Partial concentration: the break-down of the total ice coverage expressed in tenths and graded by thickness. The thickest starting from the left and in this example, 1/10 is the thickest.
Concentration partielle : les concentrations respectives, exprimées en dixièmes, des glaces de différente épaisseur, par ordre décroissant. La plus épaisse commence à la gauche du diagramme, c'est-à-dire, 1/10 est le plus épais.

Stage of development: the type of ice in each of the grades, determined by its age, that is 1/10 is medium first-year ice (1•), 6/10 is grey-white ice (5) and 2/10 is new ice (1). Trace of old ice is represented on the lefthand side (outside the egg) by the number 7.
Stade de développement : le type de glace de chacune des catégories déterminé par son âge, c'est-à-dire, 1/10 est de la glace moyenne de première année (1•), 6/10 est de la glace blanchâtre (5), et 2/10 est de la nouvelle glace (1). Une trace de vielle glace est représentée à gauche (à l'extérieur de l'oeuf) par le chiffre 7.

Floe size: the form of the ice determined by its floe size for each section. In this example, big floes (5) for medium first-year ice (1•); small floes (3) for grey-white ice (5); and undetermined, unknown or no form floes (x) for new ice (1).
Taille des floes : la forme de la glace, déterminée par la taille des floes dominants de chaque section. Dans cette exemple, grands floes (5) pour la glace moyenne de première année (1•); petits floes (3) pour glace blanchâtre (5)et floes indéterminée, inconnue ou sans forme (x) pour la nouvelle glace (1).

Note: When an ice type has a dot (•) every other value to the left of it is also considered to have a dot.

Remarque: Lorsqu'un nombre est suivi d'un point (•), toute autre valeur apparaissant à sa gauche est également pointée.

SEA ICE SYMBOLS/SYMBOLES DE LA GLACE DE MER

Open Water / Eau libre — Ice Free / Libre de glace — Bergy Water — Fast Ice / Banquise côtière

Stage of Development/Stade de développement ($S_oS_aS_bS_cS_dS_e$)

Description/Élément	Thickness/Épaisseur	Code
New ice/Nouvelle glace	<10 cm	1
Nilas; ice rind/Nilas glace, vitrée	<10 cm	2
Young ice/Jeune glace	10-30 cm	3
Grey ice/Glace grise	10-15 cm	4
Grey-white ice/Glace blanchâtre	15-30 cm	5
First-year ice/Glace de première année	30 cm	6
Thin first-year ice/Glace mince de première année	30-70 cm	7
Medium first-year/ Glace moyenne de première année	70-120 cm	1•
Thick first-year ice/Glace épaisse de première année	>120 cm	4•
Old ice/Vieille glace		7•
Second-year/Glace de deuxième année		8•
Multi-year/Glace de plusieurs années		9•
Ice of land origin/Glace d'origine terrestre		▲•
Undetermined, unknown or no form/ Indéterminée, inconnue ou sans forme		X

Floe Size/Grandeur des floes ($F_aF_bF_c$)

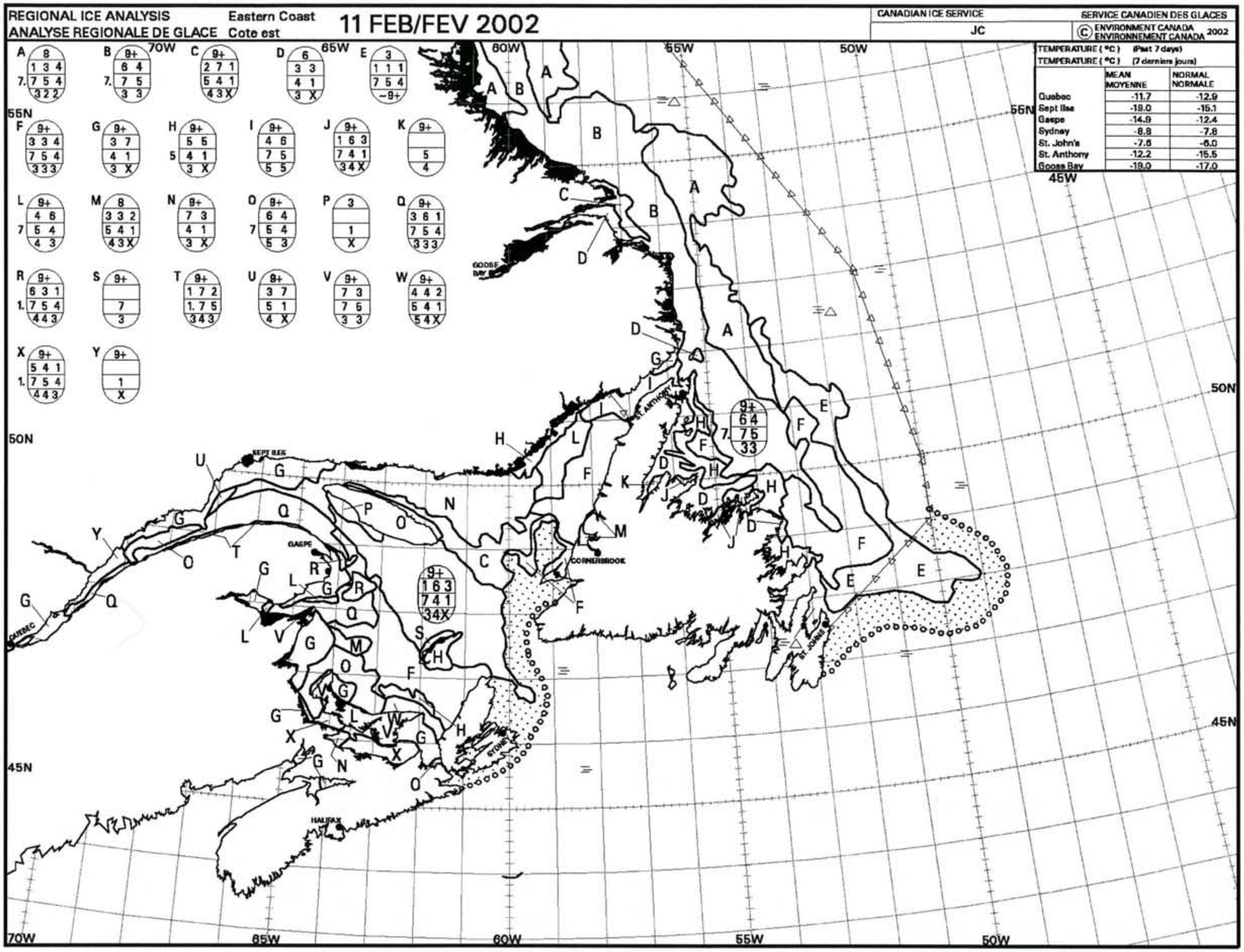
Description/Élément	Width/Extension	Code
Pancake ice/Glace en crêpes		0
Small ice cake, brash ice/Petit glaçons, sarrasins	<2 m	1
Ice cake/Glaçons	2-20 m	2
Small floe/Petits floes	20-100 m	3
Medium floe/Floes moyens	100-500 m	4
Big floe/Grands floes	500-2000 m	5
Vast floe/Floes immenses	2-10 km	6
Giant floe/Floes géants	>10 km	7
Fast ice/Banquise côtière		8
Icebergs		9
Undetermined, unknown or no form/ Indéterminée, inconnue ou sans forme		X
Strips (concentration = C)/ Glace en cordons (concentration = C)		ᔕC

Canadian Ice Service/Service canadien des glaces (CIS/SCG)

Client Services/Service à la clientèle
373 promenade Sussex Drive, E-3
Ottawa, Ontario
K1A 0H3

Tel./Tél.: 1 800 767 2885 (Canada) and/et (613) 996-1550
Fax: (613) 947-9160
Email/Courriel: cis-scg.client@ec.gc.ca
Web site/Site web: http://ice-glaces.ec.gc.ca

Canada


REGIONAL ICE ANALYSIS
ANALYSE REGIONALE DE GLACE
Eastern Coast
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11 FEB/FEV 2002
CANADIAN ICE SERVICE
SERVICE CANADIEN DES GLACES
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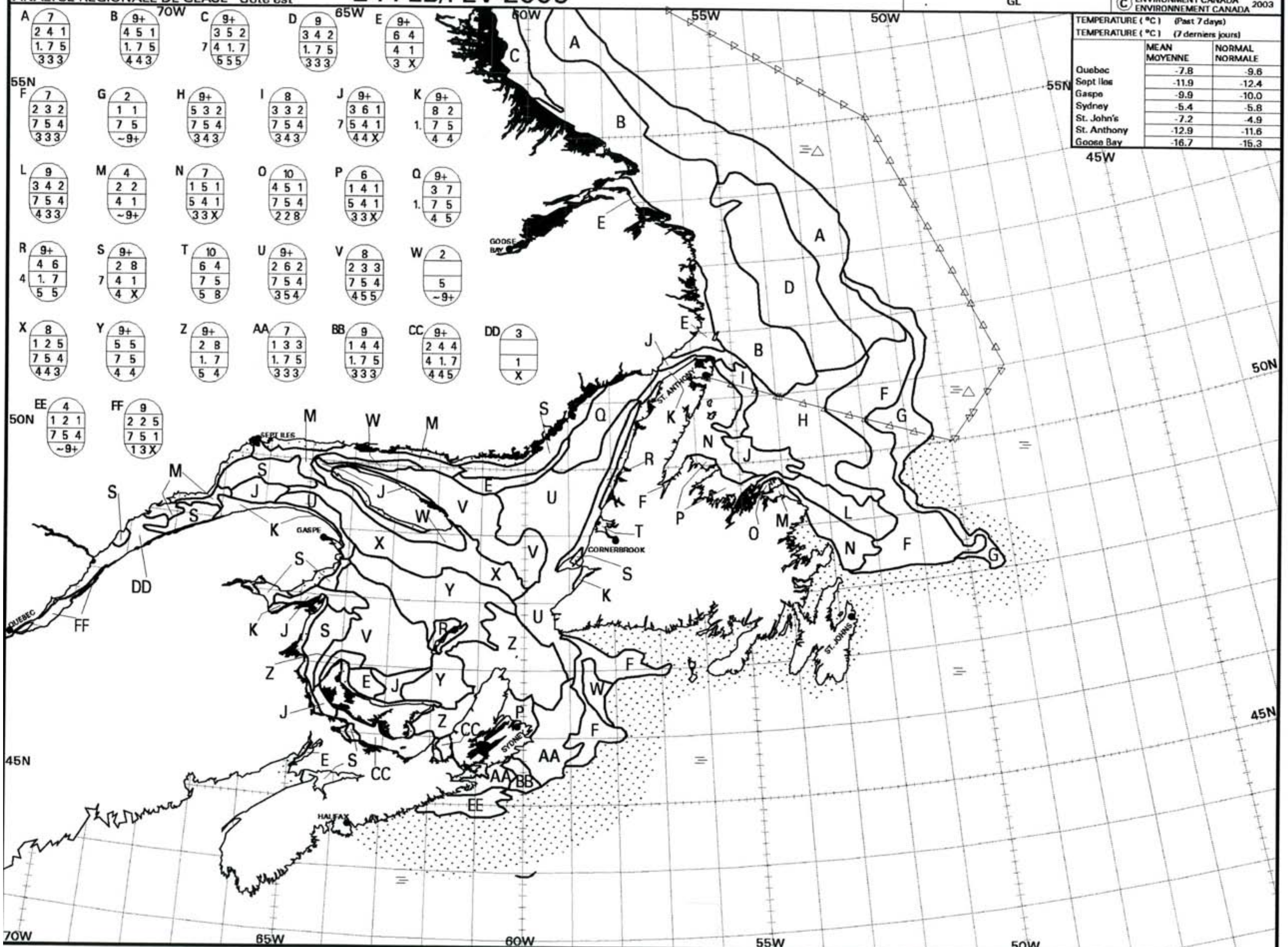
© ENVIRONMENT CANADA ENVIRONNEMENT CANADA 2002
TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)
MEAN MOYENNE
NORMAL NORMALE
Quebec -11.7 -12.9
Sept Iles -19.0 -15.1
Gaspe -14.9 -12.4
Sydney -8.8 -7.8
St. John's -7.6 -6.0
St. Anthony -12.2 -15.5
Goose Bay -19.0 -17.0
GOOSE BAY
SEPT ILES
GASPE
CORNERBROOK
HALIFAX
QUEBEC
ST. ANTHONY
SYDNEY
ST. JOHNS
70W
65W
60W
55W
50W
45W
55N
50N
45N

