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In anticipation of a demonstration project, limnological and glaciological studies were conducted on the St. Lawrence River during the period February - April 1979. The studies were planned with three overall objectives: (1) acquire additional data on the winter environment of the St. Lawrence River under nondemonstration conditions; (2) determine the extent to which environmental conditions within the proposed "Demonstration Corridor" can be predicted from monitoring sites located outside of the Corridor; and, (3) develop recommendations to assist in the design of future assessment of the environmental effects of winter navigation.

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THE ENVIRONMENTAL EVALUATION WORK GROUP FY 1979 STUDIES OF THE WINTER NAVIGATION DEMONSTRATION PROGRAM

ANALYSIS OF CONTROL SITES: LIMNOLOGY AND GLACIOLOGY

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July 31, 1979

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ABSTRACT

Previous studies have given evidence that a proposed demonstration of the technical feasibility of navigation on the St. Lawrence River during periods of ice cover could result in serious negative effects on several aspects of the riverine ecosystem. In anticipation of a demonstration project, limnological and glaciological studies were conducted on the river during the period February - April, 1979. The studies were planned with three overall objectives: (1) acquire additional data on the winter environment of the St. Lawrence River under non-demonstration conditions; (2) determine the extent to which environmental conditions within the proposed "Demonstration Corridor" can be predicted from monitoring sites located outside of the Corridor; and, (3) develop recommendations to assist in the design of future assessment of the environmental effects of winter navigation.

Sampling sites were established in wetland, shoal, bay, nearshore, and channel areas at three locations along the St. Lawrence for the limnological study plus two additional locations for the glaciological work. Water, sediment, and ice samples, taken repeatedly from each location, were characterized physically, chemically, or glaciologically. Qualitative and statistical comparisons were made on limnologic and glaciologic characteristics of the river between locations in and out of the proposed Corridor ("paired sites") to determine similarities between locations.

The results of the limnological study indicate that paired sites on main flow areas of the river, especially channel sites, may be sufficiently related with regard to water quality to permit accurate predictions of a limited number of water quality characteristics in the Corridor from measurements taken from locations outside. However, particle-related parameters could not be predicted. Water quality at paired sites in peripheral areas, especially wetlands and bays, was influenced largely by local environmental conditions and not accurately predictable between paired sites. Changes in sediment characteristics were not predictable between paired sites. For future investigations of the effects of a demonstration program on water and sediment quality, major recommendations focus on a need for more information concerning particulate matter and sediments in the river and the potential benefits to be derived from an environmentally sound, deterministic model of water quality in the St. Lawrence River.

The results of glaciologic studies indicate that bathymetric conditions and ice boom emplacement act to define four distinct glaciological reaches within the Demonstration Corridor. The reaches, identified by geogrphical location, are: Brockville Narrows, Morristown Pt.-Ogdensburg, Ogdensburg Boom, and Galop Island Booms. Natural patterns of ice formation and erosion are related to the placement of islands, midchannel shoals, and littoral areas in the Corridor. However, wholly natural patterns of ice formation and erosion appear to be rare within the Corridor. The occurrence and dynamics of open water pools within the ice cover are characteristic features of particular glaciologic reaches within the Corridor. The paired sites samples indicate a characteristic glaciological zonation of ice stratification in harbor-wetland areas. Four such zones were identified. Ice forms in bays and wetlands were highly dependent on exposure to wind and snow. At bay sites, snow ice amounted to approximately 50% of the ice thickness, while in wetland edge sites, snow ice approached 90%. Recommendations for future studies strongly suggest that greater benefits would be derived from a full winter period of study, rather than the amount of time available for the present work. Further recommendations reflect the need for increased aerial photomapping, examining the potential uses of SLAR, detailed bathymetric charts of Corridor, and better information on the structural glaciology of open water pools during the entire winter season.

SUMMARY

Water, sediment, and ice samples collected from a variety of habitats in and out of a proposed "Demonstration Corridor" were analyzed for a wide range of characteristics. The characteristics were compared between locations to assess the degree of predictability inherent in each. The results of the investigation lead to the conclusions and recommendations set forth below.

LIMNOLOGY

Conclusions

1. Water quality in the main flow of the St. Lawrence River was similar to that in Lake Ontario, as was determined from a comparison of a wide variety of water quality parameters between the two bodies of water.

2. Water quality in peripheral areas along the river, particularly wetlands and bays, was independent of water quality in the main flow during periods of ice cover and spring thaw.

3. Water quality in the main flow of the St. Lawrence River showed similarities in magnitude and direction of change for several parameters during the investigation. However, it should be noted that absent from the list of correlated parameters were those which were related to the amounts of particulate matter in the water. Lacking these parameters, a paired site approach will be strongly dependent on water quality parameters which will be relatively unaffected by vessel transits during ice cover. Bearing this in mind, the similarities suggest that main flow control sites established outside a Demonstration Corridor could be paired successfully with sites within the Corridor to predict water quality with sufficient accuracy to test the effects of vessel transit on water quality. However, data collected during the present study indicate that such an approach can be considered valid only for main flow sites, especially channel sites.

4. Water quality at the major locations selected for study, considering all habitat types together, showed relatively low correlation between locations for all parameters with the exception of water temperature. Thus, general and accurate predictions of water quality at sites within the Demonstration Corridor are not possible from simple, direct relationships to parameters measured outside the Corridor.

5. Multivariate relationships developed by CANONA showed a high degree of correlation between locations for all habitat types considered together. However, the relationships so identified were impossible to identify in ecologically meaningful terms due to intercorrelations between parameters.

6. A multivariate factor analysis of water quality at each location showed fundamental differences in the major factor affecting water quality at sites sampled in and out of the Corridor. While open water characteristics dominated water quality measurements taken outside the Corridor, within the Corridor wetland and bay sites had a greater influence on measured parameters.

7. Sediments from wetland and bay sites at Blind Bay, Morristown, and, to a lesser extent, Brandy Brook, showed elevated levels of phosphorus, zinc, and copper.

8. Sediment quality, as determined by several parameters, did not show significant changes between sampling dates at any of the habitat sites. Thus, prediction of sediment quality between locations, based on correlated changes, was not possible.

Recommendations

1. A paired site approach to assessment of vessel transit impact on water quality, wherein control sites are established outside of the Demonstration Corridor, should focus primarily on main flow habitats: channel, shoal, and nearshore sites. Other types of habitat are not suited to paired site comparisons.

2. Only those water quality parameters which correlate between locations but are uncorrelated with each other should be employed for multivariate paired site comparisons; for example, water temperature, dissolved oxygen or pH, total soluble phosphorus or soluble reactive phosphorus, nitrate, and calcium or total hardness.

3. Further studies of the relationship between levels of suspended particulate matter from one location to another along the river should be performed under non-demonstration conditions. Failure to include a particulate-related parameter which correlates between locations will reduce the effectiveness of a paired sites approach to monitoring demonstration activities.

4. Future studies should be directed toward characterization of the sediments of the Corridor with respect to particle size distribution, potential for resuspension, desorption of nutrients and metals, and biological effects of the latter materials.

5. A deterministic model of water quality, which includes hydraulic as well as important water quality parameters, could provide a more accurate control for assessment of demonstration activities than paired sites comparisons. Development and calibration of such a model should be a focal point for future investigations on the St. Lawrence River.

6. Investigations of time and spacially variant parameters of winter water quality should be initiated no later than a month before the river begins to freeze over; approximately, mid-November. Water quality parameters are not discontinuous functions of time, and studies designed to predict magnitudes and explain variability of major parameters should not be constrained by time factors which are not related to environmental conditions.

GLACIOLOGY

Conclusions

Demonstration Corridor

1. Bathymetric conditions and the resulting upwelling, together with the placement of ice booms, are the principal factors that define four glaciological reaches of the Demonstration Corridor. These reaches are the Brockville Narrows, Morristown Point-Ogdensburg, Ogdensburg Ice Boom, and Galop Island Booms.

2. The lateral boundaries of pools in the Ogdensburg Ice Boom and Galop Island Reaches are largely determined by the location of the 24' depth contour.

3. Pools in the Morristown Point-Ogdensburg Reach are the result of the packing of floes of loose slush and frazil, thermal cracks, and shear cracks kept open by currents.

4. Ice boom placement determines the pool boundaries of the Ogdensburg Ice Boom and the Galop Island Reaches.

5. In the Brockville Narrows Reach, rough bottom conditions and the resulting upwelling are the principal factor controlling the location of pools.

Control Sites

1. The maximum ice cover durations for protected shallow control sites are the following:

Chippewa Bay	139 days
Blind Bay	135+ days
Morristown Harbor	98 days
Nevins Point Area	103+ days
Tibbits Creek	118+ days
Brandy Brook	128+ days

2. Wetland edge environments are covered by a frozen three-layered formation consisting of snow ice, lake ice, and frozen organic-rich bottom sediments.

Recommendations

Demonstration Corridor

1. Aerial photomapping of the Demonstration Corridor beginning at the time of initial ice formation and extending during the whole process of ice erosion. In addition, low altitude missions are needed at selected times for stereo examination of ice conditions. It is necessary to have

a complete overview of 100-150 day period that ice covers the various riverine environments.

2. Develop the capacity for all-weather monitoring of ice formation and ice erosion in the Demonstration Corridor by utilizing SLAR (Side Looking Airborne Radar) in coordination with aerial photomapping.

3. Compile photo interpretation guide of the St. Lawrence River ice characteristics.

4. Compile a bathymetric chart of the Demonstration Corridor utilizing the vast array of soundings on NOAA field sheets. Versions of this chart in normal format and shaded relief aid in visualizing the engineering and environmental factors associated with demonstration voyages.

5. Investigate the structural geology of ice surrounding pools originating from upwelling currents and ice boom placement.

6. Carry out a full winter's study in order to define the stages and processes occurring in ice formation and ice erosion in the Demonstration Corridor. The study should extend over several winters to include winters of varying severity.

7. In the future, if winter navigation studies are to be carried out in the Demonstration Corridor, it would be helpful if the objectives of the scientific programs were carefully explained in the media prior to the studies. This would serve to inform residents along the river and help to allay suspicions. Winter navigation is not a popular subject with these people, who see their economic livelihood threatened. Attempts to develop a data base in their dooryards is often viewed with distrust. Field studies benefit from the cooperation and advice of experienced residents, and sensitivity to these issues by explanation at the local level would be productive.

Control Sites

1. Studies need to begin at the start of the winter, particularly in bays and wetlands, in order to trace the important role snow and snow ice plays in the formation of the ice cover. The stratigraphic interpretation of late winter ice cores is made difficult without these data.

2. Requests be made of federal or state authorities for detailed soundings extending from bay mouth to wetlands in bays and harbors fringing the Demonstration Corridor.

3. Contracts for studies of control sites in Demonstration Corridor be issued early in the fall to allow for recruiting of field staff. In particular, if students are utilized as field assistants, sufficient lead time is needed to arrange class schedules to permit 1-2 full days a week in the field. Commitments must be made to students for the academic year

to most efficiently meet both project and student financial requirements.

4. Safe river studies in areas of cold, moving, open water and ice mandate adequate lead time for locating riverworthy airboats, trained operators, and cold water protective garments.

5. Investigate the possibility that thin ice layers in frozen, organic-rich bottom sediments in St. Lawrence River wetlands, formerly ascribed to water level fluctuations, may be the result of the formation of segregated ice layers and lenses marking periods of slow downward freezing. Automatic water level recorders and thermocouple probes should be used to monitor ice layer formation at the wetland edge.

6. Future studies of the development of stratigraphic features in the ice canopy should utilize vertical thin sections photographed in polarized light to determine the origin of these features.

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INTRODUCTION

As part of on-going efforts to demonstrate the practicality of extending the navigation season on the Great Lakes-St. Lawrence River System, a Winter Navigation Demonstration Program has been planned for possible implementation in a selected corridor along the St. Lawrence River. Included in the Demonstration Program are modifications to existing ice booms in the Demonstration Corridor to permit ship passage, installation of additional ice stabilization structures, and a limited number of actual vessel transits through the Corridor, which extends from Brockville Rock, near Morristown, New York to Frazer Shoal, near Cardinal, Ontario.

Studies conducted during the winter of 1977-78 by the New York State Department of Environmental Conservation and the College of Environmental Science and Forestry of the State University of New York have given strong indications that activities connected with the proposed Demonstration Program could have serious adverse impacts on the environment and ecology of the St. Lawrence River within the Demonstration Corridor. Further, these studies point to a requirement for extensive characterization of baseline aspects of the Corridor as an ecosystem prior to implementation of the proposed Demonstration Program.

In recognition of the need for additional data on the St. Lawrence River, the activities set forth below are designed to provide information on physical, chemical, and glaciologic characteristics of the St. Lawrence River in a manner which would be useful for future efforts at planning a program of assessment of demonstration activities. Due to severe constraints in time and funding, the work described here cannot address baseline characterization in a comprehensive, intensive manner. Rather, this investigation focuses on a limited set of parameters for the purpose of characterizing short-term changes at selected locations along the St. Lawrence River during a late winter period of ice cover.

The investigation was conducted in two parts; the first concerned water and sediment characteristics, while the second addressed aspects of river glaciology in the vicinity of the proposed Demonstration Corridor. The objectives of the limnologic portion can be stated as follows:

1. Acquire data, under non-demonstration conditions, on water and sediment quality in five specific habitat types as they occur in the vicinity of the proposed Demonstration Corridor of the St. Lawrence River, under conditions of ice cover.

2. Determine the degree to which sites outside of the proposed Demonstration Corridor can be used as controls for assessing the impact of a Demonstration Program on water and sediment quality parameters within the proposed Corridor.

3. Recommend criteria for design of future investigations, particularly for assessing the impacts of the Demonstration Program on water and sediment quality in the St. Lawrence River ecosystem.

Similarly, the objectives of the glaciologic study can be stated:

1. Acquire ice data, under non-demonstration conditions, on the ice canopy at five specific habitat types inside and outside the Demonstration Corridor.

2. Determine the degree to which sites outside of the Demonstration Corridor can be used as controls for assessing the impact of a Demonstration Program on the ice canopy and the surrounding environment in the Corridor.

3. Recommend criteria to design future investigations for assessing the impacts of the Demonstration Program on the ice canopy and its effect on the St. Lawrence River ecosystem.

Due to distinct differences in methodology, results, and interpretation of results, the main body of this report will treat the two parts of the investigation separately.

PART 1

ANALYSIS OF CONTROL SITES: LIMNOLOGY

1.I. METHODS OF INVESTIGATION

GENERAL APPROACH

The general approach taken in this phase of the investigation was to monitor the levels of several physical and chemical characteristics of the water and sediments at three major locations along the St. Lawrence River. The major locations were selected based on two criteria:

1. Proximity to the proposed "Demonstration Corridor" which extends from Morristown, NY to Cardinal, ONT, approximately. The Corridor is the reach of the river which has been proposed for use in a demonstration of the technical practicality of winter navigation.

2. Accessibility of multiple ecological habitat types within the general area of the location, to include: wetland, near shore, bay, shoal, and deep off-shore.

Two major locations were selected outside of the Corridor, one upstream and one downstream, and one location was selected within the Corridor. Generally, upstream and downstream locations were sampled on alternate sampling dates, while the location within the Corridor was sampled on each sampling date. This sampling scheme allowed for a pairing of data collected in and out of the Corridor to determine the degree to which variability in measured parameters followed correlated and possibly predictable trends.

FIELD METHODS

Locations

The sampling location selected to represent conditions within the Corridor was placed at Morristown, NY. As shown in Figure 1 , the Morristown location, which included the Morristown harbor area plus off-shore channel and shoals, provided each of the desired habitat types. The upstream location was selected at Blind Bay and vicinity, shown in Figure 2 . Shoal sites for Blind Bay were located near Whaleback Island, downstream from the mouth of Blind Bay. The Brandy Brook-Murphy Island Shoal area was selected as the location downstream of the Corridor. Illustrated in Figure 3 are the sampling sites which were visited in the vicinity of Brandy Brook during this study. As indicated on Figures 1 , 2 , and 3 replicate samples were taken from sites where spacial variability was expected to be especially significant: wetlands, bays, and near shore sites.

Sampling Schedule

Water and sediment samples were collected from sites at the major locations according to the dates given in Table 1 . Owing to the late starting date for the investigation and an early degeneration of ice cover, samples taken prior to the first week of March are most representative of winter conditions at the locations observed during this investigation. Samples

Figure 1. Sampling Sites in the Vicinity of Morristown, NY

Site Numbers	Habitat Type
11, 12	Bay
13, 14	Near Shore
15	Channel-Near Shore (Temporary)
16, 17, 18	Wetland
27	Channel
28	Shoal

Scale: 1 in = 2500 ft

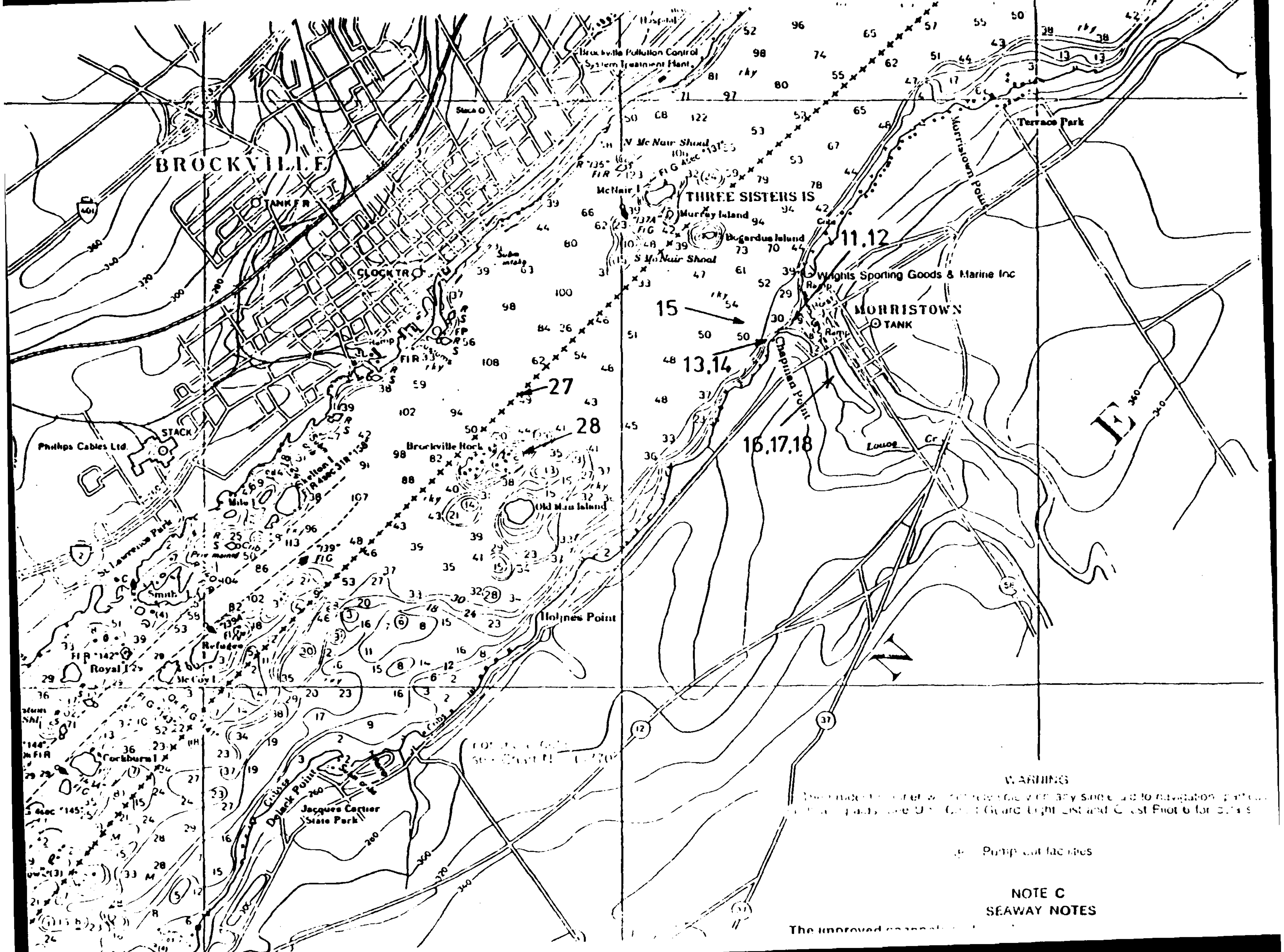
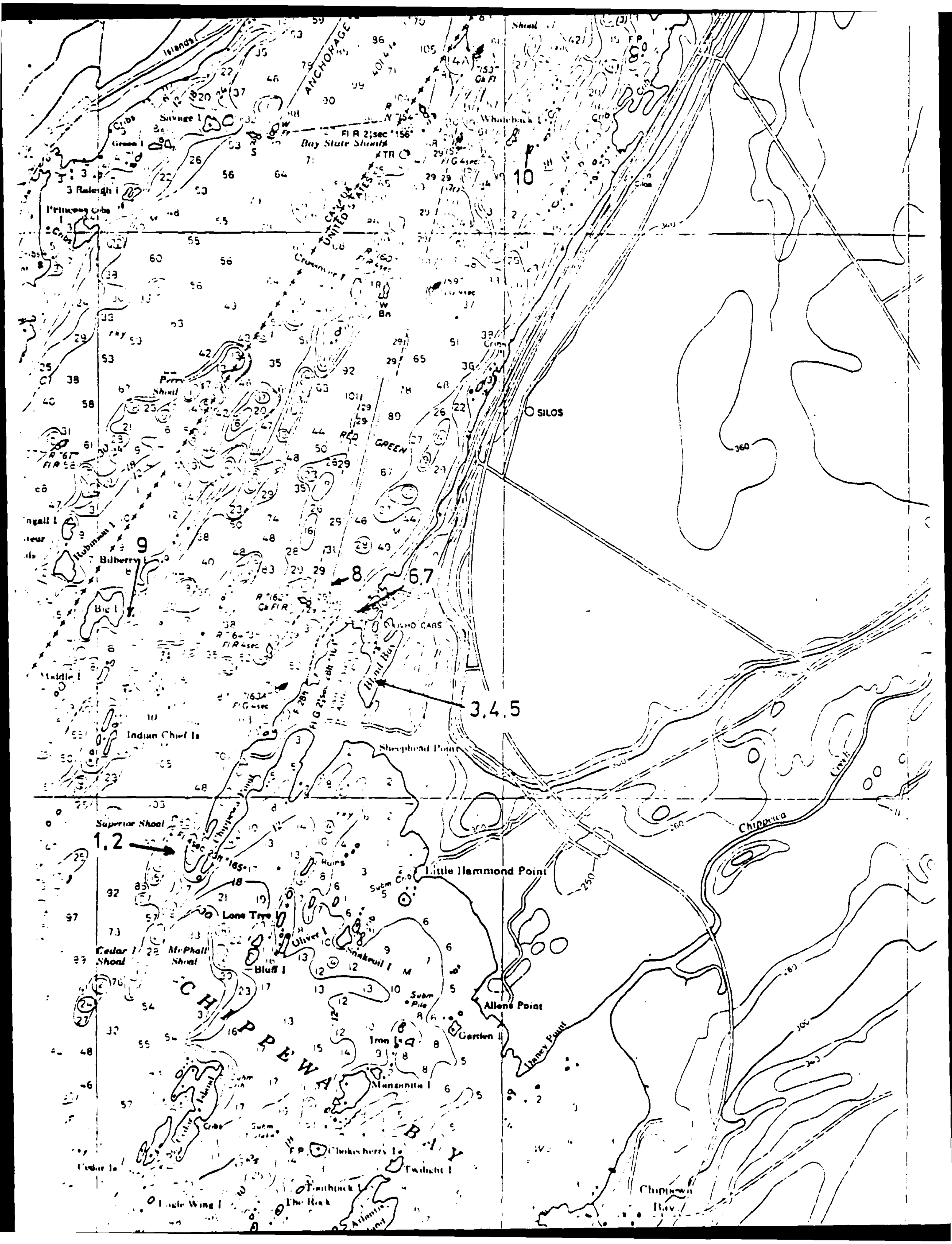

BROCKVILLE
MORRISTOWN
THREE SISTERS IS
Brockville Pollution Control System Treatment Plant
Wrights Sporting Goods & Marine Inc
Morristown Point
Terrace Park
Chapman Point
McNair I
Murray Island
Bogardus Island
N McNair Shoal
S McNair Shoal
Brockville Rock
Old Man Island
Holmes Point
Philips Cables Ltd.
STACK
CLOCK TR
TANK
St Lawrence Park
Smith
Refugee
Royal
Cockburn I
Dolack Point
Jacques Cartier State Park
Louse Cr
11,12
13,14
15
16,17,18
27
28
WARNING
Pump out facilities
NOTE C
SEAWAY NOTES

Figure 2. Sampling Sites in the Vicinity of Blind Bay

Site Numbers	Habitat Type
1, 2	Near Shore
3, 4, 5	Wetland
6, 7	Bay
8	Channel
9	Shoal
10	Shoal

Scale: 1 in = 2500 ft

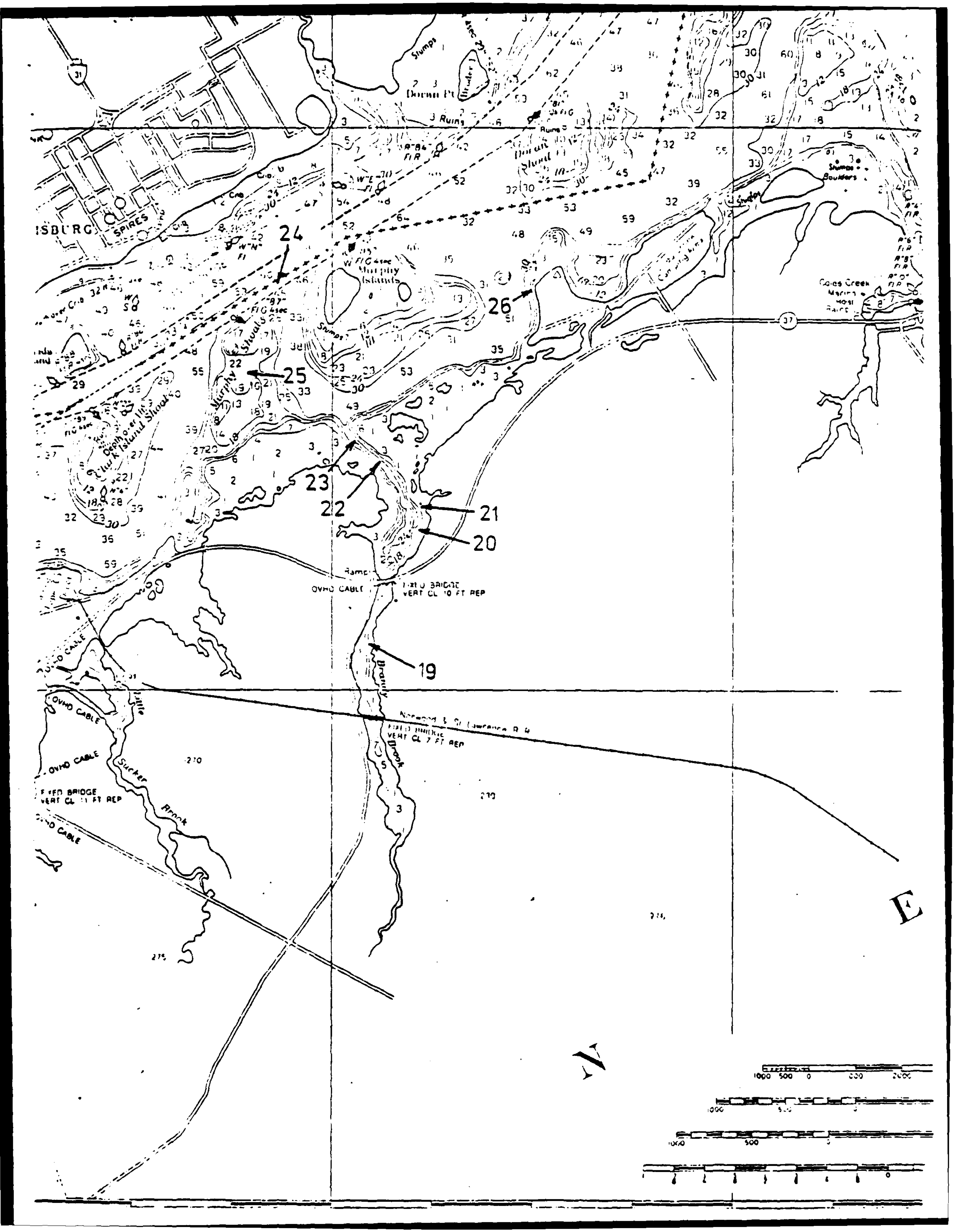


ANCHORAGE
CANADA
UNITED STATES
Savage I
Green I
Raleigh I
Bay State Shoals
Whaleback I
Crossover I
10
SILOS
Perry Shoal
RED
GREEN
Bilberry I
9
Big I
8
6,7
3,4,5
Blind Bay
Indian Chief Is
Sheephead Point
Superior Shoal
1,2
Little Hammond Point
Lone Tree I
Oliver I
Cedar I Shoal
McPhail Shoal
Bluff I
Allens Point
Garden I
Iron Is
CHIPPEWA BAY
Chokecherry Is
Twilight I
Cedar Is
Eagle Wing I
The Rock
Chippewa
Chippewa Bay

Figure 3. Sampling Sites in the Vicinity of Brandy Brook

Site Numbers	Habitat Type
19, 20, 21	Wetland
22, 23	Bay
24	Channel
25	Shoal
26	Near Shore

Scale: 1 in = 2500 ft



ISBURG
SPIRES
Doran Pt
Ruins
Stumps
Murphy Islands
Murphy Shoals
Stumps Boulders
Coles Creek Marina
Ramp
OVHD CABLE
VERT CL 10 FT REP
Brandy Brook
Little
Sucker Brook
OVHD CABLE
FIXED BRIDGE
VERT CL 7 FT REP
24
25
26
23
22
21
20
19
N
E

TABLE 1

Dates of Sample Collection, St. Lawrence River; 1979

Sample Type	River Location		
	Blind Bay	Morristown	Brandy Brook
WATER	13 FEB	13 FEB	
		23 FEB	23 FEB
	28 FEB	28 FEB	
		9 MAR	9 MAR
	13 MAR	13 MAR	
		20 MAR	
	30 MAR	30 MAR	30 MAR
	23 APR	23 APR	23 APR
SEDIMENT	28 FEB	23 FEB	23 FEB
	23 APR	23 APR	23 APR

taken after that time represent conditons during the transition to an ice-free spring condition, which was complete at all locations by the first week of April, approximately. Unsafe ice conditions made it impossible to sample all sites (habitat types) during each sampling period.

Sampling Methods

A 23 cm (9 in) diameter power auger was used for sampling water and sediments through the ice cover. After the initial boring, water temperature, dissolved oxygen, and water depth were determined and recorded. Water samples were then taken from a depth approximately midway between the ice cover and the bottom by means of a plastic Van Dorn or Kemmerer sampler and transferred to acid-rinsed polyethylene bottles. Upon return to the laboratory, an aliquot of each sample was filtered, and both filtered and unfiltered samples were frozen until later analysis for phosphorus and nitrogen. Other water quality parameters were measured on unfiltered samples upon return to the laboratory.

Sediment samples were obtained with a 225 cm^2 (34.8 in^2) Ekman dredge from all sites where the substrate could be penetrated and transferred directly into acid-rinsed plastic bags. Sediment samples were returned to the laboratory and stored wet at 4^oC (39^oF) in the dark until analysis.

ANALYTICAL METHODS

Laboratory Analyses

Presented in Tables 2 and 3 are lists of the parameters which were determined on water and sediment samples, respectively. The methods used in each analytical determination are given also in the tables. Specialized analytical equipment which was used during sample analysis included: YSI Model 54 DO Meter/Thermistor; Hach Model 2100A Turbidimeter; Corning Model 12 Research Grade pH Meter; Bausch and Lomb Spectronic 88 Visible Spectrophotometer; Beckman Model DB-G UV-Visible Spectrophotometer; Microkjeldahl digestion racks; Orion Model 901 Specific Ion Meter/Microprocessor; ASTM Hydrometer, #151 H; Muffle Furnace; Perkin-Elmer Model 107 Atomic Absorption Spectrophotometer with lamps; Mettler Analytical Balance, Model H10. All analytical separations into soluble (filterable) and particulate (nonfilterable) fractions were performed using 0.45 μ hemicellulose acetate membranes in Gelman filtration funnels. Details on analytical methods can be found by consulting the references cited in Tables 2 and 3 .

Data Analyses

After water samples for a particular date were analyzed for the parameters described above, data from replicated sites (for example: Sites 3, 4, and 5, the wetland sites at Blind Bay) were averaged to give mean values for each water quality parameter and entered into a minicomputer-based data storage and retrieval system. Available hardware for the system included a 48K RAM North Star minicomputer plus dual-drive floppy disk storage, a Lear-

TABLE 2

Water Quality Parameters and Methods of Analysis

Parameter	Method
Temperature (in situ)	Electrometric; thermistor
Dissolved Oxygen (in situ)	Polarographic; Dissolved Oxygen Electrode
Turbidity	Nephelometric; Formazine Standards
Suspended Solids	Gravimetric (Non-Filterable Residue; APHA, 1975)
pH	Electrometric; Combination Electrode
Alkalinity	Potentiometric Titration (APHA, 1975)
Phosphorus (Total, Total Soluble, Soluble Reactive)	Persulfate Digestion and/or Ascorbic Acid Colorimetric (EPA, 1976)
Nitrate-Nitrogen	UV Spectrophotometric (APHA, 1975)
Total Kjeldahl Nitrogen	Indophenol Colorimetric (Scheiner, 1976)
Calcium	EDTA Titrimetric (APHA, 1975)
Total Hardness	EDTA Titrimetric (APHA, 1975)
Chloride	Specific Ion Electrometric (EPA, 1976)

TABLE 3

Sediment Quality Parameters and Methods of Analysis

Parameter	Method
Moisture Content	Unit Weight Loss on Drying at 103°C (217.4°F)
Organic Content	Unit Weight Loss on Combustion at 550°C (1022°F)
Subsieve Particle Size Distribution	Hydrometer (ASTM, 1973)
Phosphorus (Available, Total)	0.1N NaOH Extraction and/or H_2SO_4 - HNO_3 Digestion and Ascorbic Acid Colorimetric (Sagher, 1976 ; APHA, 1975; EPA, 1976)
Metals (Fe, Zn, Cu, Cr)	HNO_3 Digestion and Atomic Absorption Spectrophotometric (EPA, 1976)

Siegler video terminal, and a Texas Instruments Omni 800 line printer. The formal programming language was BASIC. Data were stored and retrieved by date, location, site (habitat type), and parameter, and the storage system permitted single parameters to be up-dated, a significant time-saving feature. The retrieval system produced a summary listing by date of mean values of each parameter for each habitat type at each major location. The summary listing provided a convenient format for comparing parameters between dates, sites, and locations while the results were examined for relationships to results obtained during other studies on the St. Lawrence River and possible causal or predictable variations between parameters at paired sites in and out of the Corridor. The minicomputer system was programmed further to calculate zero-order correlation matrices between parameters measured at paired sites. The correlation matrices were required as input to CANONA (Canonical Correlation Analysis), the multivariate procedure selected to assess apparent similarities and differences between paired sites. An SPSS (Statistical Package for the Social Sciences) version of CANONA was employed (SPSSH-Release 6.02) and was accessed through the IBM OS360/65 at Clarkson College. As a further assist to defining patterns of variation in water quality within and between major locations, an SPSS routine was employed to factor analyze the zero-order correlation matrix.

1.II. DESCRIPTION OF WATER AND SEDIMENT QUALITY

GENERAL

The purpose of this section is to present the water and sediment physical and chemical data obtained on the St. Lawrence River during the Winter of 1979. Interpretive and comparative comments will be reserved for the following discussion section. Recall from the methods chapter that there are three locations on the River for which water and sediment data were obtained - Blind Bay (upstream of Demonstration Corridor), Morristown (in Demonstration Corridor) and Brandy Brook (downstream of Corridor). For each location 5 habitat types (sites) were sampled. Since the object of this study is the possible establishement of control sites, the data will be presented in such a manner as to facilitate comparisons among a given habitat type at all three locations. In the interest of presenting a usable summary of the data in this section, mean values of each parameter will be given for each site. Only in certain cases will a temporal profile be presented; however, for a complete listing of all data gathered refer to Appendix A.

WATER QUALITY

Channel Sites

The temporal averages of water quality data for the channel sites of the three locations of this study are presented in Table 4. The open channel of the river appears to be of good overall quality. Water clarity is good with low average turbidities and suspended solids. Dissolved oxygen is very close to saturation at all channel locations. Plant nutrients - nitrogen and phosphorus - are not excessive at these sites. Total N/P molar ratios range from about 50/1 to 70/1, suggesting that of the two phosphorus would limit primary productivity.

The pH buffering system in the open river appears to be quite stable and controlled by the carbonate system. A pH of 8.1 and an alkalinity of 1.80 meq/ℓ, such as the data indicate, would yield a total inorganic carbon content of 1.82 mM/ℓ. This is somewhat oversaturated with respect to atmospheric CO_2, as might be expected under ice. The buffer intensity for this system (assuming C_T = constant) would be $\beta_{C_T}^{C_B} = 9.45\times10^{-5}$.

The open river water has a total hardness of approximately 130 mg/ℓ as $CaCO_3$, with a calcium hardness of approximately 100 mg/ℓ as $CaCO_3$. This is a reasonably hardwater system with about 40 mg/ℓ as $CaCO_3$ of non-carbonate hardness. This relatively high non-carbonate hardness can be accounted for by association with the chloride in the system.

Shoal and Nearshore Sites

The winter water quality for the shoal and nearshore sites sampled in this study appeared to be very similar to that for the channel sites (Table 5). There is no apparent decrease in water clarity or increase in suspended solids concentration that might be expected for more shallow sites under ice. Although total phosphorus concentrations are slightly higher at the Morristown

TABLE 4

Mean Values of Water Quality Parameters in
St. Lawrence River Channel Sites, Winter 1979

Parameter	Blind Bay	Morristown	Brandy Brook
Dissolved Oxygen (mg/ℓ)	14.50	14.5	14.6
Turbidity (ntu)	1.70	1.15	2.7
Total Suspended Solids (mg/ℓ)	1.2	1.4	1.6
pH	8.07	8.29	8.09
Total Alkalinity (mg/ℓ as $CaCO_3$)	90.8	90.5	89.6
Total Hardness (mg/ℓ as $CaCO_3$)	132.5	131.0	131.5
Calcium (mg/ℓ as Ca)	41.0	40.3	40.2
Chloride (mg/ℓ)	32.8	31.7	34.8
Total Phosphorus (μgP/ℓ)	15.0	15.1	14.4
Total Soluble Phosphorus (μgP/ℓ)	10.4	6.1	8.9
Soluble Reactive Phosphorus (μgP/ℓ)	7.65	4.2	8.2
Total Kjeldahl Nitrogen (μgN/ℓ)	80	-	270
Nitrate+Nitrite-Nitrogen (μgN/ℓ)	443	314	445

TABLE 5

Mean Values of Water Quality Parameters in St. Lawrence River Shoal and Nearshore Sites, Winter 1979

Parameter	Blind Bay Shoal	Blind Bay Nearshore	Morristown Shoal	Morristown Nearshore	Brandy Brook Shoal	Brandy Brook Nearshore
Dissolved Oxygen (mg/ℓ)	14.3	14.45	13.7	14.3	14.5	14.5
Turbidity (ntu)	1.3	1.2	1.0	1.1	2.7	3.0
Total Suspended Solids (mg/ℓ)	1.05	1.2	1.1	0.5	2.5	1.2
pH	8.09	8.11	8.29	8.06	7.91	8.05
Total Alkalinity (mg/ℓ as $CaCO_3$)	91.0	91.0	90.2	90.6	80.6	86.8
Total Hardness (mg/ℓ as $CaCO_3$)	132.9	130.6	132	132.7	115.3	124
Calcium (mg/ℓ as Ca)	40.6	40.6	40.3	40.3	35.2	38
Chloride (mg/ℓ)	33.0	31.4	31.7	33.3	30.9	31.5
Total Phosphorus (µgP/ℓ)	16.4	14.6	14.0	20.1	18.8	18.1
Total Soluble Phosphorus (µgP/ℓ)	7.3	8.75	-	9.4	9.3	7.7
Soluble Reactive Phosphorus (µgP/ℓ)	6.3	5.8	4.8	5.7	8.6	7.65
Total Kjeldahl Nitrogen (µgN/ℓ)	-	-	-	75	-	-
Nitrate+Nitrite-Nitrogen (µgN/ℓ)	370	435	310	432	409	448

shoreline site and at Brandy Brook than the respective channel sites, the difference is not significant. This result suggests that there is very little direct land influence on the nearshore stations during ice cover.

Bay and Wetland Sites

There were significant water quality differences between the bay and wetland sites and the actual river sites presented above (Table 6). Since the wetland sites were the shallowest and most influenced by land, these stations exhibited the largest differences. The bay sites, being located between wetland and river sites, generally had an intermediate mean value for the various parameters.

The poorer water quality of the wetland sites is evidenced by slightly lower dissolved oxygen, increased turbidity and suspended solids, and elevated total P and N concentrations. In fact the wetland N/P molar ratios of at most 30/1 suggest their stronger dependence on the local terrestrial systems.

One other observation about the wetland sites, which also occurred to a lesser degree in the bay areas, was a consistent temporal variation in major ion concentrations during the period of study. An example of this pattern is shown for total hardness in Figure 4 . Alkalinity, calcium and chloride follow very similar patterns. A possible explanation for the low March concentrations is a dilution effect due to ice deterioration that occurred during the unseasonably warm period beginning near the end of February. The ice melt period had virtually ended by the beginning of April, and the higher concentrations in samples taken on April 23 (completely ice-free) reflect a return of these systems to a terrestrial dominated state. The correlation between ice melt and water quality levels would confound demonstration monitoring considerably in bay and wetland areas.