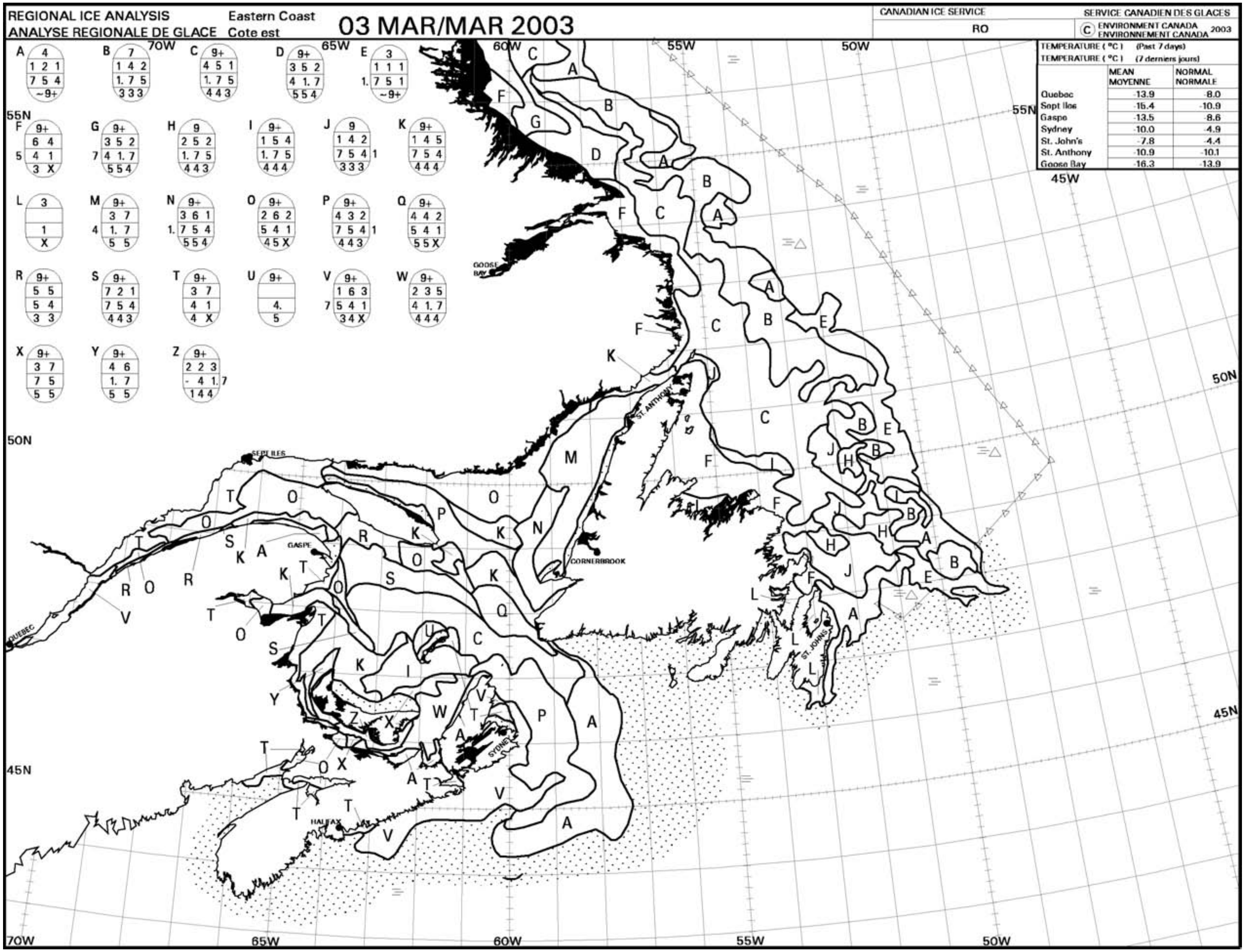
REGIONAL ICE ANALYSIS — Eastern Coast
ANALYSE REGIONALE DE GLACE — Cote est

24 FEB/FEV 2003

CANADIAN ICE SERVICE — SERVICE CANADIEN DES GLACES
GL
© ENVIRONMENT CANADA / ENVIRONNEMENT CANADA 2003

TEMPERATURE (°C) (Past 7 days) / TEMPERATURE (°C) (7 derniers jours)	MEAN MOYENNE	NORMAL NORMALE
Quebec	-7.8	-9.6
Sept Iles	-11.9	-12.4
Gaspe	-9.9	-10.0
Sydney	-5.4	-5.8
St. John's	-7.2	-4.9
St. Anthony	-12.9	-11.6
Goose Bay	-16.7	-15.3

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TEMPERATURE (°C) (7 derniers jours)
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Gaspe -13.5 -8.6
Sydney -10.0 -4.9
St. John's -7.8 -4.4
St. Anthony -10.9 -10.1
Goose Bay -16.3 -13.9
GOOSE BAY
ST. ANTHONY
CORNERBROOK
SEPT ILES
GASPE
QUEBEC
SYDNEY
HALIFAX
ST. JOHNS
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65W
60W
55W
50W
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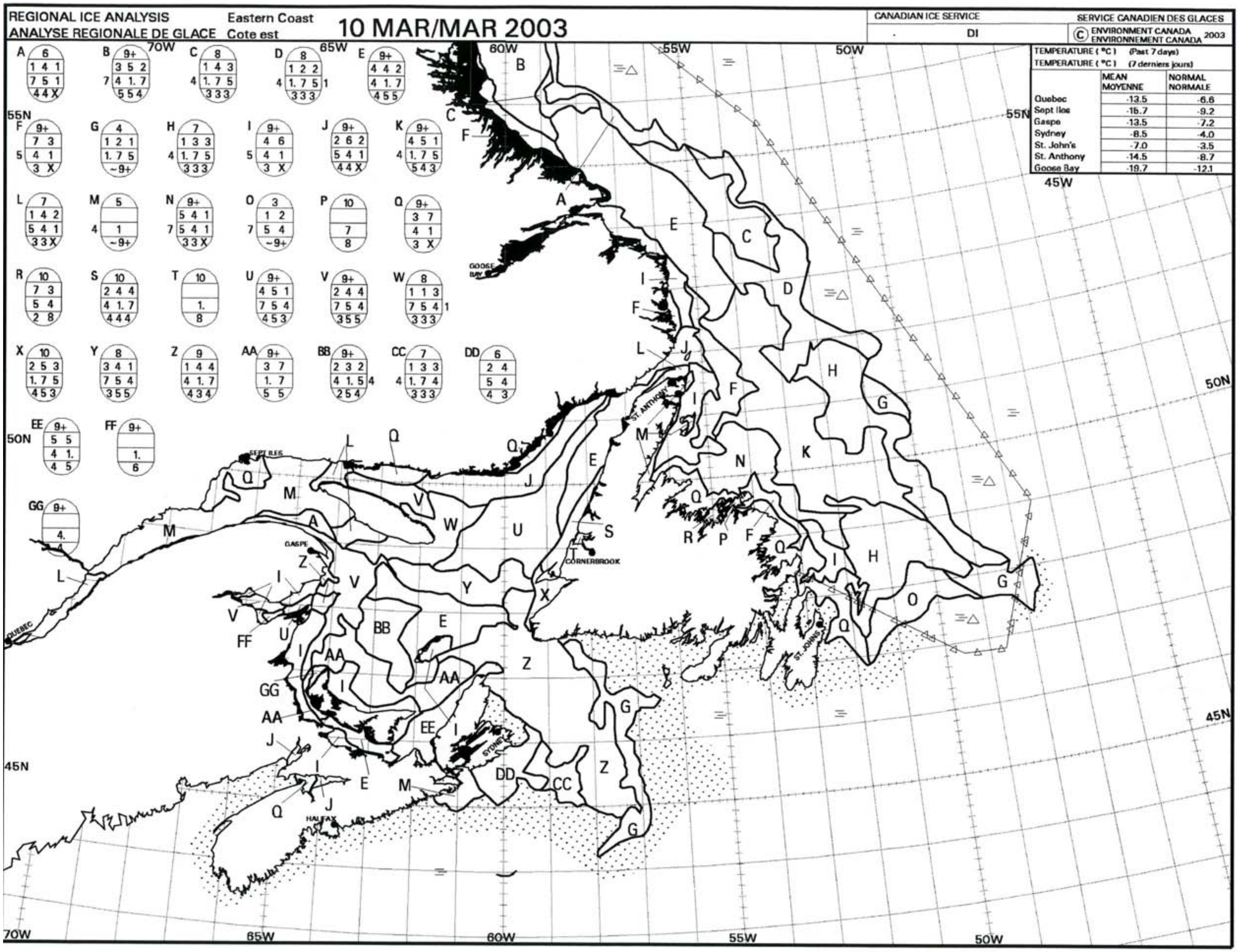
55N
50N
45N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SERVICE CANADIEN DES GLACES
© ENVIRONMENT CANADA ENVIRONNEMENT CANADA 2003
TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)
MEAN MOYENNE
NORMAL NORMALE
Quebec -13.5 -6.6
Sept Iles -16.7 -9.2
Gaspe -13.5 -7.2
Sydney -8.5 -4.0
St. John's -7.0 -3.5
St. Anthony -14.5 -8.7
Goose Bay -19.7 -12.1
GOOSE BAY
ST. ANTHONY
CORNERBROOK
SEPT ILES
GASPE
QUEBEC
SYDNEY
HALIFAX
ST. JOHNS
70W
65W
60W
55W
50W
45W
55N
50N
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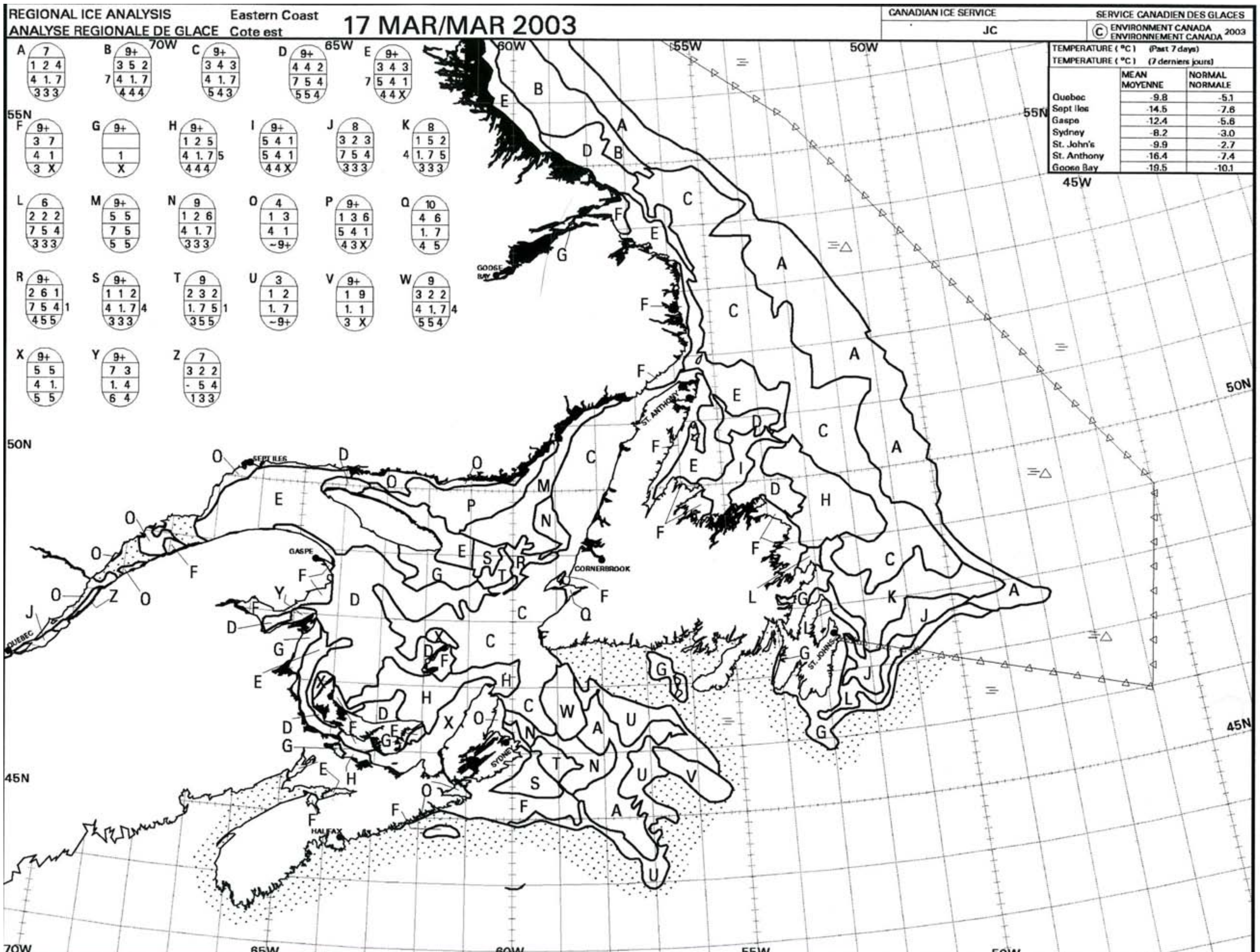
REGIONAL ICE ANALYSIS
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Cote est
17 MAR/MAR 2003
CANADIAN ICE SERVICE
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TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)
MEAN MOYENNE
NORMAL NORMALE
Quebec -9.8 -5.1
Sept Iles -14.5 -7.6
Gaspe -12.4 -5.6
Sydney -8.2 -3.0
St. John's -9.9 -2.7
St. Anthony -16.4 -7.4
Goose Bay -19.5 -10.1
GOOSE BAY
SEPT ILES
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CORNERBROOK
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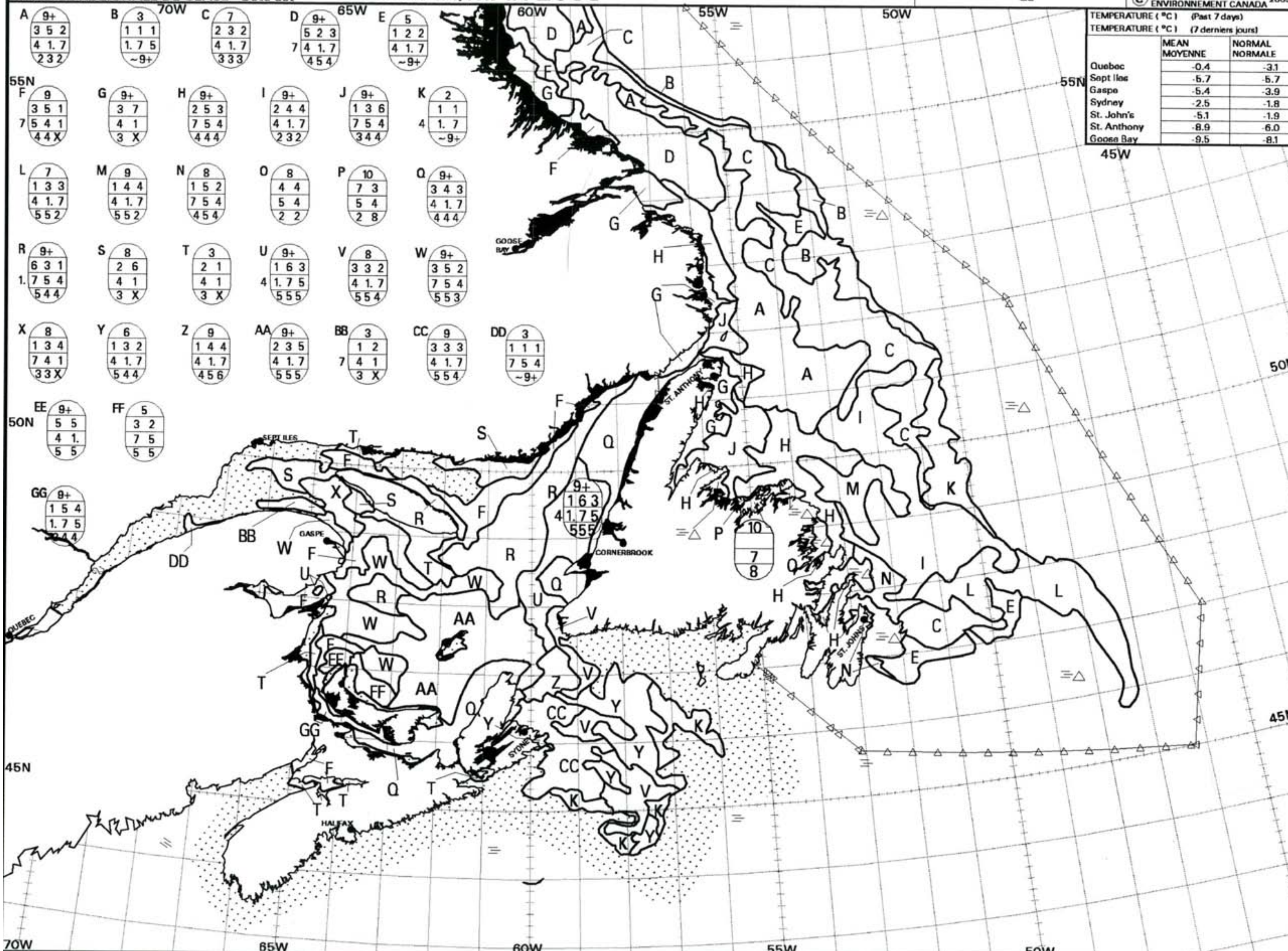
TEMPERATURE (°C) (Past 7 days) / TEMPERATURE (°C) (7 derniers jours)	MEAN / MOYENNE	NORMAL / NORMALE
Quebec	-0.4	-3.1
Sept Iles	-6.7	-5.7
Gaspe	-5.4	-3.9
Sydney	-2.5	-1.8
St. John's	-5.1	-1.9
St. Anthony	-8.9	-6.0
Goose Bay	-9.5	-8.1