The possibility that the above phenomena might be due to a non-conservative reaction (such as $CaCO_3$ precipitation) seems to be ruled out by the fact that chloride follows a very similar pattern to calcium during the melt period (Figure 5). Furthermore, the $[Ca^{++}]$ $[CO_3^{=}]$ ion product at this time does not exceed the solubility product.

There does appear to be an incongruous occurrence in the middle of February in the calcium and chloride concentrations for the Morristown wetland samples (Figure 5). Between 2/13 and 2/23 the Cl^- concentration increases rather sharply, while little change takes place for calcium. There are two possible explanations for the shift in Ca/Cl ratio during this period, both of which are consistent with the available data. First, it is possible that a considerable exchange of water with the main river occurred during this period. It is more likely that road salt runoff contributed to the unusually high chloride levels at the end of February. In either case, however, these perturbations would strongly influence a demonstration monitoring program.

TABLE 6

Mean Values of Water Quality Parameters in St. Lawrence River Bay and Wetland Sites, Winter 1979

Parameter	Blind Bay		Morristown		Brandy Brook	
	Bay	Wetland	Bay	Wetland	Bay	Wetland
Dissolved Oxygen (mg/ℓ)	14.4	12.6	13.9	11.4	13.4	12.7
Turbidity (ntu)	4.6	11.2	1.2	2.2	2.6	2.9
Total Suspended Solids (mg/ℓ)	2.4	48.2	1.0	4.3	1.7	1.7
pH	8.00	6.90	8.06	7.61	7.91	7.62
Total Alkalinity (mg/ℓ as $CaCO_3$)	88.9	130.9	90.7	113.5	82.8	85.9
Total Hardness (mg/ℓ as $CaCO_3$)	129	154.2	132.4	146.3	121.8	116.9
Calcium (mg/ℓ as Ca)	39.5	47.6	40.15	43.3	36.1	34.7
Chloride (mg/ℓ)	30.8	16.5	33.0	26.7	27.2	21.5
Total Phosphorus (μgP/ℓ)	19.65	128.8	17.7	70.0	41.8	82.6
Total Soluble Phosphorus (μgP/ℓ)	11.5	41.8	9.15	32.2	28.9	62.9
Soluble Reactive Phosphorus (μgP/ℓ)	6.6	16.0	6.1	25.6	21.6	33.3
Total Kjeldahl Nitrogen (μgN/ℓ)	-	1630	-	495	-	340
Nitrate+Nitrite-Nitrogen (μgN/ℓ)	382	213	455	445	313	282

Figure 4. Temporal Variation in Total Hardness at Wetland Sites at Major Locations

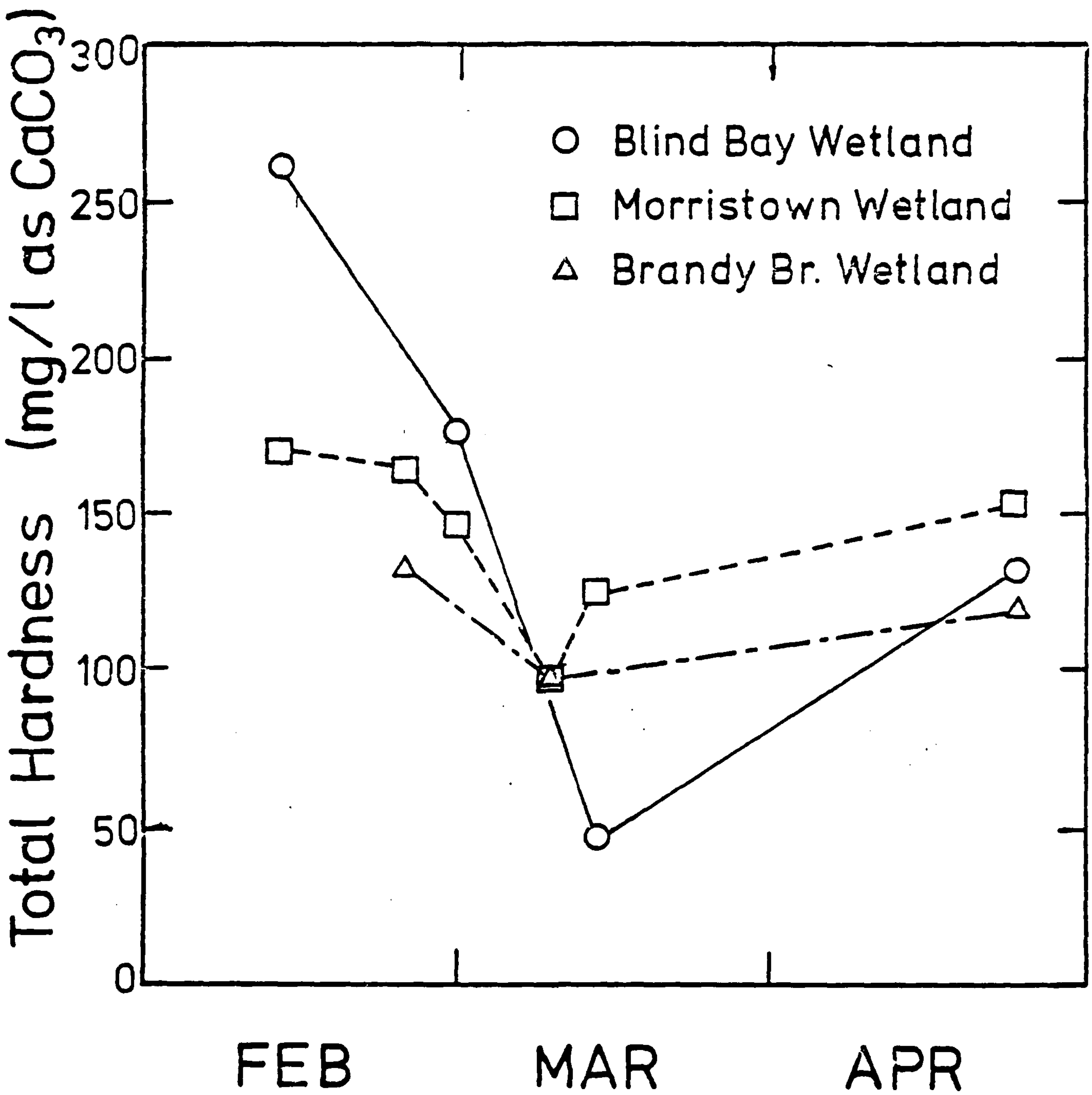
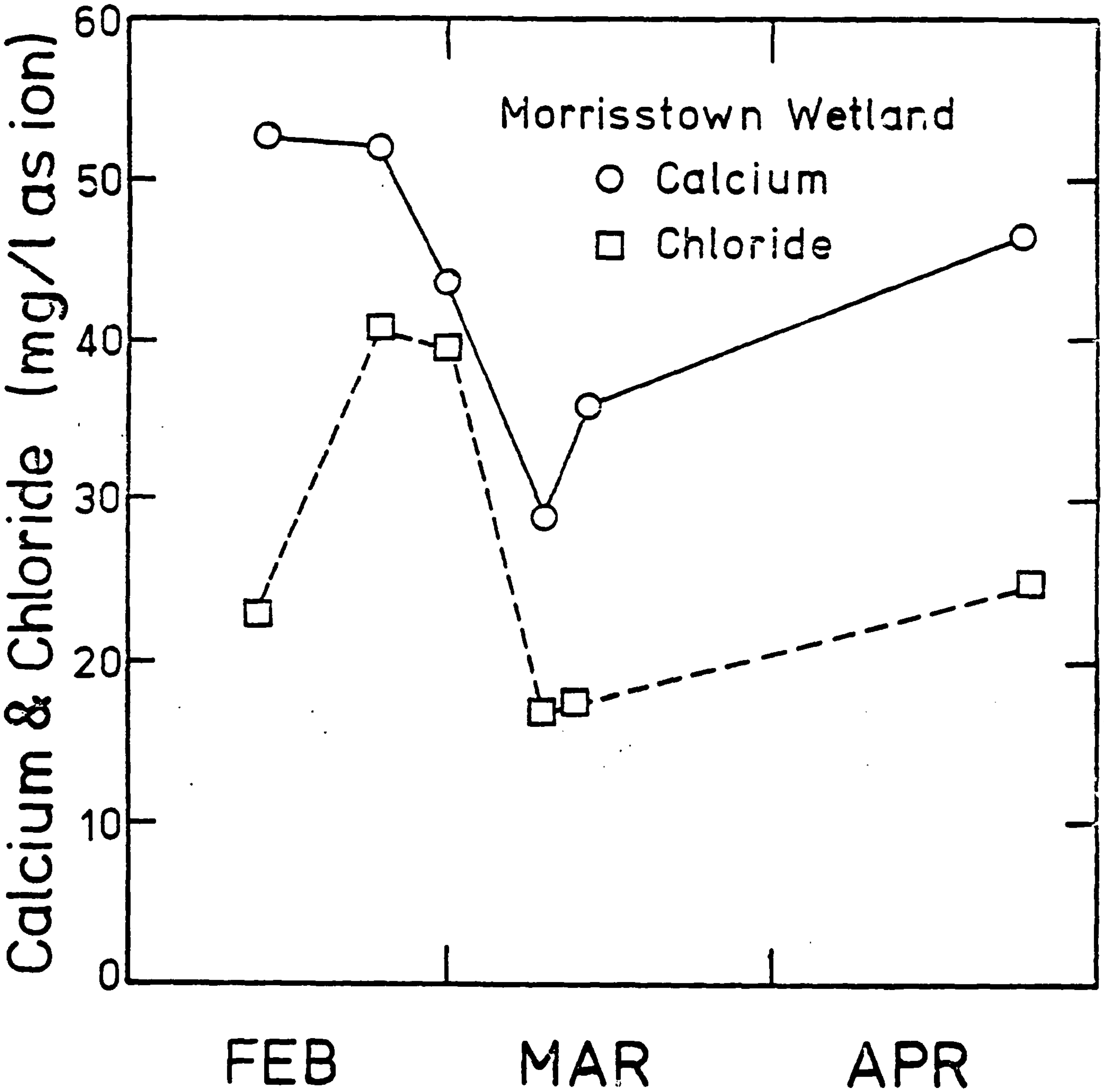

Total Hardness (mg/l as $CaCO_3$)
300
250
200
150
100
50
0
Blind Bay Wetland
Morristown Wetland
Brandy Br. Wetland
FEB
MAR
APR

Figure 5. Calcium and Chloride Concentrations in Morristown Wetland Sites



Calcium & Chloride (mg/l as ion)
0
10
20
30
40
50
60
Morrisstown Wetland
Calcium
Chloride
FEB
MAR
APR

SEDIMENTS

Repeated sampling of sediments from similar habitats of each location was performed only at wetland and nearshore sites. Other habitats were sampled when possible. However, transportation or substrate suitability prevented acquisition of sediments from a complete range of habitat types Consequently, the data presented in this chapter and discussed in the next represent summaries extracted from the more complete set of data presented in Appendix B.

Characteristics of Sediments

Shown in Table 7 is a summary of sediment quality data for wetland and nearshore sites at each of the major locations averaged over the two sampling dates.

Particle Size Distribution. Sand and larger sized particles formed the major size class in the samples from all sites and locations. Silt and clay were important only in samples taken in the Brandy Brook area where the smaller sized particles tended to occur in greater amounts at nearshore sites. Organic detritus in the form of twigs, aquatic plant fragments, and other material was common in samples from all sites, though the amounts of organic detritus appeared greater in wetland samples compared to other sites.

Moisture Content. Moisture was greater in sediment samples taken from wetland sites compared to nearshore sites. The average moisture content of wetland sediments was 76.6% of fresh sample weight while nearshore samples averaged 38.8%. The moisture content of Blind Bay wetlands (88.0%) was similar to that of the wetland sites at Morristown (83.8%). However, Brandy Brook samples from nearshore sites were closer in moisture content (30.5%) to samples from similar sites at Morristown (33.8%) than were nearshore samples from Blind Bay (52.2%). Differences in moisture content between samples taken in February and April were shown to be not significant ($\alpha > 0.05$) by a two-tailed t-test.

Organic Matter. The organic content of the sediments was quite distinctive between habitat types at all locations. Wetland sites had the highest levels of organic matter (27.1%), bay sites were next highest (see Appendix B) and nearshore sites were lowest (2.7%) among sites sampled. Organic content and moisture were directly related ($\alpha < 0.01$) as suggested by a comparison of values of the two parameters given in Table . A two-tailed comparison of February and April samples showed no significant difference ($\alpha > 0.05$) in amounts of organic matter in sediments taken from similar habitats.

Phosphorus. Total and extractable phosphorus in sediment samples was higher generally at wetland sites than other locations. Average levels of total phosphorus ranged from a low of 0.35 mgP/g dry wt at nearshore areas near Morristown to a high of 0.95 mgP/g dry wt in the Morristown wetland sites. Mean extractable phosphorus levels ranged from 0.06 mgP/g dry weight

TABLE 7

Mean Values of Sediment Characteristics at Near Shore and Wetland Sites; St. Lawrence River, 1979

Parameter	Blind Bay		Morristown		Brandy Brook	
	Wetland	Near Shore	Wetland	Near Shore	Wetland	Near Shore
Number of Samples	4	3	4	4	8	6
Sand[a,e]	96.1	91.0	89.4	94.6	77.6	52.2
Silt[a,e]	3.9	7.4	10.6	5.4	20.7	41.2
Clay[a,e]	0.0	1.6	0.0	0.0	1.6	6.6
Moisture[b]	88.0	52.2	83.8	33.8	57.9	30.5
Organic Matter[b]	40.4	5.5	26.6	1.6	14.1	1.1
Total Phosphorus[c]	0.66	0.61	0.95	0.35	0.87	0.52
Extractable Phosphorus[c]	0.30	0.19	0.44	0.06	0.44	0.14
Total Iron[c]	32.3	23.2	36.4	9.4	28.9	25.7
Total Zinc[c,d]	0.22	<0.1	0.21	<0.1	0.14	0.11
Total Copper[c,d]	0.09	0.02	0.08	0.02	0.04	-
Total Chromium[c,d]	0.06	0.06	0.18	0.08	0.07	0.12

[a] % Dry weight (103°C)

[b] % Wet weight

[c] mg/g Dry weight (103°C)

[d] Measured on 2/28 samples only

[e] Measured on a composite of samples collected on both sampling dates

at nearshore Morristown sites to 0.44 mgP/g dry weight, found in wetland samples at both Morristown and Brandy Brook.

The ratio of extractable to total phosphorus was reasonably constant within habitat types and was consistently higher at wetland sites compared to nearshore sites. The range in values for the ratio was 0.45 to 0.51 with a mean of 0.47 for wetland sites, while the range was 0.17 to 0.31 with a mean of 0.25 at nearshore sites. Differences in the averages levels of total and extractable phosphorus between February and April samples taken at paired sites was not significant ($\alpha > 0.05$).

Metals. As was true for several other sediment parameters, the levels of iron, zinc, and copper were elevated at wetland sites compared to other habitats studied. Average iron ranged from a high of 36.4 mgFe/g dry weight in the Morristown wetland to a low of 9.4 mgFe/g dry weight at nearshore sites at Morristown. Equally high levels of zinc (0.2 mgZn/g dry wt) were found on the average in wetland samples from Blind Bay and Morristown, while zinc was not detectable in sediments from nearshore sites at the same two locations. Significant levels of zinc were found in all sediment samples from the Brandy Brook location. Copper was similar to zinc in distribution among sites. The results of the analyses for chromium are summarized in Table 7 . However, difficulties encountered in the function of the atomic absorbance lamp during the analysis have rendered the results to be of uncertain accuracy.

1.III. DISCUSSION OF WATER AND SEDIMENT QUALITY

WATER QUALITY

Comparison with Previous Data

Very little winter water quality data exist for the St. Lawrence River. Mills, et al. (1978) have reported winter (Jan.-March, 1978) water chemistry data for offshore and nearshore sites between Cape Vincent and Lake St. Lawrence. Their data for mutually tested parameters were remarkably similar to the channel and nearshore results of the present study. The only major discrepancy appeared to be in the alkalinity results - about 90 mg/ℓ as $CaCO_3$ for this study (Tables 4 and 5) versus a reported 55-60 mg/ℓ as $CaCO_3$ by Mills, et al. (1978). An electroneutrality balance of the data strongly suggests that the higher value is more appropriate.

Combining the data from the two studies, a summary of deep channel winter water chemistry can be obtained and is presented in Table 8 . Comparison of the St. Lawrence channel data with available data for Lake Ontario confirms the dominance of open river water quality by Lake Ontario quality (Table 8).

Obviously the bay and wetland stations are less influenced by the Lake Ontario outflow and more determined by local land use activities. In addition to observing generally lower water quality in the wetland/bay areas, the temporal profile of most of the parameters was more variable and much less predictable from St. Lawrence River data upstream. The Blind Bay wetland suspended solids and related total phosphorus and Kjeldahl nitrogen are examples of this point. These findings in addition to those discussed below suggest that the control site concept for wetland/bay areas is of doubtful utility.

Control Sites Comparison

Tables 5,6, 7 and the raw data in Appendix A can be used as an indication of the potential for using control sites for detecting short-term changes in winter water quality due to navigation activities. Comparison of the mean parameter values as well as same date samples for the channel sites at the three locations suggests that the control site concept might work for the open river area as long as changes are not too subtle. However, the small number of channel sample pairs which were obtained during this investigation severely limits the accuracy of channel site predictions beyond the present work.

More location to location variability is encountered in the nearshore areas, and it is obvious that the wetland/bay locations are unique and very dissimilar systems. For example, with respect to nearshore sites the Brandy Brook location appears to be more dilute than the other two nearshore locations with respect to total hardness and alkalinity yet slightly more concentrated in plant nutrients and suspended solids. Mills, et al. (1978) also found slightly higher total phosphorus values at downriver sites (Galop Island and Lake St. Lawrence) and attributed the increase to resuspension by higher currents as well as point sources of nutrients in the Ogdensburg area.

Wetland and bay areas are so unique in terms of hydrology and land-water interactions that control site comparisons are virtually impossible. As seen

TABLE 8

Comparison of St. Lawrence River Channel Sites (Winter, 1978 and 1979) with Lake Ontario Water Quality Data

Parameter	St. Lawrence River	Lake Ontario
Dissolved Oxygen (mg/ℓ)	14.5[a]	11.6-13.6[c]
Turbidity (ntu)	1.0-2.7[a]	
Total Suspended Solids (mg/ℓ)	1.0-7.2[a,b]	
Total Dissolved Solids (mg/ℓ)	200-240[b]	175-200[c]
Specific Conductance (μmhos/cm @ 25°C)	300-330[b]	312-320[c]
pH	7.4-8.2[a,b]	8.0-9.0[c]
Total Alkalinity (mg/ℓ as $CaCO_3$)	87-94[a]	95-100[c]
Total Hardness (mg/ℓ as $CaCO_3$)	128-134[a]	
Calcium (mg/ℓ as Ca^{++})	38-42[a,b]	43-46[c]
Magnesium (mg/ℓ as Mg^{++})	7.8-8.4[b]	8.9-9.4[c]
Potassium (mg/ℓ as K^{+})	1.25-1.4[b]	1.4-2.1[c]
Sodium (mg/ℓ as Na^{+})	10.4-11.0[b]	11.5[c]
Chloride (mg/ℓ as Cl^{-})	30-35[a]	24.7[c]
Sulfate (mg/ℓ as $SO_4^{=}$)	24.3-27.6[b]	29.5-31.3[c]
Total Phosphorus (μg/ℓ as P)	10-25[a]	16-20[c] 20-35[d]
Total Soluble P (μg/ℓ as P)	5-10[a]	13-16[d]
Total Kjeldahl Nitrogen (μg/ℓ as N)	150-360[a]	250-350[c]
Nitrate-+Nitrite-Nitrogen (μg/ℓ as N)	0.2-2.0[b]	.85-1.6[c]

[a]this study

[b]Mills, et al. (1978)

[c]Casey, et al. (1965); weighted ave. of deep water stations

[d]Great Lakes Water Quality Bd. (1973)

in Table 6 even seasonal averages of important water quality parameters vary considerably from one wetland/bay system to the next. For example, the Brandy Brook system is associated with a larger tributary stream than the other two. As a result this system appears to be more dilute with respect to major ions, and because of its morphometry is less influenced by water exchange from the main river.

SEDIMENTS

Comparison With Previous Data

As was true for the water quality data reported above, very limited data were available from published literature on the sediment characteristics of the St. Lawrence River. The principal source available was the results of an investigation conducted the previous winter which focused on heavy metal and organic contaminants (Scrudato, 1978).

Particle Size Distribution. The range in particle size distribution among the samples taken in this study was somewhat lower than that observed by Scrudato (1978). In this study the predominant sediment type was sandy silt. Clay formed a significant component only in samples taken from two nearshore and one wetland site. However, Scrudato (1978) found significant levels of clay in sediments from sites which would correspond to bay, nearshore, channel, and shoal habitats within the definitions used in the present study. While differences in sampling locations and sampling and analytical methods may be responsible for dissimilar results for similar habitats between the two investigations, it is clear that more work is required to characterize the sediments with respect to particle size along the river. Specifically, it is important to locate major areas of deposition of fine-grained sediments since such materials are more adsorbent of nutrients and other pollutants and more prone to resuspension and transport during hydrodynamic disturbances, than coarse matter.

Organic Matter, Phosphorus, and Iron. With the exception of wetland samples, the levels of organic matter in river sediments from the present investigation were within the range reported earlier (Scrudato, 1978). However, the organic content of wetland samples, particularly from Blind Bay and Morristown, was much higher than for other habitat types.

The levels of phosphorus and iron in river sediments represent new information concerning the sediments of the St. Lawrence system. Iron and phosphorus levels are discussed with the organic content because the levels of each parameter appear to be interrelated in the sediments of other aquatic systems, particularly lakes (Williams et al., 1971a). Shown in Table 9 is an abbreviated matrix of correlation coefficients between each pair of parameters for sediment samples taken from all sites during the investigation.

The correlations in Table 9 show organic matter to be related to the amount of phosphorus, both total and extractable, in the sediments taken during this investigation. Further, total and extractable phosphorus were

TABLE 9

Triangular Matrix of Correlation Coefficients for Organic Matter, Total and Extractable Phosphorus, and Total Iron in St. Lawrence River Sediments; All Samples; Winter, 1979*

	Organic Matter	Total P	Extractable P	Total Fe
Organic Matter	1.0	0.539	0.589	0.185
Total P		1.0	0.710	0.188
Extractable P			1.0	0.247
Total Fe				1.0

*$N = 24$, $r_{crit} = 0.404$ for $\alpha < 0.05$

strongly correlated, while total iron showed no correlation of significance with the other parameters.

According to procedures described elsewhere (Williams et al., 1971b, 1971c), the extractable phosphorus fraction contains loosely-bound or dissolved phosphorus plus the potentially mobile phosphorus adsorbed to amorphous iron oxides and hydroxides. Since extractable phosphorus and total iron were not correlated, it appears likely that most of the extractable fraction was in a highly mobile form, either soluble or very loosely adsorbed. Extractable phosphorus was correlated with the organic content of the sediments, which also correlated with the moisture content (see Chapter 1.III.). Thus, the extractable phosphorus fraction was probably in a soluble state. Elevated levels of soluble phosphorus were found at wetland sites, where organic sediments predominated, which substantiates this interpretation of the extractable phosphorus data. Future analyses for the iron content of the NaOH extractant could cast additional light on the form of the extractable phosphorus.

Total phosphorus in river sediments was related to the amount of organic matter, but part of the relationship shown in Table 9 was due to the strong correlation between total and extractable phosphorus, and between extractable phosphorus and organic matter. Thus, while truly organic phosphorus was a likely component of the sediments, particularly in samples with elevated levels of organic matter, organic phosphorus does not appear to be a major component of the total sediment phosphorus. Total phosphorus was not related to total iron, which indicates that crystalline iron phosphate compounds, such as strengite ($FePO_4$) or vivianite ($Fe_3(PO_4)_2$), were unimportant as major sediment components.

It cannot be determined from the data whether calcium-bound phosphates, such as hydroxylapatite ($Ca_5OH(PO_4)_3$), were present. However, in a reasonably hard water system such as the St. Lawrence River, hydroxylapatite may be a stable solid phase phosphorus compound in sediments, Williams and Mayer (1972) found hydroxylapatite in nearshore sediments of Lakes Erie and Ontario, which were attributed to terrestrial sources. Thus, bearing in mind the harder waters found in the tributaries at two of the three major locations studied, hydroxylapatite may be a significant component of the total phosphorus in St. Lawrence River sediments, as a result of terrestrial input during runoff, or possibly diagenic formation in hard water wetland areas.

Several investigators have shown a significant relationship between biologically-available phosphorus and the extractable (0.1 N NaOH) phosphorus fraction of lake sediments (Wildung et al., 1977) and suspended matter in urban runoff and Lake Ontario tributaries (Cowan and Lee, 1976). Thus, concern for the effects of winter navigation on the river environment should include consideration of the potential increase in biologically-available phosphorus which would follow resuspension and translocation of sediments from areas rich in extractable phosphorus. The results of this investigation, though limited in scope, suggest that wetlands (Table 7) and bays (Appendix B), and nearshore areas in some instances, are the general locations of concern with respect to such potential sources of phosphorus. Given the apparent phosphorus-limited conditions under which primary producers occur in the river (see Chapter 1.II.), increased phosphorus availability has the potential to permit increased standing crops of algae, particularly in downstream areas with relatively high hydraulic retention times, as at locks and power pools. The degree to which resuspended sediments would constitute a significant load of biologically-available phosphorus to the St. Lawrence River cannot be assessed with present data.

Heavy Metals. Zinc was present in sediment samples at levels which fell within the range of values reported by Scrudato (1978), while copper was found to be generally higher than previously reported. Zinc in the sediments, taken from wetland sites at Blind Bay and Morristown was at levels which are characteristic of heavily polluted harbors, according to EPA guidelines (EPA, 1977). While the Morristown location appears to be significantly affected by cultural activities, which include water-based recreation, the Blind Bay area is undeveloped, with the exception of a small marina. Thus, the elevated zinc levels in the Blind Bay wetland are difficult to interpret with regard to source. However, cultural sources are suspected in the case of zinc in the sediments taken near Morristown. At Brandy Brook zinc was present in all sediment samples at levels classified as moderately polluted by EPA Guidelines, with the exception of a shoal sample (Appendix B) which would be classified as non-polluted.

Copper was found at levels characteristic of heavily polluted harbors in the wetlands of Morristown and Blind Bay. At Brandy Brook, copper was at moderate levels with the exception of a nearshore sample (#17) which likely was contaminated during analysis.

As was true for phosphorus, the concern for heavy metals in the sediments of the St. Lawrence River focuses on the potential for resuspension and downstream transport of metals due to activities associated with winter navigation. Both zinc and copper are toxic at low concentrations to aquatic biota. Consequently, movement of sediments containing the metals and deposition downstream, or merely desorption after resuspension, have the potential for creating toxic conditions for susceptible components of the aquatic community. The toxic action might be a direct, lethal effect, which would reduce species diversity and permit only tolerant organisms to survive. Or, the effect could be sublethal and result in biological magnification through the aquatic food web. Furthermore, the concern for heavy metal transport by sediment perturbation extends to public health and the potential for introduction of toxic metals into public supplies of drinking water. However, zinc and copper are essential elements and, at the levels observed in sediment samples, do not suggest public health problems for consumers of river water after adequate treatment.

Control Sites Comparison

As noted earlier (Chapter 1.II.), none of the sediment characteristics which were measured on repeated samplings at the same sites showed significant change from one period to the next. That is, the error variance for parameters measured on replicated samples taken during one period was greater than the variance which could be attributed to changes in parameters over the time interval which separated the samples. Thus, no significant trends were observed in sediment characteristics at any of the major locations, and no predictable changes could be delineated. The salient characteristics of the sediments at each location are presented in the discussion preceeding and Chapter 1.II.

1. IV. ANALYSIS OF PAIRED SITE RELATIONSHIPS

GENERAL APPROACH

A major objective of this investigation was to determine the degree to which changes in water quality at one location on the St. Lawrence River were related to and might be predicted from changes in water quality at a second location. In particular the investigation sought to determine the extent to which water quality in the proposed "Demonstration Corridor" could be predicted from measurements of water quality taken outside of the Corridor. Stated differently, the study sought to determine the extent to which sites outside the Corridor could serve as "experimental controls," to be monitored coincidently with sites in the Corridor during vessel transits under demonstration conditions as a check on the effects of winter navigation on water quality in the St. Lawrence River.

The approach which was taken toward assessing the degree of relationship which existed between water quality parameters measured in the Corridor (Morristown sites) and those at locations outside the Corridor (Blind Bay or Brandy Brook sites) consisted of four steps. The first step amounted to elimination of the water quality parameters which did not show significant amounts of coincident variation at sites in and out of the Demonstration Corridor. The elimination step thus provided a subset of the original variables, each member of which showed a significant degree of correlated variation in samples taken from sites at Morristown and either Blind Bay or Brandy Brook. In the second step, the subset of corrleated parameters was analyzed by the statistical procedure known as canonical correlation analysis (CANONA). CANONA is a multivariate extension of bivariate product-moment correlation analysis, a procedure which has been used commonly to study the existence of relationships between two variables. Rather than searching for relationships between single pairs of variables as in bivariate correlation, CANONA examines two groups of paired variables for relationships or patterns of variation. Accordingly, the subset of water quality parameters which showed coincident variation at sites in and out of the Corridor were used as the input variables to CANONA. Two important pieces of information obtained from CANONA are (1) the coefficient of canonical correlation, R_c; and, (2) the canonical variates. The coefficient, R_c, is similar conceptually to the more familiar product-moment coefficient of correlation, r. However, R_c amounts mathematically to the correlation between two composite variables whose membership corresponds to the grouped parameter subset. The canonical variates consist of weighting factors or coefficients which maximize the correlation between the composite variables and interpret the pattern of variation in a manner which best reproduces the original matrix of correlations between water quality parameters. Several sets of canonical variates may be required to reproduce all the intercorrelations in a specific data set. Further details concerning CANONA can be found in Harris (1975).

The third step in the approach taken to assess relationships between spacially separated measurements of water quality amounted to interpretation of the canonical variates in realistic terms. This step, while highly desirable, is not always possible since interdependent relationships (such as, dissolved oxygen and total phosphorus, dissolved oxygen and temperature) cannot be separated cleanly into the orthogonal, or uncorrelated, canonical variates as occurs during the analysis. Nonetheless, examination of the relationships identified by the variates can be valuable and may suggest which parameters are sufficiently linked between locations as to provide the potential to predict changes in water quality.

The last step in assessing water quality relationships between locations amounted to a factor analysis of the subset of parameters which showed a significant degree of correlation at sampling sites in and out of the Corridor. Basically, the analysis reduces the total number of parameters and their variances to a smaller number of "factors" which accounts for the observed correlations between parameters in a set of observations. After the major factors have been identified, comparisons are made between the factors which are responsible for variation in water quality parameters at sites in and out of the Corridor, in an attempt to find similar factors. Since the effects of time were not considered in developing the zero-order correlations between parameters, it was presumed that time related phenomena would play a major role in interpretation of the results of the factor analysis.

APPLICATION OF PROCEDURES

Selection of Site Pairs

For the analysis of paired site relationships, several potential pairing criteria were examined. However, the final selection of sites and dates was made on the basis of completeness of data as it was felt that the objectives of the analysis could best be served by examining relationships between all parameters measured. Thus, all sites from Blind Bay and Brandy Brook were paired with sites of similar habitat type at Morristown for coincident sampling dates for samples which were not missing data. The pairings are given in Table 10.

Correlation Between Parameters

Product-moment correlation coefficients (r) between all water quality variables measured at the site pairings indicated in Table 10 were calculated and tested for significance (Rohlf and Sokal, 1969). The extensive number of correlation coefficients so generated were reduced to form a manageable matrix by elimination from further consideration those water quality parameters which, individually, showed doubtful correlation ($\alpha \geq 0.05$) between sites in and out of the Corridor. The parameters which showed significant correlation ($\alpha < 0.05$) were included in the reduced matrix. The list of correlated variables consisted of temperature (TEMP), dissolved oxygen (DO), pH, total soluble phosphorus (TSP) soluble reactive phosphorus (SRP), nitrate-nitrogen (NO_3), calcium (CA), and total hardness (TH). A correlation matrix for this list of water quality variables based on sample pairings as indicated above is shown in Table 11 . Water quality parameters which did not show significant correlation for the site

Table 10

Sample Pairs Analyzed by Multivariate Methods, Given by Date, Location, and Site; St. Lawrence River, 1979

Sampling Date	Location Outside Corridor		Location Inside Corridor	
	Location	Sites	Location	Sites
22879	Blind Bay	1,2	Morristown	11,12
33079	Blind Bay	1,2	Morristown	11,12
22879	Blind Bay	3,4,5	Morristown	16,17,18
31379	Blind Bay	3,4,5	Morristown	16,17,18
22879	Blind Bay	6,7	Morristown	13,14
31379	Blind Bay	6,7	Morristown	13,14
33079	Blind Bay	6,7	Morristown	13,14
42379	Blind Bay	6,7	Morristown	13,14
22879	Blind Bay	8	Morristown	15
33079	Blind Bay	8	Morristown	15
33079	Blind Bay	8	Morristown	27
42379	Blind Bay	8	Morristown	27
33079	Blind Bay	9	Morristown	28
42379	Blind Bay	9	Morristown	28
33079	Blind Bay	10	Morristown	28
42379	Blind Bay	10	Morristown	28
22379	Brandy Brook	19,20,21	Morristown	16,17,18
30979	Brandy Brook	19,20,21	Morristown	16,17,18
22379	Brandy Brook	22,23	Morristown	11,12
30979	Brandy Brook	22,23	Morristown	11,12
33079	Brandy Brook	22,23	Morristown	11,12
33079	Brandy Brook	24	Morristown	27
33079	Brandy Brook	24	Morristown	15
22379	Brandy Brook	26	Morristown	13,14
30979	Brandy Brook	26	Morristown	13,14
33079	Brandy Brook	26	Morristown	13,14

Table 11

Matrix of Zero Order Correlation Coefficients Between Water Quality Parameters Measured in and out of Demonstration Corridor
($N = 26$, $r_{crit,\ 0.05} = 0.388$)

Sites In Corridor (Morristown)	Sites Outside Corridor (Blind Bay and Brandy Brook)							
	TEMP	DO	pH	TSP	SRP	NO_3	CA	TH
TEMP	0.967	0.194	0.515	-0.122	-0.260	-0.366	0.073	0.025
DO	0.050	0.478	0.460	-0.316	-0.400	-0.100	0.049	-0.018
pH	0.684	0.642	0.875	-0.390	-0.408	-0.290	0.260	0.192
TSP	-0.252	-0.636	-0.824	0.682	0.496	-0.090	-0.554	-0.503
SRP	-0.279	-0.603	-0.763	0.598	0.417	-0.064	-0.372	-0.322
NO_3	-0.553	-0.335	-0.604	0.513	0.655	0.612	-0.102	-0.632
CA	-0.081	0.151	0.273	-0.588	-0.391	0.106	0.558	0.538
TH	-0.163	0.028	0.111	-0.528	-0.320	0.142	0.445	0.435

pairs included turbidity (r = 0.005), suspended solids (r = 0.320), alkalinity (r = 0.305), total phosphorus (r = 0.311), total Kjeldahl nitrogen (insufficient data), and chloride (r = 0.344).

In examining the correlations presented in Table 11 it should be recognized that significance, in a statistical sense, does not imply the existence of cause-effect relationships with significance in an environmental sense. This is especially true for the present study where experimental control over the monitored variables was not mainyained. Thus, the coefficients in Table 11 indicate only the degree to which water quality parameters measured in the Corridor varied in a consistent, coincident pattern with similar parameters measured at locations outside of the Corridor. Bearing this in mind, the simple correlation coefficients in Table 11 suggest that while measured values of a specific parameter at sites in the Corridor may correlate with the same parameter at sites outside the Corridor, other parameters measured outside the Corridor may correlate with the original parameter to a greater degree than the original parameter itself. For example, soluble reactive phosphorus (SRP) measured at Morristown showed a low but significant correlation (r = 0.417) with SRP measured at the other locations. However, SRP at Morristown sites showed higher correlations with TSP (r = 0.598), DO (r = -0.603), and pH (r = -0.763) as measured on water samples from sites at the other locations. In fact, an examination of Table shows that five of the eight parameters included for detailed analysis were more highly correlated with dissimilar than similar parameters for the site pairs of interest.

With regard to the objectives of this investigation as they concern the potential for predicting water quality at a location within the Corridor from external measurements, the foregoing results indicate strongly that simple bivariate relationships oversimplify the complexity of interactions that affect water quality in the St. Lawrence River and the multiplicity of habitats therein. The oversimplification is apparent from the extent of intercorrelation between parameters as found in Table 11. As a result of intercorrelation, simple bivariate regression models are doomed to inefficiency as predictors of water quality parameters, since they cannot account for the indirect effects of uncontrolled variation in correlated parameters. A multivariate solution to the problem of making predictions is the only realistic approach. The techniques which were employed to investigate the multivariate relationships inherent in the set of water quality parameters included CANONA and factor analysis.

Canonical Correlation Analysis

The objectives of CANONA can be compared to those of a more familiar technique, multiple regression. During a multiple regression analysis the objective is to predict one dependent variable from several independent variables by determining the appropriate weighting factors, or regression coefficients, for the prediction equation. Thus, in multiple regression the dependent variable is predicted by a composite of independent variables. In CANONA the objective can be viewed as prediction of several dependent variables from several independent variables by determining the appropriate weighting factors. In either case the criterion for selection of the weighting factors is the same, maximum correlation between the composite independent and dependent variables. In CANONA, however, the distinction between dependent and independent variables becomes problematic.

The results of CANONA as applied to the paired sites data are summarized in Table 12 , which lists the coefficients of canonical correlation (R_c) and the coefficients for four canonical variables each of which describe relationships with high levels of statistical significance ($\alpha < 0.001$). The first pair of variates indicates that warm periods with low total soluble phosphorus and high calcium at Morristown sites occurred at the same time as periods of low dissolved oxygen and total soluble phosphorus, but high pH and soluble reactive phosphorus at Blind Bay and Brandy Brook sites. The second pair of variates suggests that cold periods at Morristown under conditions of low total soluble phosphorus, but high levels of nitrate and total hardness, generally occurred at the same time as periods of cold temperatures when total soluble phosphrous and calcium were low, but dissolved oxygen, soluble reactive phosphorus, and total hardness were high at the other locations. The third pair of canonical variates indicates that at Morristown periods of high pH, soluble reactive phosphorus, nitrate, and calcium, and low total soluble phosphorus and total hardness occurred at the same time as periods at Brandy Brook and Blind Bay when total hardness and total soluble phosphorus were at elevated levels and calcium was relatively low. The fourth pair of variates suggests that cold periods at Morristown, when characterized by elevated levels of pH, dissolved oxygen, soluble reactive phosphorus, and calcium, were coincident with cold periods at the other locations when dissolved oxygen and total soluble phosphorus were high and pH, soluble reactive phosphorus, and nitrate were low. Such a large cluster of relationships requires some clarification to be meaningful.

Interpretation of Paired Site Relationships

In examining the relationships betwwen the paired sites as described by the canonical variables it should be recognized that the distinction between high and low levels of a parameter is based on the magnitude of the parameter compared to its average value for all sites at a location. Nonetheless, it becomes obvious from a close examination of the paired variates that doubtful environmental significance can be attached to the relationships predicted between parameters at the paired sites. This is true even though very distinct patterns of variation existed between parameters measured at Morristown and the same parameters measured at sites outside the Corridor. For example, calcium and total hardness were correlated positively among sites at each location ($\alpha < 0.01$) and between locations ($\alpha < 0.05$). However, the canonical coefficients for these parameters in all pairs of canonical variates showed an inverse relationship rather than direct. Also, the relationship between total soluble and soluble reactive phosphorus, as shown by the paired canonical variates, was inverse, in contrast to the positive correlations ($\alpha < 0.05$) found both within and among locations for these parameters during this investigation. Thus, it appears that environmentally significant factors, such as, precipitation, dilution by runoff waters, gas exchange, organic

Table 12

Summary Statistics from CANONA Conducted on Paired Sites (N = 26)

Coefficients For Canonical Variables From Parameters Measured Outside of Corridor				
Parameters	First Variate	Second Variate	Third Variate	Fourth Variate
TEMP	0.25705	-0.34877	0.36193	-0.70431
DO	-0.44480	0.36737	0.37646	1.31643
pH	1.01132	-0.26183	0.06718	-0.48145
TSP	-0.73937	-1.31061	0.70151	0.90420
SRP	0.50492	0.92529	0.11063	-0.93957
NO_3	-0.09970	0.21876	0.44062	-0.73626
CA	0.24596	-1.44495	-0.49094	0.09493
TH	-0.28568	1.73739	0.86025	-0.03134
Coefficients For Canonical Variables From Parameters Measured In Corridor				
Parameters	First Variate	Second Variate	Third Variate	Fourth Variate
TEMP	0.49624	-0.39751	-0.16507	-1.34732
DO	0.10916	0.18344	0.16651	0.53753
pH	-0.03422	-0.21659	2.12238	2.33594
TSP	-0.37629	-0.64162	-0.60296	0.13966
SRP	-0.14376	-0.16292	1.61227	1.55491
NO_3	-0.14572	0.43744	1.76388	0.21313
CA	0.31986	-0.18958	1.68009	0.64734
TH	-0.07615	0.48872	-1.74161	-0.29968
Canonical Correlation ($\alpha < 0.001$, all variates)	0.997	0.981	0.955	0.936

decomposition, and growth are sufficiently unrelated in time and space between the locations studied that their effects on water quality are confounded beyond recognition by intercorrelations between the various parameters. Consequently, the most accurate predictions of water quality, on the basis of the paired site data collected during the present investigation, can be calculated from empirical equations (the canonical variates) which are unsound in ecological terms. The investigators do not recommend such an approach. A more useful and ecologically meaningful method for prediction of water quality along the St. Lawrence River would focus on development and use of a deterministic model of the system. A suitable model would incorporate relevant hydraulic and other physical characteristics, as well as the important water quality parameters in arriving at predictions for river reaches of interest.

As a final step in examining the relationships between water quality parameters measured at Morristown sites and the sites at Blind Bay and Brandy Brook, two separate factor analyses were conducted. One factor analytic solution was obtained to describe the major factors which related water quality parameters at Morristown sites, and another was performed to summarize the factors of importance at Blind Bay and Brandy Brook sites. The parameters which were included in the analysis were limited to those which showed significant ($\alpha < 0.05$) simple correlation between measurements in and out of the Corridor (Table 11). During the factor analysis, principal factors were extracted with iteration to improve communality estimates, and a Varimax rotation was employed to yield the final factor matrix. The factor analytic solutions are presented in Table 13 for sites at Morristown and Table 14 for sites at both Blind Bay and Brandy Brook.

Three factors were extracted which accounted for 90.8 percent of the total variance among the parameters measured at Morristown. The most important factor, the first factor, concerned pH, dissolved oxygen, and nutrients. At Morristown, conditions of low dissolved oxygen and pH were associated with elevated levels of both total soluble and soluble reactive phosphorus, and nitrate. This factor partly describes the water quality found at the wetland sites and suggests that aerobic decomposition of organic matter in the wetland areas, with the release of CO_2 (pH reduction) and soluble nutrients, may be the dominant factor in determining baseline conditions of water quality in the Morristown harbor area. It should be noted that total soluble phosphorus and soluble reactive phosphorus are affected nearly equally by the first factor. The second factor indicates that at Morristown sites, high levels of calcium and total hardness were associated with low dissolved oxygen and total soluble phosphorus. The soluble reactive phosphorus was not affected to the same extent as the total soluble fraction, which suggests that reduced levels of soluble organic phosphorus were characteristic of some sites. Again these characteristics are descriptive of wetland water quality at Morristown, particularly during the first month of sampling before thawing ice and snow began to dilute the contents of the wetlands. The third factor involves temperature, pH, nitrate and, to some extent, phosphorus and reflects changing conditions characteristic of the transition from winter to spring conditions on the river. At all Morristown sites as the ice cover was lost and the water

Table 13

Factor Analytic Solution to Relationships Among Water Quality Parameters at Sites in Corridor (Varimax Rotation)

Quantity	Factor #1	Factor #2	Factor #3
% Problem Variance	47.1	30.4	13.3
Parameter	**Factor Loadings**		
TEMP	-0.05605	-0.05785	0.88657
DO	-0.71434	-0.49223	0.04232
pH	-0.65953	-0.02440	0.74706
TSP	0.81555	-0.42223	-0.26472
SRP	0.87498	-0.16868	-0.25431
NO_3	0.48694	0.05744	-0.61094
CA	-0.14511	0.96754	-0.01913
TH	-0.00522	0.98401	-0.09751

Table 14

Factor Analytic Solution to Relationships Among Water Quality Parameters at Sites out of Corridor (Varimax Rotation)

Quantity	Factor #1	Factor #2	Factor #3	Factor #4
% Problem Variance	41.5	19.8	16.9	15.4
Parameter	**Factor Loadings**			
TEMP	0.32032	-0.42436	0.07423	0.65382
DO	0.65385	-0.11511	0.70070	-0.17714
pH	0.87431	-0.17258	0.41628	0.16493
TSP	-0.69971	0.36883	0.40664	0.37774
SRP	-0.67068	0.47361	0.45199	0.19580
NO_3	0.04515	0.20533	0.33422	-0.55470
CA	0.75752	0.61385	-0.17154	0.10797
TH	0.68080	0.68085	-0.21058	0.14848

warmed, pH increased as a result of CO_2 given off to the atmosphere and nitrate declined, possibly as a result of increased river plankton production. The moderate decline in soluble phosphorus fractions which occurred coincident with the nitrate tends to support increased biological activity as the third factor which influenced water quality at Morristown.

To describe the water quality characteristics at Blind Bay and Brandy Brook, four factors were obtained which accounted for a total of 93.6 percent of the total variance among parameters measured at the two locations. The first and most important factor indicates that as the water began to warm, the water quality at sites out of the Corridor were characterized as relatively high in pH, dissolved oxygen, and the hardness cations, but low in phosphorus. These conditions were characteristic of the water quality at channel, shoal, and to some degree near shore and bay sites at the two locations. This suggests that rather than the wetlands, the more open water sites tended to dominate characteristics of water quality at the locations picked for study outside the Corridor at least during the period of this investigation. This conclusion is biased to some extent by the rather small amount of data available for analysis from channel and shoal sites from Morristown. However, it indicates the magnitude of inaccuracy inherent in attempting to select spacially distinct sites in a riverine ecosystem and arbitrarily designate one or two as "control sites" to form the basis for assessing the significance of changes in water quality at a third.

The second and third factors affecting water quality at sites outside the Corridor describe conditions in the wetlands of Blind Bay and Brandy Brook, respectively. Both were characterized by elevated levels of nutrients under ice cover, especially phosphorus at Blind Bay and nitrate at Brandy Brook. However, the ice cover remained longer at Blind Bay and dissolved oxygen and pH stayed at low values under the ice, while hardness cations increased. On the other hand, at Brandy Brook, the ice cover in the wetlands decayed sooner which permitted dissolved oxygen and pH to rise. Low values of calcium and total hardness were characteristic of the Brandy Brook wetland and bay sites alone.

The fourth factor involving water quality at Blind Bay and Brandy Brook was similar in part to the third factor which affected Morristown sites. That is, with the transition to spring conditions, warming waters were associated with declining nitrate concentrations. The relationship was quite general and was observed to occur at all locations with the exception of the Blind Bay wetland sites.

SUMMARY

From the preceeding discussion of water quality at paired sites along the St. Lawrence River it is apparent that some similarities do exist. However, the degree of similarity is generally low and intercorrelations between parameters confound the relationships.

As indicated by the matrix of simple correlation coefficients between individual parameters measured at paired sites (Table 11), only water temperature at Morristown sites could be predicted accurately from measurements of water temperature at the other locations by a simple bivariate regression technique. The second most predictable variable was pH ($r = 0.875$). However, predicted pH values for Morristown sites still left unaccounted more than 23 percent of the variance in pH actually observed at Morristown sites. Such as level of residual variance amounts to a standard error of estimation ($S_{y/x}$) of 0.13 pH units which may provide adequate accuracy for wetland and bay habitats where the range in pH is broad. However, for channel or shoal sites, 0.13 pH units is simply too inaccurate.) The third most predictable parameter was total soluble phosphorus ($r = 0.682$). However, predictions of total soluble phosphorus at Morristown would fail to account for over 53 percent of the variance in total soluble phosphorus found at Morristown sites. None of the other correlated parameters provided sufficiently accurate predictions between locations, when data from all sites formed the basis for predictions.

The multivariate procedure, CANONA, illustrated the potential for quantifying relationships between parameters measured at spacially separated locations, and the relationships so developed were strong enough to account for over 99 percent of the variance in a set of paired site data. However, the relationships so quantified were uninterpretable in terms acceptable to recognized environmental theory. Thus, the use of canonical relationships for predicting water quality was discouraged, since the factors underlying the predictive relationships were unknown. A recommended approach was to model water quality in such a fashion that ecologically sound predictions were possible.

A factor analysis of water quality within the Corridor was compared with a similar analysis of water quality outside the Corridor. The results indicated that the predominant factors which affected water quality, as measured on samples collected at the compared locations, were different and distinct. Thus, while the water quality at Morristown appeared to be influenced strongly by the wetland and bay water chemistry, at the other locations water quality was dependent more on open water characteristics. The difference in factors occurred even though the locations were selected to provide apparently similar types of habitat to study.

CHAPTER 1.V. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The data collected and analyzed during the present investigation lead to the conclusions set forth below concerning water and sediment quality in the St. Lawrence River in the vicinity of the proposed Demonstration Corridor.

1. Water quality in the main flow of the St. Lawrence River was similar to that in Lake Ontario, as was determined from a comparison of a wide variety of water quality parameters between the two bodies of water.

2. Water quality in peripheral areas along the river, particularly wetlands and bays, was independent of water quality in the main flow during periods of ice cover and spring thaw.

3. Water quality in the main flow of the St. Lawrence River showed similarities in magnitude and direction of change for several parameters during the investigation. However, it should be noted that absent from the list of correlated parameters were those which were related to the amounts of particulate matter in the water. Lacking these parameters, a paired site approach will be strongly dependent on water quality parameters which will be relatively unaffected by vessel transits during ice cover. Bearing this in mind, the similarities suggest that main flow control sites established outside a Demonstration Corridor could be paired successfully with sites within the Corridor to predict water quality with sufficient accuracy to test the effects of vessel transit on water quality. However, data collected during the present study indicate that such an approach can be considered valid only for main flow sites, especially channel sites.

4. Water quality at the major locations selected for study, considering all habitat types together, showed relatively low correlation between locations for all parameters with the exception of water temperature. Thus, general and accurate predictions of water quality at sites within the Demonstration Corridor are not possible from simple, direct relationships to parameters measured outside the Corridor.

5. Multivariate relationships developed by CANONA showed a high degree of correlation between locations for all habitat types considered together. However, the relationships so identified were impossible to identify in ecologically meaningful terms due to intercorrelations between parameters.

6. A multivariate factor analysis of water quality at each location showed fundamental differences in the major factor affecting water quality at sites sampled in and out of the Corridor. While open water characteristics dominated water quality measurements taken outside the Corridor, within the Corridor wetland and bay sites had a greater influence on measured parameters.

7. Sediments from wetland and bay sites at Blind Bay, Morristown, and, to a lesser extent, Brandy Brook, showed elevated levels of phosphorus, zinc, and copper.

8. Sediment quality, as determined by several parameters, did not show significant changes between sampling dates at any of the habitat sites. Thus, prediction of sediment quality between locations, based on correlated changes, was not possible.

RECOMMENDATIONS

Based on the data collected and analyzed during the present investigation the recommendations set forth below are presented as a guide to the design of future investigations directed toward assessment of the impact of a demonstration of winter navigation on water and sediment quality in the St. Lawrence River.

1. A paired site approach to assessment of vessel transit impact on water quality, wherein control sites are established outside of the Demonstration Corridor, should focus primarily on main flow habitats: channel, shoal, and nearshore sites. Other types of habitat are not suited to paired site comparisons.

2. Only those water quality parameters which correlate between locations but are uncorrelated with each other should be employed for multivariate paired site comparisons; for example, water temperature, dissolved oxygen <u>or</u> pH, total soluble phosphorus <u>or</u> soluble reactive phosphorus, nitrate, and calcium <u>or</u> total hardness.

3. Further studies of the relationship between levels of suspended particulate matter from one location to another along the river should be performed under non-demonstration conditions. Failure to include a particulate-related parameter which correlates between locations will reduce the effectiveness of a paired sites approach to monitoring demonstration activities.

4. Future studies should be directed toward characterization of the sediments of the Corridor with respect to particle size distribution, potential for resuspension, desorption of nutrients and metals, and biological effects of the latter materials.

5. A deterministic model of water quality, which includes hydraulic as well as important water quality parameters, could provide a more accurate control for assessment of demonstration activities than paired sites comparisons. Development and calibration of such a model should be a focal point for future investigations on the St. Lawrence River.

6. Investigations of time and spacially variant parameters of winter water quality should be initiated no later than a month before the river begins

to freeze over; approximately, mid-November. Water quality parameters are not discontinuous functions of time, and studies designed to predict magnitudes and explain variability of major parameters should not be constrained by time factors which are not related to environmental conditions.

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PART 2

ANALYSIS OF CONTROL SITES: GLACIOLOGY

2.I. BACKGROUND

Last year's report, Ice Survey Studies Related to Demonstration Activities (Marshall, 1978), consisted of survey studies of ice as they might relate to the FY 1979 Winter Navigation Demonstration activities on the St. Lawrence River. This report surveyed the general ice characteristics of the St. Lawrence River, namely the formation of winter ice cover; periods in channel ice history; the extent of ice in average, mild, and severe winters; ice thickness; and the duration of ice cover. The report also dealt with geological ice characteristics: ice as a geological resource, ice as a geological extension of shorelands, and ice as an ice rock canopy; classification of winter ice environments; stages of ice formation; and specific geological snow and ice features such as the St. Lawrence ice bridge, snow ice spots and ridges, migrating snow dunes, and pools along the navigation channel. Seven areas were studied more specifically: Chippewa Bay, Blind Bay, Whaleback Island, Brockville Rock, the ice boom site at Ogdensburg, Tibbit's Creek, and Brandy Brook. One can refer to this original report for any of this more general survey information.

Last year's report also began an inventory of winter and spring geological features of the St. Lawrence River ice cover environments and catalogued the natural changes in the ice of the demonstration area. It also attempted to estimate some of the potential impacts of ships' traffic in this area from studies of the literature and the author's personal experience in the St. Mary's River, Whitefish Bay, eastern Lake Superior, and along the Swedish and Finnish coasts. Basically, the ice survey report of 1978 viewed the ice cover of the 20-mile Demonstration Corridor as a long, narrow, ice rock formation that forms and erodes in various stages in response to climatic and hydraulic conditions along the river and where geological time in terms of ice rock is measured in terms of 30 to 100 days for channels and 100 to 155 days for bays.

One basic conclusion was that the ice cover in the Demonstration Corridor is a naturally unstable medium due to short-term weather fluctuations. Ice cover instability currently has impact on river and critical shoreline environments. Logically one may further conclude that the passage of ships through the Demonstration Corridor will compound any already existing instability.

The purpose of this study and other on-going studies is to determine more precisely the character of the natural instabilities. The ice survey report of 1978 defined four components of the St. Lawrence River ice environment along the Demonstration Corridor: the channel, littoral shelf, embayments, and wetlands. The author chose paired control sites both inside and outside the Demonstration Corridor and in this report will set forth the glaciological framework for these sites, both generally and specifically. This report will plot the patterns of change (instabilities) which now exist, and because control sites outside of the Demonstration Corridor have been included, a controlled background has been established, against which the possible impacts caused by ships' passage can be identified.

2.II. GLACIOLOGICAL OVERVIEW OF THE DEMONSTRATION CORRIDOR

In this study, it is useful to view the ice cover of the Demonstration Corridor as a long, narrow, ice rock formation some 32 km (20 mi) in length. This concept provides a scientific framework within which to examine the changing structural and stratigraphic characteristics of ice down the length of the corridor. See Figure 6.

Primarily on the basis of general structural features, this floating formation can be divided into four distinct geological units which cover the waters of four corresponding reaches. Some stages of ice formation and erosion in the corridor occur nearly simultaneously in all four reaches, while in other stages each reach develops distinctive glaciological characteristics. These are determined in part by natural conditions and in part by the placement of engineering structures. During ice formation and erosion, various river environments become covered, uncovered, and subject to ice scour on a schedule which reflects the interaction of regional meteorology with bathymetric and hydraulic conditions that are the result of a wide variety of natural and dredged conditions in channel and shoal areas, time of placement and removal of ice booms, and river flow control. Thus, to a large degree, the ice characteristics of the Demonstration Corridor today are the product of a closely orchestrated series of engineering decisions.

This study seeks to make a general evaluation of the relative glaciological stability of various components of the St. Lawrence River environment within the four reaches comprising the Demonstration Corridor by utilizing the present data base of air photo indexes and aerial ice charts, together with field data obtained on bay and wetland sites during the late winter and early spring of 1979. In addition, it seeks to gain a general understanding of the natural glaciological stages and processes occurring in the Demonstration Corridor.

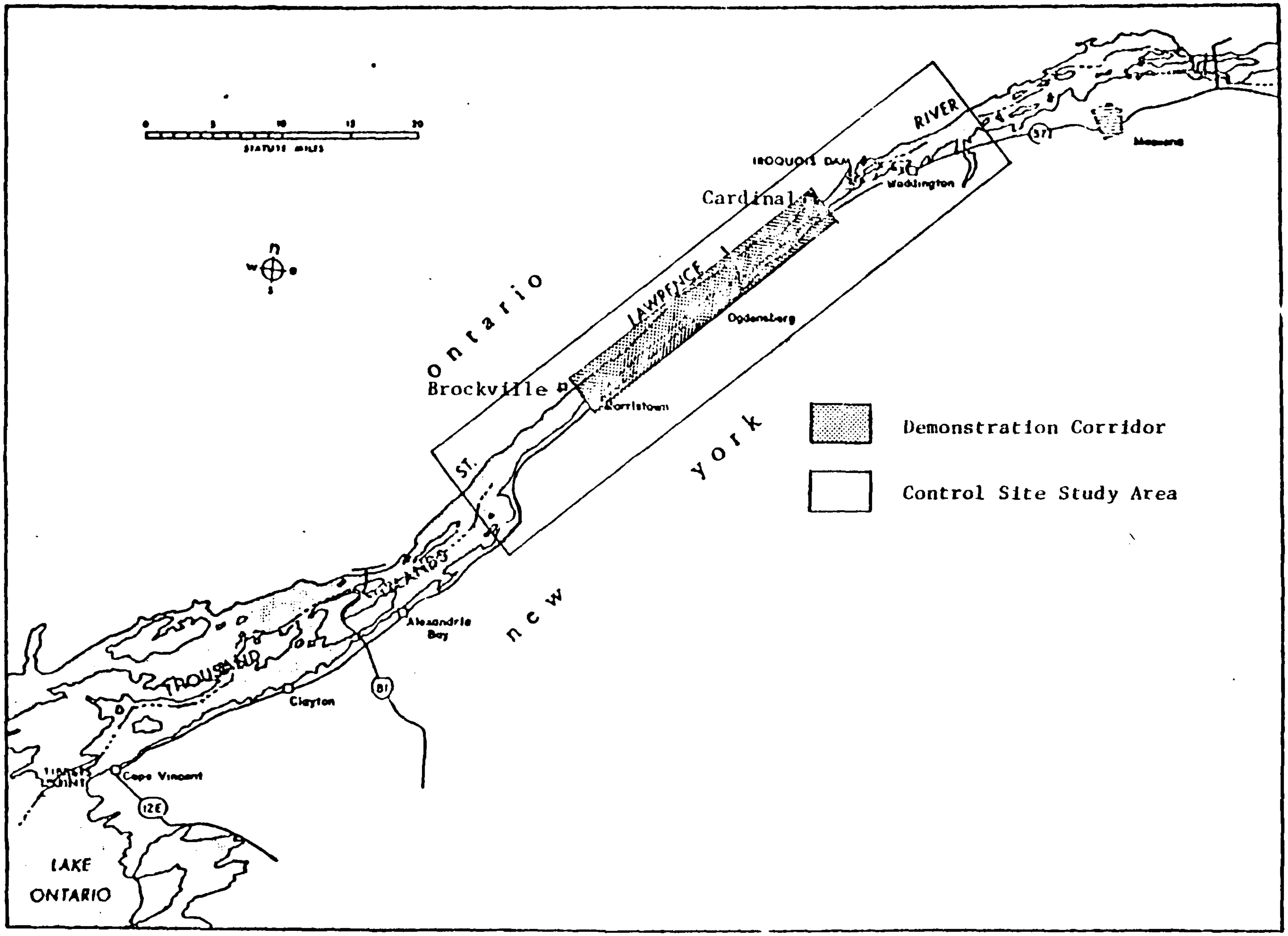


Figure 6. St. Lawrence River Demonstration Corridor and Control Site Study Area.

2.III. REACHES OF THE DEMONSTRATION CORRIDOR

In general discussions of winter navigation, the Demonstration Corridor is viewed as a narrow expanse of ice through which ships will travel. However, when the corridor is examined from an engineering and glaciological standpoint, this expanse of river or corridor can be variously subdivided, depending on the combination of parameters used. To date two approaches have been used. The first was presented in the St. Lawrence Seaway System Plan for All-Year Navigation (SPAN) (Arctec, 1975). The Seaway was divided into sixty subreaches from Montreal Harbor to Tibbett's Point, Lake Ontario, based on the constancy of hydraulic parameters (cross-sectional area, roughness, slope), navigational difficulty (breadth of navigable water), and glaciological behavior. They were developed primarily to aid the mathematical modeling of ship transit through the Seaway under winter conditions. Within this system plan, nine subreaches (#42 to #50) covered the Demonstration Corridor. They are seen in Figure 7 in relation to the Demonstration Corridor and to the basic glaciological reaches discussed in this study.

This study takes a second and slightly different approach and limits the basic subdivisions of the corridor to only glaciological parameters. This approach allows the present process of ice formation and erosion to define the naturally occurring units. On this basis the Demonstration Corridor is divided into the following four reaches: (1) Brockville Narrows, (2) Morristown Point-Ogdensburg, (3) Ogdensburg Ice Boom, and (4) Galop Island. Within this framework of reaches, the detailed ice characteristics of control sites located in specific river environments can be more readily evaluated.

BASIS OF DEFINING REACHES

Concurrently with the control site study, the writer investigated the glaciological characteristics of pools (open water areas in the ice cover) within the immediate area of influence of the Demonstration Corridor. It was found that within the ice cover, pool location and geometry were extremely sensitive indicators of bathymetric and hydraulic conditions (Marshall, 1979) and are two of the most distinctive features in defining glaciological reaches.

These glaciological reaches, defined in part by both natural conditions and by engineering structures, are units of the river where processes of ice formation and erosion have similar characteristics under pre-navigation conditions. Bathymetry is the primary basis for defining two reaches of the corridor, the Brockville Narrows and the Morristown Point-Ogdensburg Reaches, while the placement of ice booms defines the Ogdensburg Ice Boom and Galop Island Reaches. As more field data on ice characteristics is obtained in these reaches and additional information abstracted from the existing data base of aerial photos and ice charts, further glaciological subdivisions may be possible. These divisions serve as a useful first approach in understanding ice formation and erosion in the Demonstration Corridor.

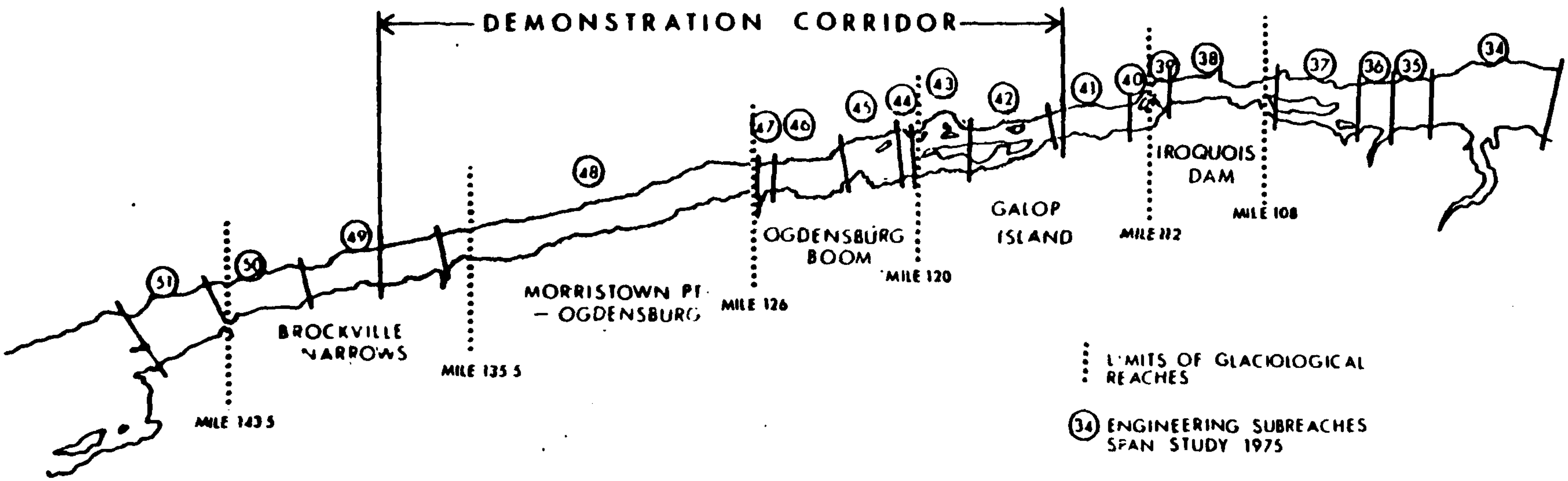


Figure 7 . Location of the St. Lawrence River Demonstration Corridor in Respect to Glaciological Reaches Defined by This Study and Engineering Subreaches Defined by the SPAN Study.

The basis for defining the four glaciological reaches included within the Demonstration Corridor is seen in Figures 8 to 15. For each reach there is included a bathymetric chart, a map of pool geometry, as well as a series of bathymetric cross sections down the length of the reach which further defines the natural bathymetry of the Demonstration Corridor.

The characteristics of each of the four reaches comprising the Demonstration Corridor are as follows:

BROCKVILLE NARROWS REACH

The reach designated as the Brockville Narrows extends from the vicinity of Oak Point, Kilometer 230.9 (Mile 143.5) to Morristown Point, Kilometer 218.0 (Mile 135.5). This 12.9 km (eight mi) reach is characterized by deep, narrow channels which pass through a complex network of islands and shoals, giving rise to a wide variety of pool shapes and sizes. Throughout this reach the navigation channel passes close to the Canadian shore, where water depths range from 9 m (30') to 43 m (140'). This great variation in water depth over short distances creates extensive upwelling.

The distinctive bathymetry of this reach is brought out by outlining the 6', 12', 18', and 24' contours, as seen in the upper portion of Figure 8. The effect of this bathymetry in controlling the pattern of ice formation and the presence of pools is seen in the lower portion of Figure 8. It should be noted that the major pools lie principally in areas deeper than the 24' contour, while the minor pools are located upstream of small shoals.

Only approximately 2 km (1.2 mi) or 6% of the Demonstration Corridor lies within this reach; nevertheless, the unit is treated as a whole since the pattern of ice formation and erosion between Oak Point and Morristown Point proceeds as a unit. Downstream of Morristown Point, the bathymetry is quite different.

The series of bathymetric cross sections (#1 to #8) for the Brockville Narrows Reach seen in Figure 9 illustrates the uniqueness of this section of the river. A section across eastern Chippewa Bay (#1) is included at the top of this figure to illustrate the diversity of riverine habitats outside the Demonstration Corridor; these are attributable to breadth of the river and bottom topography.

The stages of ice formation and erosion in the four reaches of the Demonstration Corridor are discussed in Chapter 2.V.

MORRISTOWN POINT-OGDENSBURG REACH

This 16.9 km (10.5 mi) reach extends from Morristown Point, Kilometer 218.0 (Mile 135.5), to the Ogdensburg ice boom, Kilometer 201.1 (Mile 125), just upstream of the mouth of the Oswegatchie River. Approximately 50% of the Demonstration Corridor lies within this reach.

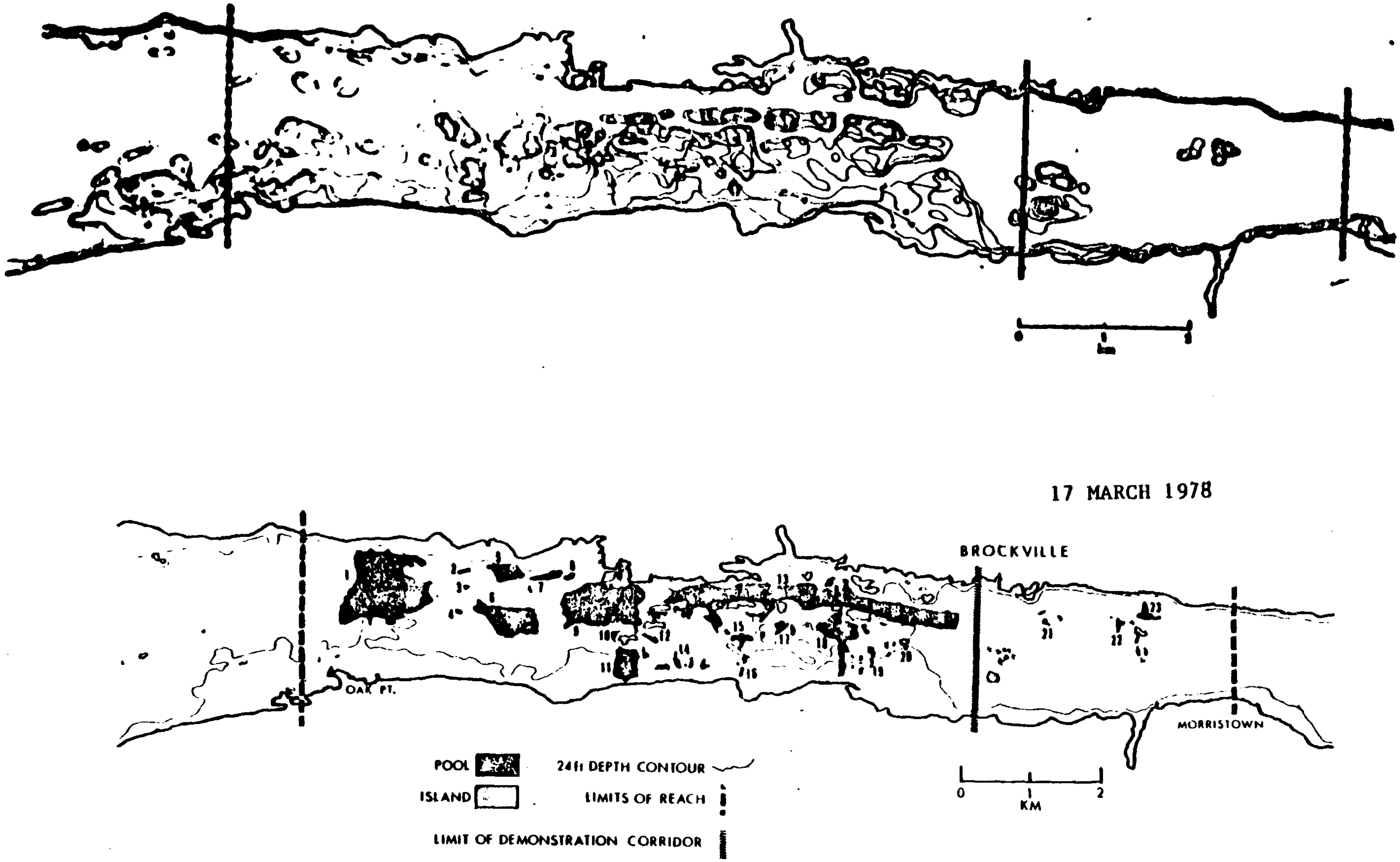


Figure 8. Relationship Between Bathymetry and Pool Geometry, Brockville Narrows Reach. Winter 1977-78 (Severe).

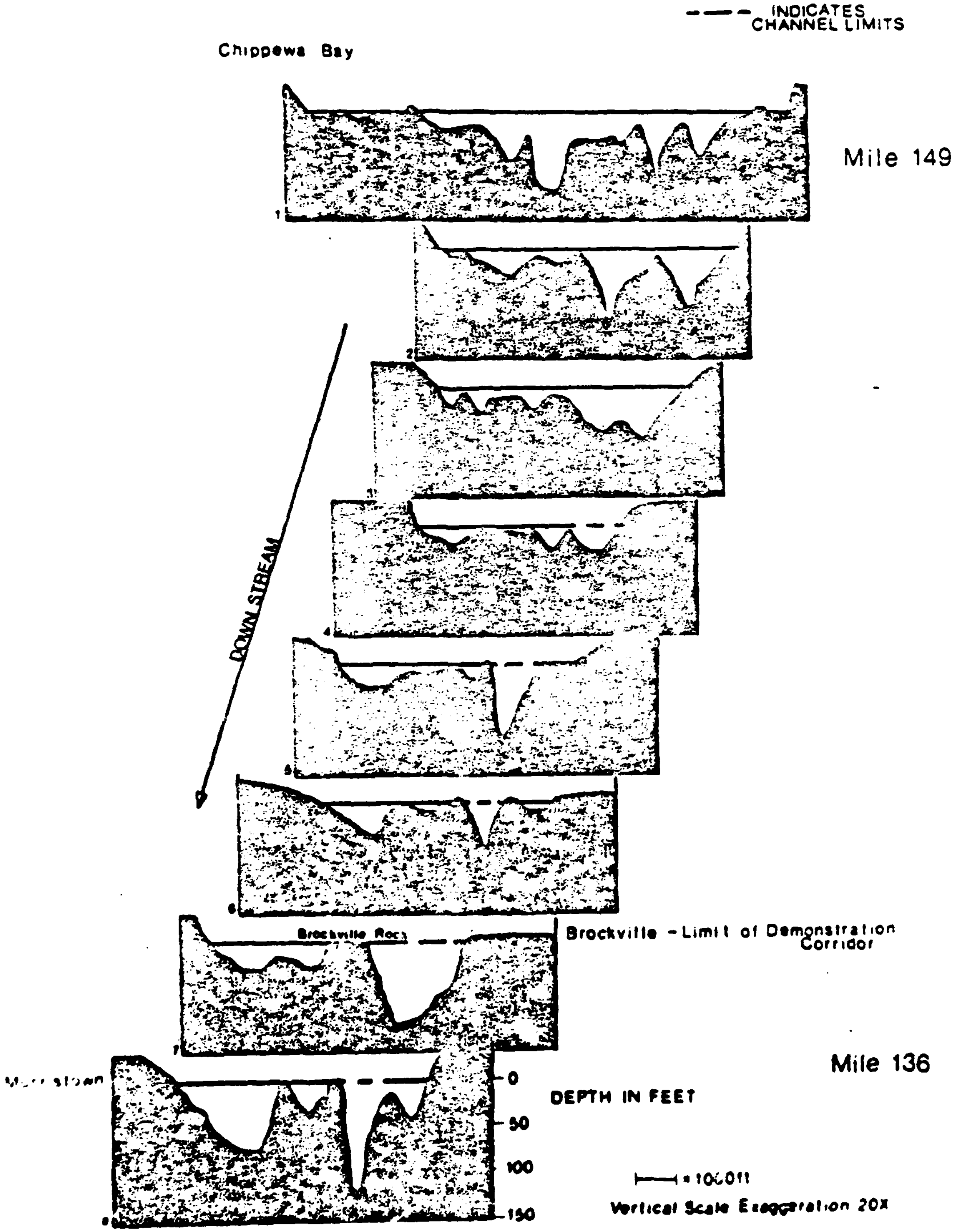


Figure 9. Bathymetric Cross Sections, Brockville Narrows Reach, St. Lawrence River.

Basically, it is a long trench with very little bottom relief and an exceedingly narrow littoral zone. The bathymetry of this reach is seen in the upper portion of Figure 10 where the 12' and 24' contours define this littoral zone. On the U. S. shore the zone varies from approximately 50 m to 500 m and is widest in the Nevin's Point and Ogdensburg area. Along the Canadian shore this zone varies from 50m to 600 m and consists of several broad reentrants connected by narrow littoral zones. Water depths in the channel areas range from 14.9 m (49') to 23.2 m (76').

In contrast to the Brockville Narrows Reach, the pattern of open water areas reflects packing of ice floes, shear cracks, and thermal cracks kept open by currents rather than upwelling off irregular bottom topography. In Figure 11 a series of bathymetric cross sections (#8 to #16) down the length of this reach illustrate the transition from the irregular bathymetry of the Brockville Narrows Reach (Section #8) to the smooth, trough-like characteristics of this reach (Sections #9 to #16).

OGDENSBURG ICE BOOM REACH

This reach extends from the Ogdensburg ice boom located just north of the mouth of the Oswegatchie River, Kilometer 202.7 (Mile 126), to the downstream end of Chimney Island Shoal, where the Galop ice boom is anchored, Kilometer 193 (Mile 120). This 9.7 km (6 mi) reach of river includes Ogdensburg harbor, Weedhouse Bay, the Chimney Point ice boom, and a series of shoals upstream of Chimney Point which extend out into the channel and on which the Ogdensburg bridge abutments are located. Thirty percent (30%) of the Demonstration Corridor is located in this reach.

Downstream of Chimney Point the channel is narrowed by Chimney Island and Chimney Island Shoal, while on the Canadian shore the channel is restricted by Drummond Island and a broad, shallow littoral shelf. On the U. S. shore, the channel swings into Chimney Bay, a former broad meander of the St. Lawrence River. Tibbits Creek flows into this bay. On the U. S. shore, the width of the littoral zone varies up to 600 m, having its widest part in the vicinity of Weedhouse Bay. The broadest littoral zone, 900 m, exists along the Canadian shore in the vicinity of Johnstown, Ontario.

Figure 12 indicates the effects of boom location (Ogdensburg ice boom) in defining the upstream limits of the reach and the 24' depth contour in determining the lateral extent of the pool.

A series of bathymetric profiles (#15 to #20) detail the characteristics of this reach of the river. See Figure 13.

GALOP ISLAND REACH

The Galop Island Reach, viewed glaciologically, extends downstream from Kilometer 180.2 (Mile 112) to Kilometer 193 (Mile 120) at the Iroquois Dam. This reach contains three channels: the main channel, which is the navigation channel, passes immediately along the northwest side of Galop Island; the shallow north channel, formerly part of the old

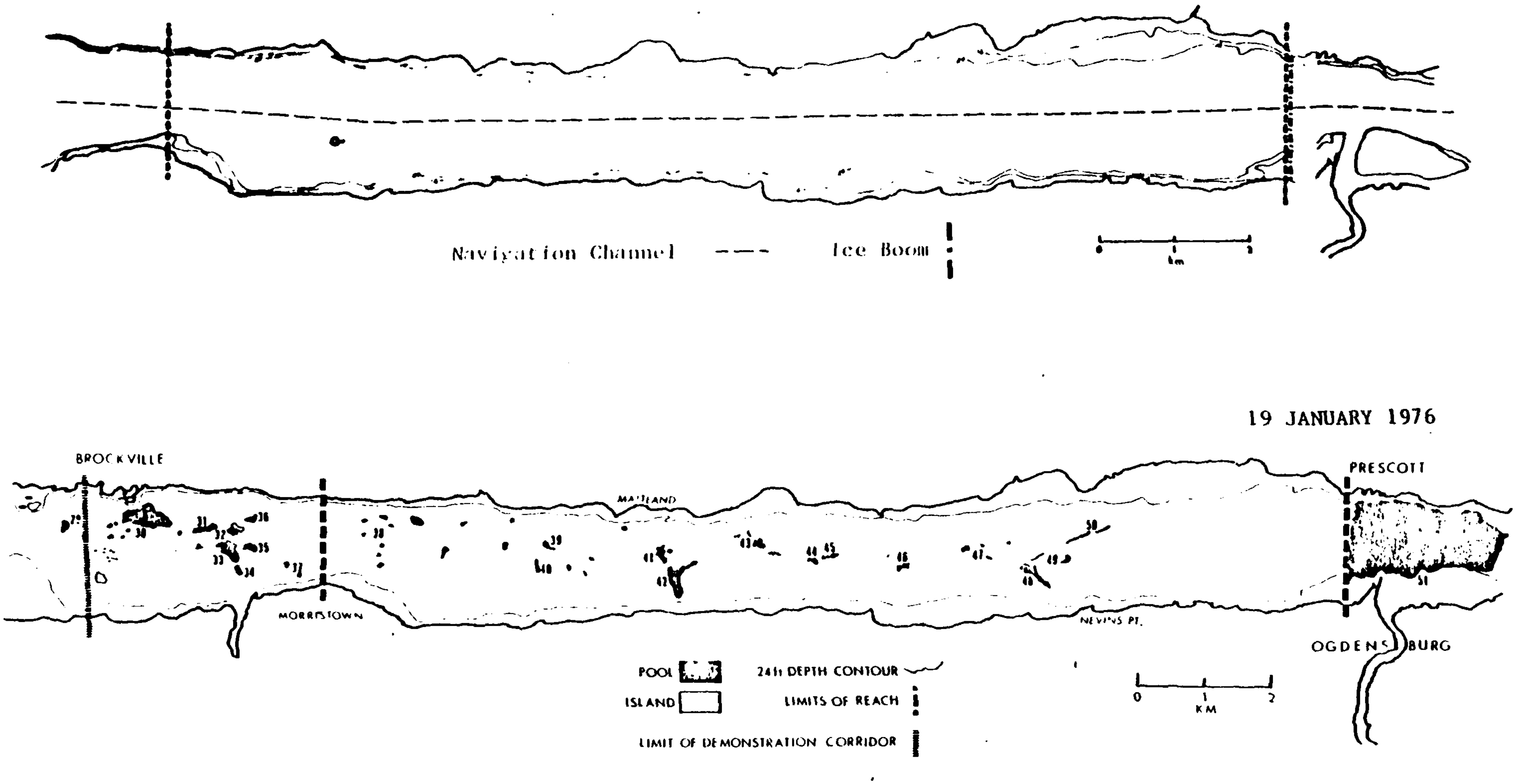


Figure 10. Relationship Between Bathymetry and Pool Geometry, Morristown Point-Ogdensburg Reach. Winter 1975-76 (Mild).