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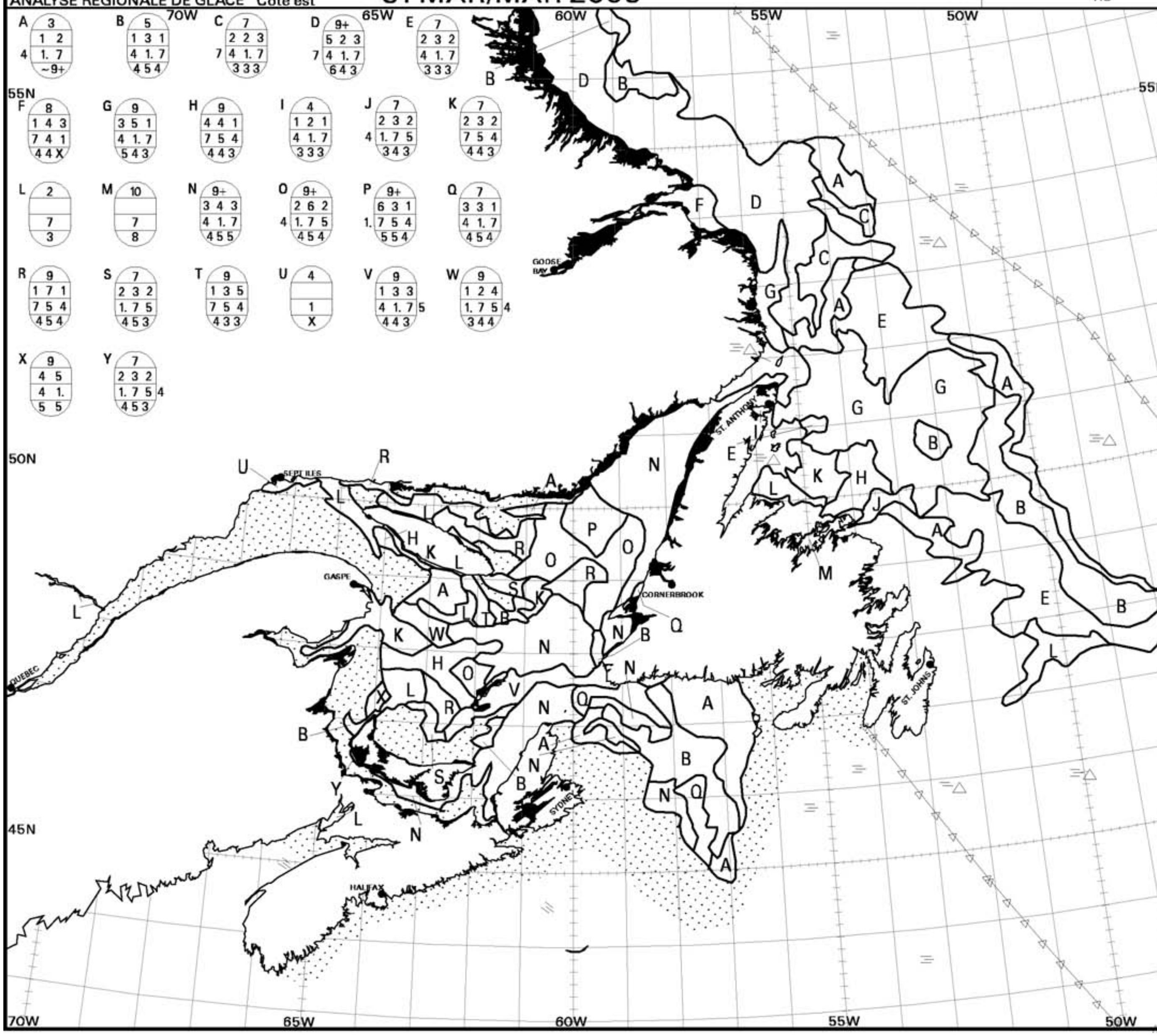

TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)

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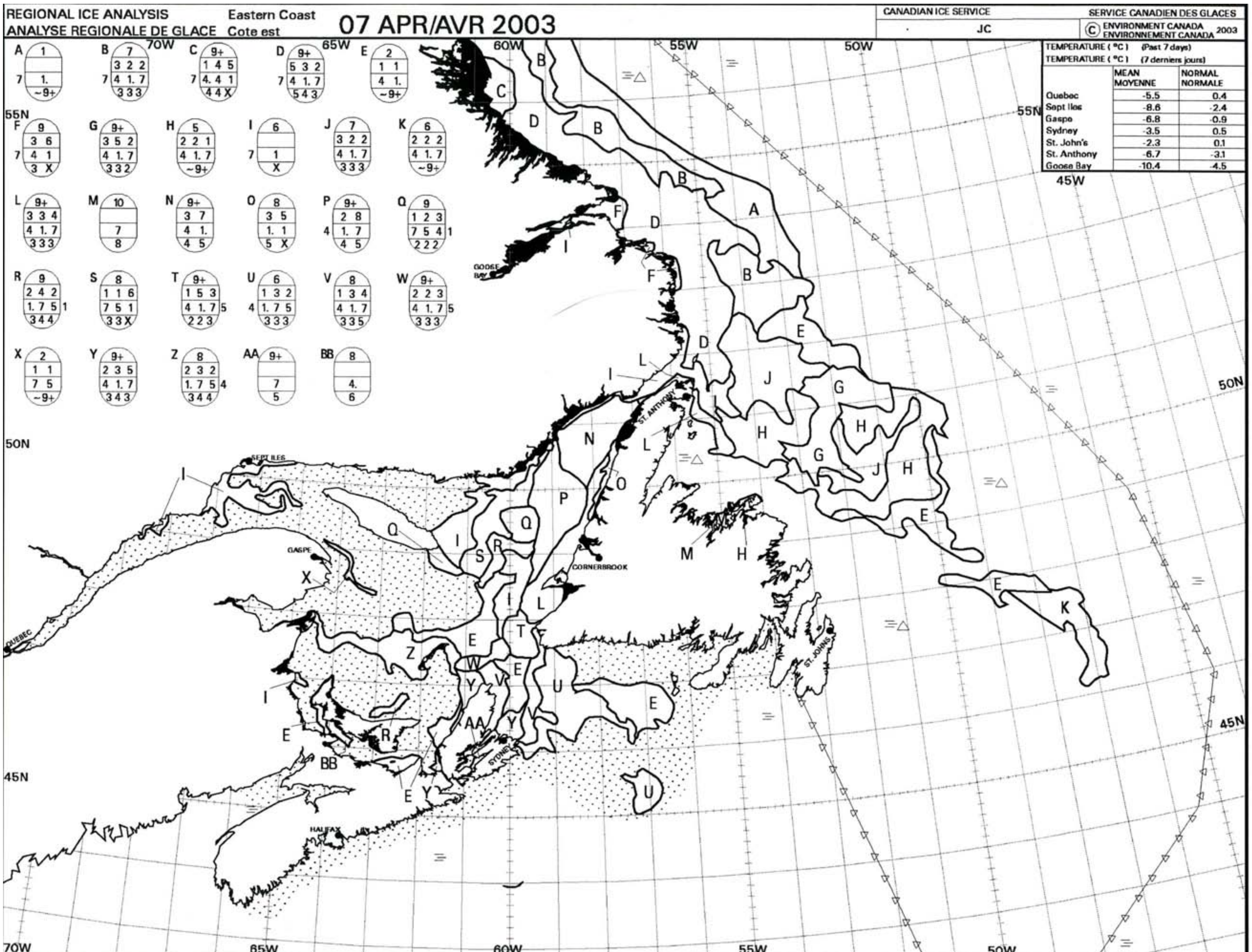
Quebec	1.1	-1.4
Sept Iles	-0.5	-3.9
Gaspe	1.4	-2.3
Sydney	2.5	-0.6
St. John's	1.9	-0.7
St. Anthony	-1.1	-4.5
Goose Bay	-5.2	-6.2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TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)
	MEAN MOYENNE	NORMAL NORMALE
Quebec	-5.5	0.4
Sept Iles	-8.6	-2.4
Gaspe	-6.8	-0.9
Sydney	-3.5	0.5
St. John's	-2.3	0.1
St. Anthony	-6.7	-3.1
Goose Bay	-10.4	-4.5
GOOSE BAY
ST. ANTHONY
SEPT ILES
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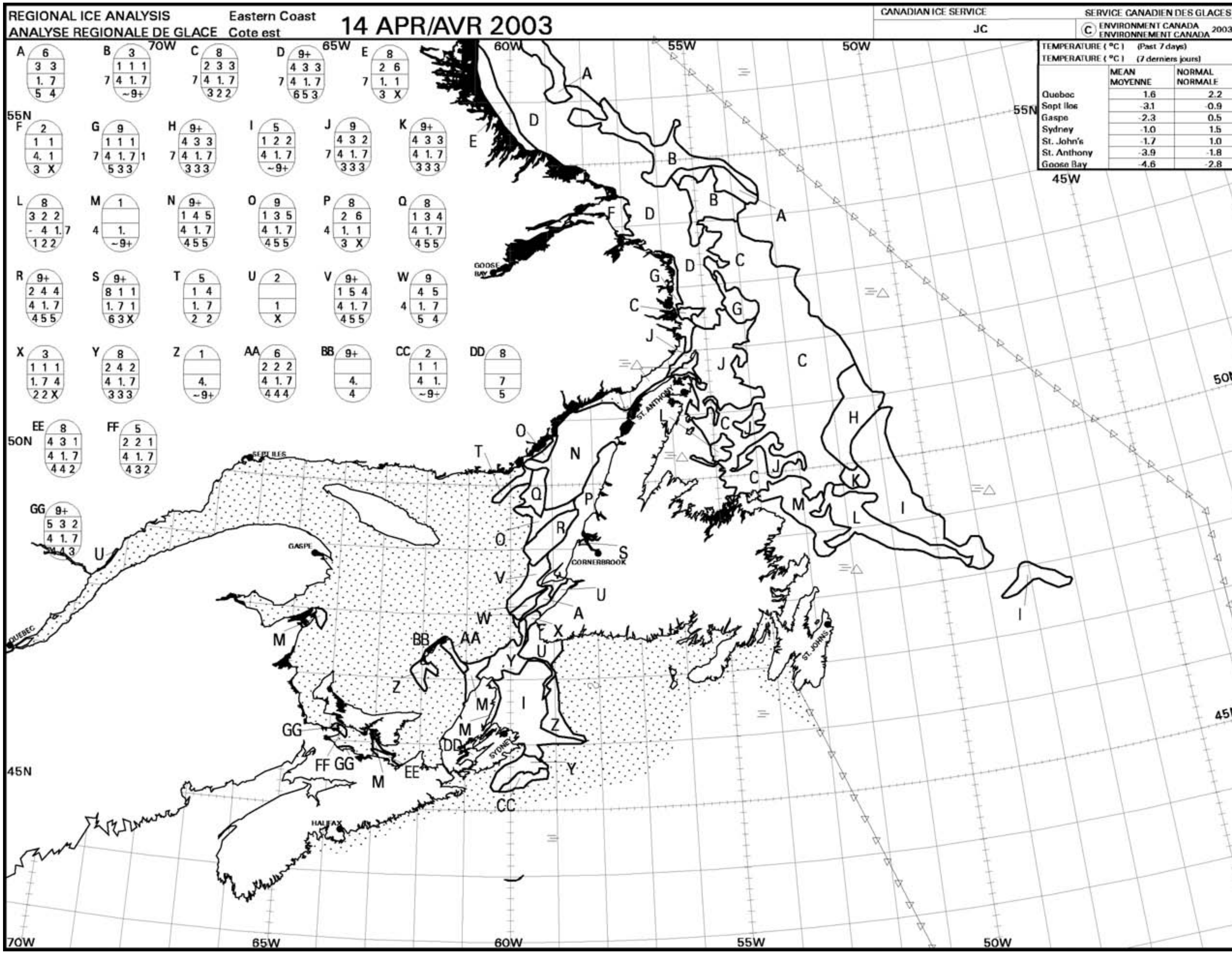