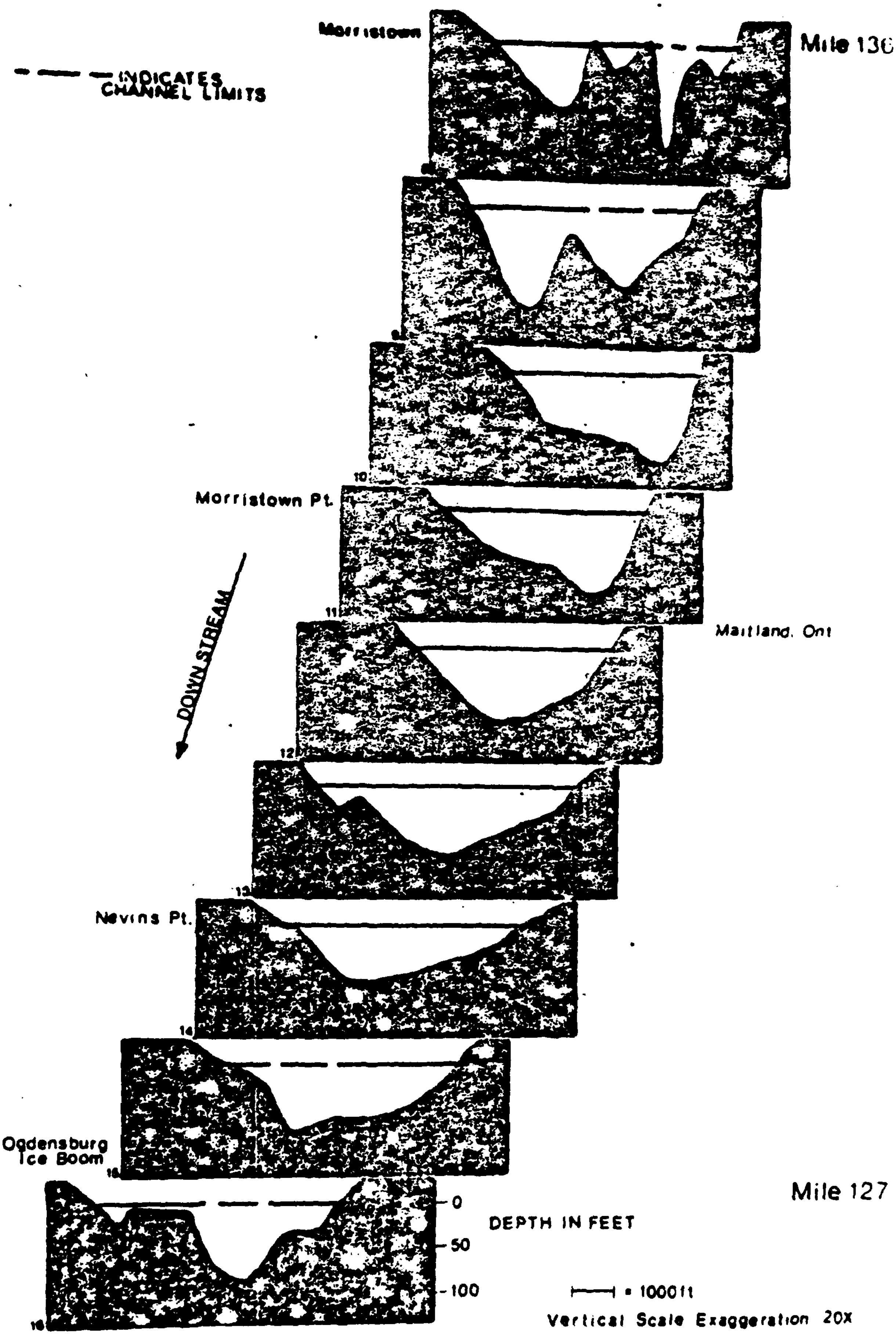


Figure 11. Bathymetric Cross Sections, Morristown Point-Ogdensburg Reach, St. Lawrence River.

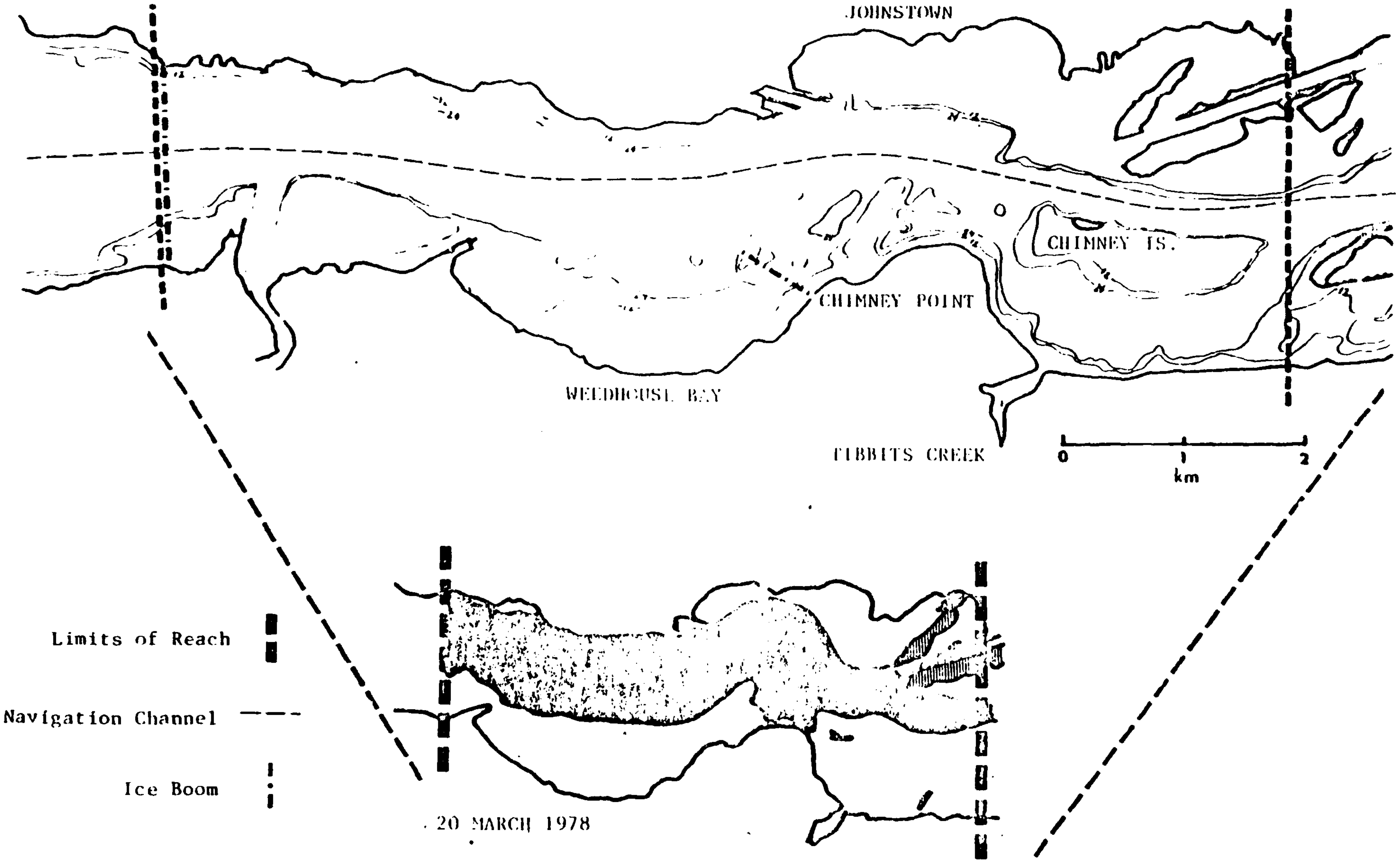


Figure 12. Relationship Between Bathymetry and Pool Geometry, Ogdensburg Ice Boom Reach. Winter 1977-78 (Severe).

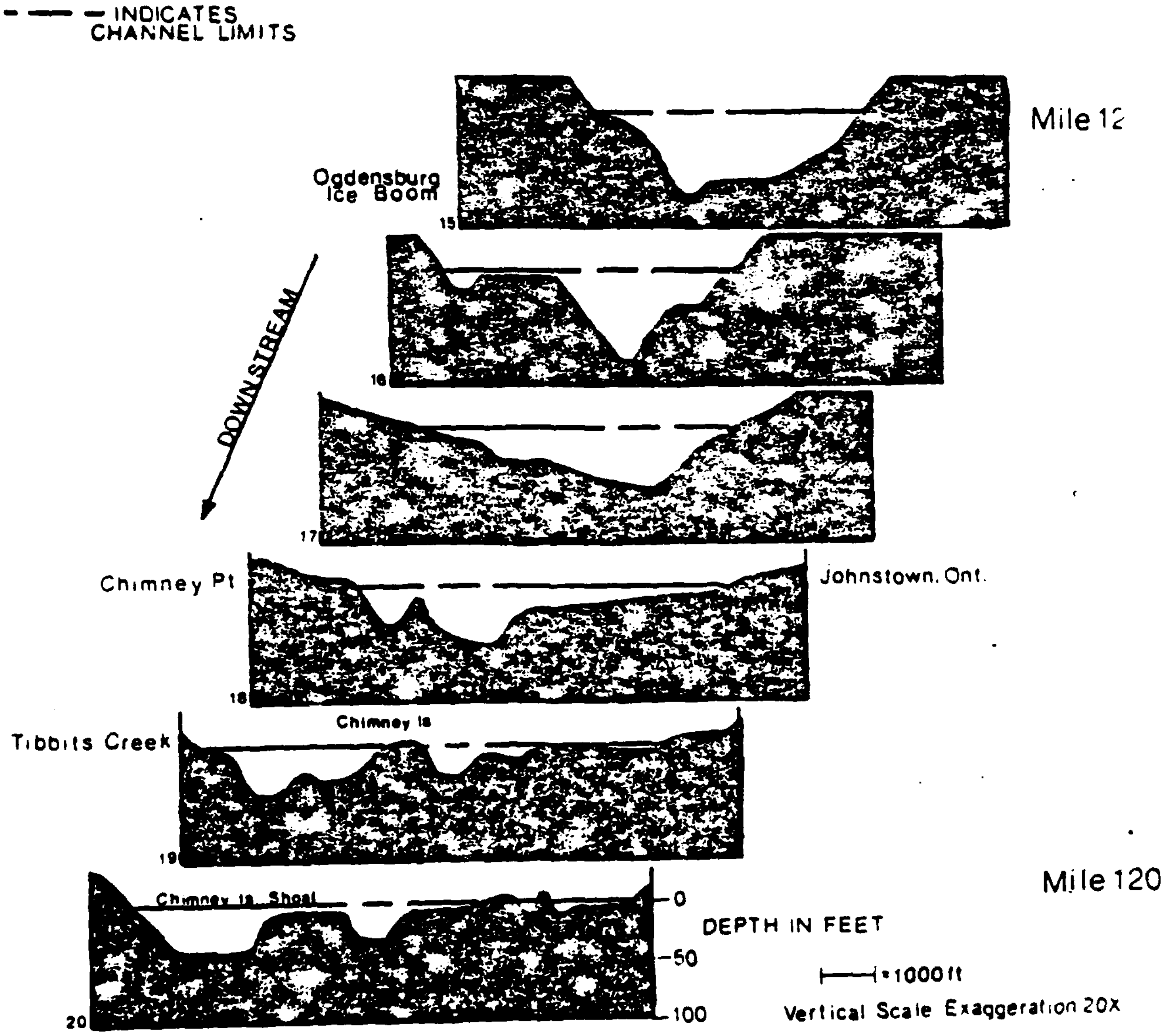


Figure 13. Bathymetric Cross Sections, Ogdensburg Ice Boom Reach, St, Lawrence River.

Galop canal, takes a broad swing along the Canadian shore and joins the main channel midway down Galop Island; and the south channel. The area of the main and north channels is characterized by small irregular basins, 6 m to 10 m (20' to 32') in depth, set in on broad littoral areas where water depths range up to 4.6 m (15'). The south channel is characterized by an irregular bed consisting of a series of roughly elongated basins with water depths of 7.6 m to 10 m (25' to 34'), separated by shallow thresholds. See Figure 14.

Prior to the construction of the Seaway, the river flow was split around Galop Island (then unmodified in shape by dredge spoils) through the Canadian and American Galop rapids. Today, 56% of the river flow passes through the main dredged Seaway channel, 20% in the Canadian channel north of Prison Island, 4% in the narrow channel south of Prison Island cut by the international boundary, and the remaining 20% in the south channel (Adams, 1979).

Figure 14 illustrates the existing Galop Island boom system, which is composed of four individual booms. From north to south, these booms are referred to as the north Galop boom (Boom E), the main Galop boom (Boom G), the Galop boom (Boom C), and the south Galop boom (Boom D). (St. Lawrence Seaway Development Corp., 1978)

Pool geometry defines this reach as extending from Boom E and G to the Iroquois Dam. The downstream limit of the Demonstration Corridor is located at Frazer Shoal just below Cardinal, Ontario, about midway down the reach. The main Galop channel is largely open water, since the lateral limits of the pool are approximately defined by the 24' depth contour. Ice covers the shallow littoral areas in the north and south channels.

In Figure 15 a series of bathymetric cross sections (#20 to #30) further defines the characteristics of this reach.

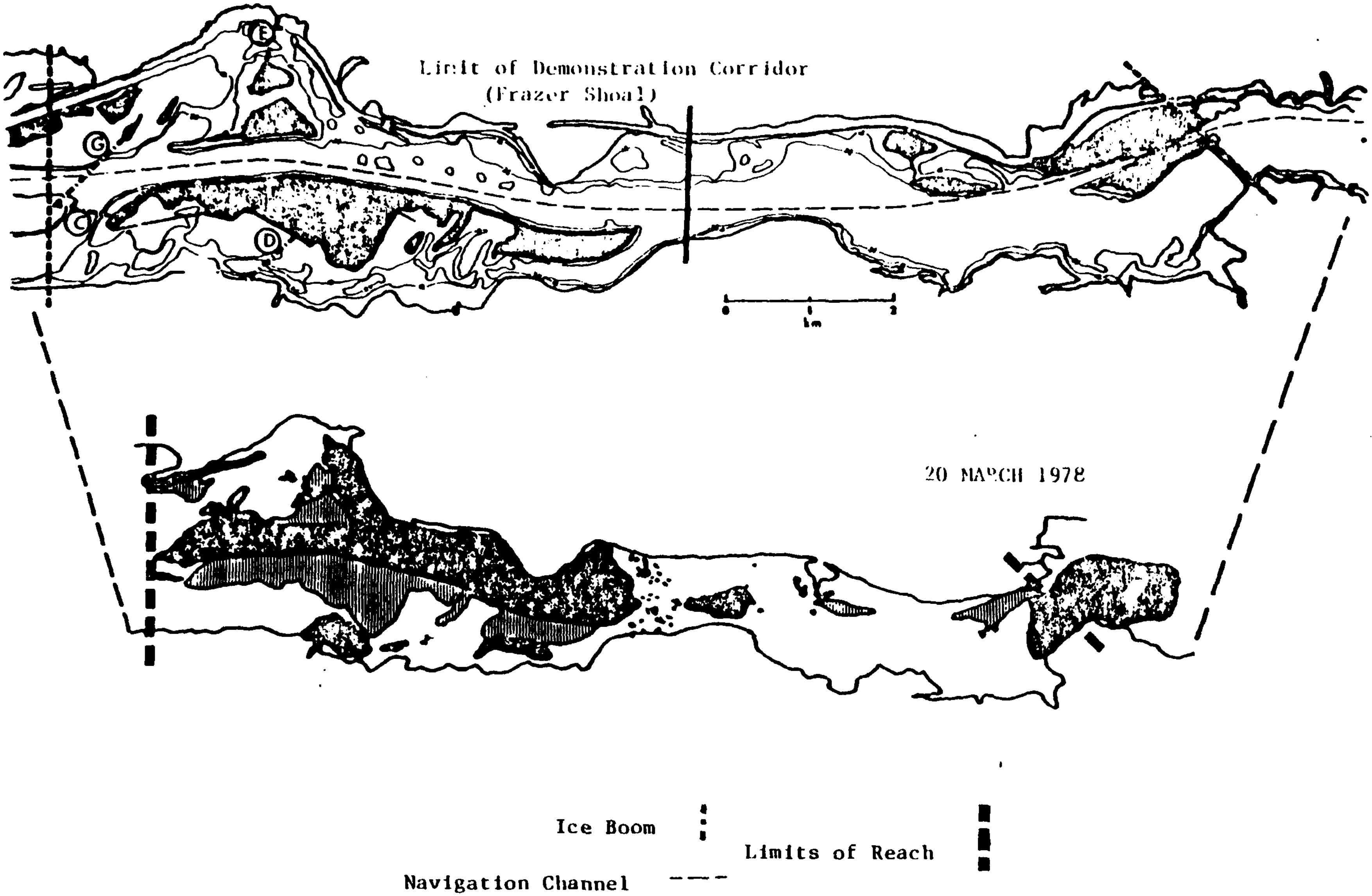


Figure 14. Relationship Between Bathymetry and Pool Geometry, Galop Island Reach. Winter 1977-78 (Severe).

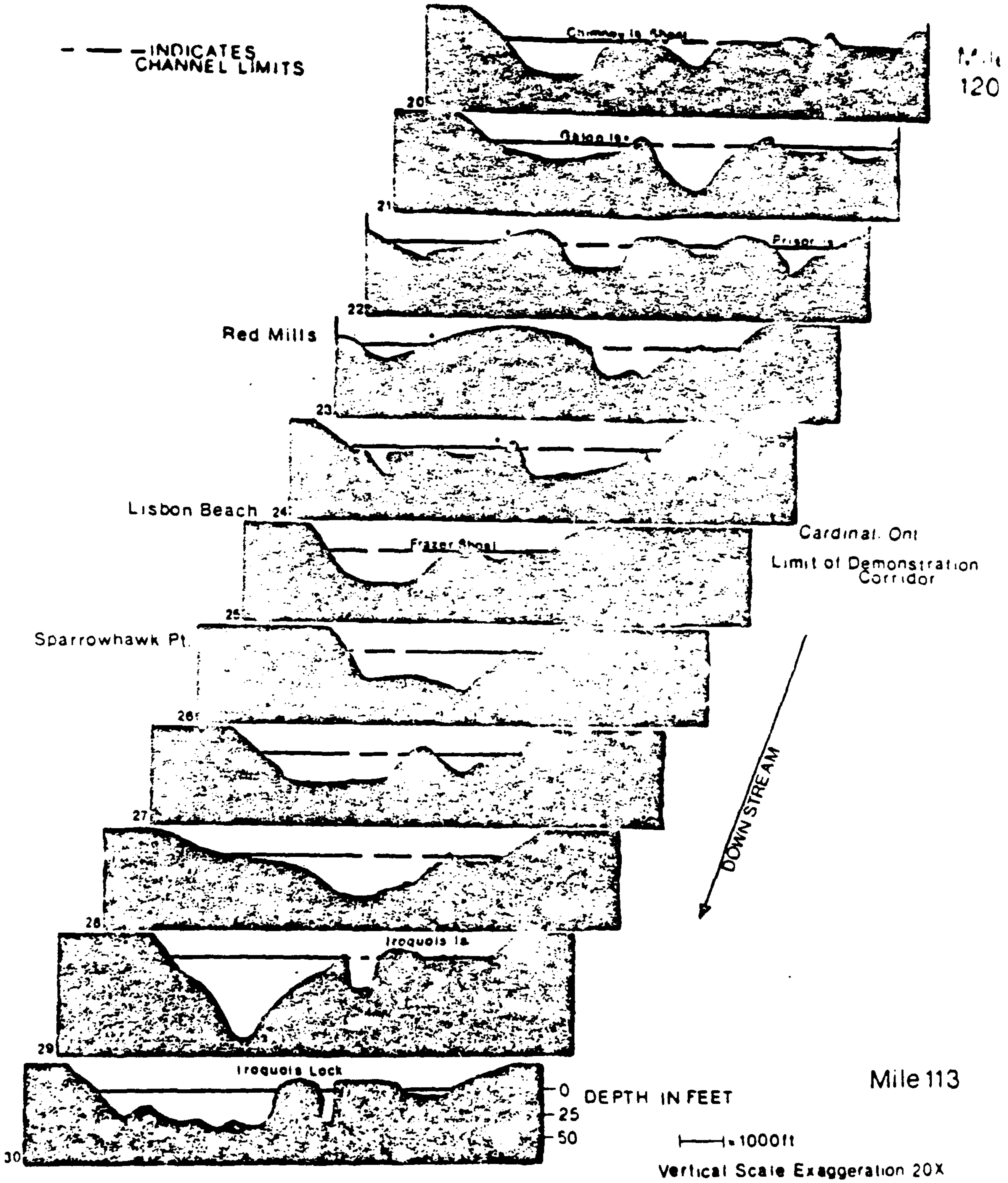


Figure 15. Bathymetric Cross Sections, Galop Island Reach, St. Lawrence River.

2.IV. METHODOLOGY

ICE INFORMATION

Air Photo Indexes

Air photo indexes were a primary source of information on various stages of ice formation and erosion within the Demonstration Corridor. The corridor was usually contained on two index sheets of approximately 50 x 135 cm, which included the reduced images of about thirty overlapping photos.

The major limitation of these indexes was the fact that photomapping usually began early in January, when the river was already ice-covered. Thus little data is available over a series of winters on the stages of ice formation and the characteristic glaciological features. See Appendix D for a list of dates of U. S. aerial photomapping. In addition, the timing of flights at 7 to 10-day intervals did not always pick up the short-term changes which occur during ice formation and erosion. Although suitable weather is a factor at these times, the photomapping flights need to be tuned to the timing of ice formation and erosion rather than be pre-scheduled. Recommendations for flight scheduling need to come not only from those in operational authority but also from those carrying out glaciological studies.

Another significant limitation of the indexes occured during the periods of one to two weeks following heavy snowfalls. The definition of snow-covered areas is poor, and ice detail is masked.

Aerial Ice Charts

Aerial ice charts prepared by the Canadian Ice Central, Ottawa, and made available by the St. Lawrence Seaway Authority, Cornwall, Ontario, were used to follow ice formation and erosion in the intervals not covered by aerial photomapping. See Appendix D for dates of Canadian aerial ice reconnaissance in the years used for parts of this study.

FIELD

The glaciological portion of the control site study was constrained by problems which were compounded by the late winter starting date. The type of ice data needed to evaluate control sites located in the various winter environments must start at the time of initial ice formation and extend through the period of ice erosion, a period which normally begins late in November and extends into early April, approximately 100 to 150 days. The political and administrative delays caused a mid-February starting date, and a ten day period of unseasonably high temperatures (mid-forties to low seventies) along the St. Lawrence River beginning in mid-March (maximum 73°F on 23 March 1979) limited the ice season to 30 to 40 days within which to organize, equip the field study, and collect samples.

The following sections discuss problems encountered this past winter as an aid to planning future studies.

Personnel

Because of the late starting date, it was not possible to hire full or half-time student assistants with firm time committments to the project. Thus it was necessary to arrange for an eight-man pool of students from the geology department, SUC Potsdam. The coordination of student availability and vehicles with weather conditions was often difficult. However, this method was used to carry out the sampling in the few remaining weeks of the winter. The normal student committments to term papers, spring field trips, and exam periods acted to slow data reduction. Following the end of the academic year in May, full-time student assistants gradually became available.

Where winter field projects utilize student assistants, it is necessary to organize the project with sufficient lead time (some six months prior to the beginning of the field season), so that students can be recruited, time committments coordinated with academic schedules, and financial conditions arranged.

The personnel problem more than any other argues for organizing these studies on at least a three year base so that trained student assistants would be available. Under a work-study program, academic credit could be arranged for the winter field training and the research performed.

Transportation

The original plan of study called for the use of airboats to reach offshore sites and snowmobiles to sample the shallow water wetland, bay, and shore sites. However, it was not possible in this year's study to arrange the use of an airboat because of time constraints. The principal modes of transport were snowmobile and man-haul toboggans.

As an aid in planning future studies, something needs to be said in regard to the problems encountered in securing insurance coverage and about safety factors in airboat operation and snowmobile use.

Insurance. The insurance requirements of the sponsoring institution demanded that the airboat owner, as a private carrier, obtain a comprehensive liability policy before personnel used the airboat. Only two airboats are available in this section of the St. Lawrence River; of these, one was interested in providing services to the winter navigation studies. It was found that private airboat owners do not have an insurance history with which to obtain such coverage. Local insurance agents (where knowledge of river conditions is the best) refused to take this risk and passed the decision on to home offices far removed from the scene.

The airboat owner aggressively pursued the quest for insurance but was met with repeated refusals and delays. When possible insurance carriers were located very late in the season, the quoted rate was prohibitively expensive for the short time the ice cover might remain, particularly in view of the fact that the ice had already begun to rapidly erode due to the unseasonably warm air temperatures mentioned earlier.

Safety Factors. A government-owned, commercially available, fiberglass airboat was in operation investigating hanging dams in the Ogden Island channels during the winter and spring of 1979. Project restrictions did not allow this airboat to be used in Demonstration Corridor control site studies. However, the writer had the opportunity to accompany the hanging dam study and to observe the operation of this particular model airboat, both of which are pertinent to future control site studies. Questions are raised concerning hull construction, freeboard, caging of airplane propellers, and rudder construction.

Winter operations in a small boat (airboat) in the St. Lawrence River channel with ice floes and currents up to 5 ft/sec have the potential of being hazardous. Adequate lead time for planning can greatly reduce these objective risks. Time is needed to carefully consider the design, materials, and powerplant needed for an airboat adequate for safe winter operation on the St. Lawrence River, and the question needs to be raised whether this boat, originally designed for the Florida Everglades and modified for Arctic lake and snow-covered tundra use, has been adequately redesigned for the rough ice and currents found in many winter reaches of the St. Lawrence. The experience of the U. S. Coast Guard station, Bay City, Michigan, in the use of a re-enforced, aluminum hulled airboat should be considered.

For those more familiar with other Great Lakes environments, a frank statement needs to be made--the St. Lawrence River is not a lake where breaking through on foot can be no more than an inconvenience. Currents over most of the river environment under study are sufficient to carry personnel beneath the ice. In channel areas it is common to see heavy floes of winter ice many times the size of airboats flip up on edge and then disappear under the ice cover when caught by currents on downstream ice edges.

Questions regarding the integrity of the present fiberglass hulls have been raised by reports of cracks and strips of fiberglass detaching themselves, resulting from possible fatigue after operating in rough ice. The writer's own experience when underway in fast-moving channel waters raised doubts whether there is adequate freeboard designed into the hull. A bow wave reflected off an ice edge met an oncoming wave, increased the amplitude, and when the boat slid into the resulting trough, heavy water was taken aboard, half filling the boat. It nearly stopped dead in the water and was being carried by currents into an ice edge situation until full power was applied and the boat slowly labored out onto the ice cover, where drain cocks were pulled.

Other situations, e.g., when rudders (which deflect the airstream) vibrated loose or when welds holding the protective cage around the airplane propeller broke and required bailing wire repairs while in channel areas, suggest that the current design of airboats is inadequate.

Other events late in the winter stressed the need for stringent safety and operative procedures, or tragedies will result. There has to be an awareness of the potential field problems that can result from political and administrative delays in setting up winter field studies.

During mid-winter at times of very low temperatures, offshore sites near or on the channel have been reached by snowmobile. However, it requires the services of someone who has a great deal of winter knowledge of the river and can not be used as a standard operating method of investigating offshore control sites, for the risks are too great. The writer's study of the glaciological characteristics of pools in various reaches of the river (Marshall, 1979) demonstrated the short-term fluctuations of ice cover thinning and pool formation that take place in offshore areas.

Sampling

Originally, it was planned that the samples collected during the coldest part of the winter would be sawed-out blocks, since cores at this time have a tendency to break into wafer-like sections due to the increased hardness and resulting brittleness. However, because of the late winter start and the warmer ice temperatures, the samples collected in wetlands, in shallow bays, and along shorelines were primarily 3" diameter cores obtained with a C.R.R.E.L. ice auger.

Transects were laid out at right angles to and parallel with wetland edges, bay mouths, and shorelines. Cores were logged and placed in narrow, plastic freezer bags with one label placed inside the bag and another one tied to the top. Plastic bags which are slightly larger than the core diameter aid in keeping the core segments in stratigraphic sequence. The bagged cores from a given transect were then placed in large, heavy guage, plastic trash compactor bags and closed with a twist tie.

Individual ice blocks were sawed out of the ice cover with a large, hand ice saw of a style formerly used in harvesting ice. They were removed from the cover with ice tongs, placed in large plastic compactor bags, and labeled.

Because most of the sampling was carried out at near or well above freezing temperatures and often under sunny conditions, it was necessary to store and transport the bagged cores in extra-large (64 gallon), plastic, picnic-type coolers with a packing of snow. During late March and early April, pre-frozen cooler trays were distributed among the cores, in addition to snow, to prevent melting due to the unseasonably high temperatures. The coolers were dragged on toboggans behind a snowmobile or were man-hauled.

Ice Storage

At first, ice samples were stored in a single twenty cubic foot, top opening deep freeze. However, because of the lateness of the season and the unusually warm weather, it was necessary to greatly accelerate sampling, and the volume of samples soon outran the available storage space. Samples were then stored in a small, rented, walk-in space for ice cube storage. Later in the spring, when this was required for commercial purposes, samples were transferred to a second twenty cubic foot deep freeze and into a portion of a small walk-in refrigerator located on the Clarkson campus.

Laboratory

A small trailer located on the Clarkson campus and equipped with a lab bench was used as an unheated working space. The two twenty cubic foot refrigerators were outside and adjacent to the trailer. A small bandsaw was purchased for sawing ice blocks.

One of the purposes of the control site study was to investigate the structure and stratigraphy of the ice canopy over various winter river environments. To this end, ice cores were illuminated by diffused, transmitted light and were photographed, using a 35 mm camera. See Figures 21 and 22, for example.

2.V. ICE CHARACTERISTICS OF CONTROL SITES

This chapter sets forth the ice characteristics for paired control sites both outside and inside the Demonstration Corridor by assembling the field data collected during late winter and early spring 1979 by this study and by drawing from published and unpublished reports on St. Lawrence River ice conditions. Three sites, Morristown Harbor, Nevins Point, and Tibbits Creek, were selected as control sites within the Demonstration Corridor; Blind Bay and Brandy Brook, located outside the corridor, served as upstream and downstream controls respectively. Chippewa Bay, with its varied riverine environments, served as a general control area for comparisons of ice cover duration.

The various control sites will be discussed beginning with Chippewa Bay and proceeding downstream through the following four reaches included within the Demonstration Corridor: Brockville Narrows, Morristown Point-Ogdensburg, Ogdensburg Ice Boom, and Galop Island. The Brandy Brook area, located just outside the corridor, serves as the downstream control.

CHIPPEWA BAY

Chippewa Bay, with its broad and varied shallow littoral areas, has one of the longest periods of ice cover of any area along this stretch of the river and can serve as a control for other sites along the corridor.

Figure 16 indicates the various zones used for comparing the duration of ice cover on bay and channel environments. The inner bay (Zone I), where the first ice cover forms from mid-late November to mid-December, extends out to approximately the 12' contour. Ice formation on the outer bay (Zone II) is usually delayed from two to four weeks and extends out to about the 30' contour. Ice formation gradually extends out onto the channel area, usually within one week where water depths are greater than 30'.

Ice cover duration for the various zones on Chippewa Bay was determined from Canadian aerial ice charts for the fourteen-year period 1965-66 to 1978-79. See Figure 17 . Ice cover duration studied in this detail for the ice-forming zones on Chippewa Bay can be compared in some respects to Lake Munuscor St. Mary's River. However, comparable aerial observations on the patterns of ice formation and erosion have not been made over that area.

The variations in ice cover duration for inner and outer Chippewa Bay and channel are as follows:

Inner Bay	64+ to 139 days
Outer Bay	56 to 136 days
Channel	52 to 116 days

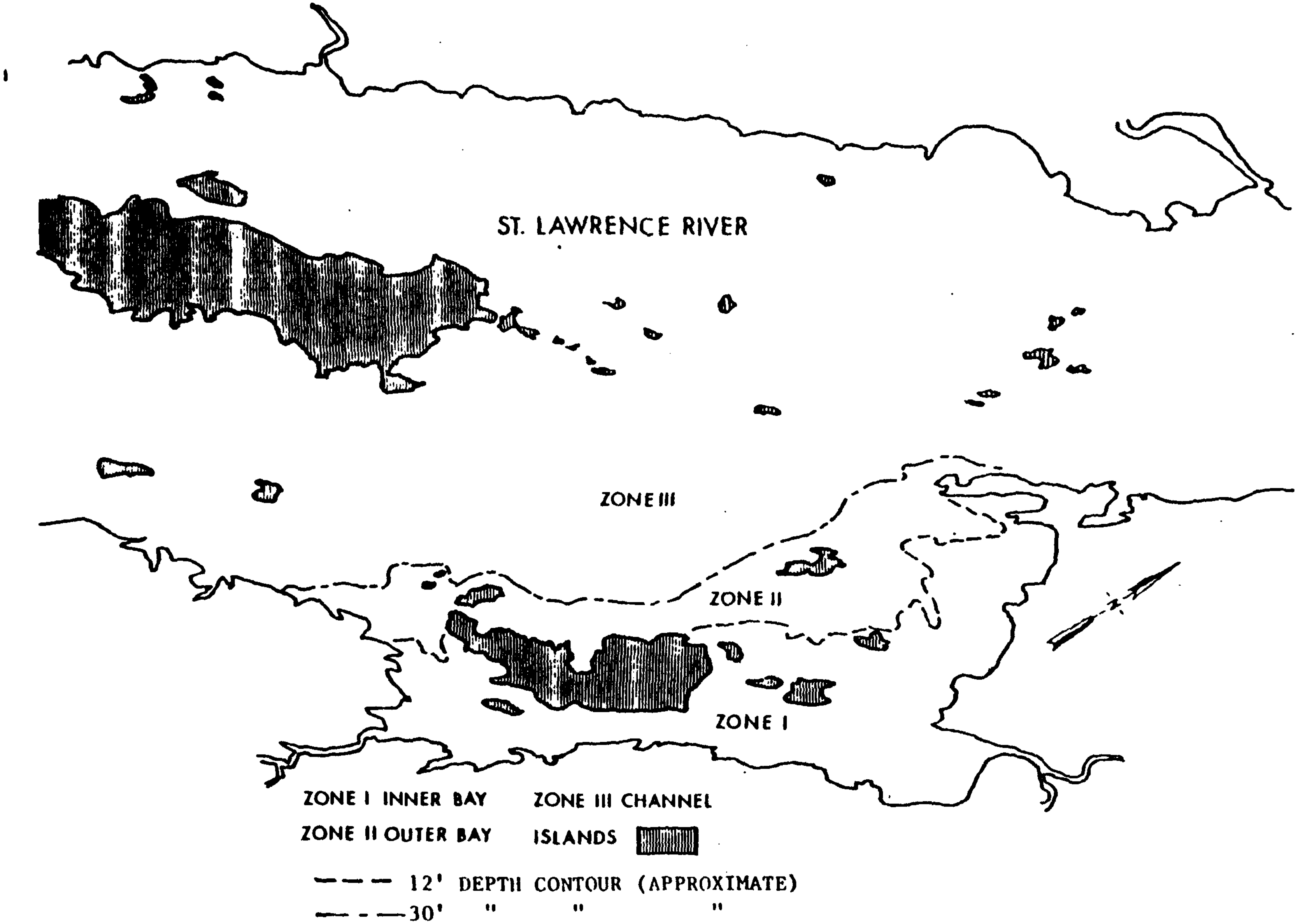


Figure 16. Location Map of Chippewa Bay Control Site Area, St. Lawrence River, Indicating Zones Used in Determining Duration of Ice Cover.

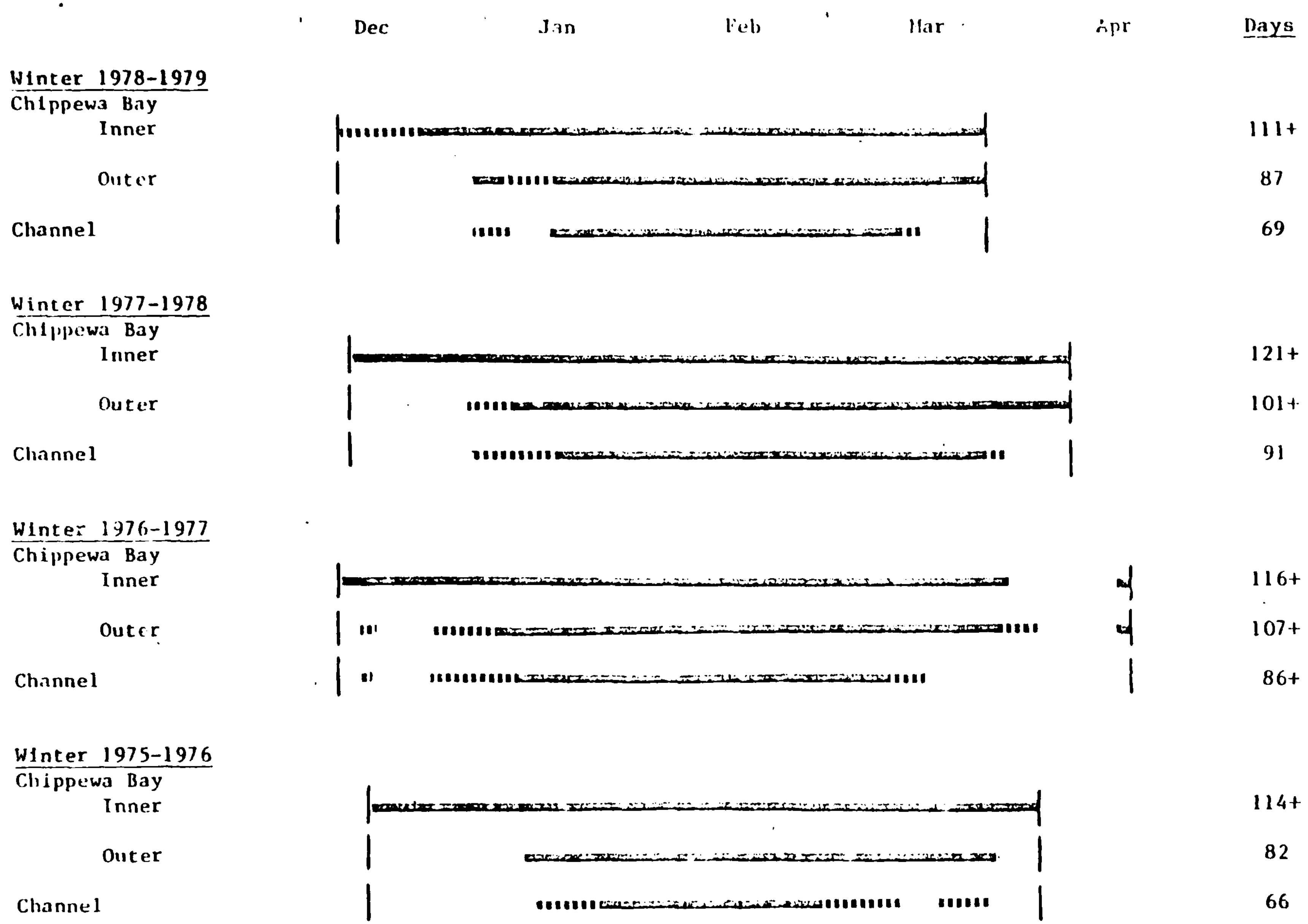


Figure 17. *Comparison of the Duration of Ice Cover on Bay and Channel Environments, Chippewa Bay, St. Lawrence River. Winters 1978-79 to 1965-66.*

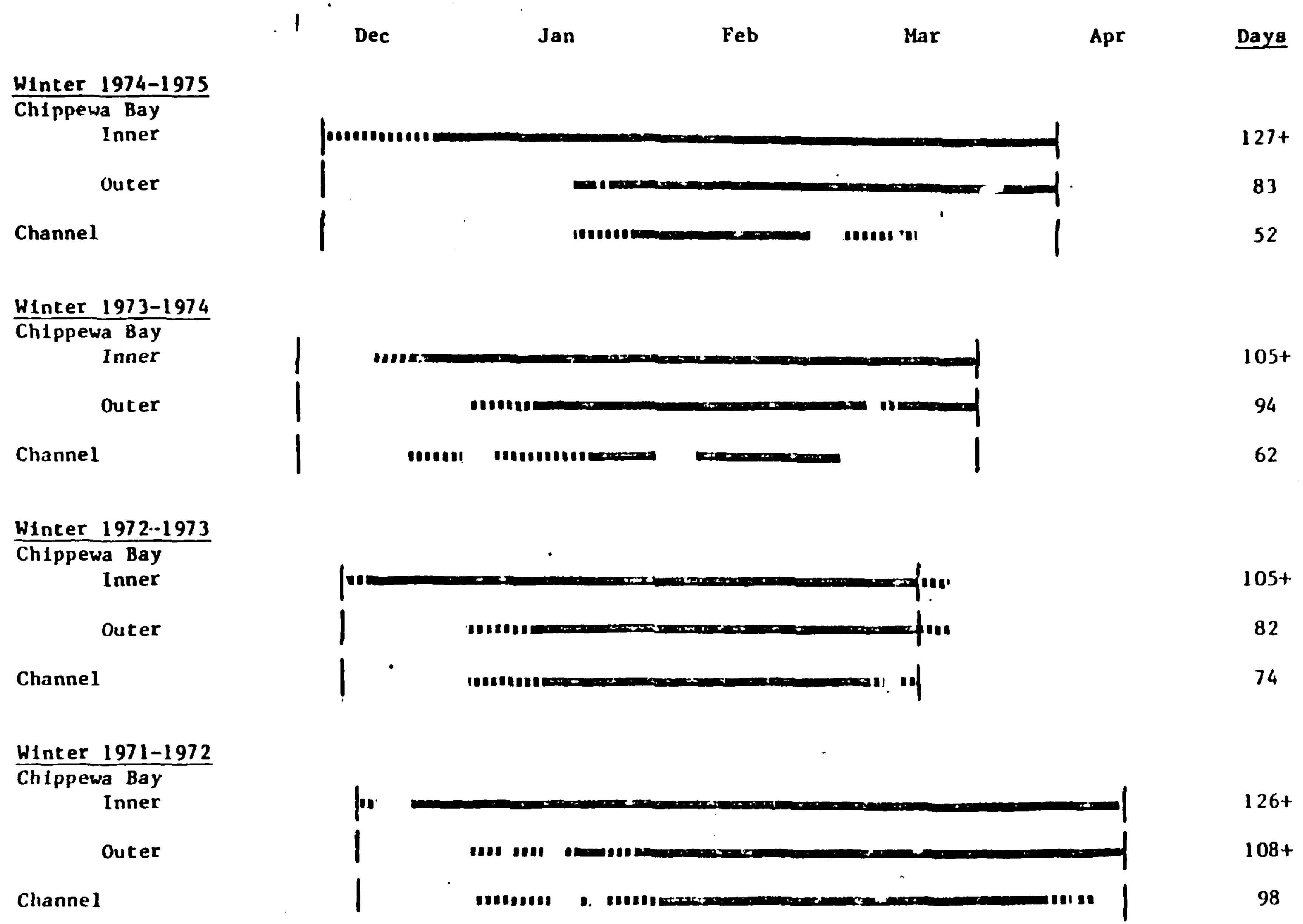


Figure 17. Continued.