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TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)
MEAN MOYENNE
NORMAL NORMALE
Quebec 1.6 2.2
Sept Iles -3.1 -0.9
Gaspe -2.3 0.5
Sydney -1.0 1.5
St. John's -1.7 1.0
St. Anthony -3.9 -1.8
Goose Bay -4.6 -2.8
GOOSE BAY
ST. ANTHONY
CORNERBROOK
SEPT ILES
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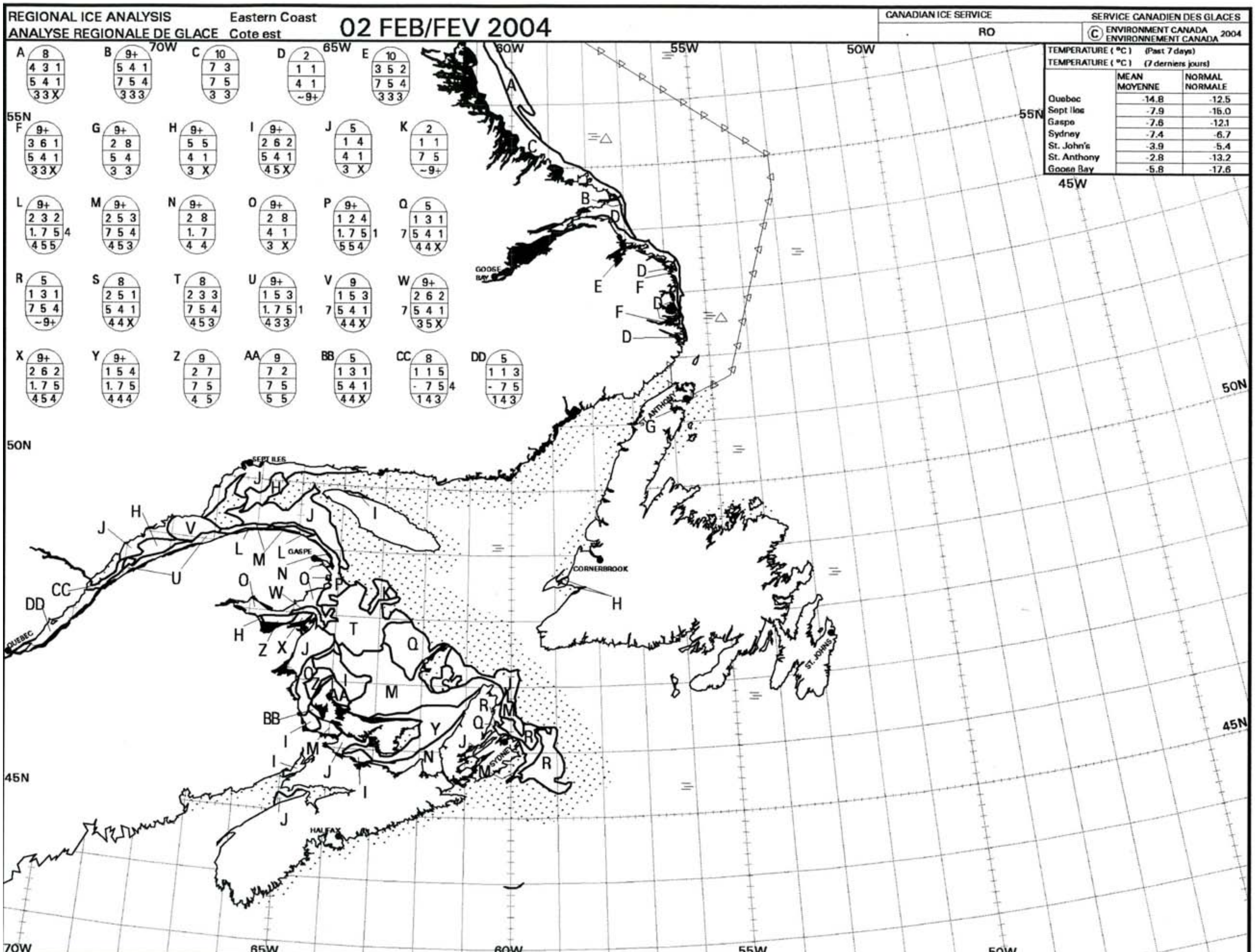
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TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)
MEAN MOYENNE
NORMAL NORMALE
Quebec -14.8 -12.5
Sept Iles -7.9 -16.0
Gaspe -7.6 -12.1
Sydney -7.4 -6.7
St. John's -3.9 -5.4
St. Anthony -2.8 -13.2
Goose Bay -5.8 -17.6
GOOSE BAY
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CORNERBROOK
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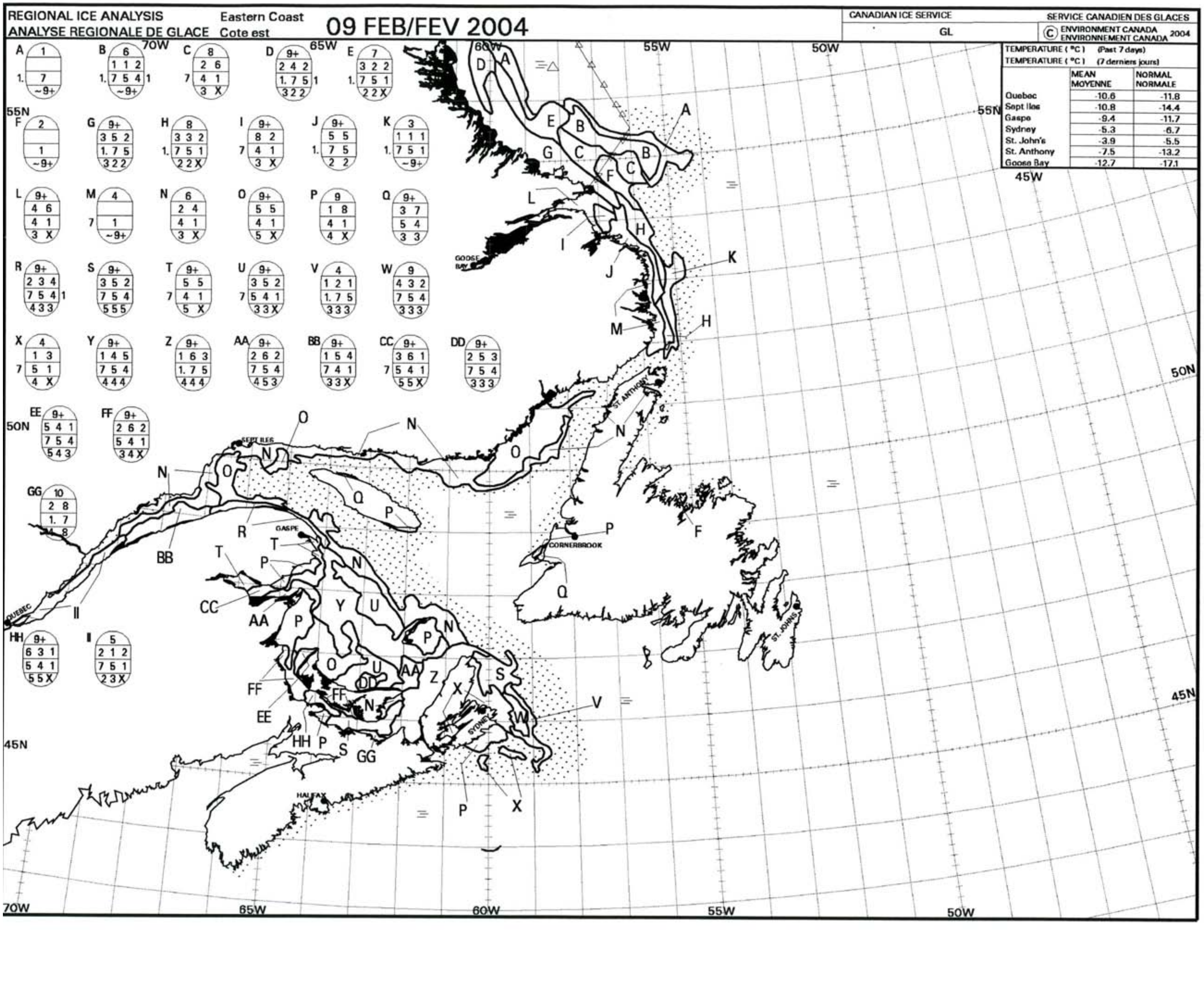

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ENVIRONNEMENT CANADA
TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)
MEAN MOYENNE
NORMAL NORMALE
Quebec -10.6 -11.8
Sept Iles -10.8 -14.4
Gaspe -9.4 -11.7
Sydney -5.3 -6.7
St. John's -3.9 -5.5
St. Anthony -7.5 -13.2
Goose Bay -12.7 -17.1
GOOSE BAY
SEPT ILES
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CORNERBROOK
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ANALYSE REGIONALE DE GLACE Cote est

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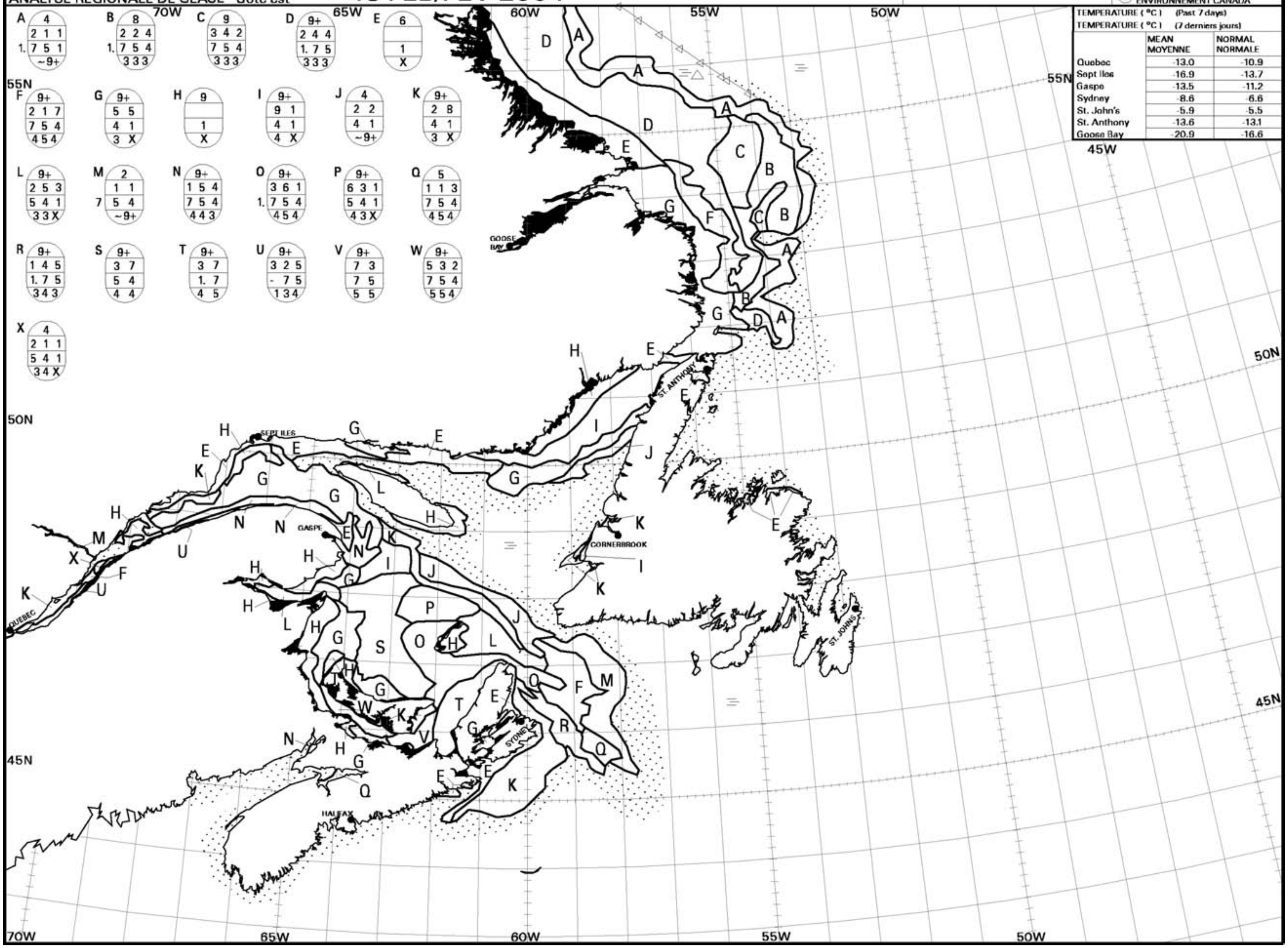
ENVIRONNEMENT CANADA



TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)

	MEAN MOYENNE	NORMAL NORMALE
Quebec	-13.0	-10.9
Sept Iles	-16.9	-13.7
Gaspe	-13.5	-11.2
Sydney	-8.6	-6.6
St. John's	-5.9	-5.5
St. Anthony	-13.6	-13.1
Goose Bay	-20.9	-16.6

REGIONAL ICE ANALYSIS
ANALYSE REGIONALE DE GLACE

Eastern Coast
Cote est

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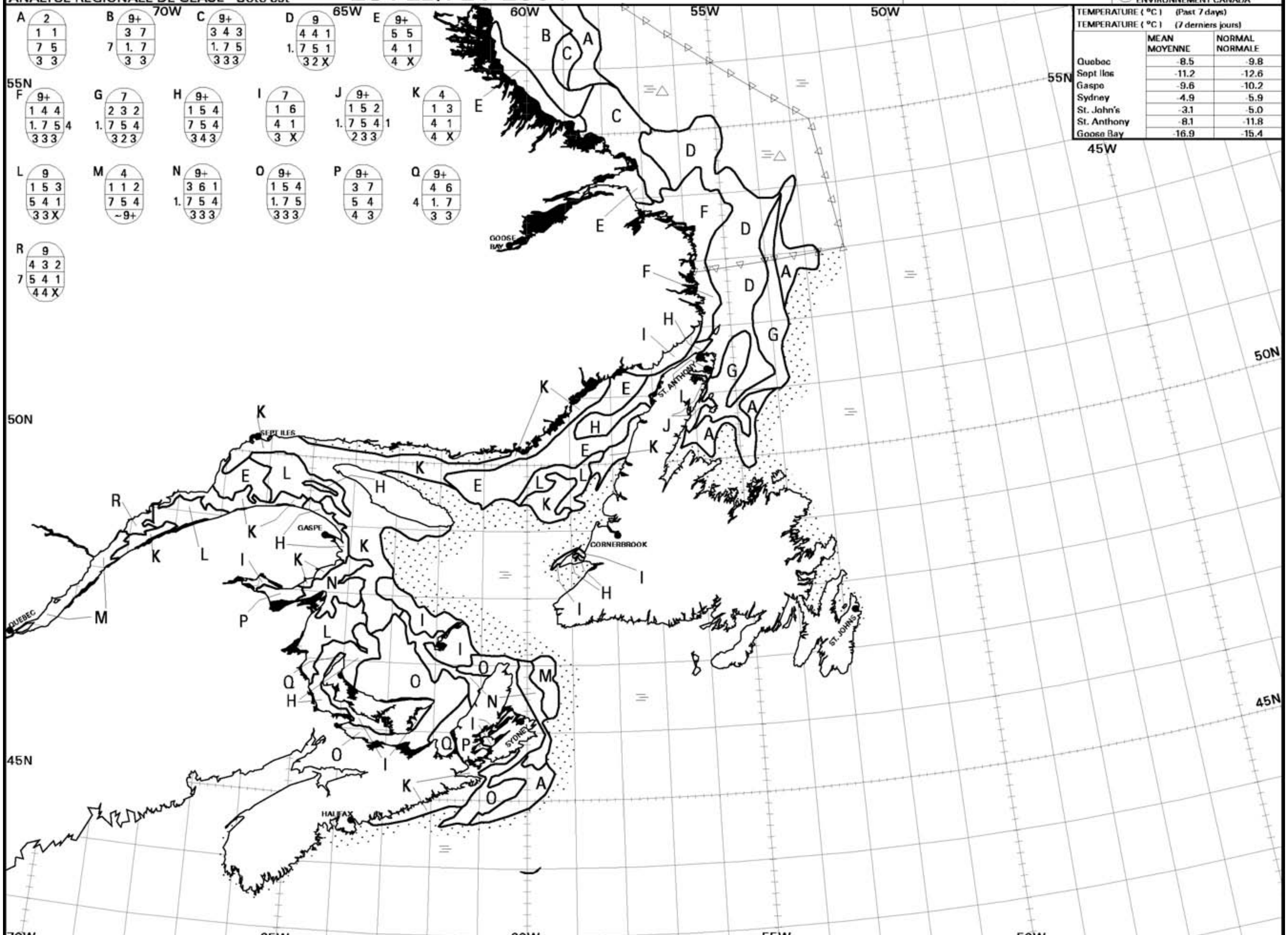