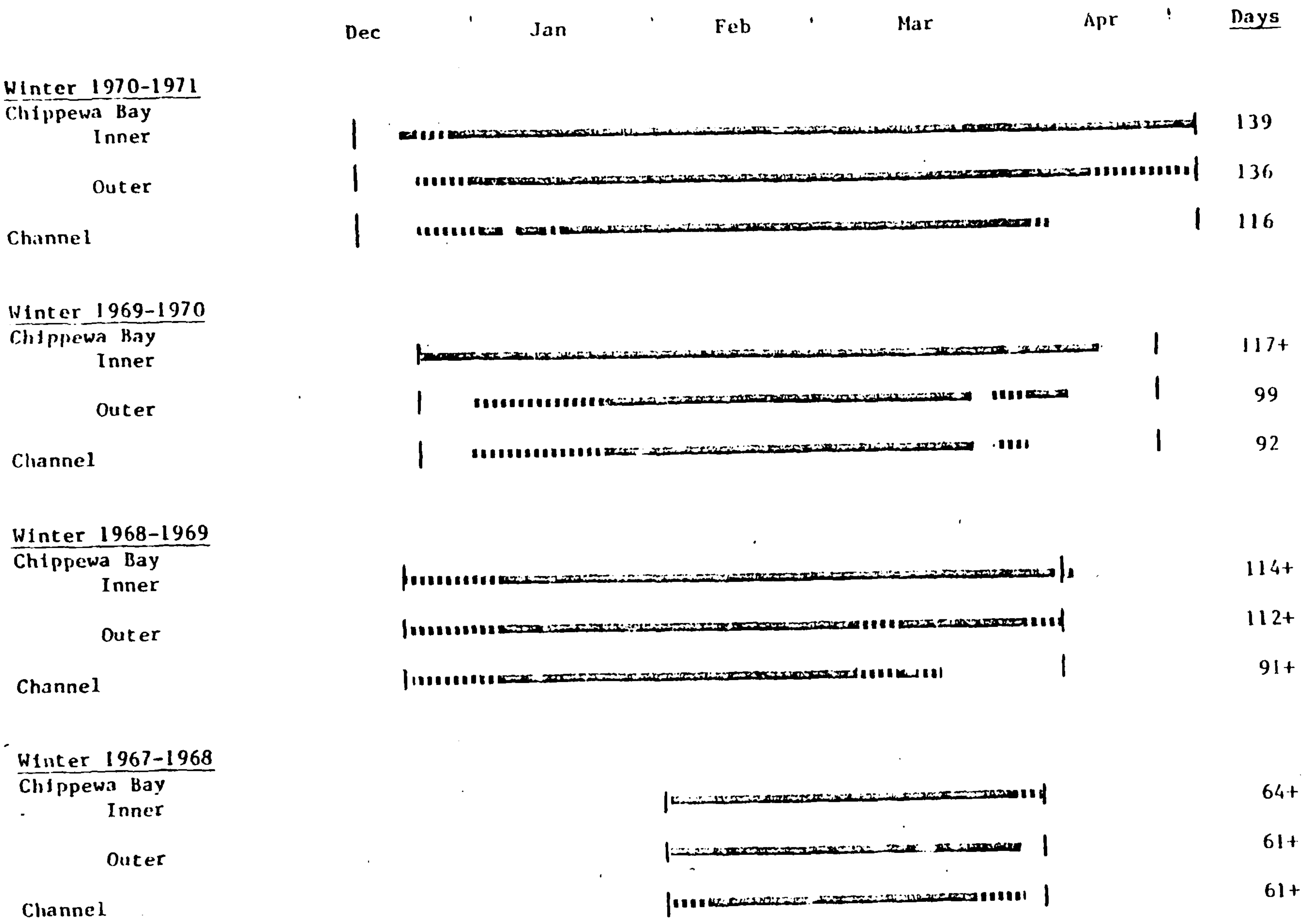


Figure 17. Continued.

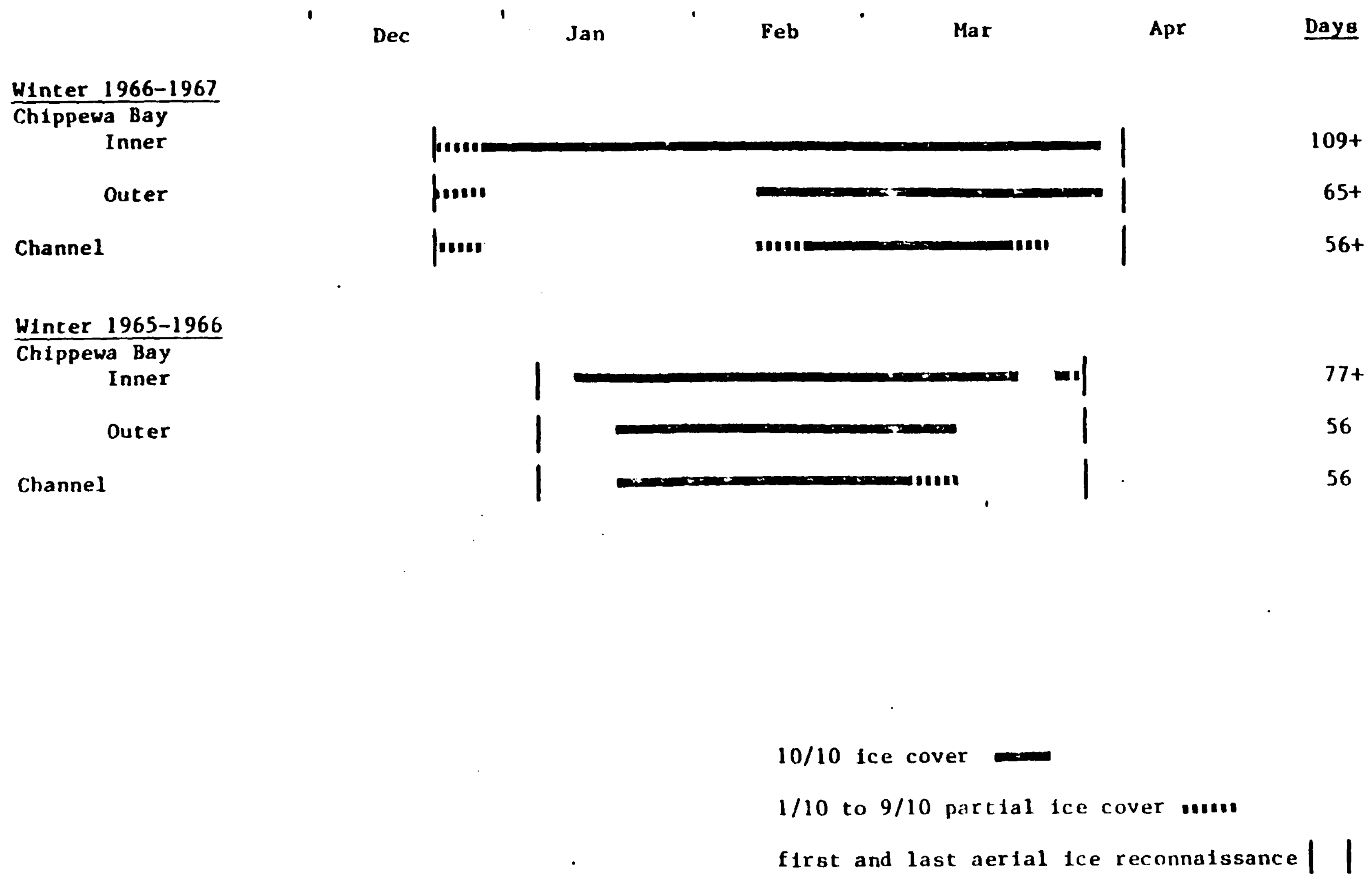


Figure 17 . Continued.

BLIND BAY

The Blind Bay control site is an extensive, shallow wetland area set in bedrock. It lies at the base of Chippewa Point and is open to the north through a very narrow entrance to the St. Lawrence River. See Figure 18. This area was selected as a control site primarily for its alignment and proximity to the shipping channel. Local residents report that because of its location, the bay is subject to the effects of ship-induced drawdown. Ice samples were obtained within the bay from wetland and nearshore sites.

Duration of Ice Cover

Because it is shallow and protected from winds, the bay freezes early and breaks up late. However, the determination of the full length of ice cover duration is limited by the first and last dates of aerial ice reconnaissance. See Figure 19.

The variations in ice cover duration between Blind Bay and the adjacent shipping channel are as follows:

Blind Bay	92+ to 135+ days
Channel	50 to 100+ days

Ice Characteristics

The ice characteristics were determined on 22 March 1979 following a period of unseasonably warm weather during which temperatures reached the low seventies. The channel areas were completely open, while wave action, concentrated by the narrow entrance to the bay, had caused an extensive system of parallel fractures approximately 3 m apart that extended 50 m to 60 m into the bay. See Figure 18 . (Site C) This suggests the possibility that bow waves could be concentrated in the same manner by the narrow bay entrance and propagated into an ice-covered bay with similar results.

Structure and Stratigraphy

Cores were taken on transects at a wetland edge (Site A) and out from a rocky shore (Site B). See Figure 18 , upper.

A cross section of the ice cover structure and stratigraphy at the wetland edge is seen in Figure 20 . This section indicates that the ice cover at this time in the spring consists primarily of snow ice and frozen bottom sediments (cores A2 to A9). In areas of the ice cover now afloat, snow ice overlies lake ice. In other cases, alternating layers of frozen bottom sediments are separated by lake ice (cores A11 to A16).

The presence of these thin lake ice zones between layers of frozen, organic-rich bottom sediments has been ascribed to water level fluctuations. However, they may also be the result of the formation of segregated ice

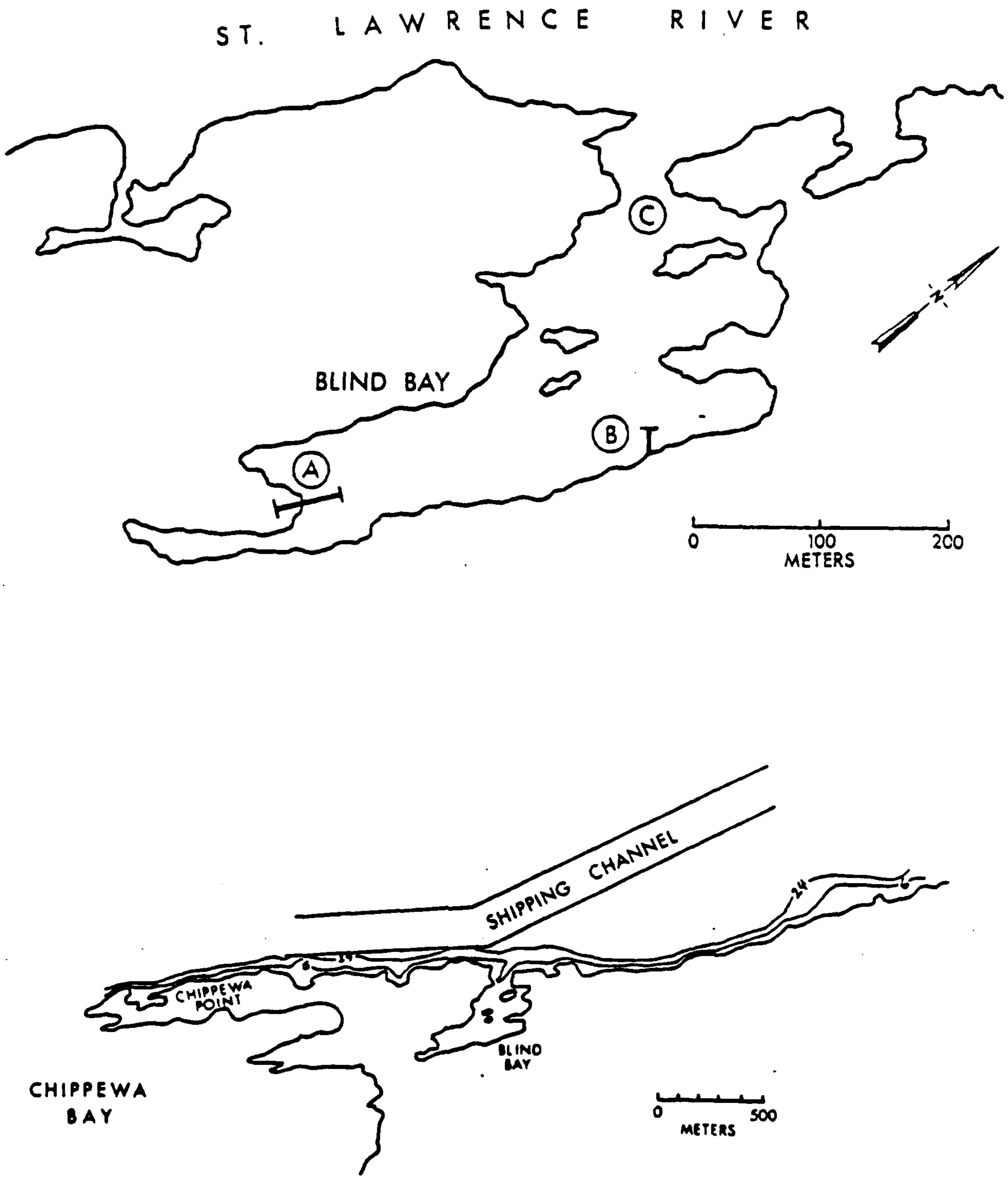
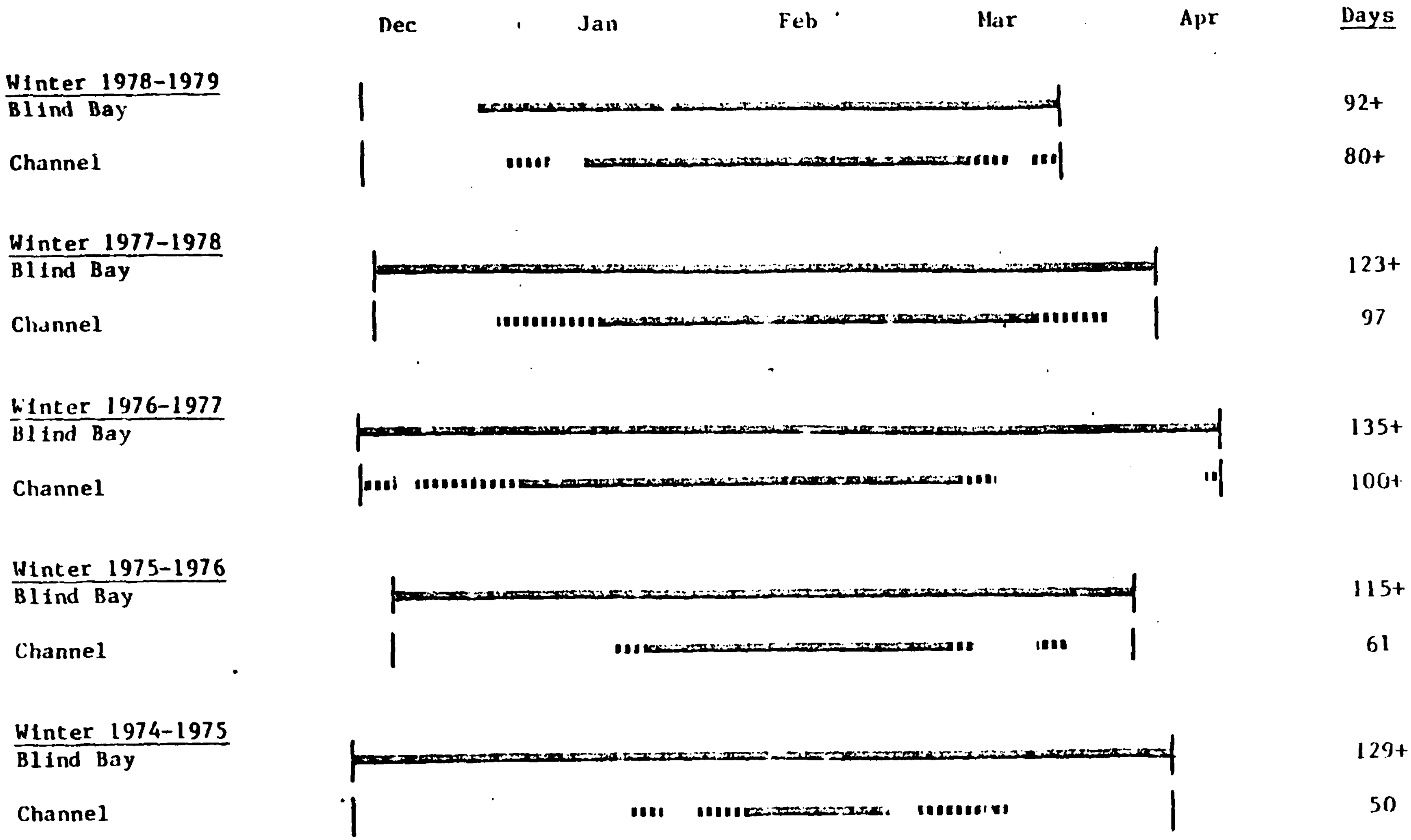


Figure 18. Location Map of Ice Sampling Sites, Blind Bay Control Site, Brockville Narrows Reach, St. Lawrence River.



10/10 ice cover

1/10 to 9/10 partial ice cover

first and last aerial ice reconnaissance

Figure 19. Comparison of the Duration of Ice Cover on Bay and Channel Environments, Blind Bay, St. Lawrence River. Winters 1978-79 to 1974-75.

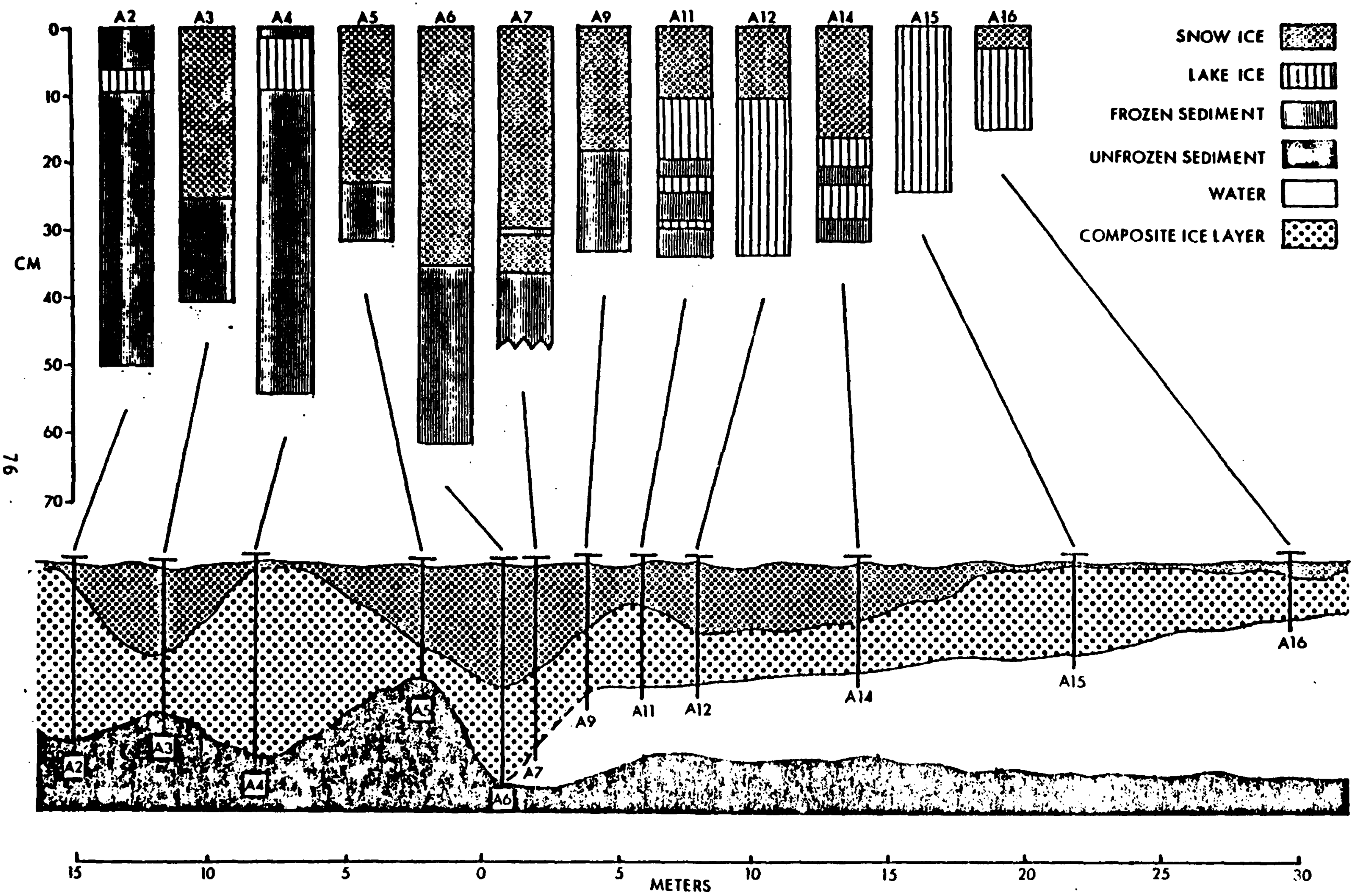


Figure 20. Cross Section of the Ice Cover Structure and Stratigraphy at the Wetland Edge, Blind Bay Control Site, St. Lawrence River. (March 22, 1979)

layers and lenses marking periods of slow downward freezing. Definitive studies of the role of ice layer formation as a disruptive force in wetlands require the identification of the various natural processes now operating in wetland control sites. Figures 21 and 22 are photographs of ice and frozen sediment cores obtained at the wetland edge.

It should be noted that the greater snow accumulations which normally occur within and just at the edge of the cattail swamp are reflected even at this date in greater snow ice thicknesses. Snow and ice thickness and water depth measurements for the Blind Bay control site are seen in Table 15.

MORRISTOWN HARBOR

The Morristown Harbor control site is located at the upstream end of the Demonstration Corridor. It consists of a long, narrow reentrant approximately 800 m in length and 100 m in width. See Figure 23. A bridge splits the harbor into an outer and inner harbor. Water depths range from 3 m at the bay mouth to only 0.5 m at the wetland edge. Piers and docks line the eastern side of the outer harbor, while the inner harbor upstream of the small bridge has only minor cottage and private dock development. It is fringed by a narrow wetland. The largest area of wetland is located at the head of the inner harbor.

Since this harbor has the largest variety of riverine environments within the Demonstration Corridor, seven ice sampling transects were carried out; they yielded a total of 31 cores. Transects A and B sampled the wetland edge and C the inner harbor, while D, E, F, and G sampled the harbor mouth, the shore, and offshore areas.

Ice Duration

Comparisons were made of the duration of the ice cover between the Morristown area, which includes Morristown Harbor and the expanse of ice stabilized by Old Man Island and Brockville Rock, and the navigation channel. See Figure 24.

The variations in ice cover duration between the stable ice of the Morristown area and the navigation channel are as follows:

Morristown area	61 to 98 days
Channel	46 to 93 days

Structure and Stratigraphy

A cross section of the structure and stratigraphy of the ice cover formed at the wetland edge (Transect A) is seen in Figure 25. Within the wetland, this area is simple in structure, consisting of snow, snow ice, and frozen sediment. A photograph of an ice and frozen sediment core (core A2) taken from the wetland edge is seen in Figure 26. At the outer edge of the wetland, where the ice cover is afloat, the cover consists of

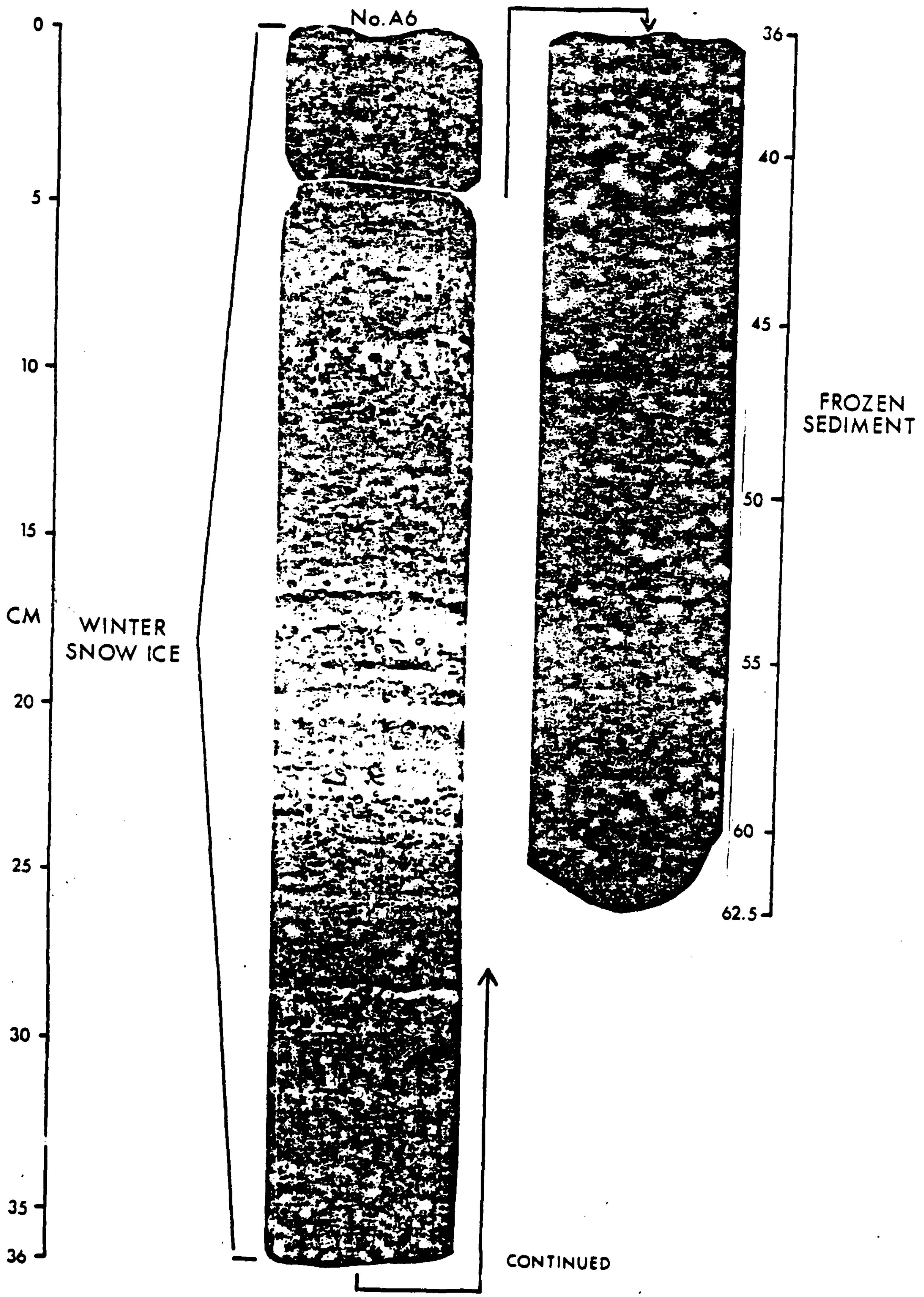


Figure 21. Photograph of Ice Core from Wetland Edge, Blind Bay Control Site, St. Lawrence River, Brockville Narrows Reach.

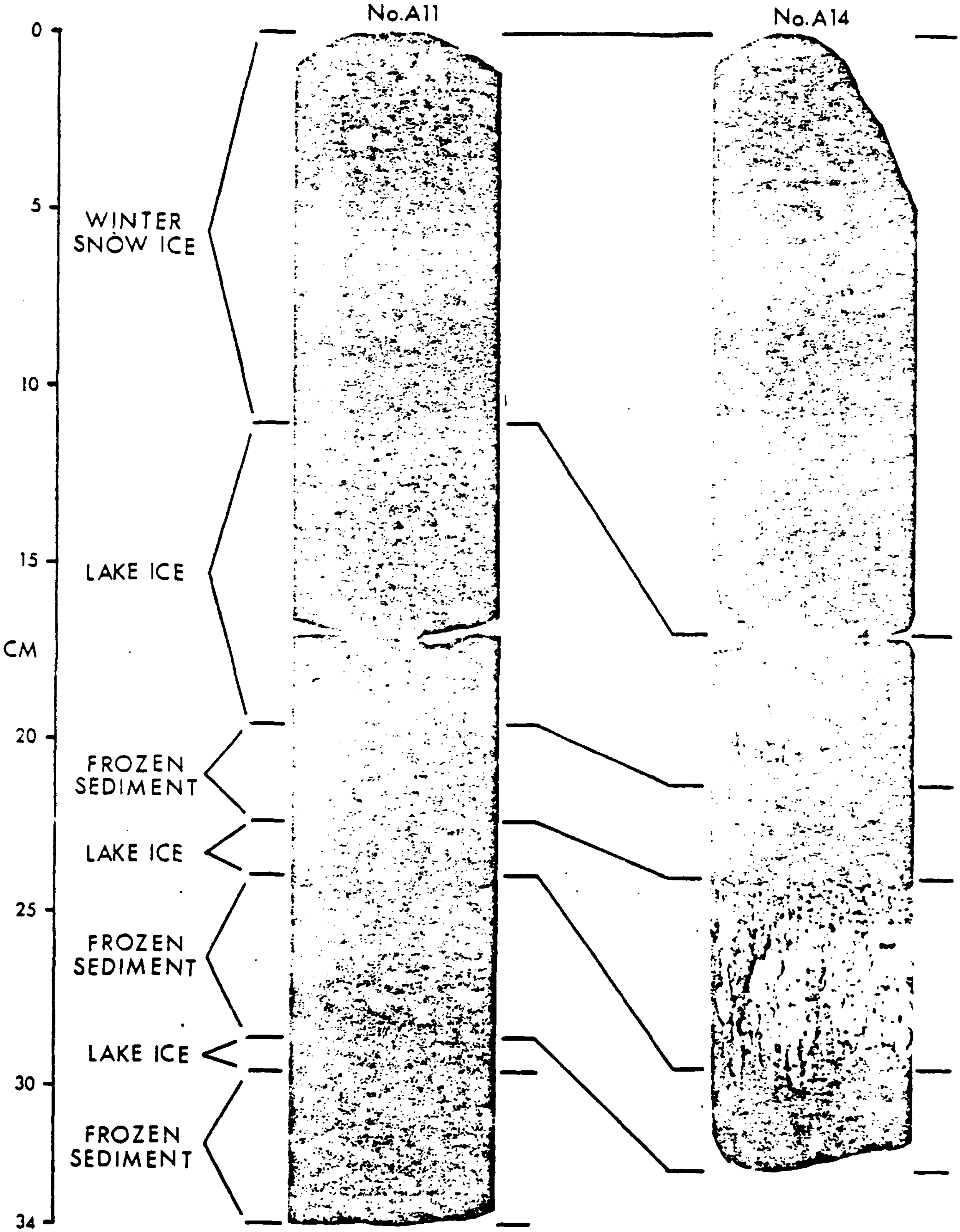


Figure 22. Photograph of Ice Cores from Wetland Edge Showing Stratigraphic Continuity of Ice Layers Included Within Frozen Organic Sediments, Blind Bay ontrol Site, St. Lawrence River, Brockville Narrows Reach. ¿2 March 1979.

Table 15. Snow and Ice Thickness and Water Depth Measurements (in Centimeters), Blind Bay Control Site, St. Lawrence River. Winter 1978-79, 24 March 1979.

Core No.	Snow	Snow Ice	Lake Ice	Frozen Sediment	Total Ice	Depth to Bottom[2]
A1[1]	0	0	8.0	11.0	19.0	*[4]
A2	0	0	0	50.0	50.0	44.0
A3	0	25.5	0	16.0	41.5	36.0
A4	0	8.5	0	46.0	54.5	49.0
A5	0	23.0	0	9.0	32.0	37.0
A6	0	36.5	0	26.0	62.5	55.0
A7	0	36.0	0	1.0[3]	37.0	67.0
A8	0	19.0	0	13.5	32.5	58.0
A9	0	18.0	0	15.5	33.5	62.0
A10	0	21.0	0	14.5	35.5	62.0
A11	0	11.0	11.0	12.0	34.0	54.0
A12	0	19.5	14.5	0	34.0	55.0
A13	0	20.5	16.0	0	36.5	71.0
A14	0	17.0	9.0	5.0	31.0	54.0
A15	0	0	24.5	0	24.5	59.0
A16	0	3.5	12.0	0	15.5	≥59.0
B1	0	19.0	4.0	0	23.0	45.0
B2	0	37.0	15.0	0	52.0	74.0
B3	0	12.5	24.0	0	36.5	86.0
B4	0	9.0	24.0	0	33.0	86.0
B5	0	10.0	24.0	0	34.0	91.0

[1]Letter denotes transect from which core was taken. See Figure 20 for transect location.

[2]Water depths measured from top of ice cover.

[3]Bottom of core containing frozen sediment not retained, data unavailable.

[4]Data not taken.

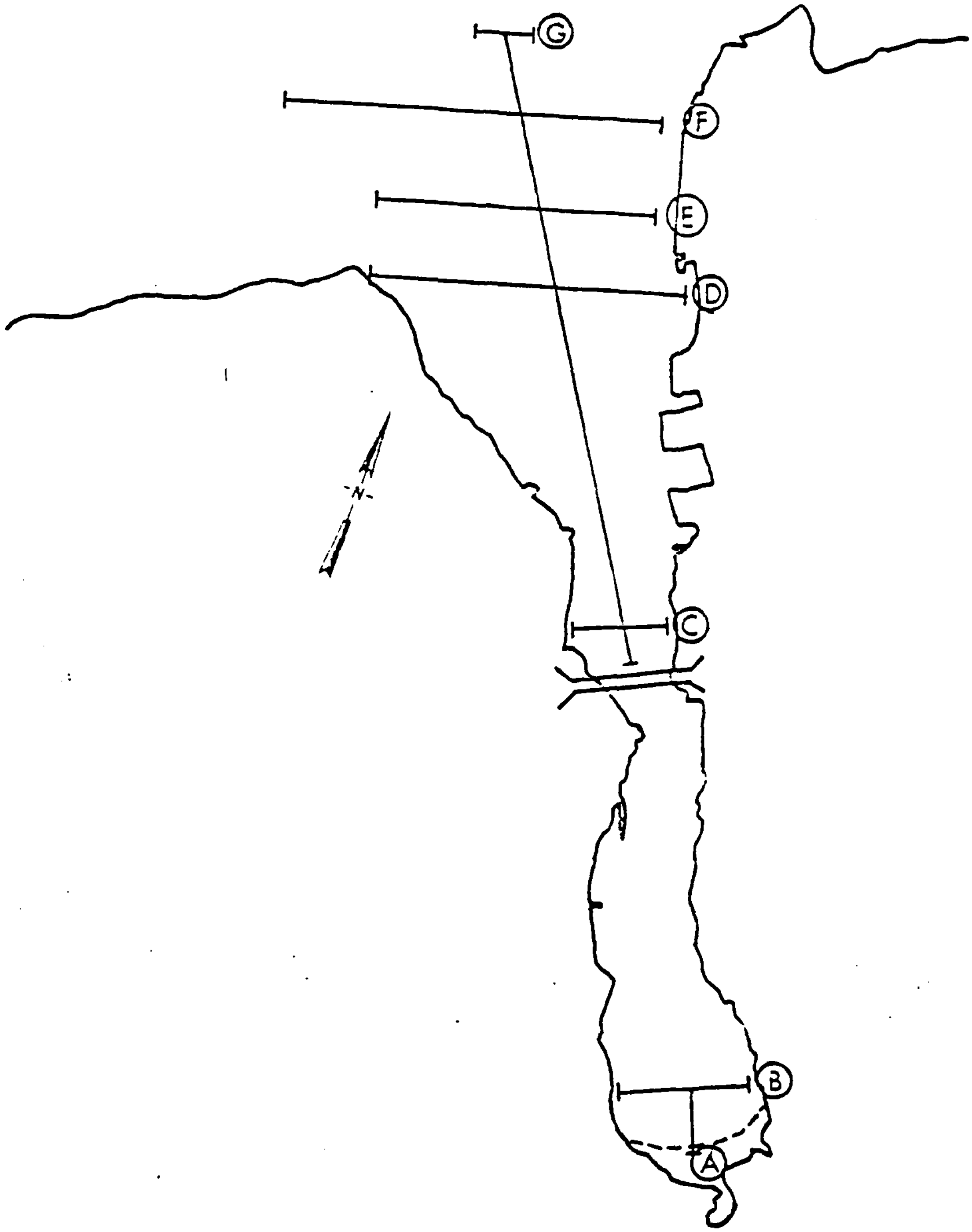


Figure 23. Location Map of Ice Sampling Transects, Morristown Harbor Control Site, Brockville Narrows Reach, St. Lawrence River.

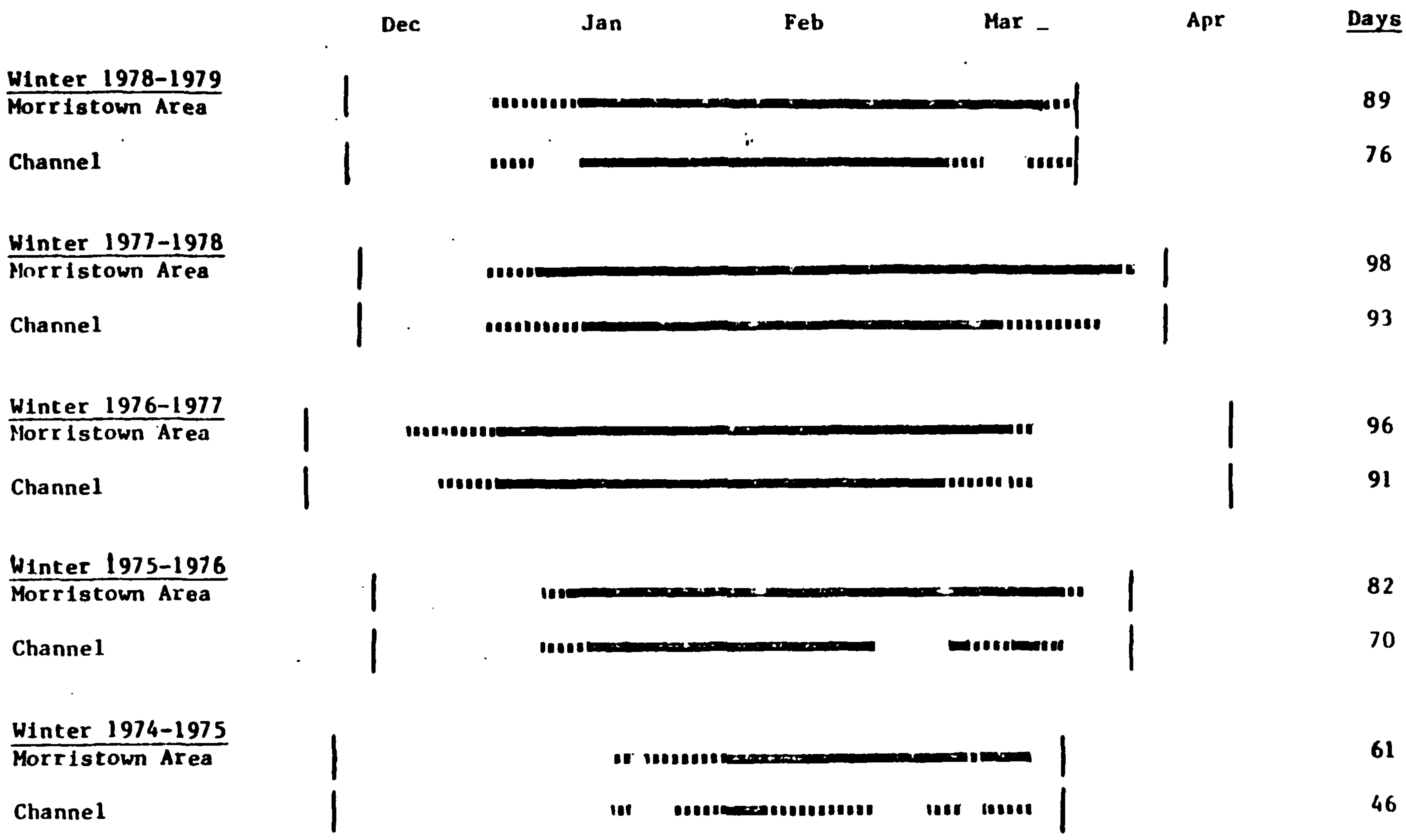


Figure 24 . Duration of Ice Cover, Morristown-Brockville Area, Brockville Narrows Reach. St. Lawrence River. Winters 1978-79 to 1974-75.

Footnotes:
(1) During the period when well-defined pools occurred in the fast ice cover of the Brockville channel, the area was considered 10/10's.