TEMPERATURE (°C) (Past 7 days) TEMPERATURE (°C) (7 derniers jours)	MEAN MOYENNE	NORMAL NORMALE
Quebec	-8.5	-9.8
Sept Iles	-11.2	-12.6
Gaspe	-9.6	-10.2
Sydney	-4.9	-5.9
St. John's	-3.1	-5.0
St. Anthony	-8.1	-11.8
Goose Bay	-16.9	-15.4

REGIONAL ICE ANALYSIS Eastern Coast
ANALYSE REGIONALE DE GLACE Cote est

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CANADIAN ICE SERVICE — RO — SERVICE CANADIEN DES GLACES

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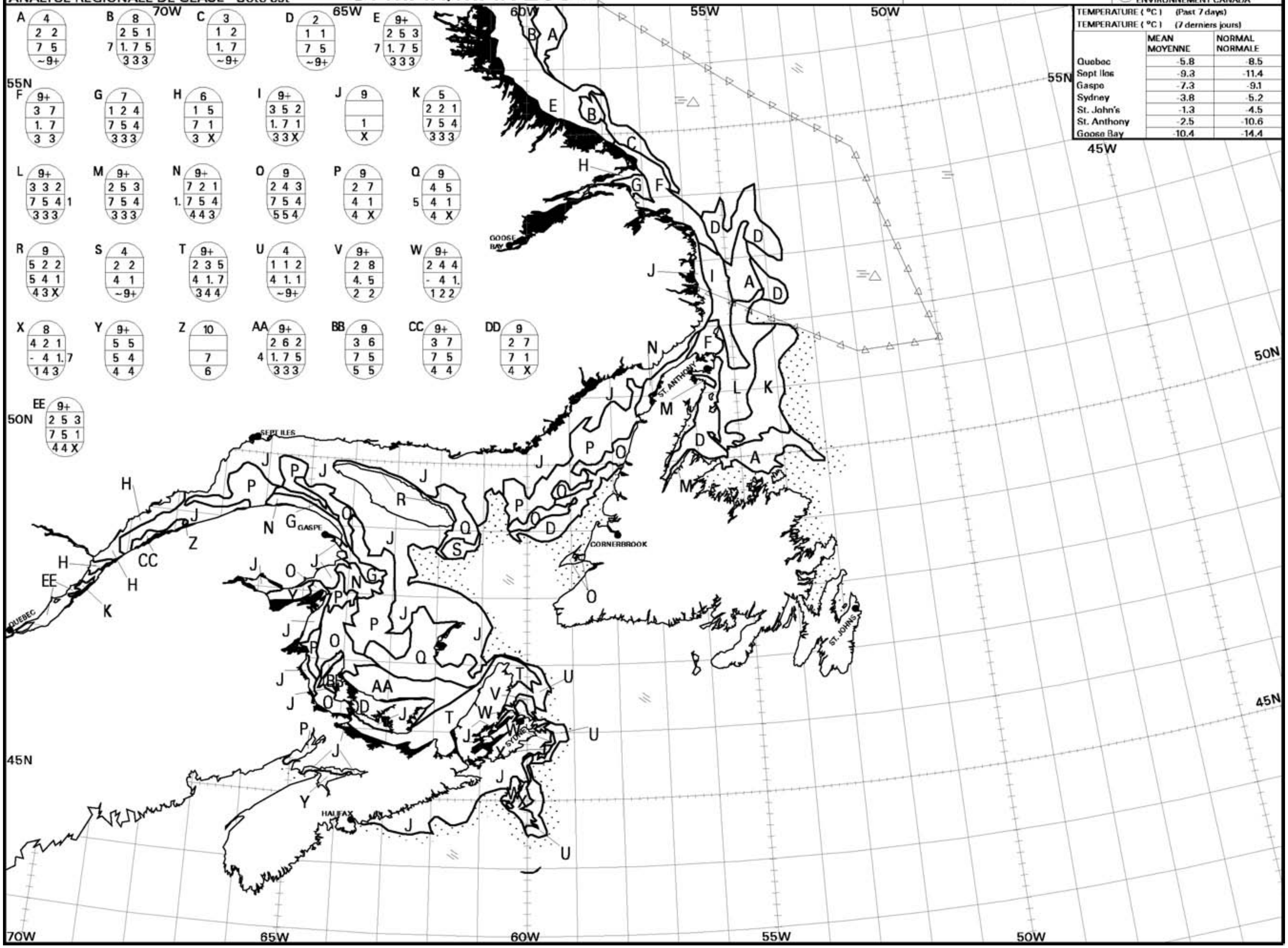
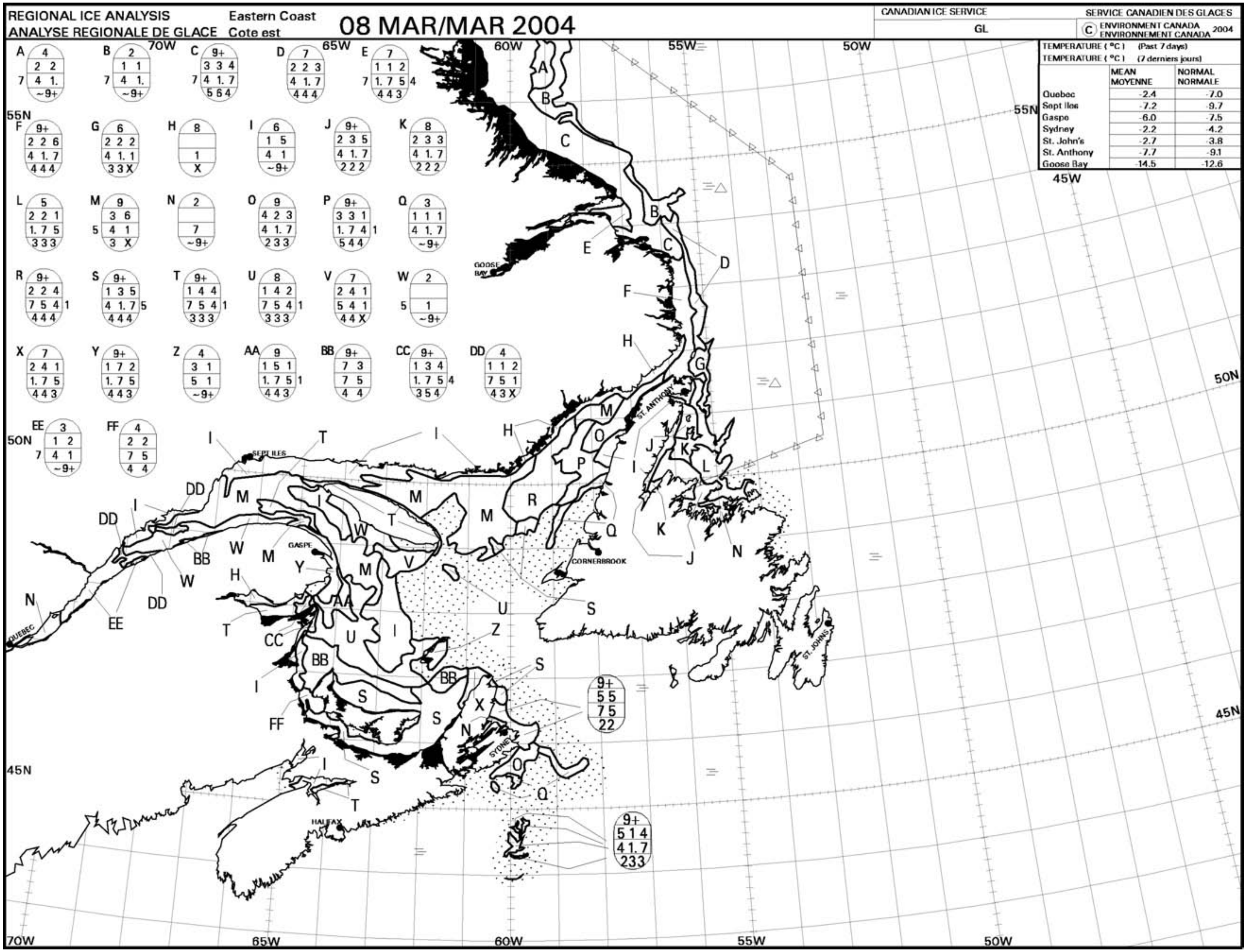
TEMPERATURE (°C) (Past 7 days) / TEMPERATURE (°C) (7 derniers jours)	MEAN / MOYENNE	NORMAL / NORMALE
Quebec	-5.8	-8.5
Sept Iles	-9.3	-11.4
Gaspe	-7.3	-9.1
Sydney	-3.8	-5.2
St. John's	-1.3	-4.5
St. Anthony	-2.5	-10.6
Goose Bay	-10.4	-14.4




REGIONAL ICE ANALYSIS
ANALYSE REGIONALE DE GLACE
Eastern Coast
Cote est
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CANADIAN ICE SERVICE
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SERVICE CANADIEN DES GLACES
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TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)
MEAN MOYENNE
NORMAL NORMALE
Quebec -2.4 -7.0
Sept Iles -7.2 -9.7
Gaspe -6.0 -7.5
Sydney -2.2 -4.2
St. John's -2.7 -3.8
St. Anthony -7.7 -9.1
Goose Bay -14.5 -12.6
GOOSE BAY
ST. ANTHONY
SEPT ILES
GASPE
CORNERBROOK
QUEBEC
SYDNEY
HALIFAX
ST. JOHNS
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REGIONAL ICE ANALYSIS — Eastern Coast
ANALYSE REGIONALE DE GLACE — Cote est

15 MAR/MAR 2004

CANADIAN ICE SERVICE — SERVICE CANADIEN DES GLACES

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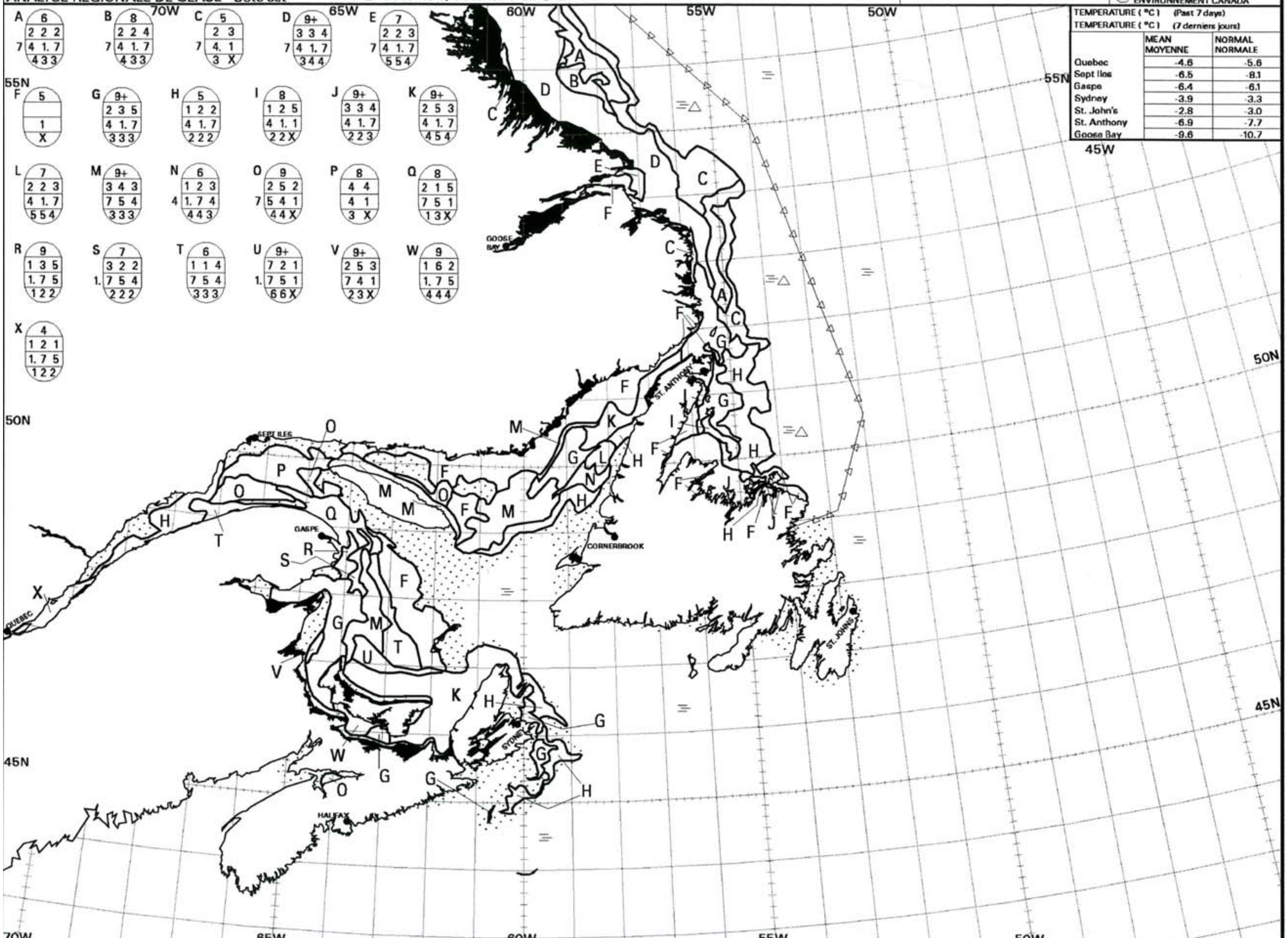
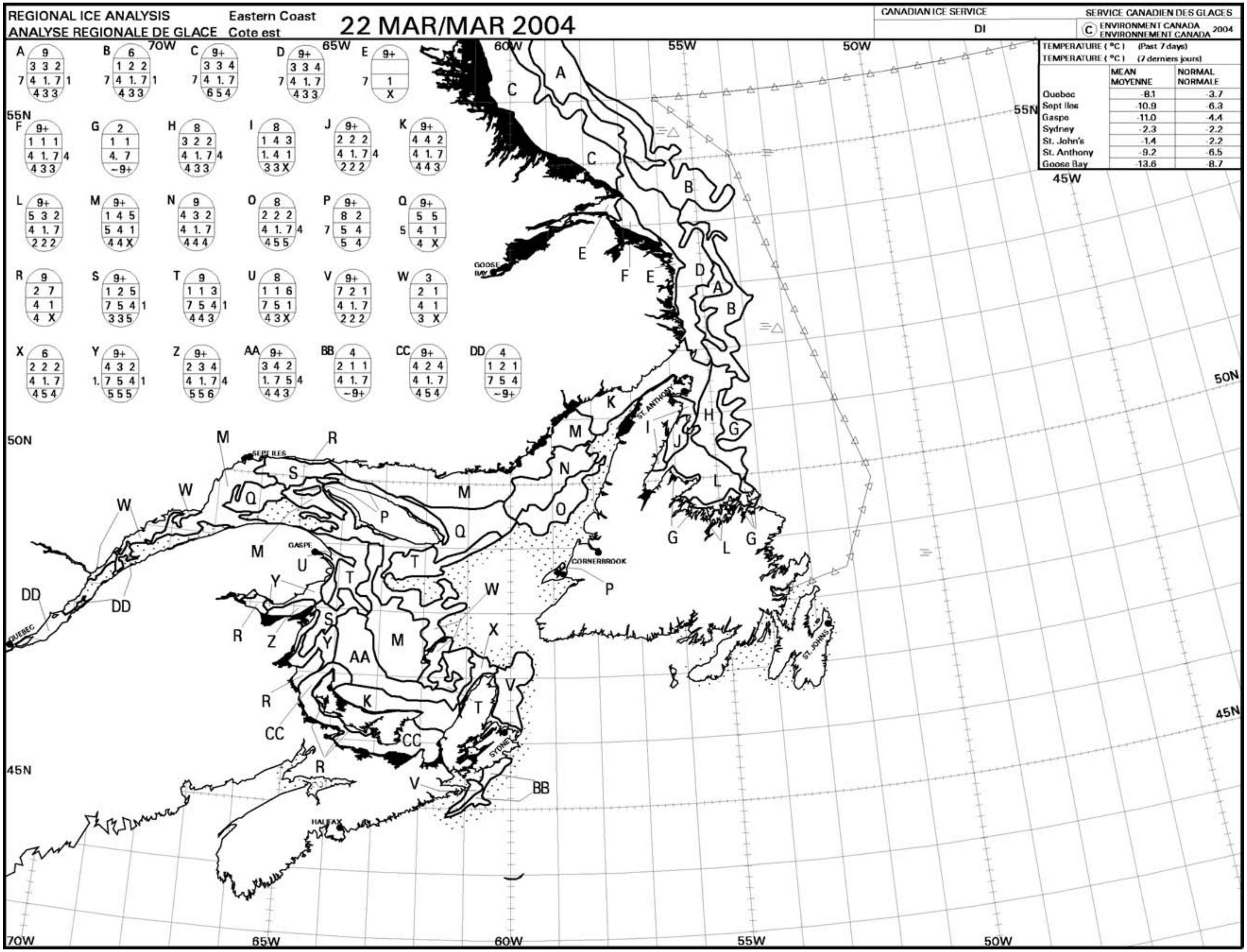
TEMPERATURE (°C) (Past 7 days) / TEMPERATURE (°C) (7 derniers jours)	MEAN / MOYENNE	NORMAL / NORMALE
Quebec	-4.6	-5.6
Sept Iles	-6.5	-8.1
Gaspe	-6.4	-6.1
Sydney	-3.9	-3.3
St. John's	-2.8	-3.0
St. Anthony	-6.9	-7.7
Goose Bay	-9.6	-10.7

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TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)
MEAN MOYENNE
NORMAL NORMALE
Quebec -8.1 -3.7
Sept Iles -10.9 -6.3
Gaspe -11.0 -4.4
Sydney -2.3 -2.2
St. John's -1.4 -2.2
St. Anthony -9.2 -6.5
Goose Bay -13.6 -8.7
GOOSE BAY
ST. ANTHONY
SEPT ILES
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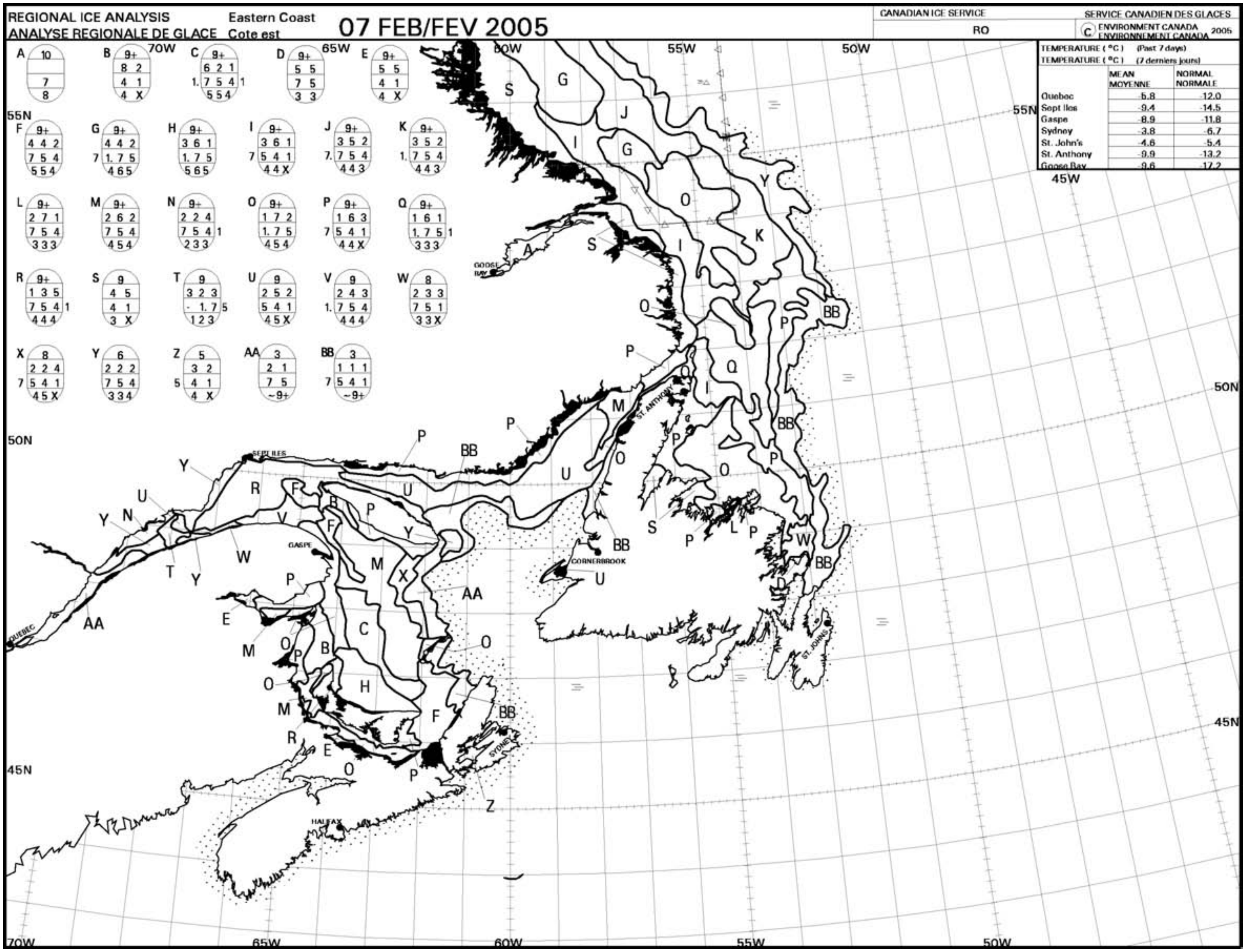
CORNERBROOK
QUEBEC
SYDNEY
HALIFAX
ST. JOHNS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ENVIRONNEMENT CANADA 2005
TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)
MEAN MOYENNE
NORMAL NORMALE
Quebec -5.8 -12.0
Sept Iles -9.4 -14.5
Gaspe -8.9 -11.8
Sydney -3.8 -6.7
St. John's -4.6 -5.4
St. Anthony -9.9 -13.2
Goose Bay -9.6 -17.2
QUEBEC
SEPT ILES
GASPE
GOOSE BAY
ST. ANTHONY
CORNERBROOK
ST. JOHNS
SYDNEY
HALIFAX
70W
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B. **Appendix Two**

1. ***Report to Atlantic Tidal Power Programming Board on Feasibility of Tidal Power Development in the Bay of Fundy: Appendix 3 Ice and Sediment*** **by Atlantic tidal Power Engineering and Management Committee, Halifax, Nova Scotia, Canada, October, 1969, pages 1-17.**

REPORT TO
ATLANTIC TIDAL POWER PROGRAMMING BOARD
ON
FEASIBILITY OF TIDAL POWER DEVELOPMENT
IN THE BAY OF FUNDY

APPENDIX 3
ICE AND SEDIMENT

BY
ATLANTIC TIDAL POWER
ENGINEERING AND MANAGEMENT COMMITTEE

HALIFAX, NOVA SCOTIA
CANADA
OCTOBER, 1969

APPENDIX 3

ICE AND SEDIMENT

A3-1 Purpose

This appendix discusses ice formation and movement in those areas of the Bay of Fundy associated with the tidal power developments investigated. In addition, it deals with sediment in its many aspects which are of importance to the reliable operation, low-cost maintenance and long economic life of a tidal power development.

A3-2 Types of Ice

Ice conditions, if severe, can constitute a major problem in operation and maintenance of tidal-power development structures and equipment. Ice formation in gate slots can prevent necessary sluice-gate operation as and when required. Indraft of ice into sluice and generating-unit waterways can result in their blockage and malfunctioning.

As relatively little study had hitherto been given to formation and movement of ice in the Bay of Fundy, it was necessary to carry out adequate surveys of these conditions. This was done during the winters of 1967 and 1968, the latter being one of the severest on record.

For convenience, the types of ice, encountered in the field surveys, may be described as follows:

1. Anchor ice is ice formed under water by growth on boulders or other bed material. Anchor ice attains its greatest thicknesses where rock ledges are exposed at low water and where steep gradients occur between low and high water. Rockfill dykes, shallow intakes and outlets from generating and sluice-gate units would form natural areas for the growth of anchor ice. Units must be adequately submerged to avoid the growth of such ice.
2. Cake ice is defined as individual masses of ice which may combine to form part of an extensive ice pack. Cake ice increases in thickness due to accretion of layers of frozen muddy water and sediment in river estuaries that empty at low tide.
3. Fast ice denotes an ice pack filling an embayment or estuary.
4. Ice floe is a sheet of floating ice or a detached portion of an ice field. Ice floes, acting as a blanket, reduce the possibility

of freezing spray overtopping a barrage, dampen wave action, and reduce the growth of cake ice within the basin.

5. Medium winter ice is ice with a thickness of six to 12 in.
6. New ice is ice less than two inches thick.
7. Rafted ice consists of ice built up by the rafting or overlapping of cake ice so as to form thicker ice.
8. Sheet ice is ice having no irregular surface features such as ridging, overlapping, or rafting arising from pressure.
9. Shore-fast ice is a type which remains attached, during the winter season, to the shores or banks of embayments and estuaries. Shore-fast ice displays many of the same characteristics as anchor ice, in that it attains its greatest thicknesses where rock ledges are exposed at low water and where steep gradents occur between low and high water. Shore-fast ice could grow over the full tidal range on the sea side of a barrage and to thicknesses determined by water levels maintained on the basin side.
10. Snow ice is a deposit of frozen snow accumulated in low-lying areas, near the sea shore, during the course of a winter season.
11. Thick winter ice is ice with a thickness greater than 12 in.
12. Young ice is ice with a thickness of two to six inches.

A3-3 General Appraisal of Conditions During Winter of 1968

Prevailing westerly winds coupled with prolonged periods of extremely cold weather and below-normal amounts of precipitation were reported during the winter months of January, February and March, 1968, in the upper reaches of the Bay of Fundy.

Ice Central reported a progressive increase in ice cover and thickness through early January and mid-February, reaching a maximum during the week of February 29, 1968, this representing the largest recorded ice field.

Photographic evidence of ice conditions over a complete tidal cycle was secured on March 8, 1968, following a 16-day period of extremely cold weather.

Throughout the winter months the upper reaches of tidal rivers emptying into Minas Basin, Chignecto Bay and their embranchments were frozen over, while estuaries were choked with grounded cake ice resembling large boulders containing up to 18% sediment.

Shore-fast ice, varying in thicknesses up to 40 ft, covered the shore line at high water levels, with the greatest accumulation at Economy Point and

Brick Kiln Island in Minas Basin, Ward Point to Cape Maringouin, and at Grindstone Island in Chignecto Bay.

Prolonged extremely cold weather, large snow falls, westerly winds and rising spring tides accounted for the greatest accumulations of shore-fast ice, cake ice and ice floes.