10/10 ice cover ▬
1/10 to 9/10 partial ice cover ▮▮▮▮▮
first and last aerial ice reconnaissance | |

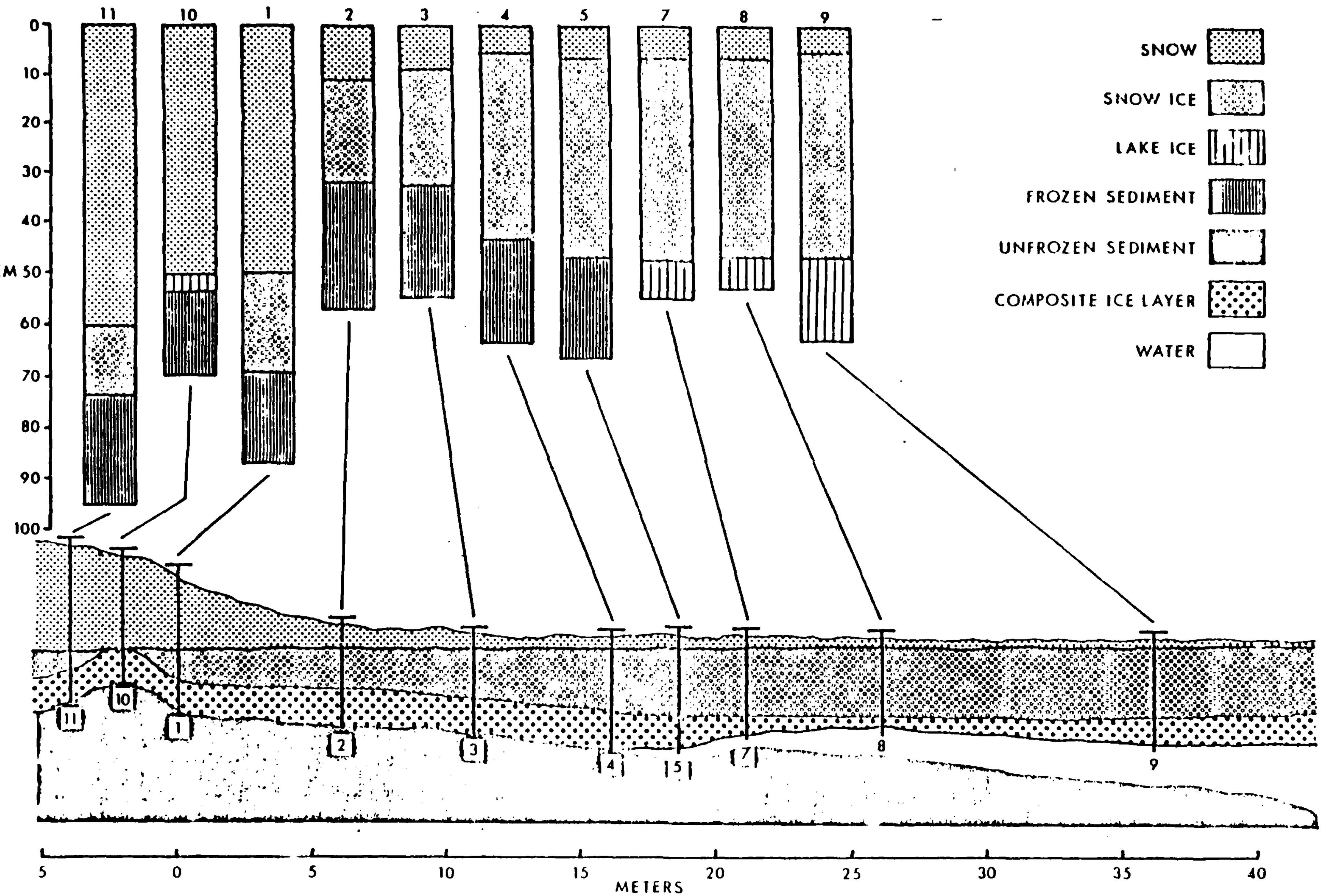


Figure 25. Cross Section of the Structure and Stratigraphy of the Ice Cover at the Wetland Edge, Morristown Harbor Control Site, St. Lawrence River. 2-3 March 1979.

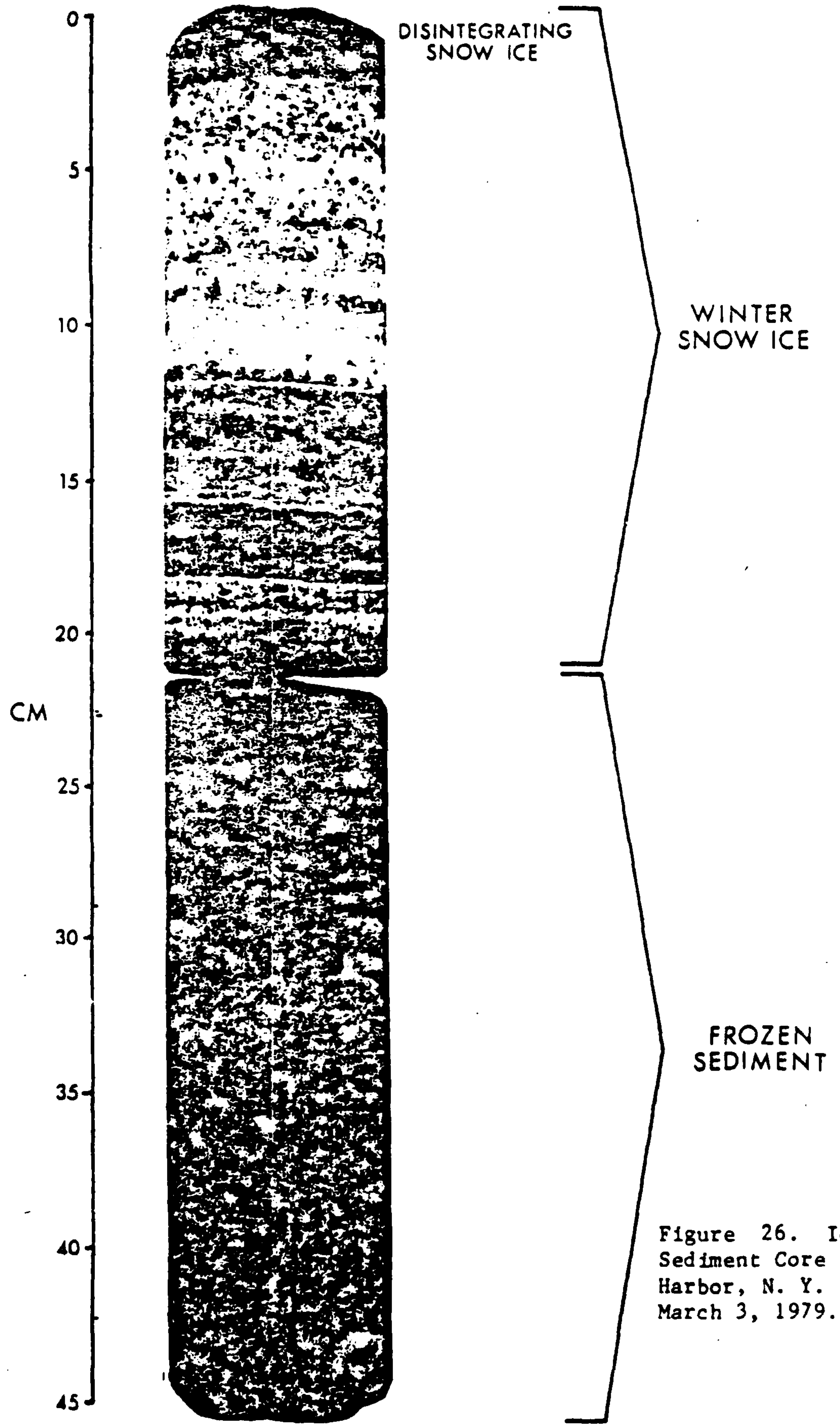


Figure 26. Ice and Frozen Sediment Core from Morristown Harbor, N. Y. Wetland Edge. March 3, 1979. (Core A2)

snow, snow ice, and lake ice. Figure 27 is a photograph of an ice core characteristic of the structure of the ice canopy at the mouth of Morristown Harbor.

Figure 28 traces the structure and stratigraphy of the ice cover from the bridge in the inner harbor to a point approximately 300 m beyond the harbor mouth. Snowdrift accumulation around the bridge abutments causes a significant increase in snow ice and total ice cover thickness in this area. In very severe winters or during winters of unusually heavy snowfall, increased ice thickness could greatly reduce or cut off the flow of water from the inner harbor by further reducing this narrow channel cross section.

Transect D extended across the mouth of Morristown Harbor and illustrates ice conditions frequently found on the downstream shore of harbor mouths. See Figure 29. Core D9 in Figure 30 indicates windrowing of ice early in the winter along this shore and shows the possibility of shoreline scour. Later snow ice accumulation buried this feature. The following five stages of ice formation can be seen in this core: Stage IA--formation of new and young ice, IB--the break-up, windrowing, and refreezing of this brash; Stage II--the formation of a thin layer of lake ice at the bottom of the refrozen brash; Stage III--the formation of winter snow ice; Stage IV--formation of spring snow ice; and Stage V--the freezing of surface melt puddles.

Table 16 lists snow and ice thickness and water depth measurements taken on transects A to G at the Morristown Harbor control site.

NEVINS POINT

Nevins Point is located in the Morristown Point-Ogdensburg Reach approximately 4.5 km upstream of the mouth of the Oswegatchie River. This area is of interest because upstream of Nevins Point is a littoral zone approximately 3 km in length. It occupies a slight reentrant which contains one of the broader littoral zones on the U. S. side of the river within this reach.

Duration of Ice Cover

The duration of the ice canopy over this littoral zone in comparison to the channel is of biological interest. The variation in ice cover duration for the Nevins Point reentrant and the channel is as follows:

Nevins Point reentrant	62 to 103+ days
Channel	56 to 89 days

See Figure 31.

TIBBITS CREEK

The Tibbits Creek control site is located in the Ogdensburg Ice

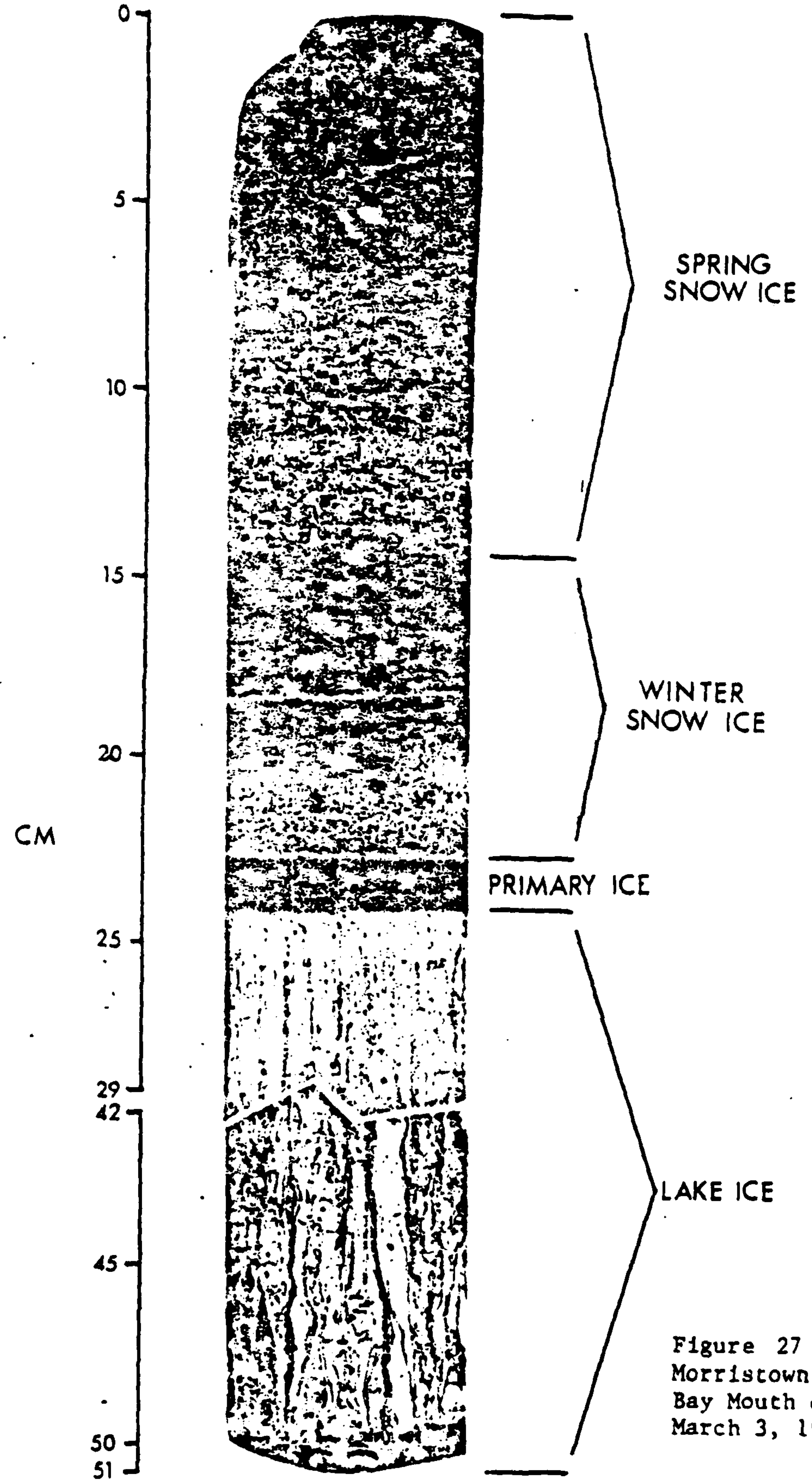


Figure 27. Ice Core from Morristown Harbor, N. Y. Bay Mouth off Chapman Pt. March 3, 1979.

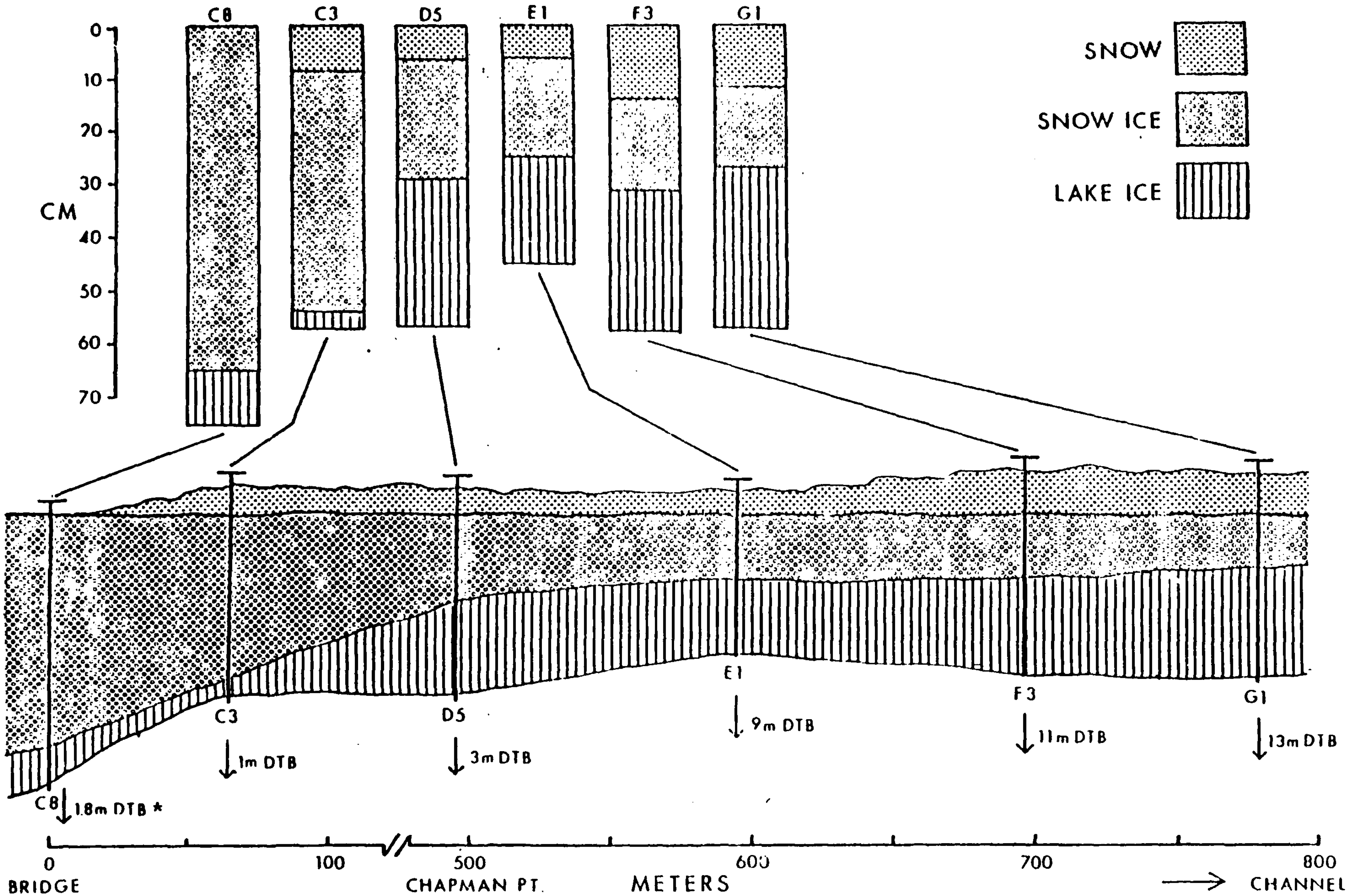


Figure 28. Cross Section of the Structure and Stratigraphy of the Ice Cover from Inner Harbor to Outer Bay, Morristown Harbor Control Site, Brockville Narrows Reach, St. Lawrence River. 2-3 March 1979.

*Depth to Bottom

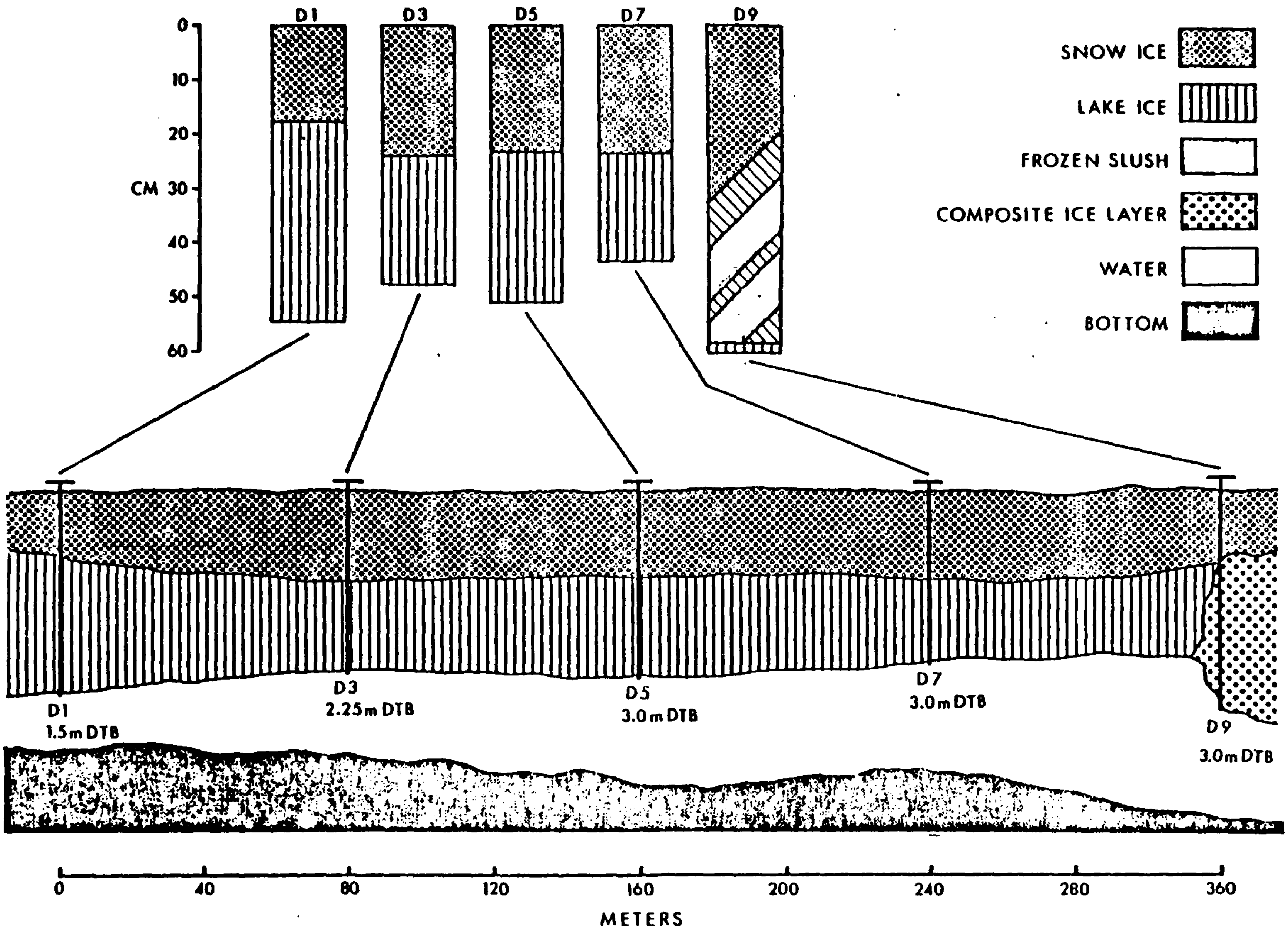


Figure 29. Cross Section of the Structure and Stratigraphy of the Ice Cover Across the Mouth of Morristown Harbor Control Site (Transect D), Brockville Narrows Reach, St. Lawrence River. 2-3 March 1979.

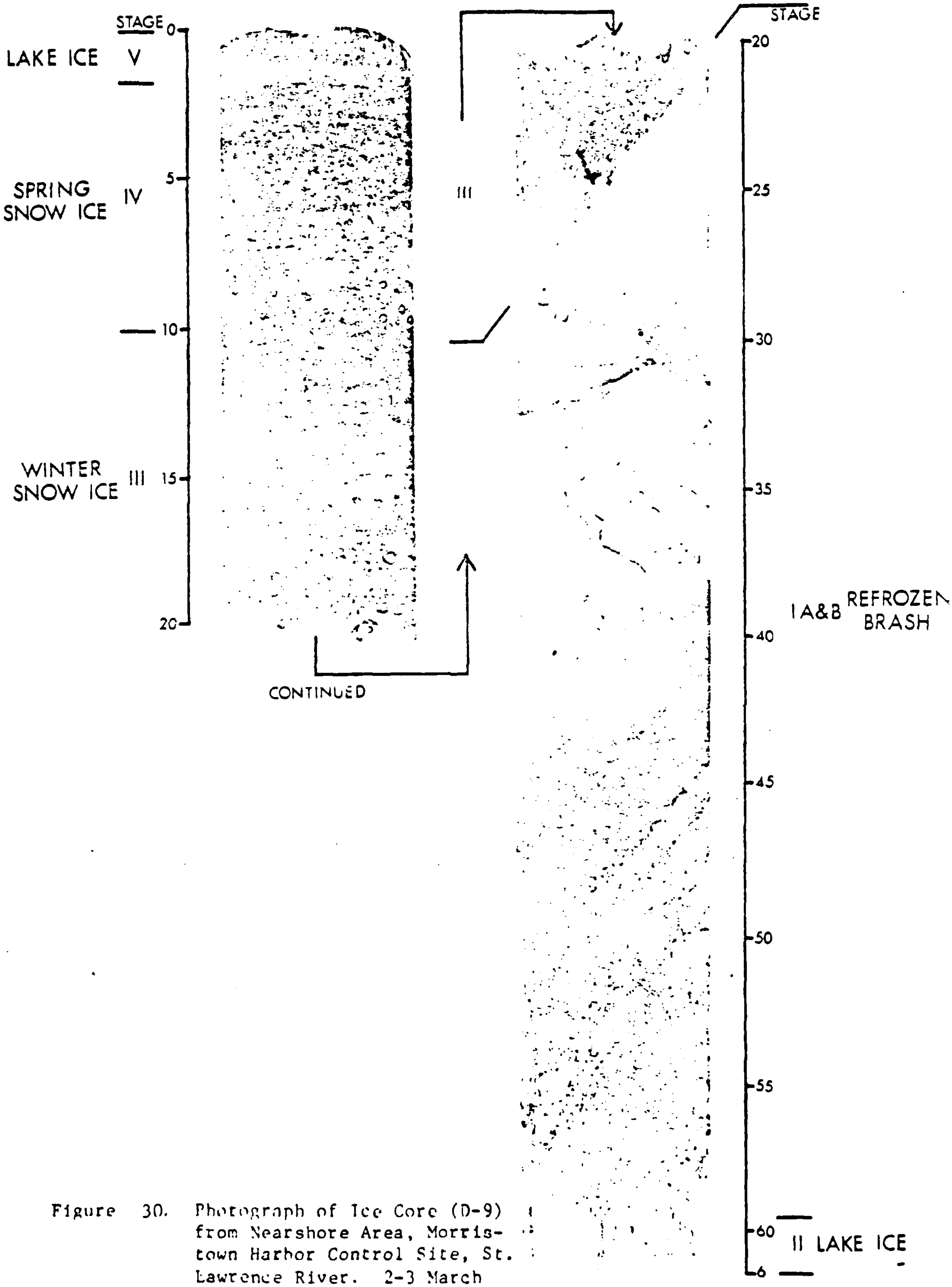


Figure 30. Photograph of Ice Core (D-9) from Nearshore Area, Morristown Harbor Control Site, St. Lawrence River. 2-3 March 1979.

Table 16. Snow and Ice Thickness and Water Depth Measurements (in Centimeters), Morristown Harbor Control Site, St. Lawrence River. Winter 1978-79, 2-3 March 1979.

Core No.	Snow	Snow Ice	Lake Ice	Frozen Sediment	Total Ice	Depth to Bottom[2]
A1[1]	49.0	19.0	0	17.5	36.5	39.0
A2	11.0	21.5	0	24.5	46.0	49.0
A3	8.0	*[3]	*	*	45.0	48.0
A4	5.0	37.5	0	20.0	57.5	55.0
A5	6.0	40.0	0	19.0	59.0	65.0
A6	5.0	42.0	0	15.0	57.0	60.0
A7	6.0	41.0	7.5	0	48.5	57.0
A8	6.0	40.0	5.5	0	45.5	61.0
A9	5.0	41.0	16.0	0	57.0	79.0
A10	50.0	0	3.0	16.0	19.0	*
A11	60.0	*	*	*	35.0	*
B1	4.0	39.5	14.5	0	54.0	59.0
B2	4.0	41.0	9.5	3.5	54.0	57.0
B3	7.0	*	*	*	56.0	62.0
B4	8.0	41.5	11.5	0	53.0	84.0
B5	0	37.0	3.0	0	40.0	*
B6	5.0	31.5	21.5	0	53.0	75.0
B7	21.0	*	*	*	23.0	23.0
C1	9.0	19.5	22.0	0	41.5	46.0
C2	8.0	49.0	5.0	0	54.0	100.0
C3	8.0	45.0	3.0	0	48.0	100.0
C4	7.0	32.0	16.0	0	48.0	100.0
C5	15.0	49.0	0	7.0	56.0	*
C6	0	*	*	*	40.0	50.0
C7	6.0	*	*	*	43.0	80.0
C8	0	65.0	10.5	0	75.5	180.0
D1	0	17.5	36.5	0	54.0	150.0
D2	0	24.0	26.5	0	50.5	*
D3	0	24.0	23.5	0	47.5	*
D4	0	22.5	27.0	0	49.5	*
D5	0	23.0	28.0	0	51.0	300.0
D6	0	34.0	11.5	0	45.5	*
D7	0	23.5	19.5	0	43.0	*
D8	0	26.0	24.5	0	50.0	*
D9	0	20.0	2.0	0	60.0[4]	300.0
E1	6.0	18.0	19.5	0	37.5	900.0
E2	8.0	31.5	19.0	0	50.5	900.0
E3	5.0	32.5	16.5	0	49.0	750.0

Table 16. Continued.

Core No.	Snow	Snow Ice	Lake Ice	Frozen Sediment	Total Ice	Depth to Bottom
E4	3.0	20.5	25.5	0	46.0	700.0
E5	7.0	18.5	25.5	0	44.0	550.0
E6	14.0	23.0	23.5	0	46.5	450.0
E7	17.0	23.5	23.5	0	47.0	130.0
F1	*	*	*	*	35.0	1030.0
F2	15.0	14.0	23.0	0	37.0	1300.0
F3	13.0	17.5	26.5	0	44.0	1100.0
F4	12.0	15.0	29.5	0	44.5	1300.0
F5	4.0	15.0	23.0	0	38.0	1400.0
F6	13.0	12.5	28.5	0	41.0	1400.0
G1	12.0	15.0	29.5	0	44.5	1300.0
G2	4.0	15.0	23.0	0	38.0	1400.0
G3	13.0	12.5	28.5	0	41.0	1400.0

[1]Letter denotes transect from which core was taken. See Figure for transect location.

[2]Water depths measured from top of ice cover.

[3]Data not taken.

[4]Total includes 38 cm brash ice between snow and lake ice.

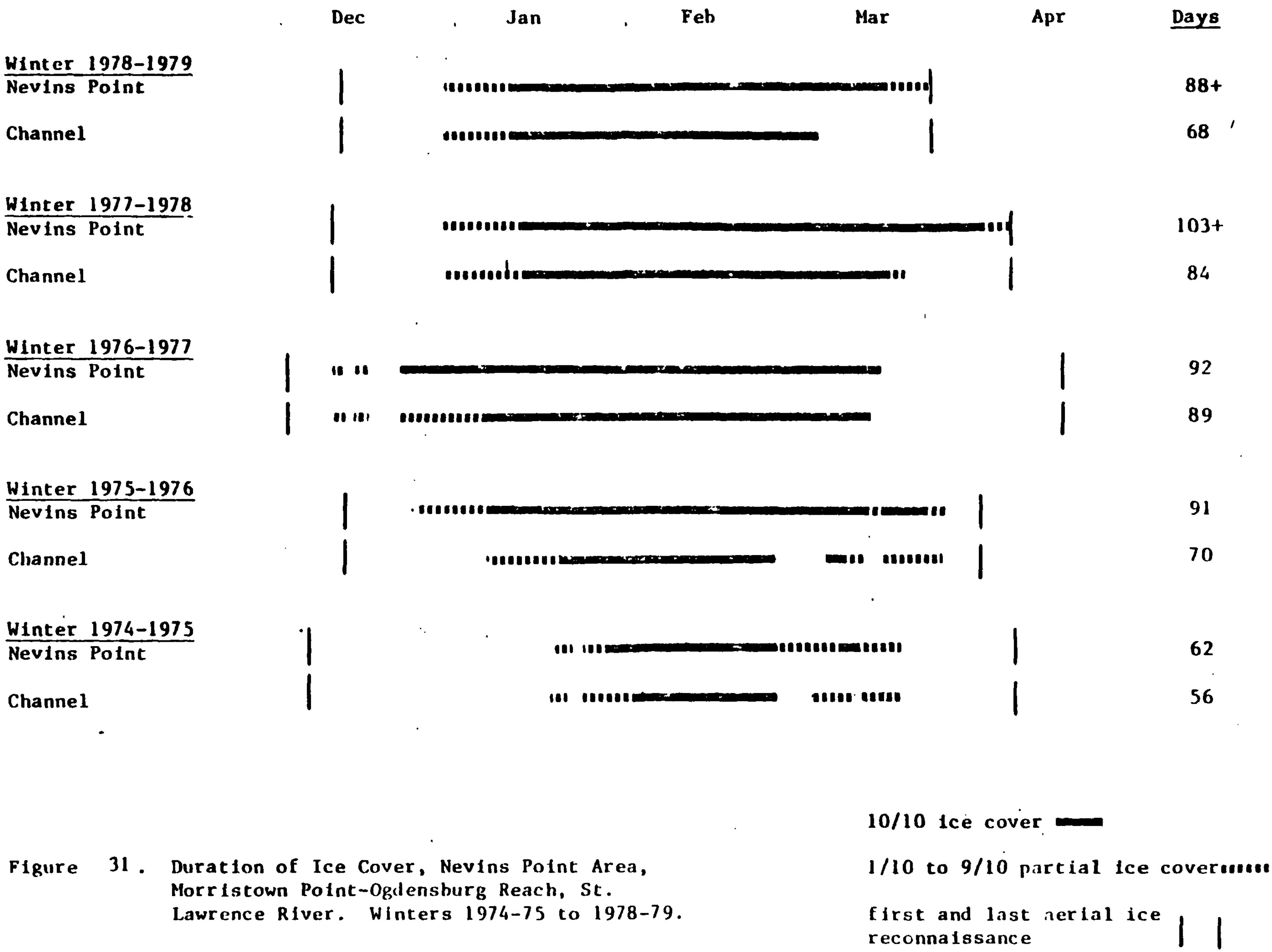


Figure 31. Duration of Ice Cover, Nevins Point Area, Morristown Point-Ogdensburg Reach, St. Lawrence River. Winters 1974-75 to 1978-79.

Boom Reach approximately 1.7 km downstream of the Ogdensburg-Prescott bridge. See Figure 32. It consists of a small, shallow creek and wetland together with a narrow littoral zone in front of the creek (zone I). Zone II is a former channel of the St. Lawrence River; Zone III is Chimney Island Shoal; and Zone IV is the present navigation channel.

The ice cover duration has been determined for these four zones for the years 1978-79 to 1974-75. The variation in ice cover duration is as follows: (See Figure 33.)

Tibbits Creek	85 to 118+ days
Old (Inner) Channel	45 to 93 days
Chimney Island Shoal	41 to 93 days
Channel	45 to 83 days

Table 17 lists snow and ice thickness and water depth measurements for the Tibbits control site. The creek was open on this date. The only ice remaining was located on the shallow littoral shelf, or zone I.

BRANDY BROOK

The Brandy Brook control site is located 21.5 km on the downstream side of the Cardinal-Frazer Shoal limit of the Demonstration Corridor. It consists of Brandy Brook and a few short tributaries, a broad, shallow littoral shelf, a former channel of the St. Lawrence River, Murphy Island Shoal, and the navigation channel. See Figure 34.

Ice Cover Duration

The two ice-covered units used in the determination of ice cover duration consist of (1) Brandy Brook and the littoral shelf and (2) the former channel, Murphy Island Shoal, and the navigation channel.

The variation in ice cover duration for these units is the following:

Brandy Brook	115+ to 128+ days
Channel	57 to 96 days

See Figure 35.

Ice Characteristics

Ice and frozen sediment cores were obtained in a small tributary on the west side of the brook (see boxed area), Figure 34.

The ice cover in these areas is subject to collapse and freeze-down due to drawdown of water levels for power generation. During the spring run-off, the ice melts free from the bottom and rises to the surface. Although ice thickness and water depth measurements were taken, the advanced state of erosion of the floating ice floes did not lend

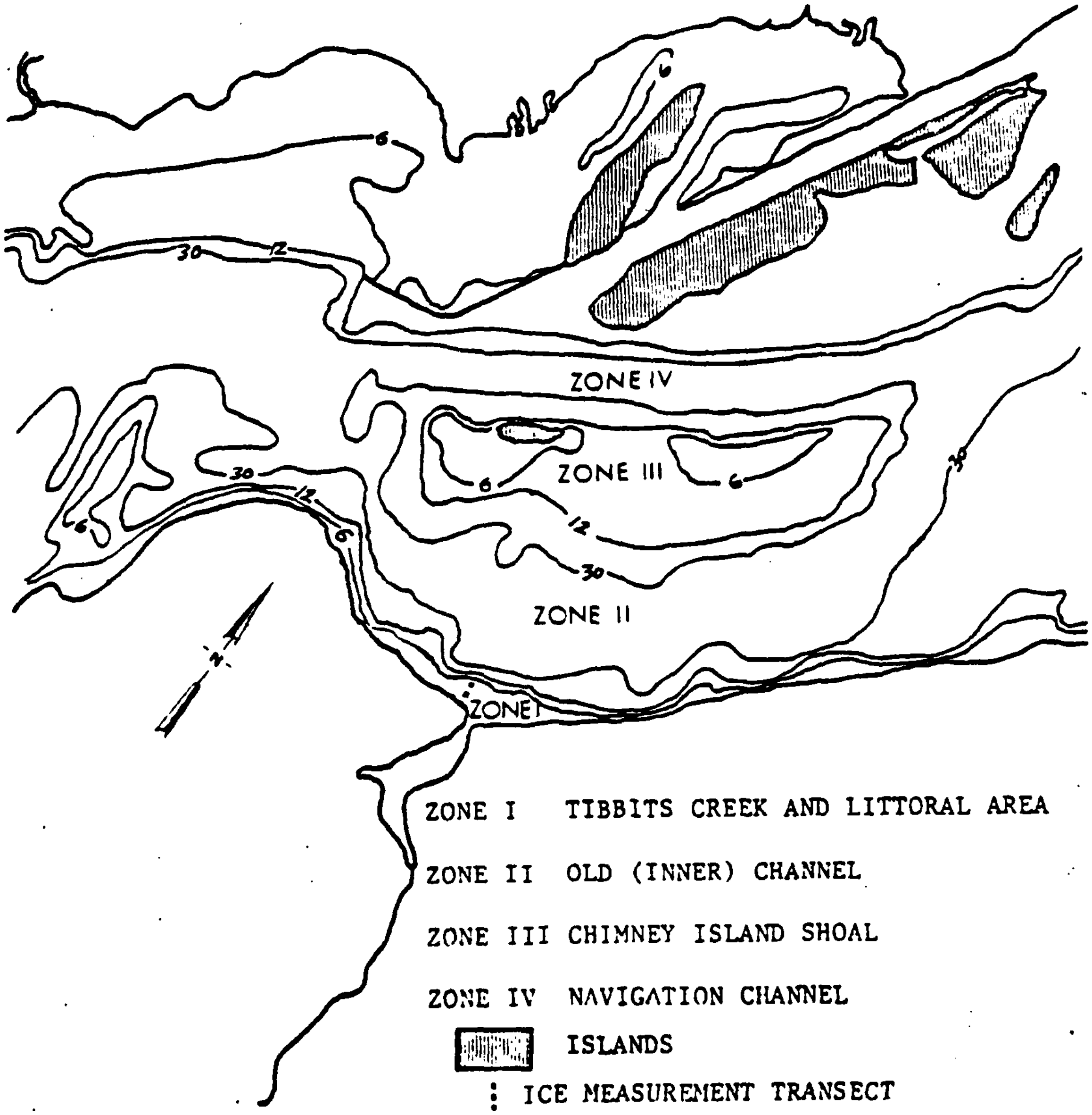


Figure 32. Location Map, Tibbits Creek Control Site, Ogdensburg Ice Boom Reach, St. Lawrence River. Ice Sampling Sites and Zones Used in Determining Duration of Ice Cover.

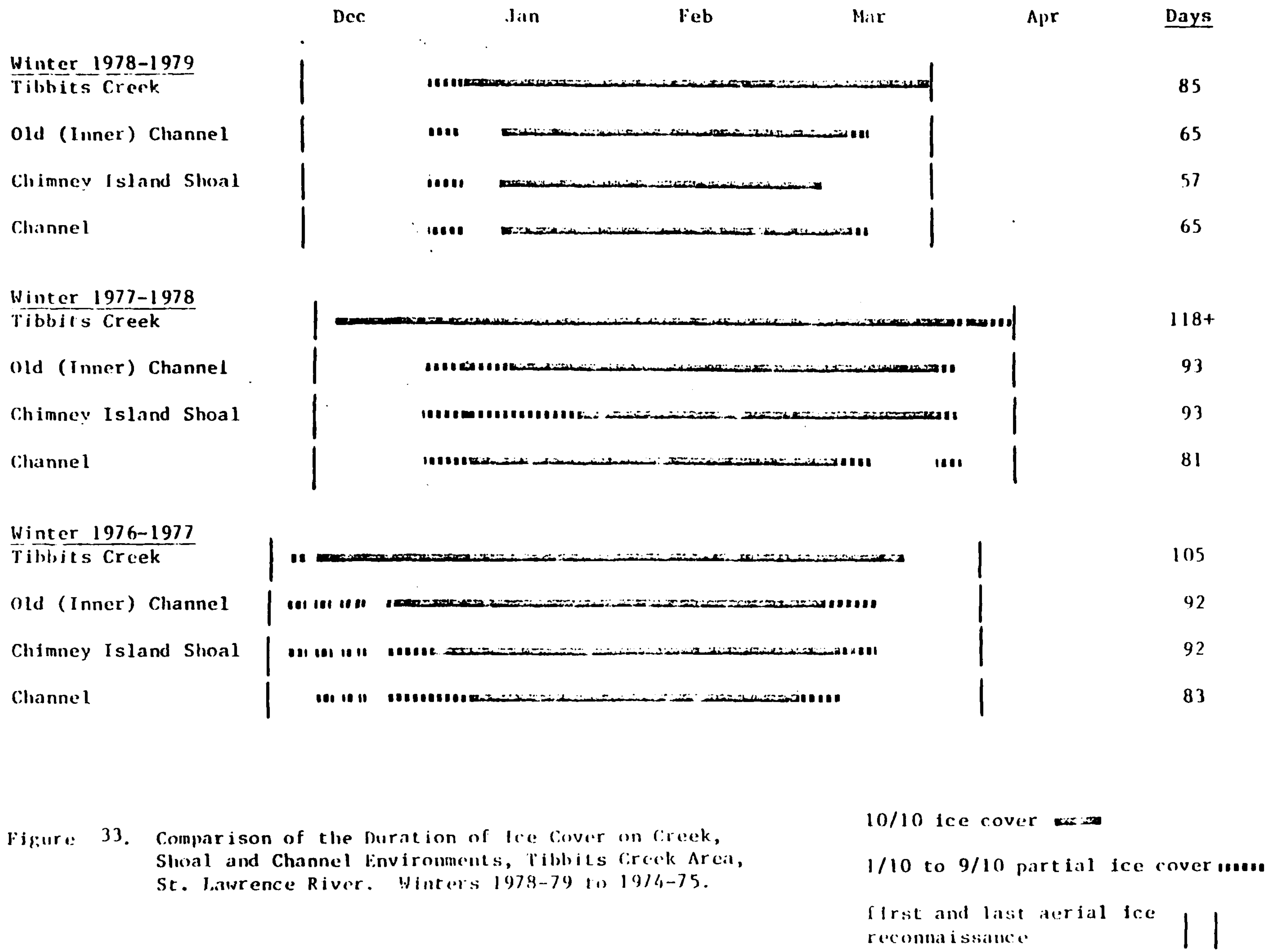


Figure 33. Comparison of the Duration of Ice Cover on Creek, Shoal and Channel Environments, Tibbits Creek Area, St. Lawrence River. Winters 1978-79 to 1974-75.

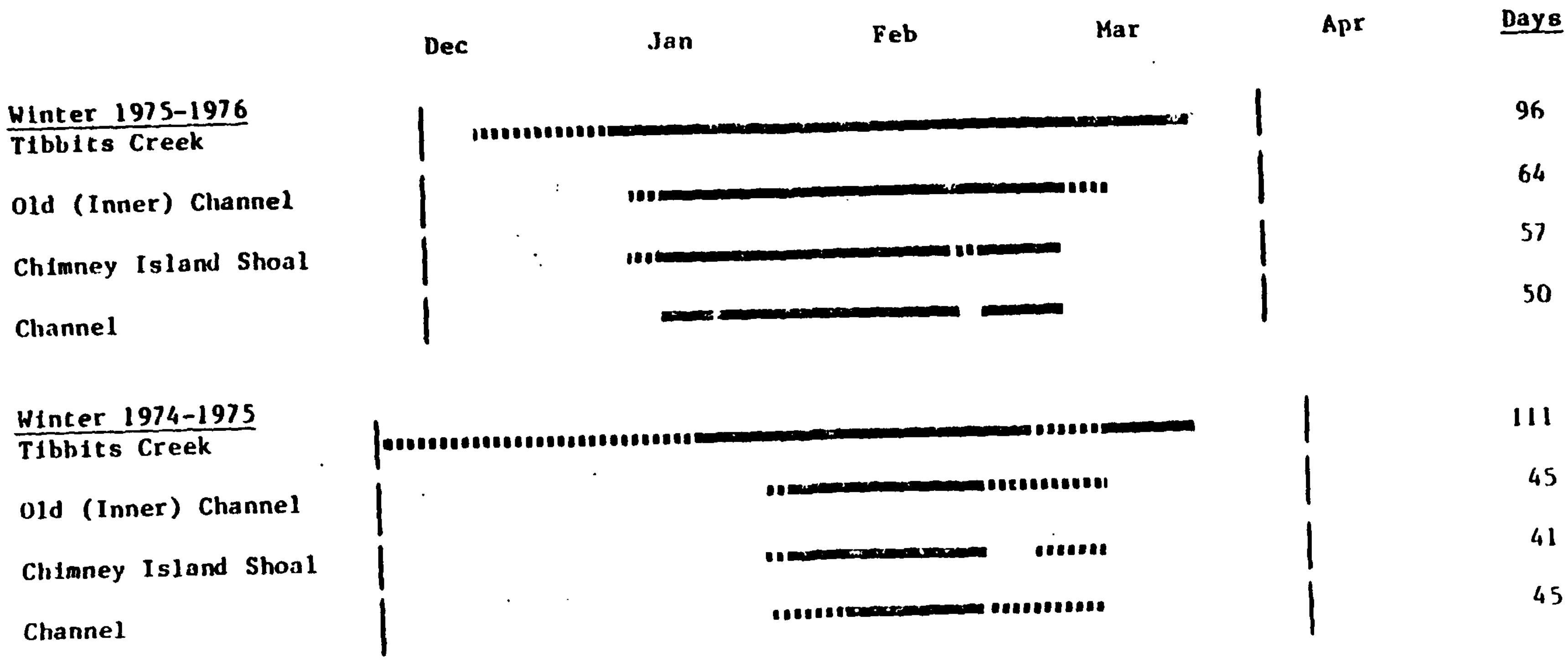


Figure 33. Continued.

Table 17. Snow and Ice Thickness and Water Depth Measurements (in Centimeters), Tibbits Creek Control Site, St. Lawrence River. Winter 1978-79, 22 March 1979.

Core No.	Snow	Snow Ice	Lake Ice	Frozen Sediment	Total Ice	Depth to Bottom[2]
A1[1]	0	*[3]	*	*	38.0	68.5
A2	0	*	*	*	38.0	74.0
A3	0	17.0	10.0	0	27.0	61.0
A4	0	5.0	26.0	0	31.0	79.0
A5	0	13.0	20.0	0	33.0	101.5
A6	0	7.0	22.0	0	29.0	106.5
A7	0	11.0	14.5	0	26.5	109.0
A8	0	12.0	12.0	0	24.0	109.0
A9	0	*	*	*	33.0	145.0

[1] Letter denotes transect from which core was taken. See Figure for transect location.

[2] Water depths measured from top of ice cover.

[3] Data not taken.

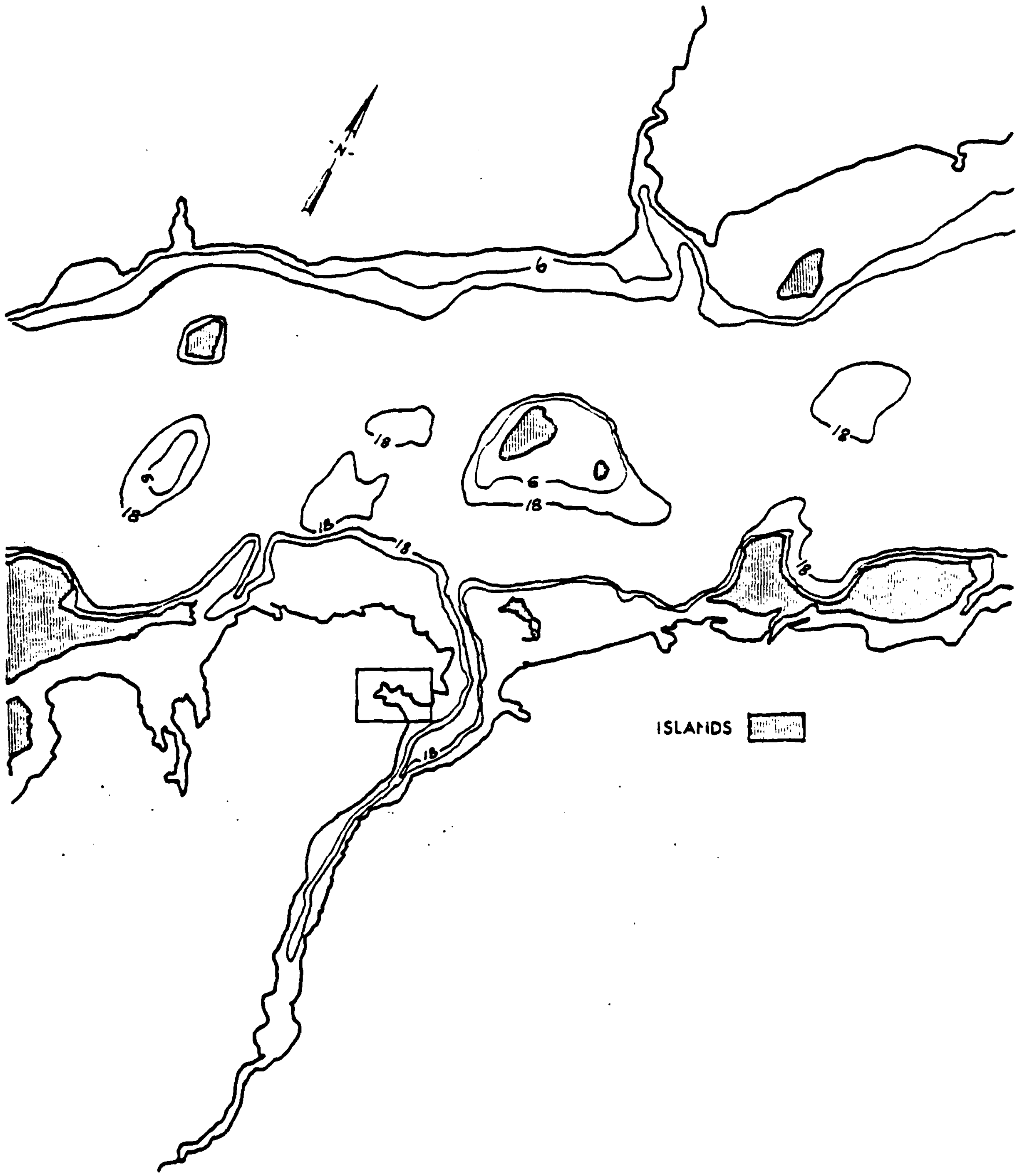


Figure 34. Location Map of the Brandy Brook Control Site, St. Lawrence River, Showing Ice Sampling Site and Zones Used for Ice Cover Duration.

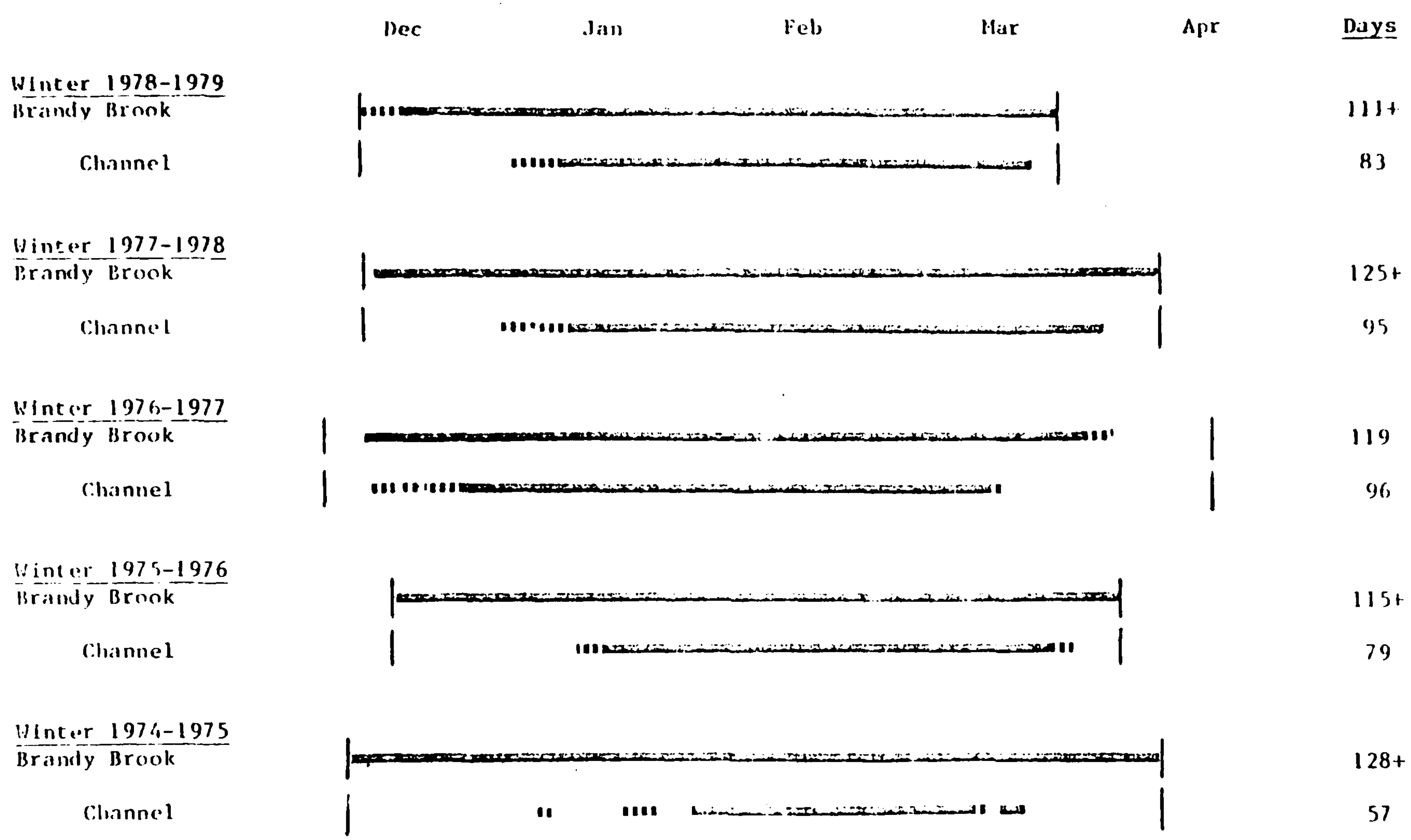


Figure 35. Comparison of the Duration of Ice Cover on Brook, Bay and Channel Environments, Brandy Brook Area, St. Lawrence River. Winters 1978-79 to 1974-75.

10/10 ice cover

1/10 to 9/10 partial ice cover

first and last aerial ice reconnaissance itself to stratigraphic studies. The ice cover on Brandy Brook was unsafe for travel at this time.

Table 18 lists the ice thickness and water depth measurements for the Brandy Brook control site area.

Table 18. Snow and Ice Thickness and Water Depth Measurements (in Centimeters), Brandy Brook Control Site, St. Lawrence River. Winter 1978-79, 28 March 1979.

Core No.	Snow	Snow Ice	Lake Ice	Frozen Sediment	Total Ice	Depth to Bottom[2]
A1[1]	0	29.0	10.5	0	39.5	251.0
A2	0	31.0	13.0	0	44.0	259.0
A3	0	28.0	14.0	0	42.0	277.0
A4	0	20.0	15.0	0	35.0	272.0
A5	0	20.0	12.0	0	32.0	262.0
A6	0	28.0	6.0	0	34.0	213.0
A7	0	*[3]	*	*	28.0	183.0
B1	0	26.0	10.0	0	36.0	229.0
B2	0	19.0	15.0	0	34.0	226.0
C1	0	30.0	7.0	0	37.0	79.0
C2	0	23.0	3.0	0	26.0	36.0
C3	0	42.0	0	0	42.0	51.0
D1	0	16.0	0	0	16.0	18.0
D2	0	26.0	2.0	0	28.0	38.0
D3	0	26.5	4.5	0	31.0	56.0
D4	0	21.0	8.0	0	29.0	66.0
D5	0	31.0	9.0	0	40.0	70.0
D6	0	26.5	9.5	0	36.0	63.0
D7	0	25.5	0	0	25.5	44.0
D8	0	17.0	0	0	17.0	20.0
E1	0	21.0	0	0	21.0	26.0
E2	0	41.0	0	0	41.0	42.0
E3	0	16.0	10.5	0	26.5	53.0
E4	0	16.0	5.5	0	21.5	47.0
E5	0	42.0	2.5	7.5	52.0	49.0
E6	0	37.0	0	13.0	50.0	46.0
E7	0	30.0	0	10.0	40.0	38.0
E8	0	*	*	*	25.0	27.0
E9	0	*	*	*	19.0	19.0
F1	0	22.5	0	0	22.5	26.0
F2	0	29.0	0	0	29.0	44.0
F3	0	41.5	0	10.5	52.0	44.0
F4	0	48.5	0	7.5	56.0	52.0
F5	0	28.5	0	0	28.0	47.0
F6	0	28.5	0	2.0	30.5	40.0
F7	0	37.0	0	3.5	40.5	37.0
F8	0	44.0	0	0	44.0	39.0

Table 18. Continued.

Core No.	Snow	Snow Ice	Lake Ice	Frozen Sediment	Total Ice	Depth to Bottom
F9	0	24.5	0	0	24.5	20.0

[1]Letter denotes transect from which core was taken. See Figure for transect location.

[2]Water depths measured from top of ice cover.

[3]Data not taken.

2.VI. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Demonstration Corridor

1. Bathymetric conditions and the resulting upwelling, together with the placement of ice booms, are the principal factors that define four glaciological reaches of the Demonstration Corridor. These reaches are the Brockville Narrows, Morristown Point-Ogdensburg, Ogdensburg Ice Boom, and Galop Island Booms.

2. The lateral boundaries of pools in the Ogdensburg Ice Boom and Galop Island Reaches are largely determined by the location of the 24' depth contour.

3. Pools in the Morristown Point-Ogdensburg Reach are the result of the packing of floes of loose slush and frazil, thermal cracks, and shear cracks kept open by currents.

4. Ice boom placement determines the pool boundaries of the Ogdensburg Ice Boom and the Galop Island Reaches.

5. In the Brockville Narrows Reach, rough bottom conditions and the resulting upwelling are the principal factor controlling the location of pools.

Control Sites

1. The maximum ice cover durations for protected shallow control sites are the following:

Chippewa Bay	139 days
Blind Bay	135+ days
Morristown Harbor	98 days
Nevins Point area	103+ days
Tibbits Creek	118+ days
Brandy Brook	128+ days

2. Wetland edge environments are covered by a frozen three-layered formation consisting of snow ice, lake ice, and frozen organic-rich bottom sediments.

RECOMMENDATIONS

Demonstration Corridor

1. Aerial photomapping of the Demonstration Corridor beginning at the time of initial ice formation and extending during the whole process of ice erosion. In addition, low altitude missions are needed at selected

times for stereo examination of ice conditions. It is necessary to have a complete overview of 100-150 day period that ice covers the various riverine environments.

2. Develop the capacity for all-weather monitoring of ice formation and ice erosion in the Demonstration Corridor by utilizing SLAR (Side Looking Airborne Radar) in coordination with aerial photomapping.

3. Compile photo interpretation guide of the St. Lawrence River ice characteristics.

4. Compile a bathymetric chart of the Demonstration Corridor utilizing the vast array of soundings on NOAA field sheets. Versions of this chart in normal format and shaded relief aid in visualizing the engineering and environmental factors associated with demonstration voyages.

5. Investigate the structural geology of ice surrounding pools originating from upwelling currents and ice boom placement.

6. Carry out a full winter's study in order to define the stages and processes occurring in ice formation and ice erosion in the Demonstration Corridor. The study should extend over several winters to include winters of varying severity.

7. In the future, if winter navigation studies are to be carried out in the Demonstration Corridor, it would be helpful if the objectives of the scientific programs were carefully explained in the media prior to the studies. This would serve to inform residents along the river and help to allay suspicions. Winter navigation is not a popular subject with these people, who see their economic livelihood threatened. Attempts to develop a data base in their dooryards is often viewed with distrust. Field studies benefit from the cooperation and advice of experienced residents, and sensitivity to these issues by explanation at the local level would be productive.

Control Sites

1. Studies need to begin at the start of the winter, particularly in bays and wetlands, in order to trace the important role snow and snow ice plays in the formation of the ice cover. The stratigraphic interpretation of late winter ice cores is made difficult without these data.

2. Requests be made of federal or state authorities for detailed soundings extending from bay mouth to wetlands in bays and harbors fringing the Demonstration Corridor.

3. Contracts for studies of control sites in the Demonstration Corridor be issued early in the fall to allow for recruiting of field staff. In particular, if students are utilized as field assistants, sufficient lead time is needed to arrange class schedules to permit 1-2 full days a week

in the field. Commitments must be made to students for the academic year to most efficiently meet both project and student financial requirements.

4. Safe river studies in areas of cold, moving, open water and ice mandate adequate lead time for locating riverworthy airboats, trained operators, and cold-water protective garments.

5. Investigate the possibility that thin ice layers in frozen, organic-rich bottom sediments in St. Lawrence River wetlands, formerly ascribed to water level fluctuations, may be the result of the formation of segregated ice layers and lenses marking periods of slow downward freezing. Automatic water level recorders and thermocouple probes should be used to monitor ice layer formation at the wetland edge.

6. Future studies of the development of stratigraphic features in the ice canopy should utilize vertical thin sections photographed in polarized light to determine the origin of these features.

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APPENDICES

APPENDIX A

Averaged Water Quality Data per Site by Sampling Period, St. Lawrence River; Winter, 1979

Location, Site, Depth at Site, and Date	Parameter												
	TEMP (°C)	DO (mgO_2/L)	TURB (NTU)	SS (mg/L)	pH	ALK ($mgCaCO_3/L$)	TP (μgP/L)	TSP (μgP/L)	SRP (μgP/L)	NO_3/N (μgN/L)	KJLD (μgN/L)	Ca ($mgCaCO_3/L$)	TH ($mgCaCO_3$)	Cl (mgCl/L)
BLIND BAY														
Bay Sites: (#1,4.5m; #2,5m)														
2/13/79	-	-	2.2	3.1	7.76	86.0	18.1	15.2	11.0	526.5	-	98.0	126.0	30.2
2/28/79	-1.0	14.6	0.8	0.2	7.88	95.0	14.1	4.5	7.1	500.0	-	103.0	134.0	34.8
3/30/79	1.0	14.7	14.0	1.0	8.24	82.7	12.8	0.0	5.0	254.5	-	94.0	125.0	28.9
4/23/79	5.0	13.8	1.4	5.5	8.40	92.0	33.6	18.8	3.3	247.0	-	100.0	131.0	29.2
Wetland Sites: (#3,1m; #4,1m; #5,0.6m)														
2/13/79	-	-	13.7	28.3	6.92	250.3	238.2	111.7	37.9	174.0	2940.0	210.0	261.3	21.2
2/28/79	-1.0	-0.55	26.0	143.5	6.91	145.4	194.6	33.2	18.5	184.5	-	128.0	176.0	11.6
3/13/79	0.0	3.02	4.4	18.0	6.59	35.1	53.9	6.6	4.2	270.0	-	36.0	48.0	2.6
4/23/79	8.0	12.6	0.9	3.0	8.34	93.0	28.4	15.7	3.5	224.0	320.0	102.0	132.0	30.6
Near Shore Sites: (#6,4m; #7,4m)														
2/13/79	-	-	1.4	0.5	7.96	91.8	13.3	9.3	6.6	549.0	-	100.0	132.0	30.8
2/28/79	-1.0	14.6	0.9	0.8	7.96	93.6	12.5	10.9	10.4	630.0	-	104.0	134.0	32.0
3/13/79	0.0	14.2	1.0	0.3	8.14	88.8	18.1	3.3	2.8	383.5	-	98.0	130.0	30.8
3/30/79	0.0	14.8	1.4	0.6	8.26	87.8	8.5	2.3	4.9	296.0	-	101.0	125.0	32.1
4/23/79	4.5	14.2	1.2	4.0	8.36	93.0	20.4	11.5	4.3	315.5	-	104.0	132.0	31.1

APPENDIX A (cont.)

Location, Site, Depth at Site, and Date	Parameter												
	TEMP (°C)	DO (mgO_2/L)	TURB (NTU)	SS (mg/L)	pH	ALK ($mgCaCO_3$/L)	TP (μgP/L)	TSP (μgP/L)	SRP (μgP/L)	NO_3/N (μgN/L)	KJLD (μgN/L)	Ca ($mgCaCO_3$/L)	TH ($mgCaCO_3$)	Cl (mgCl/L)
BLIND BAY														
Channel Site: (#8, 16m)														
2/13/79	-	-	1.4	0.0	7.95	90.8	14.1	9.3	9.3	544.0	50.0	100.0	132.0	31.8
2/28/70	-1.0	14.6	1.2	0.3	7.92	92.8	15.0	10.9	11.5	603.0	-	104.0	134.0	35.0
3/30/79	0.0	14.6	3.0	0.7	8.2	87.0	6.1	0.0	4.9	300.0	-	102.0	132.0	32.2
4/23/79	4.0	14.3	1.2	3.7	8.35	92.5	24.9	10.9	4.9	326.0	110.0	104.0	132.0	32.3
Shoal Site: (#9, 3m)														
2/13/79	-	-	1.3	0.0	7.97	92.6	9.3	7.7	7.1	396.0	-	100.0	134.0	32.8
3/30/79	0.0	14.8	1.6	1.0	8.26	87.2	12.1	0.0	4.9	299.0	-	102.0	132.0	31.9
4/23/79	4.5	14.0	1.2	4.7	8.34	93.5	28.1	7.7	4.9	315.0	-	100.0	132.0	31.9
Shoal Site: (#10, 3.5m)														
2/13/79	-	-	1.3	0.1	7.93	90.6	12.5	0.3	7.1	378.0	-	100.0	134.0	32.5
2/28/79	-1.0	14.6	0.8	0.3	7.85	92.8	9.3	6.1	12.5	585.0	-	102.0	134.0	36.5
3/30/79	1.0	14.4	1.9	1.2	8.25	87.6	15.7	2.9	2.8	301.0	-	102.0	132.0	32.3
4/23/79	4.0	13.7	1.1	0.0	8.35	92.5	28.1	10.9	4.9	317.0	-	104.0	132.0	32.8

APPENDIX A (cont.)

Location, Site, Depth at Site, and Date	Parameter													
	TEMP (°C)	DO (mgO_2/L)	TURB (NTU)	SS (mg/L)	pH	ALK ($mgCaCO_3/L$)	TP (μgP/L)	TSP (μgP/L)	SRP (μgP/L)	NO_3/N (μgN/L)	KJLD (μgN/L)	Ca ($mgCaCO_3/L$)	TH ($mgCaCO_3$)	Cl (mgCl/L)
MORRISTOWN														
Bay Sites: (#11, 3.5m; #12, 3.5m)														
2/13/79	-	-	1.1	0.1	7.95	92.0	17.3	15.4	14.7	459.0	-	100.0	134.0	34.4
2/23/79	-1.0	14.6	1.1	0.0	8.06	94.4	14.9	9.3	0.9	490.5	-	103.0	136.0	39.9
2/28/79	-1.0	14.6	0.8	0.3	7.81	93.0	15.9	10.1	13.6	612.0	-	101.0	134.0	37.0
3/09/79	0.0	11.2	1.6	0.0	7.99	87.8	17.3	9.3	4.9	749.0	-	96.0	129.0	29.8
3/13/79	0.0	14.0	1.0	0.9	8.10	89.0	16.5	6.1	2.8	386.5	-	98.0	130.0	30.0
3/20/79	0.0	14.2	1.1	0.3	8.18	88.7	17.3	3.7	4.9	338.0	-	98.0	129.0	28.0
3/30/79	1.0	14.6	1.2	1.2	8.29	88.1	14.1	2.9	2.8	297.0	-	103.0	135.0	32.6
4/23/79	-	-	1.6	5.2	8.37	93.2	28.4	11.7	4.4	308.0	-	104.0	132.0	32.1
Near Shore Sites: (#13, 10m; #14, 9m)														
2/13/79	-	-	1.2	0.2	7.88	91.8	30.9	16.5	10.9	499.5	-	103.0	138.0	30.9
2/23/79	-1.0	14.6	1.2	0.0	8.02	93.0	15.7	7.7	10.4	432.0	-	102.0	136.0	37.6
2/28/79	-1.0	14.6	1.0	0.2	7.85	92.6	18.8	9.3	7.7	612.0	-	103.0	134.0	39.8
3/09/79	0.0	12.3	1.0	0.0	8.01	87.6	18.8	7.7	4.4	661.0	-	96.0	128.0	31.4
3/13/79	0.0	14.4	0.9	0.7	8.13	89.0	22.0	5.3	2.8	380.0	-	99.0	131.0	32.1
3/20/79	0.0	14.6	1.1	0.8	8.21	89.1	17.3	2.9	5.5	335.5	-	98.0	130.0	29.0
3/30/79	1.0	14.6	1.2	1.5	8.28	88.0	14.1	4.2	3.4	304.0	-	102.0	134.0	33.6
4/23/79	4.5	14.2	1.1	0.4	8.36	93.0	24.4	10.9	4.3	318.0	-	104.0	132.0	31.6

APPENDIX A (cont.)

...cation, Site, ...epth at Site, and Date	Parameter													
	TEMP (°C)	DO (mgO_2/L)	TURB (NTU)	SS (mg/L)	pH	ALK ($mgCaCO_3$/L)	TP (μgP/L)	TSP (μgP/L)	SRP (μgP/L)	NO_3/N (μgN/L)	KJLD (μgN/L)	Ca ($mgCaCO_3$/L)	TH ($mgCaCO_3$)	Cl (mgCl/L)
...ORRISTOWN														
Temporary Channel Near Shore Site: (#15, 12m)														
2/13/79	-	-	1.2	0.0	7.90	91.0	26.8	9.3	3.8	504.0	90.0	100.0	132.0	31.7
2/28/79	-1.0	14.6	0.8	0.0	7.80	92.8	15.7	9.3	9.3	612.0	-	100.0	134.0	40.5
3/20/79	0.0	14.4	1.0	0.8	8.21	89.0	17.3	2.9	3.8	345.0	-	98.0	130.0	29.5
3/30/79	1.0	14.6	1.2	0.5	8.26	88.0	15.7	2.9	2.8	304.0	-	102.0	134.0	34.0
4/23/79	-	-	1.1	1.3	8.35	93.0	23.6	18.5	4.7	308.0	60.0	104.0	132.0	31.6
Wetland Sites: (#16, 1m; #17, 1m; #18, 0.8m)														
2/13/79	-	-	1.1	0.1	7.34	138.3	135.5	33.5	28.8	288.0	540.0	132.0	180.0	22.9
2/23/79	-1.0	8.8	6.5	18.1	7.67	133.6	69.2	14.2	26.1	576.0	-	130.0	175.0	40.9
2/28/79	-1.0	10.5	1.6	7.7	7.52	109.2	29.2	21.2	24.0	643.5	-	109.0	146.0	39.6
3/09/79	0.0	13.5	2.7	0.0	7.69	77.9	53.5	47.6	41.9	570.0	-	72.7	98.0	16.8
3/13/79	0.0	12.8	0.6	0.1	7.57	98.2	103.0	35.3	27.4	441.0	-	90.0	126.0	17.0
4/23/79	-	-	0.6	0.0	8.36	124.0	29.5	26.3	5.6	151.0	450.0	116.0	153.0	22.8
Channel Site: (#27, 25m)														
3/20/79	0.0	14.8	1.0	1.8	8.30	89.6	12.5	1.3	3.8	341.0	-	100.0	130.0	29.9
3/30/79	0.0	14.8	1.0	1.3	8.20	88.0	14.1	2.9	3.8	286.0	-	102.0	132.0	33.5
4/23/79	4.0	13.8	1.5	1.0	8.38	94.0	18.8	6.1	4.9	315.0	-	100.0	132.0	31.7

APPENDIX A (cont.)

ocation, Site, epth at Site, and Date	Parameter TEMP (°C)	DO (mgO_2/L)	TURB (NTU)	SS (mg/L)	pH	ALK ($mgCaCO_3/L$)	TP (µgP/L)	TSP (µgP/L)	SRP (µgP/L)	NO_3/N (µgN/L)	KJLD (µgN/L)	Ca ($mgCaCO_3/L$)	TH ($mgCaCO_3$)	Cl (mgCl/L)
ORRISTOWN														
Shoal Site:														
(#28, 4m)														
3/20/79	-	-	1.0	1.5	8.36	89.6	14.1	1.3	3.8	324.0	-	100.0	132.0	30.2
3/30/79	1.0	14.8	0.6	1.7	8.22	88.0	12.1	1.3	3.8	286.0	-	102.0	132.0	33.2
4/23/79	4.5	12.6	1.4	0.0	8.36	93.0	15.7	2.9	6.9	319.0	-	100.0	132.0	31.8
RANDY BROOK														
Wetland Sites:														
(#19, 2.5m; #20, 2m; #21, 2.5m)														
2/23/79	-1.0	14.2	1.4	0.1	7.83	93.2	11.4	7.2	11.1	471.0	320.0	102.7	132.7	40.8
3/09/79	0.0	11.2	2.9	0.0	7.28	77.9	153.6	137.6	47.3	255.0	-	92.7	98.0	5.3
4/23/79	-	-	4.5	5.0	8.30	86.5	82.7	43.9	41.5	121.0	360.0	85.0	120.0	18.5
Bay Sites:														
(#22, 8m; #23, 7m)														
2/23/79	-1.0	14.2	1.3	0.8	7.80	92.2	12.5	6.1	13.6	333.0	-	102.0	132.0	39.6
3/09/79	0.0	12.3	3.9	0.0	7.64	79.8	112.3	93.9	64.2	450.0	-	78.0	108.0	15.2
3/30/79	2.0	13.7	3.2	3.2	8.14	71.4	22.0	5.3	3.8	207.0	-	89.0	120.0	25.3
4/23/79	-	-	2.0	1.0	8.32	88.0	20.4	2.9	4.9	262.0	-	92.0	127.0	28.6

APPENDIX A (cont.)

ocation, Site, epth at Site, and Date	Parameter													
	TEMP (^oC)	DO (mgO_2/L)	TURB (NTU)	SS (mg/L)	pH	ALK ($mgCaCO_3/L$)	TP (μgP/L)	TSP (μgP/L)	SRP (μgP/L)	NO_3/N (μgN/L)	KJLD (μgN/L)	Ca ($mgCaCO_3/L$)	TH ($mgCaCO_3$)	Cl (mgCl/L)
RANDY BROOK														
Channel Site:														
(#24, 16m)														
2/23/79	-1.0	14.6	1.6	0.8	7.90	92.2	12.5	9.3	11.5	468.0	360.0	104.0	134.0	41.2
3/09/79	-	-	6.7	3.0	8.06	89.0	18.8	12.5	9.3	720.0	-	100.0	128.0	33.2
3/30/79	1.0	14.6	1.0	1.5	8.17	86.8	12.1	2.9	2.8	295.0	-	102.0	132.0	33.2
4/23/79	-	-	1.5	1.0	8.36	90.5	14.1	10.9	9.3	297.0	180.0	96.0	132.0	31.6
Shoal Site:														
(#25, 6m)														
2/23/79	-1.0	14.4	1.4	0.7	7.95	93.2	12.5	9.3	9.3	396.0	-	104.0	134.0	42.5
3/09/79	-	-	5.0	4.0	7.67	55.6	25.2	9.3	9.3	522.0	-	62.0	80.0	18.1
3/30/79	1.0	14.6	-	-	-	-	-	-	-	-	-	-	-	-
4/23/79	-	-	1.7	3.0	8.38	93.0	18.8	2.9	7.1	309.0	-	98.0	132.0	32.2
Near Shore Site:														
(#26, 7m)														
2/23/79	-1.0	14.6	1.3	0.5	7.92	90.8	14.1	9.3	12.5	522.0	-	100.0	128.0	39.0
3/09/79	0.0	14.2	8.0	0.0	7.90	82.2	26.8	10.9	9.3	684.0	-	90.0	118.0	26.9
3/30/79	1.0	14.8	1.2	1.2	8.15	81.4	14.1	2.9	2.8	288.0	-	96.0	124.0	30.2
4/23/79	-	-	1.5	2.0	8.38	93.0	17.3	9.3	6.0	296.0	-	94.0	126.0	30.0

APPENDIX B

Mean Values of Chemical Constitutents in Sediment Samples Taken from the St. Lawrence River, Duplicate Samples Except as Noted (*)

Sampling Date, Site Number, and Location	Water Depth at Sample Site (m)	Moisture (% Wet Wt)	Organic Matter (% Dry Wt)	Total Phosphorus (mg/g Dry Wt)	Extractable Phorphorus (mg/g Dry Wt)	Total Metals (mg/g Dry Wt) Fe	Zn	Cu
28 FEB 79								
Blind Bay								
#1 Wetland	1.0	88.8	46.0	0.44	0.35	32.5	0.22	0.09
#2 Near Shore	2.0	31.3	1.9	0.33	0.27	11.0	<.01	0.02
Morristown								
#6 Wetland	1.0	83.9	22.8	0.95	0.43	26.4	0.21	0.08
#7 Bay	3.0	70.5	8.1	0.63	0.20	19.5	0.19	0.06
#8 Near Shore	6.0	28.[illegible]	0.7	0.14	0.04	[illegible].0	<0.01	0.01
T Near Shore*	13.0	41.4	1.7	0.49	0.09	15.4	<0.01	0.04
Brandy Brook								
#11 Wetland	1.0	47.7	5.1	0.61	0.30	24.4	0.12	0.03
#12 Bay	1.0	48.3	5.4	0.22	lost	27.4	0.18	0.04
#13 Shoal	6.5	46.8	22.6	0.82	0.18	8.7	0.08	0.01
#16 Near Shore	5.0	35.0	1.0	0.56	0.11	37.0	0.10	0.04
#17 Near Shore*	5.0	38.4	1.6	0.50	0.09	44.2	0.14	0.66
#18 Wetland	2.0	72.4	34.5	1.42	0.59	20.7	0.15	0.04
23 APR 79								
Blind Bay								
#1 Wetland	1.0	87.3	34.9	0.87	0.253	32.1	-	-
#2 Near Shore	2.0	60.2	7.9	0.69	0.183	30.0	-	-
#3 Near Shore	6.0	65.2	6.8	0.80	0.11	28.5	-	-
#5 Shoal	4.0	41.0	2.9	0.50	0.07	19.8	-	-
Morristown								
#6 Wetland	1.0	83.7	30.4	0.95	0.44	46.4	-	-
#7 Bay	3.0	70.9	11.9	0.56	0.15	29.3	-	-
#8 Near Shore*	6.0	36.4	3.3	0.64	0.09	14.4	-	-
Brandy Brook								
#11 Wetland	1.0	44.8	5.6	0.71	0.33	40.8	-	-
#12 Bay	1.0	64.8	8.4	0.86	0.43	33.7	-	-
#16 Near Shore	5.0	22.7	1.0	0.39	0.16	41.9	-	-
#17 Near Shore*	5.0	29.0	1.2	0.70	0.23	30.4	-	-
#18 Wetland	2.0	66.8	11.2	0.75	0.52	29.8	-	-

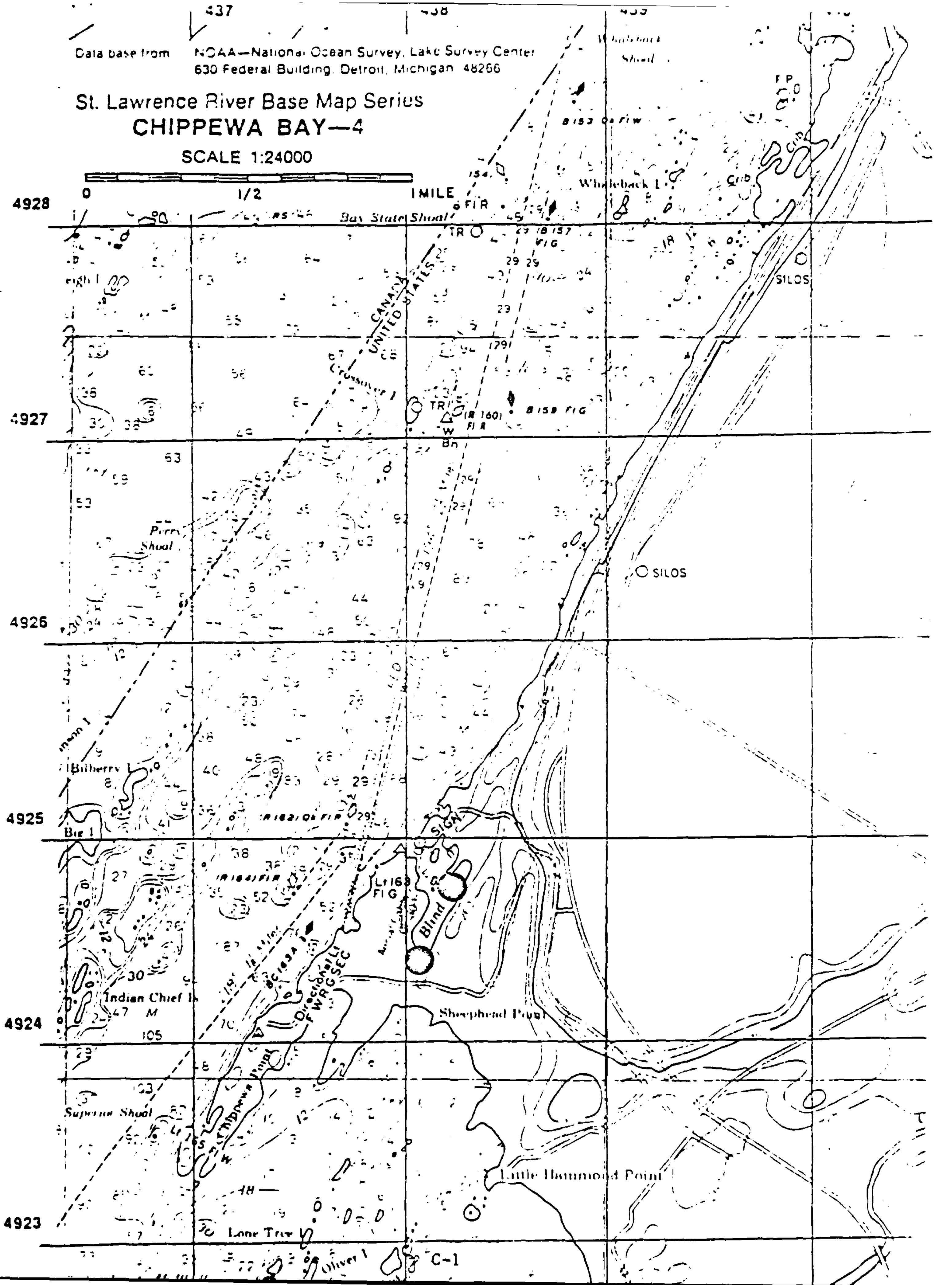
APPENDIX B (cont'd)

Particle Size Distributions in Time-Composited Sediment
Samples from the St. Lawrence River, 1979;
Percent of Oven-Dry Weight

Sample	Particle Size Class (Diameter)		
	Sand or Greater (> 0.05 mm)	Silt (0.002-0.05 mm)	Clay (< 0.002 mm)
Blind Bay			
#1 Wetland	96.1	3.9	0.0
#2 Near Shore	86.8	9.9	3.3
#3 Near Shore	95.1	4.9	0.0
#5 Shoal	90.1	8.3	1.6
Morristown			
#6 Wetland	89.4	10.6	0.0
#7 Bay	84.5	13.8	1.7
#8 Near Shore	94.4	5.6	0.0
#T Near Shore	94.9	5.1	0.0
Brandy Brook			
#11 Wetland	72.0	24.7	3.3
#12 Bay	76.9	21.4	1.7
#13 Shoal	93.5	4.9	1.6
#16 Near Shore	52.2	41.2	6.6
#18 Wetland	83.3	16.7	0.0