A3-4 Meteorological Conditions

A3-4.1 General conditions

Meteorological data covering wind directions and velocities, daily and normal temperatures, and weather conditions for Moncton, N. B., (Plate A3-1) and Truro, N. S., (Plate A3-2) were plotted in conjunction wi predicted tide heights for January, February and March of 1968, the months when ice was prevalent in the upper reaches of the Bay of Fundy.

A3-4.2 Wind

Westerly winds prevailed for 65 and 72% of the time in Minas Basin a Chignecto Bay, respectively, during January, February and March, with an increase in the easterly direction throughout the latter part of January, early February and through mid-March.

A3-4.3 Temperature

Temperatures through the early part of January ranged below normal : 12 consecutive days, returning to near normal and above normal through the latter part of January and the first week in February. Night-time tempera tures (daily lows) plunged below normal levels for 17 consecutive days during mid-February, representing one of the longest periods of extremely cold weather recorded in the region, with temperatures ranging from -15°F : night to 32°F during the day-time, equalling the record set in 1961.

Night-time temperatures in Minas Basin and Chignecto Bay ranged bel the freezing point of sea water (28.8°F) from January 1 to March 15, 1968 rising above or equalling the freezing point on three occasions during th 75-day period.

Temperatures shown on Plate A3-1 for Moncton, N. B., on the average are four degrees colder than for Truro, N. S., shown on Plate A3-2.

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A3-4.4 Precipitation

Below-normal amounts of snow fell throughout the three-month period, with a total of 53.7 in. at Truro, N. S., near the head of Cobequid Bay, and 77.6 in. at Moncton, N. B., some miles above Shepody Bay.

A3-5 Aerial Reconnaissance Ice Surveys (Ice Central)

Plate A3-3 displays ice conditions reported by Ice Central* for January, February and March, the months when ice was found in the upper reaches of the Bay of Fundy in 1968.

On January 17, 1968, the heaviest ice, composed of medium winter ice mixed with new ice, occurred along the south shore of Minas Basin and Cobequid Bay. New and young ice had formed along the north shore of Minas Basin, Cobequid Bay, Chignecto Bay and embranchments in below-normal temperatures.

On January 30, Chignecto Bay was reported to be ice free while easterly winds transported a concentration of new, young, medium and thick winter ice into Minas Passage and the central portion of Minas Basin, leaving Cobequid Bay 70 to 100% covered with new and young ice.

A progressive increase in ice cover and thickness occurred through the month of February, reaching a maximum during the week of February 29, when Chignecto Bay, Minas Basin, Passage and Channel were 70 to 90% covered with medium and thick winter ice. The Avon River in Minas Basin, Shepody Bay, Cumberland Basin and embranchments were filled with shore-fast ice.

With temperatures climbing well above normal following below-normal temperatures during the first week in March, a five per cent reduction in ice cover was reported on March 7, and a decrease in ice thickness in both Minas Basin and Chignecto Bay on March 14, 1968, indicating the advance of the spring break-up period.

A3-6 Ground Reconnaissance Ice Survey (Feb. 6-9, 1968)

A ground reconnaissance made February 6-9, 1968, revealed the conditions discussed in this Section. The locations referred to may be found

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*Sea Ice Forecast Central, a Meteorological Branch centre responsible for ice reconnaissance, forecasting and movement in Canadian waters.

on Plates A3-4 to A3-7, inclusive.

A3-6.1 South shore of Minas Basin

A3-6.1.1 Kennetcook River

Ten to 15-ft thicknesses of shore-fast ice had accumulated along the north bank of the river upstream of the highway bridge. Ice had completely filled the area between the north river bank and the first bridge pier to the high-water level, with rafted and cake ice two to 10 ft thick covering tidal flats to the river channel. It was noted that one to two-foot thicknesses of ice had accumulated at the high-water line on all bridge piers.

Several hundred yards downstream from the highway bridge, at a bend in the river, rafted and cake ice mixed with snow and slush formed large masses of shore-fast ice in thicknesses of 15 ft.

Tidal flats and sand bars at low water were covered with scattered, stranded cakes of ice measuring five to 10 ft thick, while the river channel remained open. At several locations along sand bars on the river bottom, tidal currents had undercut the frozen overhanging sand ledges.

A3-6.1.2 Cogmagun River

The Cogmagun River, six miles northwest of Kennetcook River on Highway No 15, revealed its river channel at low water to be completely frozen over with broken sheet ice, 12 to 24 in. thick, while both river banks were covered with small cakes of ice measuring up to 24 in. thick.

The downstream side of the highway bridge piers had a streamlined appearance from accumulations of ice, while the upstream side retained its original shape. Trapped between broken sheet ice and the downstream side of bridge piers, cake ice resembling spherical boulders had been rolled and tumbled on the rising and falling tides.

A3-6.1.3 Walton River

Downstream from the Highway No 15 bridge at Walton, N. S., cake ice was rafted onto shore-fast ice in thicknesses up to 10 ft along both river banks. The river channel was open to Minas Basin. Open water extended several hundred feet upstream from the highway bridge, beyond which the river was covered with broken sheet ice two feet thick with the occasional stranded cake of ice over the high-water marsh area.

Minas Basin and the Cambridge tidal flats viewed at low water were completely ice free.

A3-6.1.4 Cape Tenny and Burntcoat Head

Offshore at Cape Tenny on the flood tide on February 6, 1968, a ribbon ice floe, 200 to 300 ft wide, 80% covered, stretched from Minas Basin into Cobequid Bay, eddying on either side of Burntcoat Head, i. e. Moose Cove and Noel Bay. The estimated maximum thickness of ice in the floe was three feet.

The intertidal zone in both areas was free of ice; however, large basalt boulders foreign to the area, weighing up to 15 tons, were observed several hundred feet offshore from the base of cliffs at Cape Tenny.

Shore-fast ice up to three feet thick, ranging in width from 10 to 18 ft, extended along the base of cliffs from Cape Tenny to Burntcoat Head.

A3-6.1.5 Shubenacadie River

The upper reaches of the river and its embranchments, from a point seven miles upstream from the Dominion Atlantic Railway bridge, to its head-waters were frozen over with a continuous sheet of ice covered with snow, ranging in thickness from six inches at Shubenacadie, to 14 in., six miles downstream from Shubenacadie. Scattered pieces of broken sheet ice were observed on high-water tidal flats and shore-fast ice up to eight feet thick was visible along both river banks, indicating changes in water levels.

At low water, the downstream portion of the river (below the Highway 102 bridge) was partially choked with cake and shore-fast ice; however, the river channel remained open to Cobequid Bay.

Tidal flats stretching into Cobequid Bay at the Salmon and Shubenacadie River estuaries were 70% covered with cake ice grounded at low water. The ice had the appearance of being grounded for several weeks, as the neap-tide high-water mark was visible on the light sand-coloured cakes of ice.

A3-6.2 Salmon River and estuary

The Salmon River was frozen over with a continuous sheet of ice measuring 14 in. thick from Central Onslow to its head waters above Truro, N. S. Six to eight-ft thicknesses of shore-fast ice were observed along both river banks, separated from the continuous sheet of ice by longitudinal cracks, indicating that the sheet ice rose and fell with the tides.

Tidal flats and sand bars exposed at low water in the Salmon River estuary, viewed from Lyons Head near Lower Onslow, were 70% covered with grounded cake ice. Closer observations revealed the maximum thickness of ice measured 15 ft. The high-water, neap-tide mark was clearly visible on all large cakes of ice, ranging from five to six feet from the bottom. Since nine-tenths of the thickness of ice is submerged when floating, it was apparent the ice stayed grounded during the neap-tide cycle only, floating on high-water spring tides. Occasional parabolic-shaped cakes of ice had rolled over on the side after grounding on falling spring tides. They had begun to take on a new shape below the neap high-water mark.

A3-6.3 North shore of Minas Basin

A3-6.3.1 Masstown and Glenholme

Long sloping foreshores at both locations were bare of ice. The central part of Cobequid Bay viewed from both locations, at low water, revealed only a scattering of grounded cake ice over extensive sand bars. Shore-fast ice covering the shore at the high-water line was very thin, measuring two to three feet thick.

A3-6.3.2 Economy Point

A mass of shore-fast ice resembling an island was conspicuous at the eastern extremity of a rock shoal, approximately 0.5 mi. offshore at Economy Point. The rising tide prevented a closer evaluation of the ice mass; however, the estimated size was 30 to 40 ft thick, 400 to 500 ft long and 200 ft wide.

Shore-fast ice ranging in thickness up to 20 ft at the high-water level and widths of 50 to 100 ft from the shore line extended to the most southern point of land. As sandstone cliffs decrease in height to the north of Economy Point, shore-fast ice reduces proportionally in thickness.

Several hundred yards offshore to the northeast of Economy Point great masses of shore-fast ice, lodged on sandstone ledges, measured 30 ft thick and over 100 ft in length and width.

The immediate foreshore along the neap high-water line at the proposed abutment area for Site 8.1 at Economy Point was 20 to 30% covered with cake ice measuring up to five feet thick. Fifteen foot thicknesses of shore-fast ice had accumulated at the base of sandstone cliffs to the spring high-water level, varying in depth from the shore line and traversing the entire southern shore of Economy Point to the west.

To the west of Economy Point shore-fast ice had grown to rock ledges that extend under low water around Brick Kiln Island. The estimated ice thickness was 30 to 40 ft below the extreme high-water level with ice on the western side somewhat thicker than that on the eastern side.

Minas Basin viewed from Economy Point was ice free; however, a small ice floe was moving up-bay on the flood tide in Cobequid Bay adjacent to Economy Point.

A3-6.3.3 Clarke Head

Shore-fast ice in small amounts at the high water level marked the shore line from Parrsboro, N. S., east to Clarke Head. Minas Basin, viewed from Clarke Head one hour before high water on February 7, 1968, was completely free of ice floes.

A3-6.3.4 Parrsboro, N. S.

Small amounts of shore-fast ice were visible along the shore line within the harbour. Local residents reported the harbour to be choked with cake ice during the cold spell in January and cleared during mild weather early in February.

A3-6.4 Cumberland Basin

A3-6.4.1 Joggins Head

Shore-fast ice three to four feet thick was visible along the extreme high-water line from Boss Point to Ragged Point on February 7, 1968. Offshore from Joggins Head cake ice three to five feet thick, mixed with young ice four to six inches thick, 100% cover, covered an area from Boss Point to Ragged Point, to a distance approximately 1.5 mi. offshore. A return trip to Joggins Head two days later on February 9, 1968, revealed a considerable change in ice cover. There was no visible evidence of the three to five feet thick cakes of ice seen on the first visit to the area, indicating the change in wind direction, on February 8, carried the ice into the Bay of Fundy. A large floe of young ice four to six inches thick covered an area east from a line between Ragged Point to just west of Ward Point, filling the entrance to Cumberland Basin. The ice cover ranged from 50 to 100% over the area with the greatest accumulation southwest of Joggins Head.

Small leads developing south of Boss Point indicated an ice movement into Cumberland Basin on the flood tide.

Open water was visible in the central portion of Chignecto Bay, south of Cape Maringouin.

A3-6.4.2 South shore of Cumberland Basin

Cake ice, grounded at low water on broad tidal flats, in thicknesses up to eight feet, extended several hundred feet offshore, covering approximately 70% of the tidal flats along the south shore of Cumberland Basin, the western, the northern and eastern tidal flats of the Elysian Fields, and at Amherst Point.

A3-6.4.3 Maccan River and River Hébert

The estuaries of both rivers at low water were choked with grounded cake ice ranging in thicknesses up to eight feet. Shore-fast ice up to 10 ft thick was visible along river banks, encroaching in the river channels. The rivers above the villages of Maccan and River Hébert were covered with broken sheet ice approximately two feet thick.

A3-6.4.4 Black Point

The falling tide on February 8, 1968, grounded cake ice five to 10 ft thick along tidal flats, to the northeast and southwest of Black Point. Shore-fast ice four to five feet thick was visible along the high-water level.

A3-6.4.5 Ward Point

Large masses of shore-fast ice, 15 ft thick, encompassed the entire Ward Point area at the high-water level, ranging in widths from 75 to 100 ft offshore from the base of the sandstone cliffs.

Offshore in Cumberland Basin, falling snow produced a 50% cover of four to six inches of mud-stained slush, turning into ice in 10° temperatures after being washed on shore by high winds and stranded on the falling tide.

A3-6.5 Shepody Bay and embranchments

A3-6.5.1 Memramcook River

At College Bridge, N. B., the river was characterized by steep walls of shore-fast ice, 15 to 20 ft thick, encroaching on the river channel. The channel portion of the river was 100% covered with broken sheet ice several feet thick that rose and fell with the tide.

At upper Dorchester, N. B., where the second-longest covered bridge in North America crosses the Memramcook River, typical parabolic-shaped cakes of ice, one to three feet in thickness, rafted one on top of another to the spring high-water level, were found along the river banks and high-water tidal flats.

A3-6.5.2 Petitcodiac River

Eight inches of new fallen snow on February 8, 1968, covered sand bars, tidal flats and mud banks at low water on the Petitcodiac River. Floating and forming slush on the flood tide, ice began to develop in 10^{o} to 15^{o} temperatures. The river on February 9, at high water, was 100% covered with new and young ice, from the Petitcodiac River Dam downstream to lower Coverdale. Leads and pools reduced the ice cover on the river continuing downstream to Shepody Bay, where great stretches of open water reduced the ice cover to 30%. As the tide began to ebb, large ice floes began to move from the Petitcodiac River into Shepody Bay increasing the ice cover.

Shore-fast ice in thicknesses up to five feet was visible along with river banks, at the spring high-water level, with the greatest accumulations occurring between the high and low-water levels on the down-stream side of the southern approach of the rockfill dyke section of the Petitcodiac River water control structure, reaching a maximum thickness of 20 ft. The ice was increasing in thickness by rafting of cake ice and accumulations of snow. Lesser amounts and thickness of shore-fast ice were observed on the north approach to the dam, both upstream and downstream. Sediment deposits flanking the Petitcodiac water control structure were 100% covered with ice three feet thick as closure work was continued on the structure.

A3-7 Aerial Reconnaissance Ice Survey

Following a four-day 17 in snow fall February 8 to 11, 1968, and 16 consecutive days of prolonged extremely cold weather, an aerial reconnaissance ice survey was carried out for a complete tidal cycle on March 8, 1968, over the upper reaches of the Bay of Fundy, i.e. Minas Channel, Passage and Basin, Cobequid and Windsor Bays, Chignecto and Shepody Bays, and Cumberland Basin, together with their embranchments.