APPENDIX C

Location Maps of Ice Sampling Sites.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630 Federal Building, Detroit, Michigan 48266
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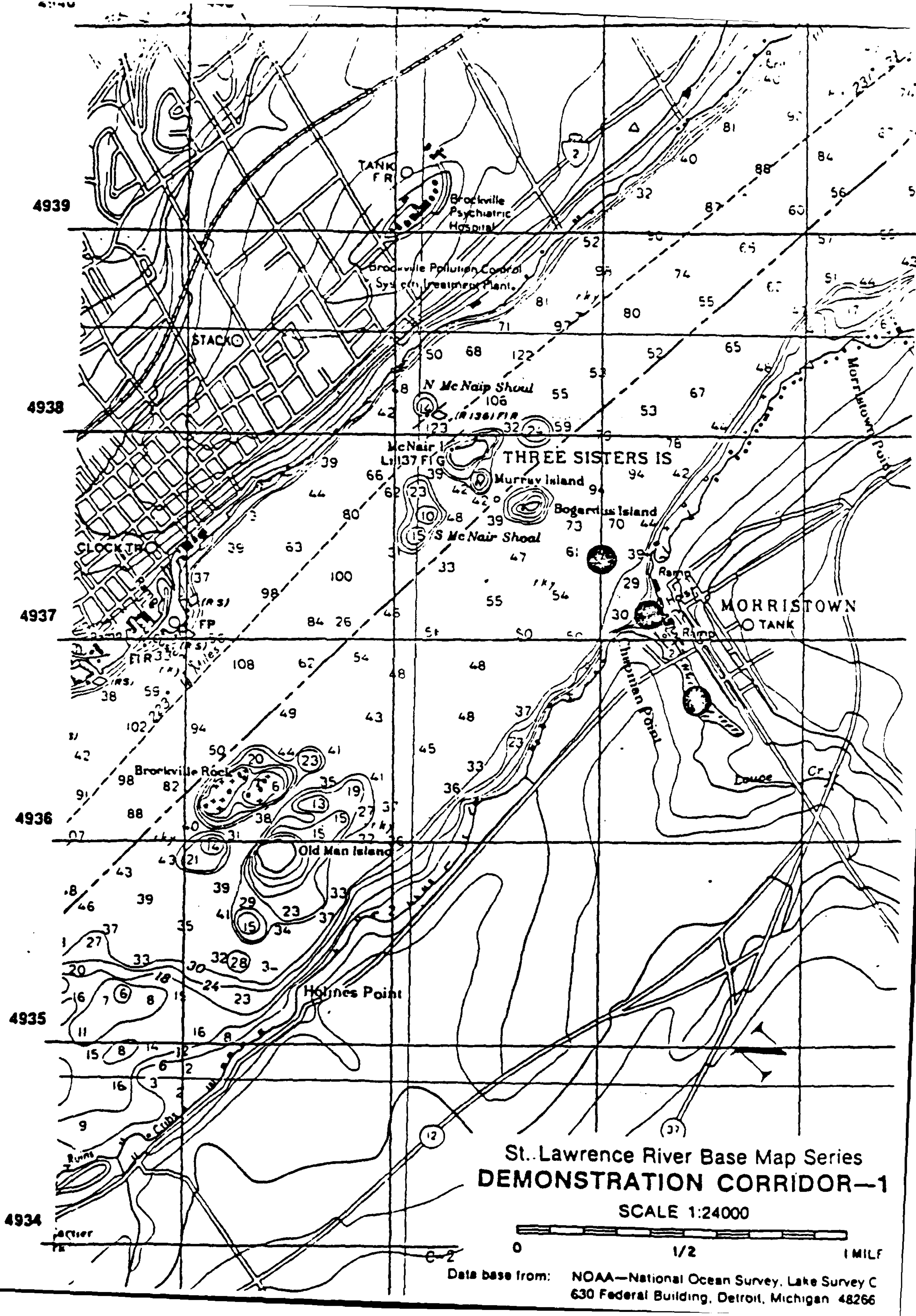
0
1/2
1 MILE
437
4928
4927
4926
4925
4924
4923
Bay State Shoal
Whaleback I
Crossover I
CANADA
UNITED STATES
SILOS
Perry Shoal
Bilberry I
Big I
Indian Chief Is
Blind
SIGN
Sheephead Point
Superior Shoal
Chippewa Point
Little Hammond Point
Lone Tree
Oliver I
C-1



4939
4938
4937
4936
4935
4934
Brockville Psychiatric Hospital
Brockville Pollution Control System Treatment Plant
TANK
STACK
CLOCK TR
N McNair Shoal
McNair I
THREE SISTERS IS
Murray Island
Bogardus Island
S McNair Shoal
MORRISTOWN
TANK
Morristown Point
Chippewa Point
Brockville Rock
Old Man Island
Holmes Point
St. Lawrence River Base Map Series
DEMONSTRATION CORRIDOR—1
SCALE 1:24000
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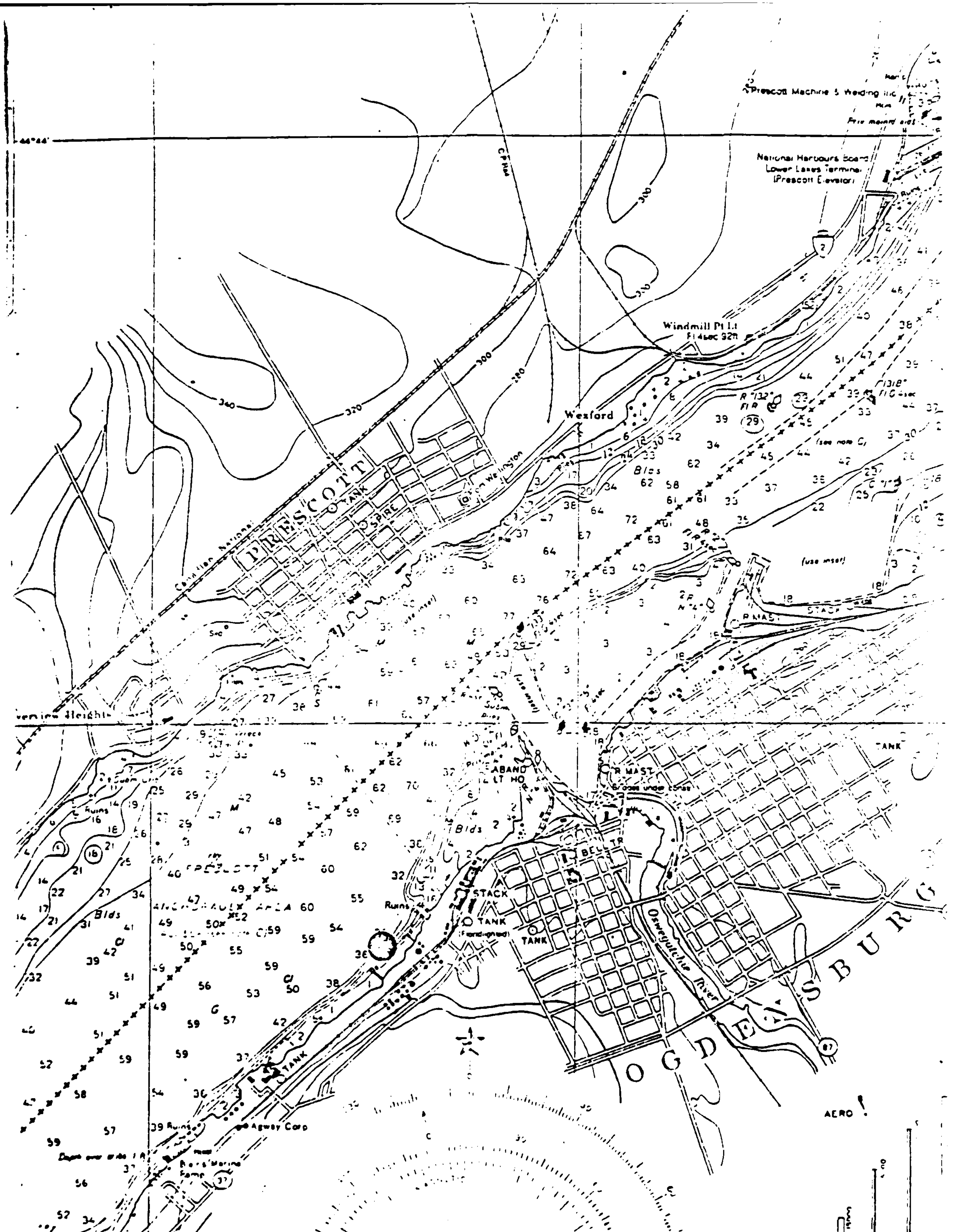
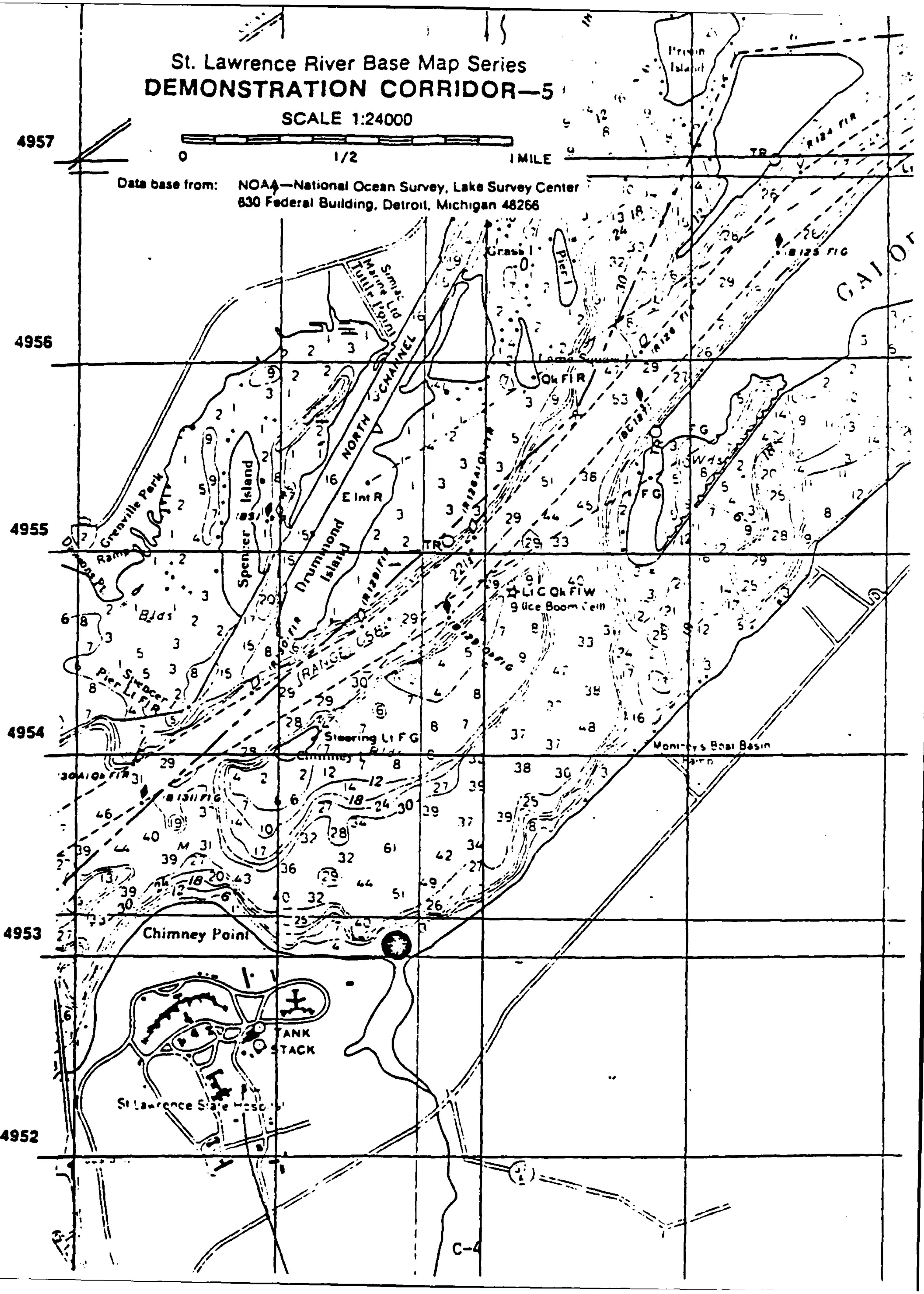
Data base from: NOAA—National Ocean Survey, Lake Survey C
630 Federal Building, Detroit, Michigan 48266


Prescott Machine & Welding Inc
National Harbours Board
Lower Lakes Terminal
(Prescott Elevator)
Windmill Pt Lt
Wexford
PRESCOTT
Canadian National
TANK
SPIRE
(use inset)
Bids
R MAST
ABAND LT HO
BELL TR
STACK
TANK
TANK
Ruins
Oswegatchie River
OGDENSBURG
Agway Corp
AERO


St. Lawrence River Base Map Series
DEMONSTRATION CORRIDOR—5
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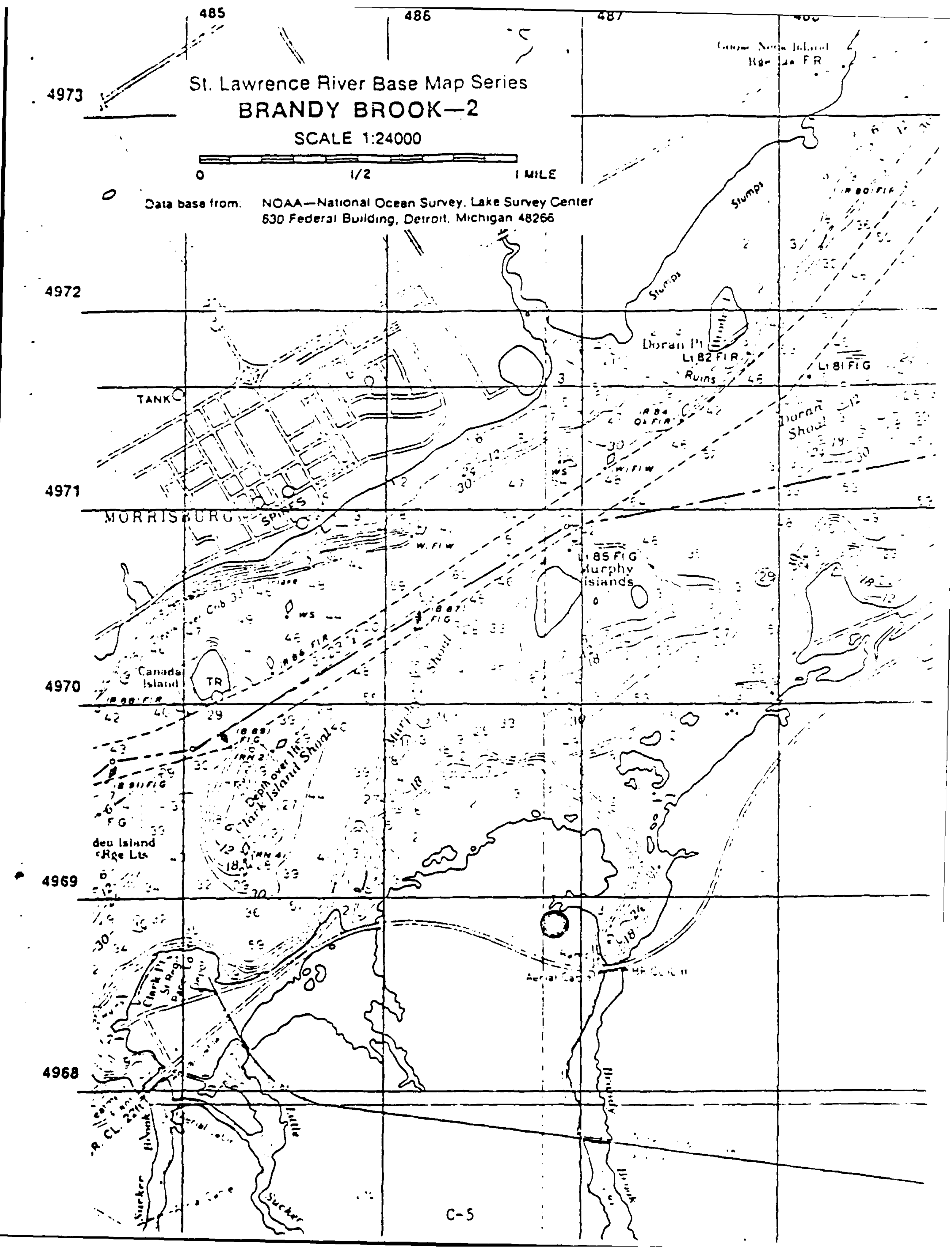
1 MILE
Data base from: NOAA—National Ocean Survey, Lake Survey Center
630 Federal Building, Detroit, Michigan 48266
4957
4956
4955
4954
4953
4952
Grass I
Pier I
Simi...
Marine Ltd
Tuttle Point
NORTH CHANNEL
Spencer Island
Drummond Island
Grenville Park
Ramp
Bldg
Spencer Pier Lt Fl R
E Int R
TR
Lt C Ok Fl W
Ice Boom Cell
RANGE
Steering Lt F G
Chimney
Chimney Point
Monty's Boat Basin
Ok Fl R
F G
TANK
STACK
St Lawrence State Hospital


St. Lawrence River Base Map Series
BRANDY BROOK—2
SCALE 1:24000
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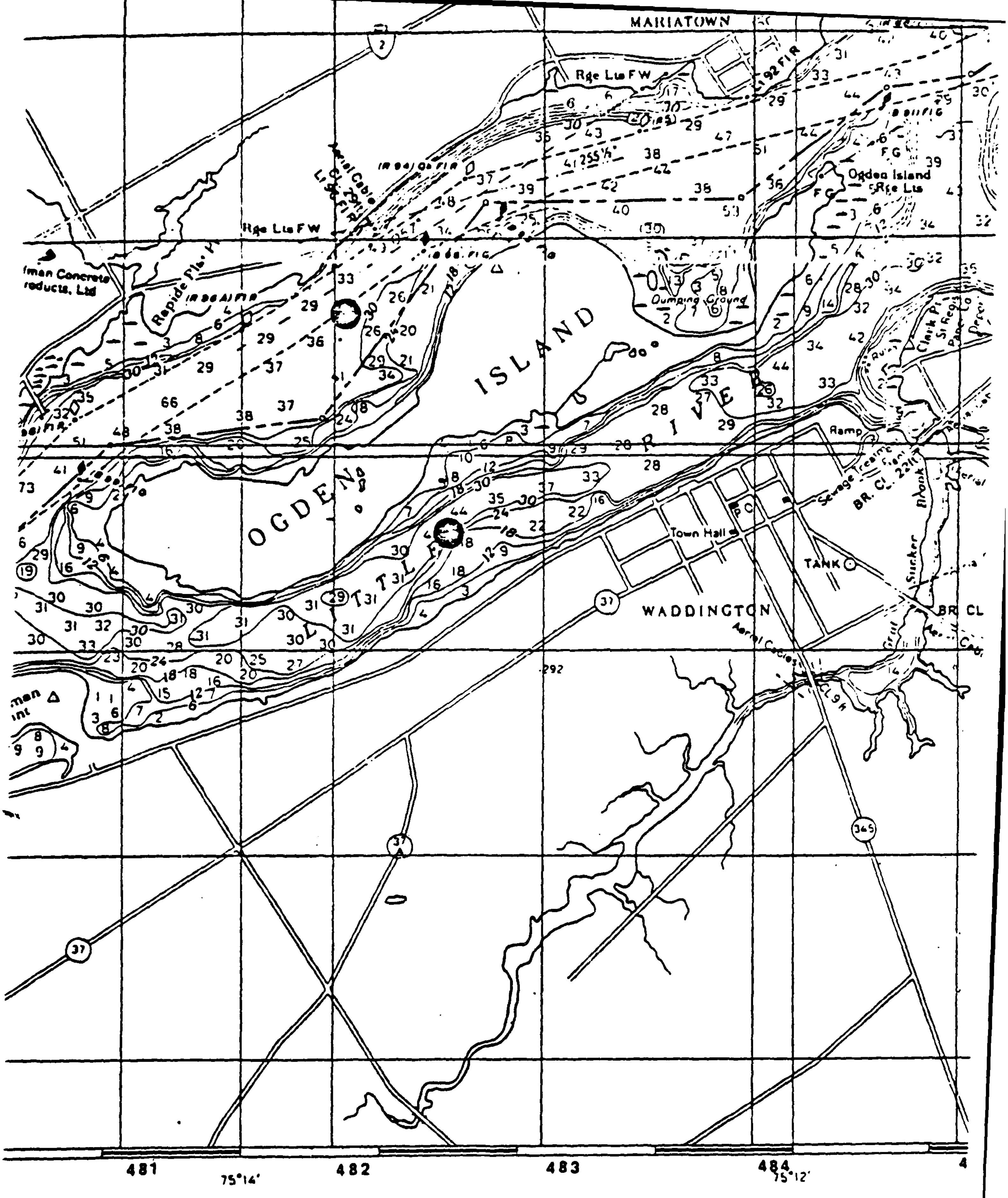
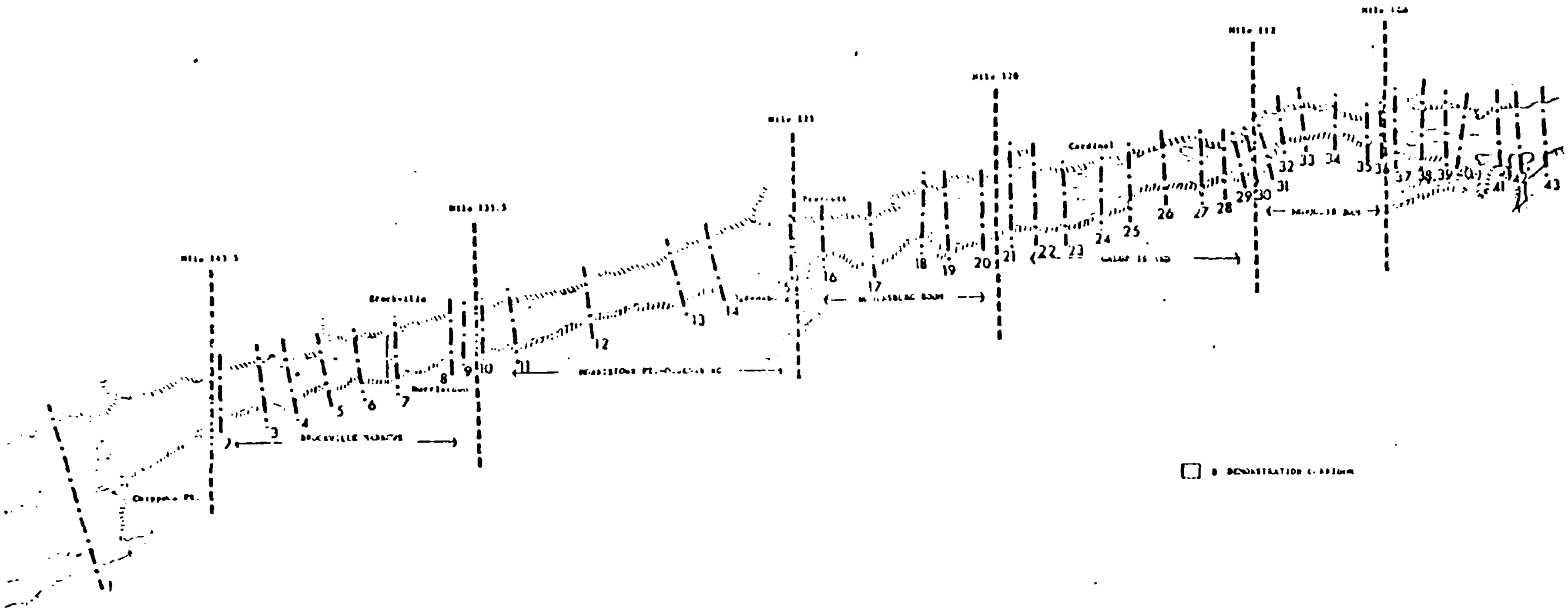
1 MILE
Data base from: NOAA—National Ocean Survey, Lake Survey Center
530 Federal Building, Detroit, Michigan 48266
485
486
487
4973
4972
4971
4970
4969
4968
TANK
MORRISBURG
SPIRES
Stumps
Doran Pt
Lt 82 Fl R
Ruins
Lt 81 Fl G
Doran Shoal
Lt 85 Fl G
Murphy Islands
Canada Island
TR
Clark Island Shoal
Depth over these
deu Island
Rge Lts
Clark Pt
Aerial Cable
Sucker
Brook


MARIATOWN
Rge Lts F W
Ogden Island
Rge Lts
Rapide Plat
Dumping Ground
ISLAND
OGDEN
LITTLE
RIVER
Ramp
Town Hall
P O
TANK
WADDINGTON
BR CL
Aerial Cables
Sucker Brook
481
482
483
484
75°14'
75°12'

APPENDIX D

Location Map of Bathymetric Cross Sections



Location of Bathymetric Cross Sections
Used in Defining Glaciological Reaches.

APPENDIX E

List of Dates of
Canadian Aerial Ice Reconnaissance,
St. Lawrence River,
Winters 1975-76 to 1978-79.

Appendix E. Aerial Ice Charts

Aerial ice charts of the St. Lawrence River, prepared by the Canadian Ice Central, Ottawa, and made available by the St. Lawrence Seaway Authority, Cornwall, Ontario, were used in this study. The dates for Canadian aerial ice reconnaissance flights during the winters of 1971-72 to 1974-75 were as follows:

Winter 1971-72

December 1971:	10, 13, 19, 21, 23, 27, 28, 29, 31.
January 1972:	3, 5, 8, 11, 14, 16, 18, 20, 26, 27, 31.
February 1972:	1, 7, 10, 16, 23, 27.
March 1972:	6, 8, 9, 15, 19, 21, 24, 27, 29.
April 1972:	1, 3, 5, 7, 9, 10, 11, 12, 14, 17, 18, 20, 21.

Winter 1972-73

December 1972:	7, 11, 14, 17, 20, 27, 29.
January 1973:	3, 8, 12, 16, 19, 26.
February 1973:	5, 9, 23, 27.
March 1973:	5, 7, 8, 9, 11, 13, 16, 19, 21, 23, 26, 28.

Winter 1973-74

November 1973:	29.
December 1973:	12, 13, 18, 19, 24, 28.
January 1974:	3, 7, 10, 14, 17, 24, 30.
February 1974:	1, 7, 15, 21, 26.
March 1974:	4, 6, 8, 11, 14, 18, 19, 22, 24, 26, 27, 28, 29.
April 1974:	1, 3, 5, 10.

Winter 1974-75

December 1974:	4, 6, 10, 20, 23, 30.
January 1975:	3, 6, 10, 14, 17, 20, 22, 27, 30.
February 1975:	3, 7, 10, 14, 20, 27.
March 1975:	3, 5, 10, 13, 14, 17, 21, 26.
April 1975:	1, 2, 8, 11.

APPENDIX F

Glossary of Technical Terms

Appendix F. Glossary of Technical Terms

AIR PHOTO INDEX - A collection of overlapping, numbered individual aerial photos laid out by flight line and rephotographed to provide in one photographic print an overview of an area photomapped.

BEGINNING OF BREAK-UP - Date of visual evidence of initial erosion along shoreline--the appearance of a shore moat or lead.

BEGINNING OF FREEZE-UP - Date on which ice forming stable winter ice cover first observed on the water surface.

BRASH - Small fragments of lake, river, or sea ice less than 2 m in diameter.

BREAK-UP - The period in the history of a lake, river or sea ice cover when the ice layer is fragmented by wind and wave action and/or thinning by melting. Mid-winter storms can break up an ice cover; however, the term is commonly used for the disappearance of the ice cover in the spring.

BREAK-UP DATE - The date on which a body of water is first observed to be entirely clear of ice and remains clear thereafter.

BREAK-UP PERIOD - Period of erosion of the ice cover.

COASTAL ZONE - Includes the shorelands, the coastal waters, the icelands and the submerged lands lying under the coastal waters out to the limit of state jurisdiction.

CRACK - A break or split without complete separation of parts such as a thermal crack in the ice, in contrast to a fissure.

CRYOCONITE HOLE - A small, dry or water-filled pit in an ice surface produced by the absorption of radiation by windblown dust which causes it to sink into the ice. The diameters of these pits is usually less than 1 centimeter but have been observed to be several tens of centimeters in diameter. The dusts can result from deflation from open agricultural fields, or as was observed on Brandy Brook, Waddington, N.Y. area, originate as sediments frozen to the bottom of the ice cover and later put into suspension.

FAST ICE - An ice cover which remains fast generally in the position where it originally formed. It is found along coasts where it may be attached to the shore, or over shoals where it may be held in position by islands or grounded hummocks or ridges.

FRAZIL - Dendrites or discoids of ice suspended in water (formed in supercooled, turbulent waters).

FREEZE-UP PERIOD - Period of initial formation of an ice cover.

FREEZE-UP DATE - The date in which the body of water was first observed to be completely frozen over.

FROST SMOKE - Fog-like wispy clouds due to contact of cold air with relatively warm water which can appear over openings in the ice and may persist while ice is forming. Seen over open water areas on the St. Lawrence River during periods of very low temperatures.

GLACIOLOGY - The science of the geology of ice. Includes fresh water ice covers on rivers and lakes, salt and brackish ice, as well as the ice in glaciers, ice caps and continental ice sheets.

HANGING DAMS - Accumulations of frazil, new and young ice that collects under the ice cover to form long ridges. A hanging dam approximately 1800' long and 15' deep was observed in the vicinity of Sparrowhawk Point, Ogden Island area, St. Lawrence River during the winter of 1978-79. (Batson, G. et al, 1979)

HINGE-LINE CRACK - A crack or a zone of several cracks formed between the floating ice and the grounded ice foot due to water level fluctuations caused by wind or changes in atmospheric pressure. The same as a TIDE CRACK.

ICE BOOM - An engineering structure frequently composed of 15'-30' timbers (14" x 22") linked by steel cable and chains which is strung across a river's and harbor's mouth to restrain the movement of ice floes. Examples include the Ogdensburg boom, and the booms across the North, Main, and South Galop Island Channels, St. Lawrence River, and Buffalo harbor.

ICE COVER - A significant expanse of ice of any type and form on the surface of a body of water. Although the term "ice sheet" is commonly used interchangeably with "ice cover", the writer prefers the latter in order to avoid the glacial connotation of a continental ice sheet, i.e., the Greenland or Antarctic ice sheets. When it is used with an adjective such as lake-ice cover, the meaning is clear.

ICE COVER DURATION - The period of time during which a body of water or an area under study is completely covered with ice.

ICE FLOE - A single piece of pack ice. The size of an ice floe can range in size from fragments 2 meters in diameter to vast floes several kilometers in diameter.

ICE FOOT - A fringe of grounded ice observed in Chippewa Bay, St. Lawrence River, up to 5-10 meters in width attached to the shore and unmoved by fluctuations in water level. On shorelines exposed to wind and wave action it is composed of accumulations of frozen slush, sludge, brash, and spray.

ICE WEATHERING - The process by which ice rocks disintegrate into ice grains and melt. This occurs by grain boundary melting, internal liquefaction of the ice grain in the plane of the secondary axis (0001), and by external melting.

ICELANDS - The ice covering the Great Lakes and the St. Lawrence River is viewed as a geological extension of the shorelands which the writer designates as icelands. These icelands consist of stable and unstable icelands.

LAKE ICE - The freshwater ice sheet resulting from the freezing or congelation of lake waters. The lake ice sheet is composed of grains commonly columnar and on occasion tabular in habit.

LITTORAL SHELF - Those water areas of intermediate depth along the St. Lawrence River between the bays and the deep navigation channel. The zone outside Chippewa Bay ranges in depth from 12'-50' and freezes over as a geographic unit after the bays.

MEDIUM WINTER-ICE - A winter ice cover with a thickness 15 to 30 cm (6 to 12 in).

NEW ICE - A general term which includes frazil, slush, and sludge and pancake ice.

OPEN WATER - A relatively large area of ice-free navigable water in an ice-encumbered lake or sea. Characterized by less than 1/10 ice cover.

PACK ICE - A general term used to include any form of floating ice other than fast ice regardless of its form or concentration.

POLYNYA - A Russian term for an unfrozen portion of a river surrounded by river ice - other than a lead.

POOL - Any relatively small ice-enclosed water area in the midst of pack ice other than a lead. Areas of this type are observed as annual features in the St. Lawrence River caused by up-welling, as in the Brockville Narrows, and by currents at the Ogdensburg boom, Galop Island booms, and below Iroquois Dam.

RAFTED ICE - A type of pressure ice formed by one ice layer over or under-riding another. These layers may or may not be frozen together.

RAPTOR - A bird of prey, such as a hawk or eagle.

REACH - A stretch of water visible between bends in a river or channel (nautical).

SASTRUGI - Wave-like and tongue-like ridges of snow formed by the scouring action of wind on a dense snow cover. Frequently observed on the surface of an ice cover and when water-soaked, refreezes into snow ice.

SLUDGE - The myriad of randomly oriented tabular and acicular, skeletal crystals growing in the supercooled surface waters of a lake or river and only slightly frozen together. This thin layer gives the lake surface a greyish color. With light wind no ripples appear.

SLUSH - Snowflakes falling into the water in great numbers create a layer of water-soaked snow or slush. Slush layers are also formed on the surface of a lake ice sheet due to snow loading which depresses the ice, allowing lake waters to flow up into the overlying snows along cracks and along lake-ice grain boundaries.

SHEAR CRACK - A crack produced in the ice cover by a shearing motion. Observed in the Brockville Narrows where channel ice was sheared away from fast ice attached to the islands by currents.

SNOW COVER - The snow layer covering the lake ice and frozen ground of the shorelands. This layer commonly consists of several stratigraphic layers and often becomes water-soaked and freezes into snow-ice.

SNOW ICE - The ice which forms from the freezing of water-soaked snows. Grain sizes commonly range from fractions of a millimeter to 1 centimeter.

SUBREACH - A subdivision of a reach based on navigational, hydraulic, or glaciological characteristics.

THAW MOAT - The zone of open water formed between the shore and the ice cover by the melting action of run-off during winter or spring thaws. This limits access to the ice cover for mammals and detaches the ice cover from the land allowing wind action to drive the ice sheets ashore causing destruction of marshland habitats, docks, and cottages.

THERMAL CRACKS - Cracks in the ice cover formed by the thermal contraction of the ice and range in width from fractions of millimeters to several centimeters, extending in length from a few meters to many kilometers.

THICK WINTER ICE - An ice cover more than 30 centimeters thick. On the Great Lakes thick winter ice may range up to 60 to 90 centimeters. On the St. Lawrence River, 40 to 90 cm.

TIDE CRACK (HINGE-LINE CRACK) - An active crack between the fast grounded ice and the floating ice cover subject to short term water level fluctuations due to wind tides and winter-long water level changes.

WATERBIRD - Any swimming or wading bird.

WATERFOWL - A swimming bird, such as a duck or goose.

WINTER ICE - An ice cover with a thickness of greater than 30 centimeters. (See MEDIUM WINTER-ICE and THICK WINTER-ICE.)

YOUNG ICE - Newly formed level ice generally in the transition stage of development from ice rind or pancake ice to winter ice; thickness from 5 to 15 centimeters.

APPENDIX G

RESPONSES TO REVIEWER QUESTIONS AND COMMENTS

Clarkson

July 24, 1979

Ms. Madonna McGrath, Chief
Environmental Planning Staff
Great Lakes National Program Office
U.S. Environmental Protection Agency
Region V
Room 932
536 South Clark Street
Chicago, IL 60605

Dear Ms. McGrath:

Dr. Joseph V. DePinto and I wish to thank you for your comments and questions concerning our draft report on "Analysis of Control Sites," a study performed for the Environmental Evaluation Work Group FY 1979 Studies of the Winter Navigation Demonstration Program under the auspices of the Great Lakes Basin Commission. We fully agree with your statements concerning the exercise of caution in use of the conclusions which stem from such limited studies and the need for setting priorities for studies of those potential impacts which have been identified.

Enclosed you will find our responses to your questions and comments. Should further clarification appear necessary to you, do not hesitate to contact either Dr. DePinto or me.

Sincerely yours,

Thomas C. Young
Assistant Professor
Department of Civil and
Environmental Engineering

TCY:jd

Enc.

RESPONSES TO MS. MCGRATH'S QUESTIONS/COMMENTS

Question a: If only water quality "may be sufficiently predicted" from control sites, what are the merits with proceeding with the idea?

Response: As we attempted to state in Conclusion 3 of the report, our examination of paired site data led us to the conclusion that soluble characteristics of water quality in main flow habitats (channel, shoal, near-shore) were similar at the three major sampling locations. That is, for longitudinal changes in magnitude of soluble parameters were similar. Thus, a main flow sampling site located outside of the Demonstration Corridor can serve as a control site for soluble parameters which may be measured at sites within the Corridor during vessel transits. Differences in magnitude between Corridor and control sites may be tested for statistically significance to determine whether observed differences are due to chance or possibly due to Demonstration activities.

The merits of continuing with a control site approach to monitoring water quality during a Demonstration program rest on several considerations. Maintenance of the biological community of the St. Lawrence depends in large part on maintaining continuity in the physicochemical environment of the river. However, vessel transits, under Demonstration conditions, have the potential to alter various aspects of the aquatic environment. For example, besides affecting light penetration, vessel-induced sediment resuspension can facilitate desorption and dissolution reactions which result in increased levels of soluble nutrients, such as phosphorus, or toxic heavy metals, which have been found at elevated levels in sediment samples from some locations in the river. Further, disturbance of sediment deposits which possess an oxygen demand can increase the rate of oxygen utilization by the sediments through enhancement of the transport of oxygen to the sediment particles and, thus, result in lower oxygen concentrations in the river. These examples of potential effects of winter navigation on water quality are not inclusive. However, they serve to indicate the existance of water quality parameters which are biologically significant, potentially vulnerable to Demonstration activities, determinable by field sampling, and testable by a paired site approach. It is our feeling that the potential changes in water quality which could result from a Demonstration of winter navigation constitute sufficient justification for a monitoring plan which, as a minimum, includes paired control and Corridor sites for sampling and analysis.

Question 5: What are the confidence limits of parameter correlations; if water quality is apparently uniform (showing only minor variations) would a paired site approach strongly dependent on water quality parameters, be effective?

Response: Two questions are apparent here, one of which concerns the statistical reliability of the correlations between parameters, and another of which concerns the value of strongly correlated parameters to paired site comparisons. Regarding the former question, the signficance of computed correlations between parameters measured at paired sites is indicated in Table 11 (p. 32). In Table II are presented simple correlation coefficients between parameters measured at sites paired in and out of the Demonstration Corridor. The parameter list in Table 11 was restricted to those parameters which showed significant ($\alpha<0.05$) intraparameter correlation between locations (ie., diagonal elements of the correlation matrix). Also given in Table 11 is the critical value ($\alpha<0.05$) which is to be used in testing each correlation coefficient against the null hypothesis of no correlation. If desired, an approximate confidence interval can be calculated for each coefficient from the following equation (p224, Rohlf and Sokal, Statistical Tables, Freeman, 1969). For a 95% confidence interval:

$$r - \{t_{0.05,24}[(1-r^2)/24]^{1/2}\} \leq \rho \leq r + \{t_{0.05,24}[(1-r^2)/24]^{1/2}$$

where: ρ = true correlation coefficient
r = sample correlation coefficient
$t_{0.05,24}$ = student's t statistic for α = 0.05, and degrees of freedom = 24

With regard to the second question, a paired site approach to water quality monitoring during a Demonstration program would have an efficiency for detecting ship-induced changes in water quality which would be directly related to the degree of uniformity present in baseline water quality, or water quality under non-demonstration conditions. That is minor differences in baseline water quality between paired sites permit smaller differences in water quality to be detected with equal statistical certainty or large differences to be detected with greater statistical confidence, than would be possible if water quality varied greatly between locations.

Question c: What is the reasoning for the recommendation that "only those water quality parameters which correlate between locations but are uncorrelated with each other should be employed for multivariate paired site comparisons"?

Response: When multivariate comparisons are made between data sets which show strong intercorrelations between parameters, as was the case with the paired site data presented in this report, important relationships become confounded to the point that interpretation of each may be impossible. Thus, while the canonical analysis of the paired site parameters identified statistically significant relationships between parameters at paired locations, the relationships themselves made no sense in ecologically significant terms.

The confounding arises from the fact that intercorrelated variables are not independent from each other and provide redundant information. For the paired site study, individual water quality parameters varied over time between locations in a manner which was related to variation in other parameters. For example, levels of total soluble phosphorus and soluble reactive phosphorus were correlated both within and between paired sites. Thus, a multivariate test of site similarity for phosphorus concentrations, which included both types of phosphorus, would reject the null hypothesis with a greater degree of certainty than a univariate test which considered either type alone. However, the multivariate procedure tests the relationship between a linear combination of the two measures of phosphours, and, due to intercorrelation between the measures, the test must account for reduncancy of information. Accordingly, the redundancy is translated into prediction equation coefficients which do not reflect ecological reality even though they yield accurate predictions.

By avoiding intercorrelated parameters, each variable selected for study tends to focus on a relavitely distinct ecological force within the aquatic system, such as, heat input, point source pollutant loadings, ice melt, and bed erosion. It should be noted that intercorrelated parameters are responsible for the patterns of correlation observed between parameters by the family of statistical techniques known as principal compone s, or factor analysis. In fact, a factor analytic solution was presented in our report. However, statistical signficance testing for principal components and factor analyses has not progressed to the point where such tests can be easily applied. Thus, overall tests of water quality similarity between paired sites will be most efficient in economic and ecologic terms if the variable list includes parameters which are uncorrelated for measurements taken at individual sites.

Questions d: What would it take to develop a "determinitive model of water quality"?

and

e: What would be the approximate cost to implement the recommendations?

Response: We feel that there is an urgent need to synthesize current and future environmental quality information on the St. Lawrence River ecosystem into a unified description of the overall environmental status of the river. Bringing together all of the fragmentary information is mandatory if meaningful river management decisions are to be made on an informed basis. It's our feeling that the best approach to such a synthesis is the development of what is known as a deterministic ecological model for the St. Lawrence River aquatic ecosystem. A model of this nature would allow simulation of the behavior of physical, chemical, and biological characteristics of the river ecosystem for a given set of basic inputs and forcing functions. The model itself would consist of a verified mathematical formulation of the important physical, chemical, and biological processes in the system.

The development of such a model would require a unified ecological monitoring program for the river in order to quantify inputs of the parameters of interest. Specific objectives of the monitoring program would be to obtain a temporally and spatially varying data set for calibration of the model and to obtain a second, unique data set for verification of the model. It is also likely that, in addition to system monitoring, a research program would be necessary to identify further and quantify the important physical, chemical, and biological processes and their respective interactions.

We estimate that the development of an ecological model for the St. Lawrence River would require an intensive, well-coordinated project period of three to five years. An effort of this nature is not inconceivable, since similar models have been successfully developed for large lake systems such as Lakes Erie and Ontario. The total cost of such a project would propably be on the border of a million dollars; however, it should be pointed out that a savings would probably be realized over the current environmental monitoring program for the river by the more coordinated approach necessary for the model development.