A3-7.1 Minas Channel, Passage, Basin and embranchments

A3-7.1.1 High water

The wind direction for four days prior to and on the day of the survey was from the north and northwest.

The major ice field during the high-tide period in Minas Basin was located in Windsor Bay and along the south shore of Minas Basin east to Cape Tenny. Consisting of medium and thick winter ice, the area was 70 to 90% covered, with leads and open water developing along the western shore of Windsor Bay as the tide began to ebb around Cape Blomidon.

Shore-fast ice ranging from three to five feet thick at the high-water line was visible along the south shore of Minas Basin and Cobequid Bay to Salter Head, filling all bays and inlets.

The falling tide was depositing medium and thick winter cake ice along the foreshore from Walton in Minas Basin to Salter Head in Cobequid Bay.

Leads and open water developing on the ebb tide produced a 70 to 90% ice cover, as young and new ice formed on the lower portion of the Shubenacadie River. Upstream medium and thick winter ice occupied the middle-third portion of the river while the remainder of the river to its headwaters was frozen over with a continuous sheet of ice as recorded in the ground-reconaissance ice survey of February 6, 1968.

Tidal flats in the Salmon River estuary were 90% covered with grounded, mud-stained, thick rafted winter ice, having a maximum thickness of 15 ft. The river channel on the falling tide remained open from Cobequid Bay to Central Onslow, where a continuous sheet of ice was observed to the head-waters above Truro, N. S.

Overnight temperatures of -3°F produced quantities of new ice along the north shore of Cebequid Bay and Minas Basin. Driven by northerly winds and tidal currents, young ice was developing as rafting of new ice produced leads and areas of open water from Salter Head in Cobequid Bay to Cape Sharp in Minas Passage, forming a 70 to 90% ice cover.

The greatest thicknesses and quantities of shore-fast ice occurred at Economy Point in Cobequid Bay and Brick Kiln Island in Minas Basin. Adhering to rock ledges exposed at low-water and extending under high-water levels, ice reached the height of high-water spring tides. Lesser amounts of shore-fast ice 10 to 15 ft thick at high-water levels surrounded islands offshore along the north side of Minas Basin and five to ten ft thicknesses covered the shore line from Clarke Head to Cape Sharp in Minas Passage.

A 0.75 mi. wide ribbon ice floe of medium winter ice, 70 to 90% cover, moving through Minas Passage, approximately 0.5 mi. offshore from Cape Blomidon, was dispersed into patterns by tidal currents after moving around Cape Split and Cape D'Or into Minas Channel.

Nine mile per hour northerly winds were instrumental in holding a three-mile wide, medium winter, ice field along the south shore of Minas Channel from Cape Split to Margaretsville, N. S., in the Bay of Fundy.

Ice conditions at high water are shown on Plate A3-4 for March 8, 1968.

A3-7.1.2 <u>Low water</u>

At low water in Minas Basin the major ice field was still located in Windsor Bay and along the south shore of Minas Basin; however, a re-distribution of the ice was evident. Pushing further into Minas Basin as the tide continued to ebb from the Avon and Cornwallis Rivers, the 70 to 90% ice cover increased in width and developed an area of 100% cover off-shore along the Cambridge flats. Along the south shore of Minas Basin the inter-tidal zone from Split Rock to Burntcoat Head was 80 to 90% covered with medium and thick cake ice grounded at low water. Low water exposed extensive ice-free tidal flats and areas of open water along the north shore of Minas Basin and Cobequid Bay while offshore the 70 to 90% young and new-ice cover viewed at high water was reduced to 50%.

The ice-floe ribbon of medium winter ice moving through Minas Passage on the ebb tide had increased with width of the ice field along the south shore of Minas Channel and the Bay of Fundy southwest to Margaretsville. At low water, ice ebbing through Minas Passage began to grind to a halt, widen and move further offshore from Cape Blomidon, as the tide began to flood around Cape Split.

Tidal flats and sand bars on the Avon River at the St. Croix River estuary and at the convergence of the Salmon and Shubenacadie River estuaries were relatively ice free; however, low water exposed extensive areas of grounded cake ice in the Salmon River estuary and in the Avon River at Windsor, N. S.

Low water exposed steep walls of shore-fast ice 30 to 40 ft thick at Brick Kiln Island and Economy Point.

Plate A3-5 portrays ice conditions at low water on March 8, 1968.

A3-7.2 Chignecto Bay, Shepody Bay, Cumberland Basin and embranchments

A3-7.2.1 Mean water level

A north and northeast wind two days prior to the aerial-reconaissance ice survey was responsible for relocating the major ice field from the upper reaches of Chignecto Bay as reported by Ice Central (Plate A3-3) on March 7, 1968, to its entrance.

Along the south shore of Chignecto Bay an ice field of medium and thick winter ice, 100% cover, occupied an area varying in width up to two miles from Cape Chignecto to Boss Point. Offshore the ice fields decreased in coverage to 70% of medium winter ice. It covered an area from Cape Chignecto to Sand River and extended into the upper reaches of Chignecto Bay where it was mixed with young ice.

New ice forming along the north shore of Chignecto Bay continued to develop into young ice by rafting as leads became more prevalent on the ebb tide, at the entrance to Shepody Bay and Cumberland Basin.

Shore-fast ice along the south and north shores of Chignecto Bay varied in thickness up to 15 ft, with the greatest thickness and accumulations occurring along the base of sandstone cliffs from Ward Point to Cape Maringouin and anchored to rock ledges exposed at low-water and extending under high-water levels at Grindstone Island.

Ice cover on Cumberland Basin and its embranchments varied in thickness and quantity as the ebb tide continued to develop leads and areas of open water along the north shore, reducing the young and new ice cover.

Thick winter cake ice covered extensive tidal flats in the Maccan and River Hébert estuaries and offshore from the Elysian Fields. Small rivers emptying into Cumberland Basin, i.e. the Tantramar and the LaPlanche, were frozen over.

Shore-fast ice up to 15 ft thick covered the entire shore line from Joggins to Ward Point, engulfing small bays, rivers and inlets.

Shepody Bay, like Cumberland Basin, was covered with young and new ice; however, the lower portions of tidal flats flanking either side of Shepody Bay were free of ice with shore-fast, medium and thick winter ice occupying the foreshore adjacent ot. high-water levels.

The Memramcook was completely frozen over, as recorded in the ground reconaissance ice survey of February 8, 1968, and reported by Ice Central on

February 17 and 29, 1968.

The lower portion of the Petitcodiac River on the ebb tide was 30% covered with young and new ice, scattered thick winter cake ice along the foreshores, and five feet thicknesses of shore-fast ice along high-water levels. Increasing in thickness up to 20 ft, shore-fast ice, medium and thick winter cake ice encroached on the open river channel from Moncton, N.B., to the Petitcodiac River Water Control Structure, above which it was frozen over.

Ice conditions at mean water level, on March 8, 1968 are portrayed on Plate A3-6.

A3-7.2.2 Low water

With the exception of an increase in exposure of tidal flats and areas of open water, very little change took place in the ice conditions and coverage between reconnaissance flights at mean and low water over Shepody Bay, Cumberland Basin and their embranchments.

However, the 100% medium and thick winter ice cover along the south shore of Chignecto Bay had dispersed into a 70 to 90% young, medium and thick winter ice cover, over 70% of Chignecto Bay and into the Bay of Fundy with leads and areas of open water developing between ice floes.

Along the north shore of Salisbury and Chignecto Bays and at the head of Chignecto Bay the young and new ice cover had decreased as leads and open water continued to develop at low water.

Plate A3-7, for low water on March 8, 1968, reveals, by comparison with Plate A3-6, little change from mean water-level ice conditions the same day.

A3-8 Ground Reconnaissance Ice Survey (March 21-22, 1968)

A ground reconnaissance ice survey was carried ou t March 21 and 22, 1968, with the observations noted below.

A3-8.1 Salmon River estuary

The Salmon River estuary at the head of Cobequid Bay was 30 to 60% covered with grounded cake ice at low water on March 21, 1968. The ice covered approximately the same general area as seen on two earlier reconnaissance trips.

Under the influence of warmer water and air temperatures, the spring breakup period was well advanced. Resembling large brown boulders, five to 15 ft thick, grounded cakes of ice were melting in place and altering in physical appearance: (1) losing their rafted forms and visible tide-level markings; (2) developing spherical shapes; and (3) changing in colour from a light-sandy to a dark-reddish brown, brought about by sediment oozing from the ice.

In order to determine the solidity and amount of sediment trapped within the ice in the estuary, a relatively typical sample cake of ice grounded on a sand bar was chosen. Several six inch diameter holes were drilled into the ice, encountering a hollow interior at depths of three to five feet. Cutting a three by five foot block of ice from the lower portion of the sample cake exposed a honeycombed interior. The block of ice was reduced in size to one cubic foot, melted and bottled as Sample A for analysis, with the results shown in Tables A3-1, A3-2, and A3-3.

The outer three to five feet thick layer of ice, when drilled and cut with an axe, was solid ice, relatively easy to cut, coarse grained, and resembled dirty rock salt.

Sediment appeared throughout the ice in layers, and as dense areas on a cut face. The gradual reduction of cake ice by moderating temperatures deposited several inches of sediment on the top. The occasional cake of ice had frozen within it a block of dense fresh-water ice.

Assuming 50% of the Salmon River estuary covered with grounded cake ice five to 15 ft thick, weighing 54.36 lb/cu ft and containing 18% sediment (Sample A, Table A3-1) the total quantity of sediment suspended in the ice field in the estuary on March 21, 1968, would amount to 3.6 million tons.

A second representative sample cake of ice was chosen off shore on the tidal flat at Highland Village near Spencer Point. Measuring nine feet thick, the cake of ice had plowed a nine-inch-deep trench several hundred yards long in the tidal flat before coming to rest on the falling tide.

Sampling of the ice was carried out in two areas, removing six-inch cubes, melted and bottled as Samples B and C. Resembling Sample A in texture, samples B and C contained lesser amounts of sediment (See Tables A3-1, A3-2, and A3-3). However, the sample cake contained many scattered areas of dense sediment.

A3-8.2 Economy Point

To further evaluate the shore-fast ice condition to the east of Economy Point, a ground-reconnaissance survey of the area was carried out on March

22, 1968.

At the time of the visit, a light snow was falling, and the tide was low, exposing the thick sandstone ledges running to the east from Economy Point.

The large masses of shore-fast ice resembling islands, visible on earlier reconnaissance trips, had completely disappeared. However, up to one-foot thicknesses of ice remained along the southern exposures of rock ledges and from two to eight-foot thicknesses of ice remained at various locations along the top of ledges, indicating that ice had grown to the spring high-water levels, which cover the ledges.

The colour of the ice was that of light sand, indicating only small amounts of fine sediment present within the ice. The ice was soft, coarse-grained and appeared to be deteriorating quickly under the unfluence of warmer water and weather.

A3-9 Principal Observations

Periods of prolonged, extremely cold weather coupled with large snow falls, westerly winds and rising spring tides apparently account for the greatest accumulation of ice floes, with shore-fast, rafted and cake ice found in Minas Basin and Chignecto Bay.

Shore-fast ice grows to its greatest thicknesses where rock ledges are exposed at low water, and where relatively steep gradients exist between low and high water, whereas cake ice grows to its greatest thickness in river estuaries which are broad and dry out at low tide, i.e., Salmon and Shubenacadie Rivers, St. Croix and Avon Rivers, Maccan River and River Hébert, and the Petitcodiac River above Moncton, N. B. Growing by accretion of layers of frozen muddy water and sediment, in freezing temperatures, cake ice after grounding in an estuary on falling neap tides remains in place until successive rising spring tides carry it further up the estuary, since currents on the flood tide are greater than the ebb.

If the spring breakup occurs on the neap-tide cycle, cake ice located within the estuary or on the bay or basin foreshore will be the last to leave, remaining in place until its size has been sufficiently reduced by melting before being carried away on the neap tide or the next spring tide, whichever occurs first.

Several times throughout the winter months from January to March, easterly and northerly winds blowing for several consecutive days, combined with ebb tides, flushed ice floes that covered all or parts of Minas Basin, Chignecto Bay and embranchments into the Bay of Fundy.

The ice cover during the prolonged period of extremely cold weather in February, 1968, exceeded that reported in the record winter of 1961. Covering the whole of Minas Channel, Passage and Basin, Chignecto Bay and its embranchments, and extending into the Bay of Fundy to Margaretsville, N.S., on the south shore, it represented the largest recorded ice field at the head of the Bay of Fundy.

It can be concluded that a tidal power plant located within the upper reaches of the Bay of Fundy will be subjected to severe ice conditions.

Since the basin limiting capacities (including pumping) have been selected between elevations +24.5 and -25.5 for Site 7.1, +25 and -25 for Site 7.2, and +30 and -29 (GSCD) for Site 8.1, a build-up of ice over the basin water-level range at the tidal power works of up to 50 ft at Sites 7.1 and 7.2 and up to 59 ft at Site 8.1 may occur under extremely cold weather.

On the sea side, the ice build-up would be somewhat smaller due to the reduction in tidal range when the power plant is in operation; however, a build-up of about 42 ft at Sites 7.1 and 7.2 and 50 ft at Site 8.1 may occur.

If rockfill dyke sections are employed in conjunction with floated-in, precast-concrete caisson elements in the construction of a tidal power plant, similar growth of ice may occur on both basin and sea sides, since the dyke would simulate natural conditions.

Acting as a blanket, ice floes covering a basin would reduce the possibility of freezing spray overtopping a barrage by dampening wave action.

A basin or bay enclosed by a barrage in the upper reaches of Chignecto Bay or Minas Basin will probably freeze over sometime in January and remain in this condition until the spring breakup in March or April. Resembling a typical frozen-over tidal river such as the Memramcook or Salmon Rivers, the ice cover would rise and fall with the filling and emptying cycles, increasing in thickness from accumulations of snow and freezing rains. Acting as an insulating blanket, the ice cover would reduce the growth of ice by accretion of layers of frozen muddy water and sediment. Increased thicknesses of shore-fast ice may occur, along the foreshore of the intertidal zone within the enclosed basin, from rafting against headlands and where steep gradients occur between low and high water.

A3-10 The Sediment Problem

The treatment of sediment from the point of view of a tidal power development involves six areas of concern. These are: