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Shoreline conditions and bank recession along the U.S. shorelines of the St. Marys, St. Clair, Detroit and St. Lawrence rivers

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Shoreline conditions and bank recession along the U.S. shorelines of the St. Marys, St. Clair, Detroit and St. Lawrence rivers

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The purpose of this investigation was to provide data to be used in evaluating the effects of winter navigation on processes that cause bank erosion. The specific objectives were to document bank conditions and erosion sites along the rivers, to monitor and compare the amounts of winter and summer bank recession and change, and to estimate the amount of recession that occurred prior to winter navigation.

Shoreline conditions and bank recession were documented during field surveys each spring and fall. Bank changes were evaluated by comparison to observations from a previous survey. Aerial photointerpretation was done to estimate the amount of bank recession that occurred prior to winter navigation.

20. Abstract (cont'd)

Three hundred forty-five miles of river shoreline were surveyed. Banks were eroding along 21.5 miles (6.2%). The common types of bank failures were soil falls (sloughing) and block sliding and slumping. The erosion along approximately 15 miles (70%) of the 21.5 miles was occurring along reaches not bordering winter navigation channels.

PREFACE

This report was prepared by Lawrence W. Gatto, Research Geologist, Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. The work was funded by the Detroit District, U.S. Army Corps of Engineers, under Order No. NCE-IA-78-29 and NCE-IA-79-028, *Inventory and Evaluation of Shoreline Erosion Conditions,* and Order No. NCE-IA-80-035EK, *Shoreline Erosion and Shore Structure Damage Monitoring on the St. Marys River.*

The author thanks Guenther Frankenstein, Chief, Ice Engineering Research Branch, CRREL, for assistance in project coordination; James Wuebben, David Deck, James Sirois, Carl Martinson and John Gagnon, Ice Engineering Research Branch, for their assistance during the field surveys; Eleanor Huke, Earth Sciences Branch, for assistance in initial photo interpretation and for preparation of maps and figures; Roger Gauthier, Great Lakes Hydrology and Hydraulics Branch, Detroit District, Corps of Engineers, for several helpful suggestions on the report; and Bill Willis of the Detroit District, Dr. George Alger of Michigan Technological University, and Dr. Daniel Palm of the St. Lawrence–Eastern Ontario Commission for technical reviews of the report.

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These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	*By*	*To obtain*
inch	25.4*	millimetre
foot	0.3048*	metre
mile	1.6093	kilometre

*Exact

SHORELINE CONDITIONS AND BANK RECESSION ALONG THE U.S. SHORELINES OF THE ST. MARYS, ST. CLAIR, DETROIT AND ST. LAWRENCE RIVERS

Lawrence W. Gatto

INTRODUCTION

Previous Corps of Engineers investigations indicated the need for additional studies of the effects of the Great Lakes–St. Lawrence Seaway Navigation Season Extension Program on natural bank erosion processes along the Great Lakes connecting channels, the St. Marys, St. Clair, Detroit and St. Lawrence rivers (Fig. 1). These investigations were limited to specific locations along the shoreline of the St. Marys River. An assessment of the entire shoreline of each river was necessary to evaluate adequately the potential impacts of winter navigation on bank erosion.

The interrelationships of the natural processes that contribute to riverbank erosion are varied and complex (Simons et al. 1979). Most riverbank erosion is caused primarily by the direct action of river water on the bank. Water waves and currents impinge against the toe of the riverbanks and loosen and displace toe material, eventually collapsing the overlying sediments (Fig. 2). The waves and currents then remove the slumped material, and toe erosion continues. This process usually occurs faster during high water and slower during low water. Waves and currents can also erode river bottom material in shallow nearshore areas. The riverbank will eventually collapse if enough nearshore material is removed.

Rainfall on unvegetated banks can increase erosion by direct impact. Surface runoff, either as sheet flow across the bank face or channeled in gullies or rills, can erode unvegetated banks during storms (Fig. 3). Groundwater seepage (springs) on the banks can increase the susceptibility of the soils to erosion; if enough water is released by the spring, it can sap the bank material directly. Chemical weathering of the bank material can also make the bank soil more susceptible to erosion, although this process is usually minor at most locations.

In cold climates the freeze–thaw cycle can also disrupt riverbank soils, allowing the surface material to be more easily eroded by other processes or adding directly to the amount of slumping on the face of a bank. River ice can gouge and remove sediment by pushing against and retreating from the beaches and banks. During spring thaw and breakup, when shorefast ice breaks from the shore, it can tear away vegetation and sediment frozen in and to the ice, and when the ice moves, it can scour the riverbanks and shoals.

An ice cover can also change the river hydraulics from an open channel to a type of closed conduit flow (Wuebben, in press). Usually the current velocity decreases and the flow depth increases. Also, sediment discharge is generally reduced. Where ice jams, frazil dams or other ice irregularities form, the resulting changed or deflected flow can cause bank damage (Martinson 1980).

Of the effects caused by ships, the most year-round shoreline damages are commonly considered to be caused by drawdown, surge and waves. However, the alterations of flow depth,

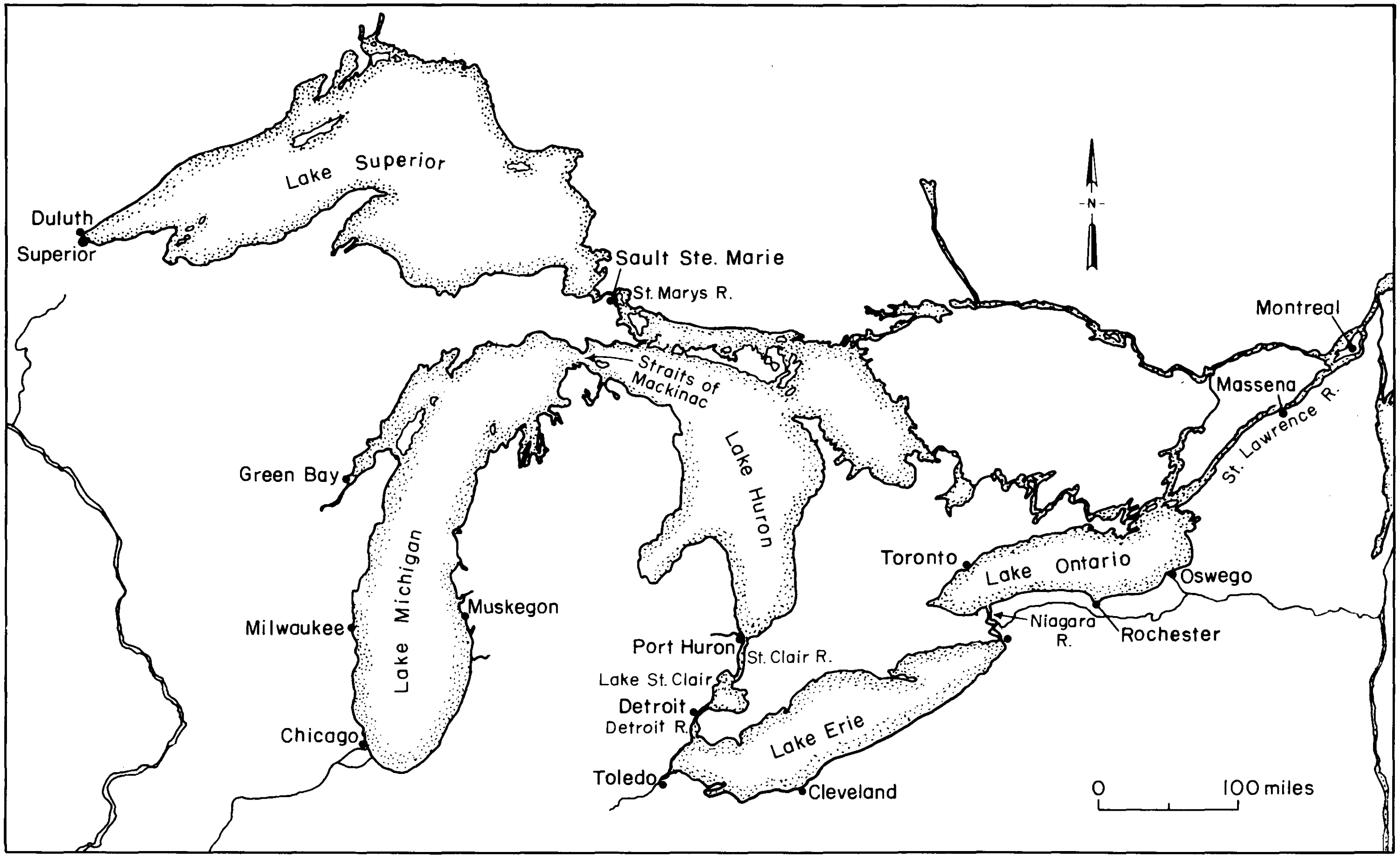


Figure 1. Map of the Great Lakes region.

a. Undercutting.

b. Collapse of overlying sediments.

c. Removal of slumped material.

Figure 2. Typical erosion sequence (St. Clair River Reach 17).

velocity and direction caused during ship passage can potentially be more damaging where ships pass through narrow channels. Also, the rapid water level changes associated with ship passage can occur faster than the pore water pressure in river bottom sediments can adjust. This imbalance can create "explosive liquefaction," in which a mass of bottom sediment is rapidly resuspended (Wuebben et al. 1978a).

This disruption of river bottom sediments can cause an unstable situation.* As usually envisioned, the shoreline condition and the offshore

*Personal communication with G. Alger, Michigan Technological University, 1980.

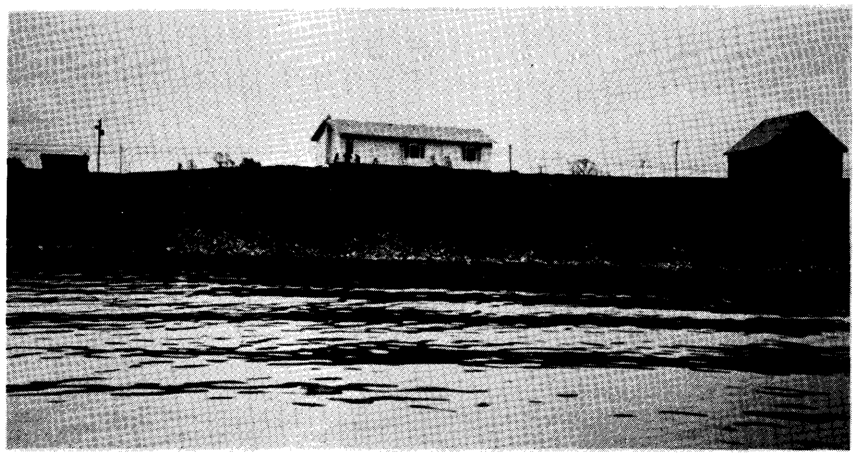


Figure 3. Gullies and rills along the bank crest and face (St. Lawrence River reach 12).

river bottom are adjusted to a form that maintains equilibrium. When the offshore slope is altered by this ship-induced resuspension, a readjustment at the shoreline can eventually result. This vessel-induced hydraulic resuspension can occur in restricted reaches, usually where wind waves are insufficient to cause offshore changes. Vessel movement can also affect natural sediment transport processes and increase bank erosion and damage during the winter by the direct movement of ice in contact with vessels and by disruption of an otherwise stable ice cover, allowing subsequent movement by natural forces, propeller wash and wave action (Wuebben 1978b).

The amount of bank erosion that results from these ship-induced and natural processes depends on site-specific bathymetry, water levels, soils, vegetative protection and ice conditions. Ship-induced effects could be more significant than natural processes where wind waves are usually small and river currents are slow.

This project was part of a Cold Regions Research and Engineering Laboratory (CRREL) program to evaluate the effects of winter navigation on processes of erosion and to determine the amount of additional bank erosion caused by ship passage during the winter (Gatto 1978a, b; Wuebben 1978a,b; Wuebben et al. 1978a,b). The specific objectives of this project were:

1) Document bank conditions and erosion sites along the navigation channels of the entire U.S. shoreline of the St. Marys, St. Clair, Detroit and St. Lawrence rivers.
2) Monitor and compare the amount of bank recession and change that occurred during the winter and the summer.
3) Estimate the amount of bank recession that had occurred prior to winter navigation.

This project was not designed to measure the various processes or site properties that cause or influence bank erosion, nor was it intended to determine if winter navigation increases natural winter erosion. However, the results of the project show where erosion was active from 1977 to 1980 and whether winter or summer erosion processes are more active. Data from this project, taken with those from other CRREL projects, could provide reliable insights into the effects of winter navigation on bank erosion processes.

PREVIOUS INVESTIGATIONS

Although there are many reports addressing bank erosion along the Great Lakes, there are comparatively few studies of bank erosion along the St. Marys, St. Clair, Detroit or St. Lawrence rivers. The Great Lakes Basin Commission (1976) has estimated bank erosion rates for selected rivers and streams within the Great Lakes basin, but extensive studies of the four rivers have not been done.* In 1975 and 1976 the Michigan Department of Natural Resources delineated several reaches of the St. Marys River that are high-risk erosion area: Waiska Bay, Izaak Walton Bay, the Shallows area northeast of Brush Point, and Six Mile Point (Fig. 6). The department provided the recommended and minimum required setbacks for construction along the shores in these areas.

*Personal communication with T. Montieth, Great Lakes Basin Commission, 1977.

The Corps of Engineers, Detroit District (1975a) profiled sites along the St. Marys River from November 1972 to April 1975. Their findings and those from another analysis (Corps of Engineers, Detroit District 1974) are as follows:

1) Bank recession varied from 0 to 3 feet.
2) Recession at many of the sites was higher during or shortly after the high water period from November 1972 to September 1973.
3) Nearshore topography near the toe of the bank changed significantly.
4) Most bank erosion occurred during summer high-water periods.
5) Minimal erosion occurred when the river was ice-covered and the banks were frozen.
6) Erosion caused by vessel-produced waves was insignificant compared to that caused by wind waves, because wind waves impinge on the bank almost continuously, while the boat waves, which are usually larger, hit the bank much less frequently.
7) Most erosion occurred during the normal navigation season, not the winter navigation season, because the processes that cause the most erosion are virtually inactive during the winter.

Wuebben et al. (1978a) measured current changes and drawdown during ship passage under ice-free and ice-covered conditions along the St. Marys River. Their data and observations confirm that the hydraulic effects produced by ship passage cause sediment translation along a river bottom in the summer and winter.

Alger (1977, 1978, 1979) studied bank erosion along the St. Marys, St. Clair and Detroit rivers as part of the CRREL program. He used data on bank profiles, nearshore bathymetry, soils, river current velocities, sedimentation and river water levels and flows to conclude that

1) River bottom sediment transport under ice is greater during ship passage than with ambient flow conditions.
2) Vessel-induced nearshore current velocity is higher with than without an ice cover.
3) Vessel-induced erosive forces can be large during spring breakup.
4) There is no evidence that erosion is greater with than without an ice cover when vessels are moving at regulated speeds.
5) It appears that minor bank recession will continue due to erosion from occasional high water or wind waves.

Wuebben (in press), who studied shore damage due to ice along the St. Marys River, found that during ship passage with and without an ice cover, the ice cover usually moved vertically about 8 inches with ship-induced drawdown and surge, although ice level fluctuations of 2–3 feet have been observed offshore. Ice tends to dampen out these waves shoreward. Nearshore cracks frequently develop in the ice cover nearly parallel to river bottom contours, and they separate mobile ice from nearshore anchored ice.

Bank profile data taken after the 1979–80 limited winter navigation season show no bank recession north of Six Mile Point, bank recession similar to previous annual amounts along Sugar Island, and local measurable recession at Nine Mile Point (Fig. 6) (Wuebben, in press). However, some of this recession could have occurred as a result of the high water levels during the summer of 1979. Riparian landowners reported noticeable bank recession during this limited winter navigation season at sites that remained stable during winter navigation seasons from 1977 to 1980. Wuebben concluded that there is no clear evidence that winter navigation causes more bank erosion than occurs naturally.

Ofuya (1970) summarized previous Canadian studies of wave-induced riverbank erosion along the St. Clair, Detroit and St. Lawrence rivers and evaluated the relative importance of ship-induced wave erosion along the Canadian shoreline of these rivers. Judging from model studies and ship wave measurements on the St. Lawrence River, he concluded that the total navigation-induced erosive effects decrease with distance from the sailing line, while the total natural erosive effects increase.

In his model work Ofuya assumed that wind, ship or cruiser wave action on the shoreline stops while there is an ice cover. He concluded that during the ice-free seasons, wind waves with a wave period greater than 1.75 seconds transmit more energy to most river shorelines than do ships. Of course, ship waves may become more important in narrow reaches, along shorelines nearer the navigation channels, and when ship speeds are high.

Normandeau Associates, Inc. (1979) reported that ship wakes along the St. Lawrence River shoreline near and in Tibbits Creek (Fig. 15) were less than 1 inch, and that drawdown and surge were usually 3 inches or less. They concluded that no statistically significant linear predictive relationship existed between vessel parameters and drawdown and surge. The variability of the data also made it infeasible to determine any non-linear relationships. However, the offshore shoals and vegetation and the 4500-foot distance to the navigation channel probably reduced ship passage effects at these sites.

The St. Lawrence-Eastern Ontario Commission (1977a) described the geology and resources of the area bordering the St. Lawrence River; they mentioned that bank erosion is a problem along some reaches of the river. The Corps of Engineers, Buffalo District (1977) assessed bank erosion along the U.S. portion of the St. Lawrence River and reported that most erosion occurs from Chippewa Bay downstream to the Canadian-U.S. border, where the bank sediments are marine and freshwater silts and clays. The upstream bank is predominantly bedrock.

The St. Lawrence Seaway Development Corporation (1977) surveyed the U.S. shoreline and delineated three areas of potential erosion due to winter navigation—Galop Island, Ogden Island and Long Sault Island (Fig 15). The St. Lawrence-Eastern Ontario Commission (1977b) subsequently did a detailed evaluation of the susceptibility of the bank to erosion. The evaluation was done to determine the nature and extent of bank erosion that occurs in the absence of winter navigation. Six sites were monitored, and 19.23 miles of bank were considered to be actively eroding. Additional sites of erosion were reported along Coles Creek State Park in Waddington, N.Y., and Robert Moses State Park near Massena, N.Y. (Fig. 15).*

Canadian investigators have described St. Lawrence River erosion processes between Quebec and Montreal where wave action is most important (Ouellet and Baird 1978). They concluded that where the river is wide, wind waves dominate; where it is narrow, ship waves may cause considerable bank erosion. They reported that the ice cover tends to protect the bank from erosion. Brochu (1961) and Dionne (1969, 1974) studied ice-rafting and ice-erosion processes on the tidal flats of the St. Lawrence River estuary and concluded that ice may be one of the most important agents causing sedimentation along the estuary.

*Personal communication with C. Elliot, Thousand Island Park Commission, 1978.

APPROACH

Shoreline conditions

An initial boat survey of the U.S. shoreline adjacent to the main navigation channels was made along the St. Marys, St. Clair and Detroit rivers in May 1977 and along the St. Lawrence River in November 1977. This survey was done to become familiar with the geologic, geomorphic and geographic characteristics of the shore, to document conditions for comparison with past and future observations, and to select sites for monitoring on-going changes and recession.

The following were mapped based on observations made during this initial survey (Appendices A-C): 1) reaches of the riverbank with partially vegetated or bare bank faces (Fig. 4), where erosion was or had been active, 2) the riverbank height and slope, and the conditions of its vegetation along the reaches, and 3) the kinds of beach sediment, shoreline vegetation, shoreline development, and bank protection. I did not prepare maps for the St. Lawrence River, since much of this information is already available (St. Lawrence-Eastern Ontario Commission 1977a,b).

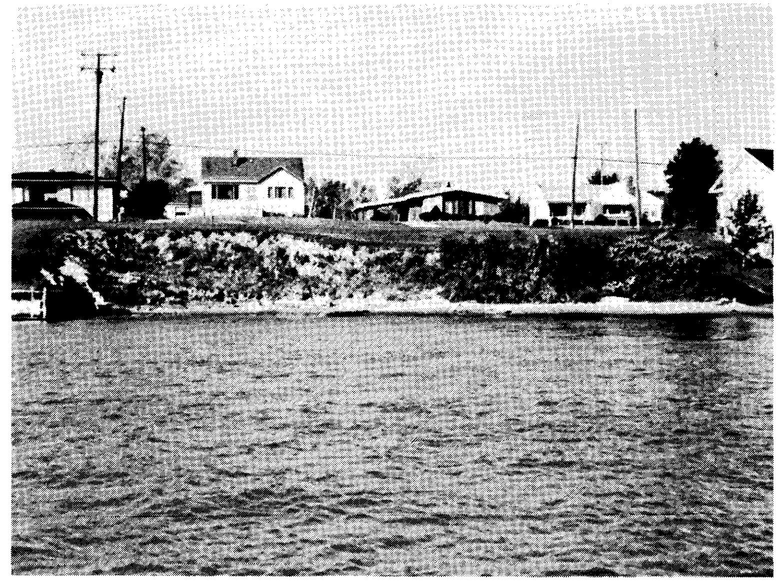
Of course, it was not possible to determine if these sites were actually eroding based on a single observation. Therefore, the sites delineated during this initial survey were considered to be potential erosion sites.

Within some of the sites there were reaches of partially vegetated and bare banks separated by reaches of stable, completely vegetated banks, but because the reaches of partially vegetated or bare banks were close, they were included in the same site. I estimated the lengths of partially vegetated and bare reaches by marking the end points of the reaches on USGS 7½-minute topographic maps and measuring the distance between them.

The bank heights were estimated; the slopes of the bank faces were measured with a Brunton compass. In general, higher, steeper banks erode more quickly than low, gentle banks because they are more unstable. These height and slope data would be useful in predicting locations of future erosion. I also documented the conditions of the vegetation at the crest of a bare bank; this information was useful in assessing if that bank was eroding.

The type of beach sediment was mapped because it may influence the amount of bank erosion. Gravel and larger beach material have an armoring effect, protecting the riverbank toe by dissipating wave energy. A sand beach provides

a. St. Marys River reach 16b.



b. St. Clair River reach 4a.

c. Detroit River reach 21b.

d. St. Lawrence River reach 38.

Figure 4. Partially vegetated and bare riverbanks typical of those mapped during the initial survey.

a. Slumped soil blocks (St. Clair River reach 17).

b. Newly exposed, unvegetated bank face surfaces (St. Marys reach 6c).

c. Fallen trees, brush and grass clumps (St. Lawrence River reach 20f).

d. Newly formed small scarps (St. Clair River reach 5a).

Figure 5. Visual evidence of bank erosion.

less protection for the toe of a bank. The width of the beach varies, depending on the river stage. It was fortunate that the water level was low enough during the initial survey so that the beach sediment could be mapped. I observed during subsequent surveys that some reaches have a beach when the water level is low but have no beach when the water level is higher.

The type and location of shoreline vegetation was mapped because it can also influence bank erosion. Offshore vegetation can dissipate wave energy. The root systems of riverbank vegetation bind the soil in the root zone and may slow the rate of erosion if the bank is not too high and the root zone extends to the bottom of the bank. Simons et al. (1979) described the various influences vegetation has on bank stability and erosion.

The locations of existing bank protection structures were recorded, since they may indicate areas of past erosion. The information on shoreline development was mapped because it may be useful in evaluating the relative importance of different locations if bank protection measures are planned; a more developed site may have a higher priority than a site where development is sparse.

Bank changes

After the initial survey I resurveyed the sites each spring and fall until May 1980.* I described and photographed site conditions to determine if bank changes indicative of active erosion had occurred since the previous survey. I used the following bank changes as visual evidence of the degree of erosion (Fig. 5):

1) Fresh slides or slumped soil blocks.
2) Newly exposed, unvegetated bank face surfaces.
3) Additional fallen trees, brush or grass clumps.
4) Newly formed small scarps along the toe of the bank at the waterline.

A reach was classified as having no apparent erosion (NAE) if none of these changes were evident. If these changes were present but were isolated and scattered along a reach, it was classified as having minor erosion (ME). If the changes were common along most of a reach, it was classified as having major erosion (E). Observations from these spring and fall surveys were used to determine which reaches were receding and whether erosion was more active in the winter or the summer.

*The last survey on the St. Lawrence River was in October 1979.

A shortcoming of these repetitive visual comparisons is that there can be a lag between the time of erosion and the time that bank changes due to that erosion are observable. Because of this, bank changes could be attributed to erosion processes that did not cause the changes. For example, bank undercutting by waves may occur throughout the summer, but the collapse of the unsupported material above may not occur until the following winter. I know of no way to account for this lag.

As part of this monitoring, aerial photographs of the eroding reaches were taken each spring and fall to provide a permanent record of the bank conditions. The scale of the aerial photography was approximately 1:5000. Initially I tried to measure the on-going recession with these photographs, but I was unable to detect measurable bankline recession. The minimum measurable distance on the photographs is approximately 2 feet. It is unlikely that the recession of the bank crest at most of the sites between the spring and fall during this 3-year project was more than 2 feet. Consequently it could not be measured on the photographs.

Bank recession before winter navigation

Vertical aerial photography was used to estimate the amount of bank recession that occurred at specific sites prior to winter navigation, which began in 1970 on the St. Marys, St. Clair and Detroit rivers.* There is considerably more aerial photography of the rivers than was used (Gatto 1978a,c); however, I selected the oldest photographs available and those taken as near but prior to 1970 as possible .

Using an Old Delft stereoscope (4.5X magnification), I located the crest of the river bank at each site and marked where it intersected a transect drawn perpendicularly to the shoreline from a reference point. These reference points were usually man-made features, such as bridges, buildings or road intersections, although trees were occasionally used where man-made objects were not present.

The riverbank crest was usually evident as a distinct change in topography, color, shadow, texture or type of land surface between the upper land surface and the bank face. At some sites the crest location had to be estimated because it was obscured by trees, vegetation or shadows.

*From 1961 to 1970 navigation stopped between 14 December and 11 January and began again between 1 and 17 April. After 1970 the Coast Guard kept the navigation channel open by ice-breaking (Wuebben, in press).

The distance along each transect from the reference point to the crest was measured on the photograph while viewing with 4X magnification. I read the measurement to the nearest 1/240 inch using the 1/60 scale on an engineer's rule. This measurement was converted to an equivalent ground distance using the average photographic scale, and the measurements from various years showed the amount of recession.

Tanner (1978) and Wolf (1974) discuss in detail some of the sources of error in making these types of aerial photographic measurements. They include scale variations caused by the camera lens distortions and aircraft altitude changes; radial, relief and tilt distortions; lack of stable reference points; obscured crestline and measurement points; and human error during measurement.

To minimize the effects of photographic distortion, distances were measured from photographs that showed sites in the middle of the picture. The average photographic scale was determined for the portion of a photograph that contained a measurement site, using a procedure described by Wolf (1974).

Because of the potential errors, Tanner (1978) specified the limitations of aerial photographic measurements in terms of a minimum measurable distance (MMD). This MMD is based on the average photographic scales of the pairs of photographs used in measuring the change during a time interval. The MMD is used to define the minimum change in distance that could be measured on the two photographs. The MMDs for each photograph are added, and the sum is compared to the measured change in distance. If the MMD is greater than the measured change, the conclusion is that there is "no measurable change." If the measured change is greater than the MMD, the change is considered valid and an average annual rate of recession (ft/yr) is computed by dividing the measured change by the number of years between the dates of the photographs.

Occasionally the measured distance on a newer photograph was longer than that measured on an older photograph. However, shoreline erosion processes cause the bank to recede landward; the bank cannot move farther into the water. Usually, visual interpretations of features on the photographs verified that these changes were not real. Consequently, these "positive" values are considered unreliable and were probably the result of man-made bank changes or measurement errors. These values, however, are recorded in the tables to indicate the potential errors involved with particular measurements.

Even when measured distances are greater than the MMD, the measurements obtained are not absolute values but are only estimates of the true recession. These estimates provide reliable insights into the historical patterns and rates of bank recession.

ST. MARYS RIVER

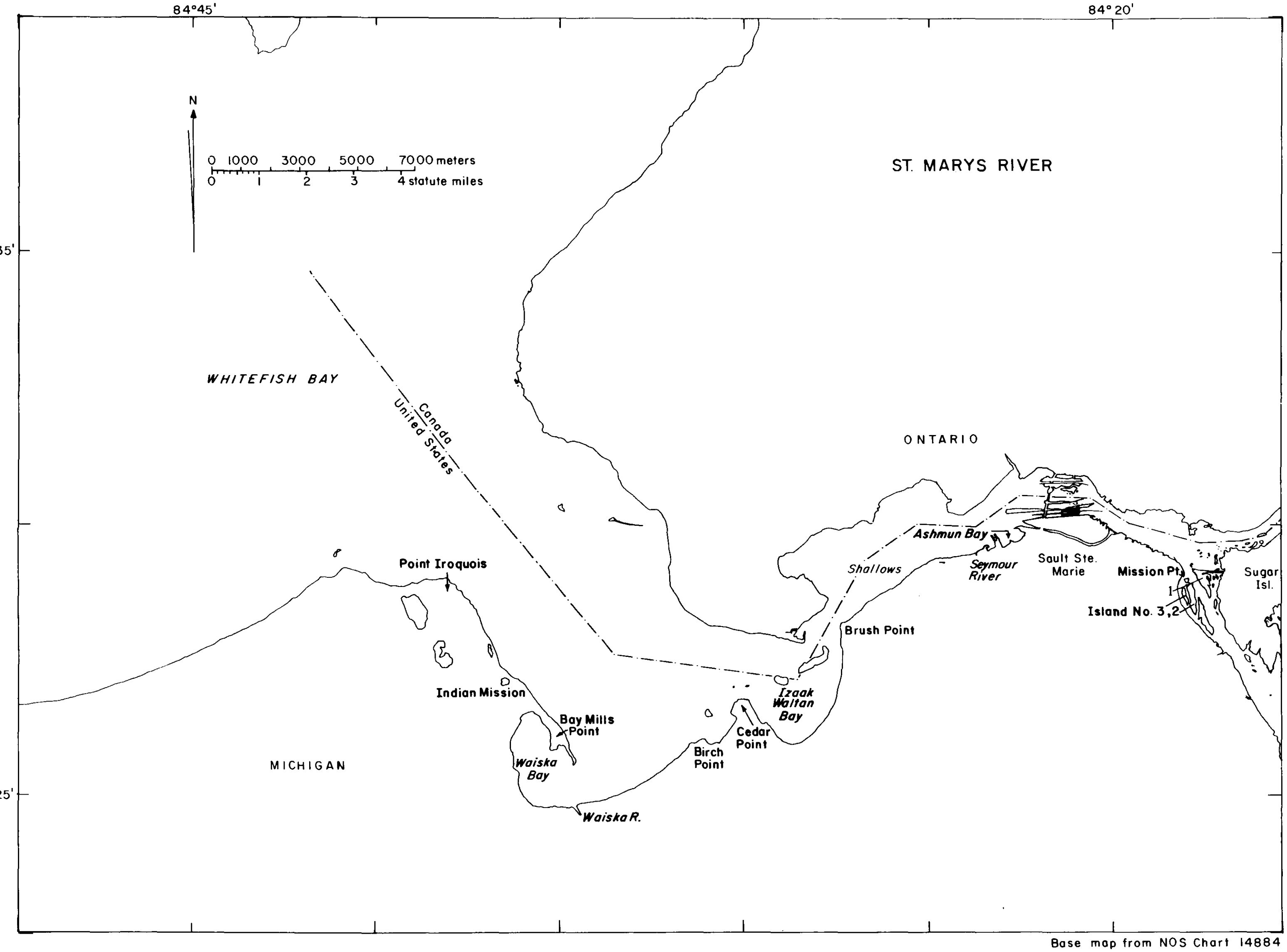
Bank changes

The initial boat survey of the St. Marys River (Fig. 6) was made on 25 and 26 May 1977. The shoreline characteristics and conditions observed are shown in Figures A1–A6. Twenty-eight sites, with 66 partially vegetated or bare banks covering a total of 10.7 miles (Table A1, Fig. A1), were delineated during this survey. The banks at 29 of these reaches (5.2 miles) showed evidence of erosion from May 1977 to May 1980. This is 4.3% of the 122 miles of shoreline surveyed. The banks at 37 reaches (5.5 miles) showed no apparent changes.

Many of these stable reaches are probably sites where erosion was active during previous periods of high water. Many have low banks, virtually flat ground surfaces, and dense grasses, brush and trees landward of the bankline. I suspect that erosion at these reaches was slow in the past and would be slow in the future if water levels were raised for an extended period.

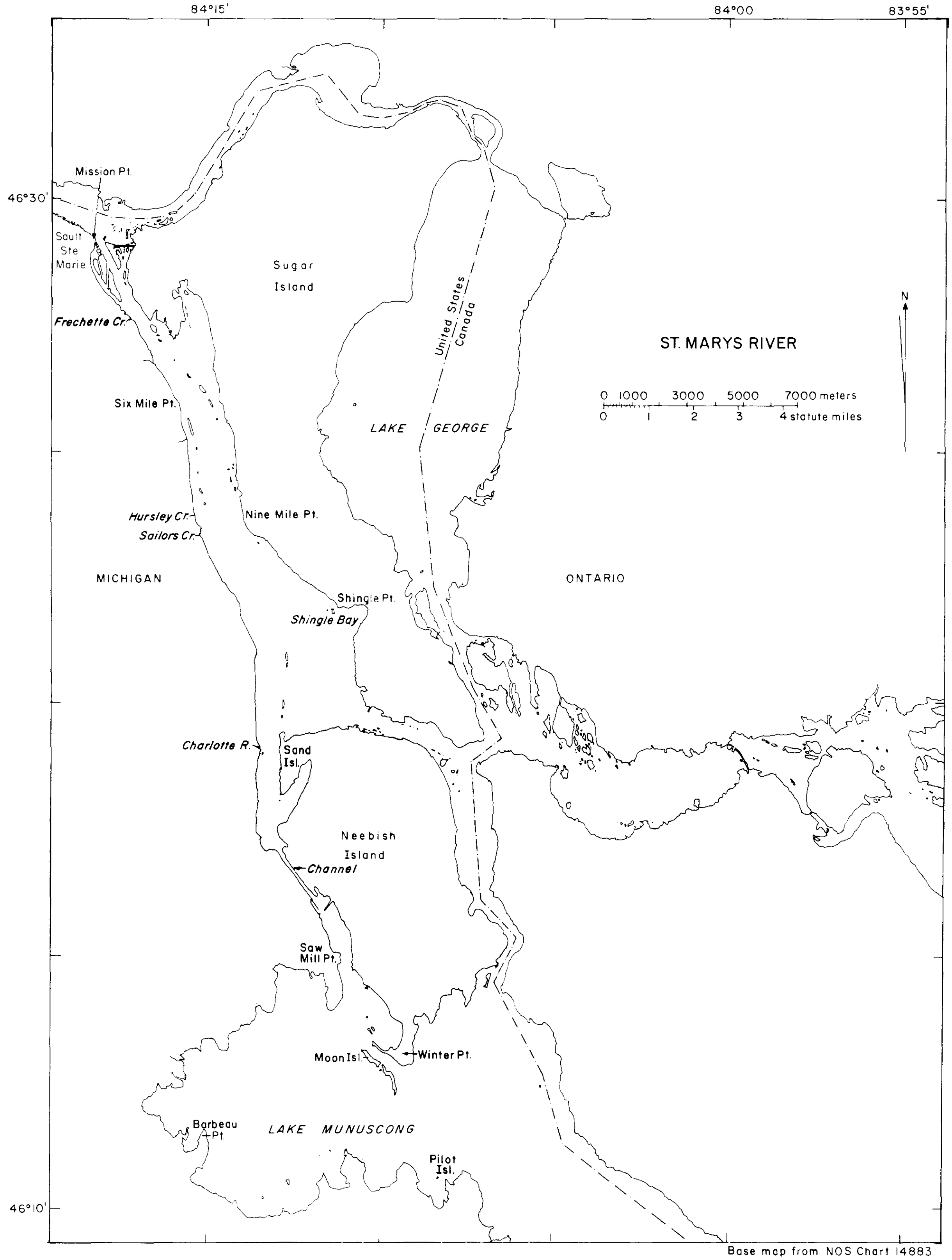
The types of bank failure along most of the eroding reaches were soil falls and slides (Fig. 7) (Code 1973). Soil falls generally result from extreme undercutting at the toe of a bank, and they usually produce vertical bank faces. Slides are due to shear failures, which result in relatively undeformed masses of soil moving along a single slide plane. These are common, especially where banks are composed of massive lake sediments or fine-grained tills. The slides along the St. Marys River are also due to the loss of support at the bank toe resulting from undercutting and material removal by river water. A few reaches show rotational slumping, and some show evidence of surface erosion (i.e. rills and gullies).

Twenty-three reaches showed minor erosion during this project (Table A1); they varied in distance from the navigation channel from about 80 to 3200 feet, with an average distance of 800 feet. Six reaches were classified as showing major erosion and were from 350 to 850 feet from



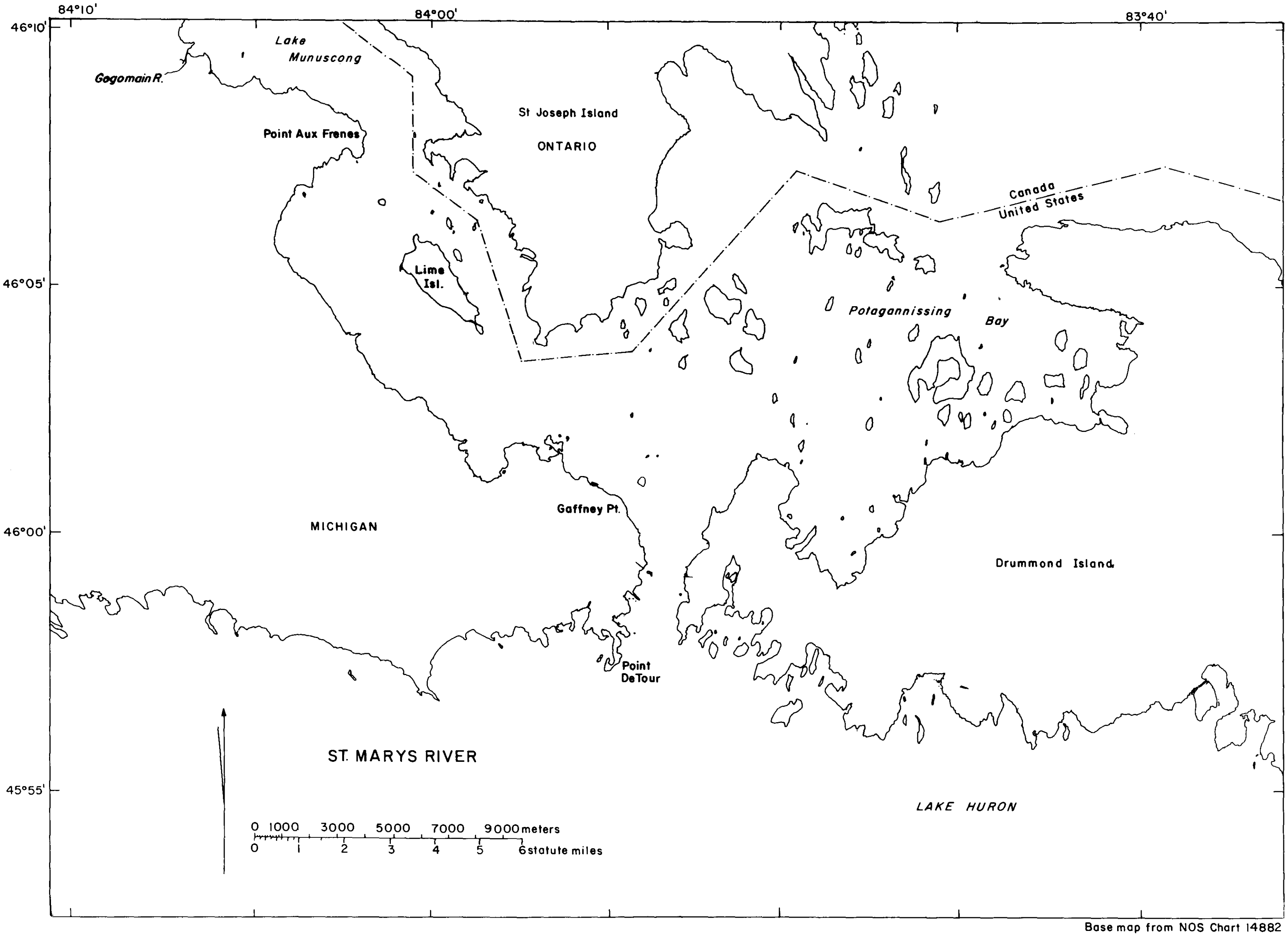
a. Whitefish Bay to Sugar Island.

Figure 6. Map of St. Marys River.



b. Sugar Island to Lake Munuscong.

Figure 6 (cont'd). Map of St. Marys River.



c. *Lake Munuscong to Lake Huron.*

Figure 6 (cont'd). Map of St. Marys River.

a. Soil fall (St. Marys River reach 27b).

b. Soil fall (St. Clair River reach 5a).

Figure 7. Most common types of bank failures.

the channel, with an average of 650 feet. This distribution suggests that the hydraulic effects of vessel passage may contribute to causing more severe erosion along banks near the navigation channel.

On 22 May 1978, while at reach 4b along Brush Point, I observed some of the hydraulic effects of ship passage. The weather was clear with a mild breeze, and there were no breaking waves along the shore (Fig. 8a). Two ships, the *Mesabi Miner* (downbound) and the *Canadian Olympic* (upbound), passed Brush Point simultaneously. The water level was drawn down, the river currents reversed, and water flowed upstream at a

c. Soil fall (Detroit River reach 18).

d. Soil slide (St. Lawrence River reach 26).

Figure 7 (cont'd).

noticeably higher velocity than the normal currents. Shortly after the sterns of the ships passed, the water surface rose rapidly behind an 8-inch wave to a level higher than the pre-passage level, and nearshore currents returned to a downstream flow. The velocity was still higher than that of the pre-passage downstream currents and 6- to 8-inch waves broke while the water was at this higher level (Fig. 8b). This sequence of changes also occurred when the *A.H. Ferbert* (downbound) passed Brush Point a half hour later, but the changes were much less pronounced.

a. Nearshore conditions prior to ship passage.

b. Ship-induced changes in waves.

Figure 8. Hydraulic effects of ship passage (St. Marys River reach 4b, 22 May 1978).

In spite of these drastic hydraulic changes along reach 4b, I did not observe bank changes indicative of erosion along this reach during three years of monitoring. Ofuya's (1970) results suggest that the energy continually acting on an erodible bank from natural river currents and wind waves is greater than the intermittent energy from waves and currents caused by passing ships.

Several of the eroding reaches, 11b and c, 16a–c, 18, 19, 20a, 21 and 22, border that portion of the navigation channel not used after a stable ice cover forms. Winter navigation does not occur along these reaches, yet erosion appears to be more rapid and extensive here than at location adjacent to the winter navigation channel. This suggests that winter navigation does not contribute significantly to bank erosion.

The lack of new evidence observed during spring surveys along many of the eroding reaches indicates that the bank remains unchanged at the sites during the winter and suggests that erosion does not occur during the winter (Table A2). For example, the number of bank changes observed along site 20 during the May 1978 and 1979 surveys was less than in October 1977 and November 1978. Also, bank changes along reaches 11, 18, 21, 22 and 25 were less in May 1980 than in October 1979. The 1979-80 winter navigation season was limited; except for seven trips by the USCGC *Katmai Bay* and one by the *Mackinaw,* winter navigation stopped on 15 January 1980 and did not begin again until 24 March.

These observations suggest that bank changes occurring during the winter are less obvious than those that occur during the summer or that the bank remains unchanged during the winter. It is likely that winter erosion processes are less effective than summer processes along these reaches.

Bank recession before winter navigation

Aerial photographs were used to measure the amount of bank recession along 14 reaches where the banks are partially vegetated or bare (Table A3). When measured changes were large, I made a visual check of the photographs to verify that the measurements were reliable.

The bankline recession from 1939 to 1977 along reaches 1, 4i, 6d, 11b, 24b and 27a was measurable. Changes were not visible and the measured distances were less than the MMDs along the remaining eight reaches (4b and k, 5a, 7a and b, 8b, 9a and 23b).

Four of the six banks (4i, 11b, 24b, and 27a) that eroded from 1939 to 1977 were also eroding during this project. The bankline along reach 27a receded 227 feet from 1939 to 1977 and showed minor erosion from 1977 to 1980. Along reach 11b it receded 124 feet and also showed minor erosion during this project. The banklines along reaches 4i and 24b receded 87 feet and showed almost no erosion from 1977 to 1980.

From 1939 to 1964 pre-winter-navigation bank recession varied from 22 to 160 feet along 8 of the 14 reaches. There were 10 eroding reaches during the 1964-1977 interval. Along the remaining 6 reaches, bank recession was not detectable. The amount of recession decreased along 4 of the 8 reaches from 1964 to 1977. Recession increased at 6 reaches during the 1964-1977 period. It is not possible to attribute the greater number of eroding reaches during the 1964-1977 interval to winter navigation, because there were record high water levels during this time. These data do show, however, that riverbank erosion was active along the St. Marys River prior to winter navigation.

ST. CLAIR RIVER

Bank changes

The initial boat survey of the St. Clair River (Fig. 9) was done on 23 May 1977. The shoreline conditions and bank characteristics are shown in Figures B1-B3. Partially vegetated or bare banks were delineated along 56 reaches at 25 sites (Fig. B1), covering a total of 3.2 miles. The approximate lengths of the banks at the 24 eroding reaches are given in Table B1. The estimated total length of eroding bankline is 2.1 miles. From May 1977 to May 1980 approximately 5.3% of the banks along the 40 miles of surveyed shoreline were eroding.

As along the St. Marys River the banks along many of the reaches are old erosion sites that were stable during this project. Erosion would probably begin anew along some of these banks if water levels were high for an extended time.

The types of bank failure along most of the banks were soil slides and falls along the face of the bank. These were caused by undercutting at the water line, loss of support for overlying sediment, and subsequent collapse. Rotational slumping occurred at reach 11b only (Fig. 10).

The banks along 20 reaches showed minor erosion during this project, and their approximate distance from the navigation channel varied between 150 and 650 feet, with an average distance of 350 feet. The approximate distances from the navigation channel of four banklines that showed major erosion varied from 20 to 350 feet, with an average of 250 feet. This implies that erosion may be more severe nearer the navigation channel, due to the hydraulic effects of ship passage. However, reaches 11a, b, and c, where erosion appeared to be most active, are approximately 200-250 feet from the navigation channel. The offshore slope along these reaches is very steep (Gatto 1982), and I observed that the

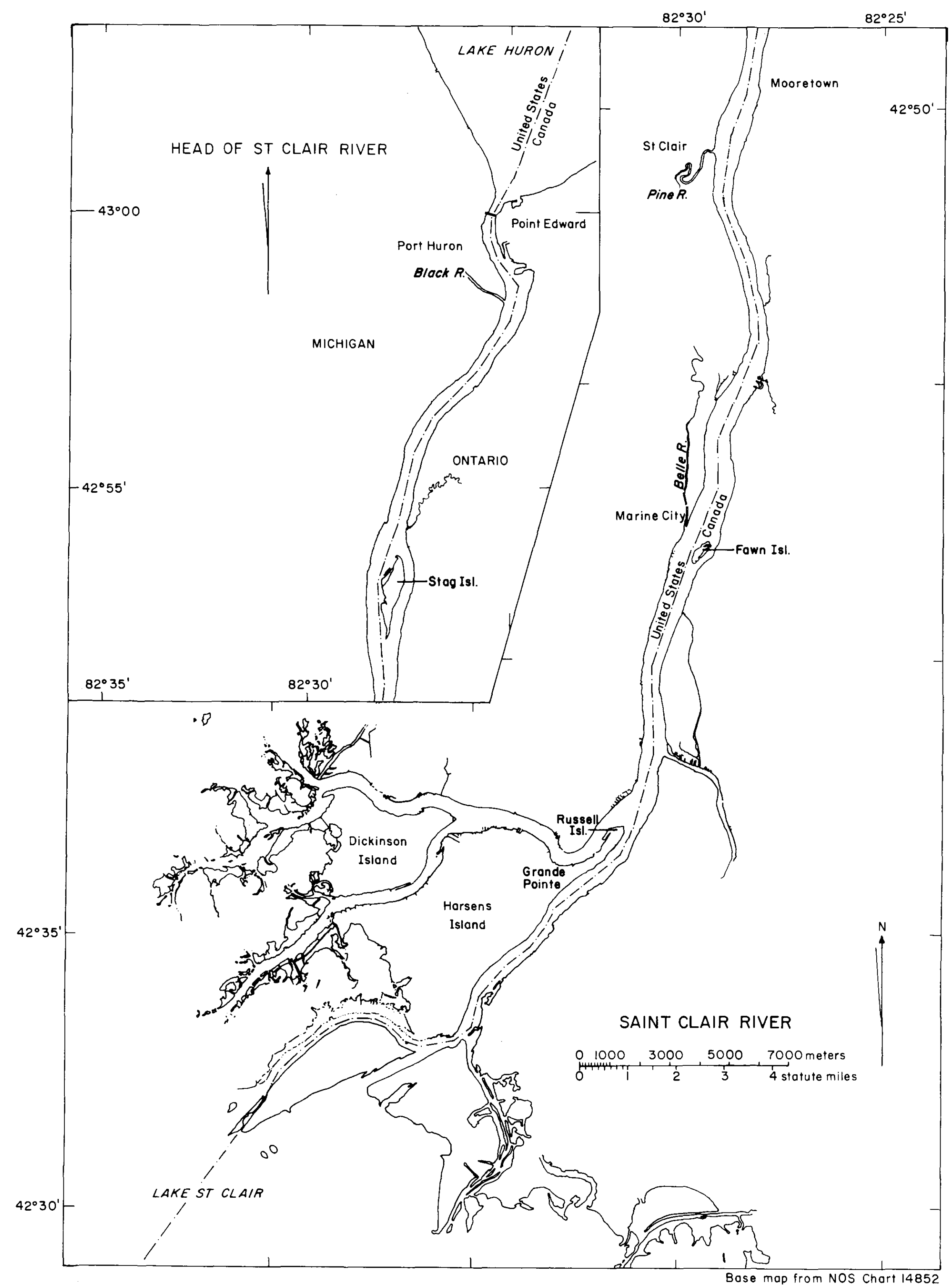


Figure 9. Map of St. Clair River.

nearshore currents along these reaches do not change much during ship passage.

Wuebben et al. (1978a) showed that ship effects are greater along shorelines with gentle offshore slopes. Most of the eroding sites along the St. Clair River are less than 700 feet from the navigation channel but have steep offshore slopes (Gatto 1982). It is unlikely that ship passage during the summer or winter produces hydraulic effects large enough to contribute significantly to bankline erosion.

Along the St. Clair River the degree of erosion

a. Viewed from the river.

b. Crack formed on top of the ground surface delineating a future slump block.

Figure 10. Rotational slumping (St. Clair River reach 11b).

over the winter was greater than the previous survey more often than it was less. However, it did not change along most of the reaches (Table B2). The erosion along site 12 was greater from October 1977 to May 1978 and from October 1978 to May 1979 than during the previous summers. Erosion along six sites (4, 6, 9, 10, 17 and 19) was greater from October 1979 to May 1980, while the degree of erosion was less than the previous survey at site 12 during this time.

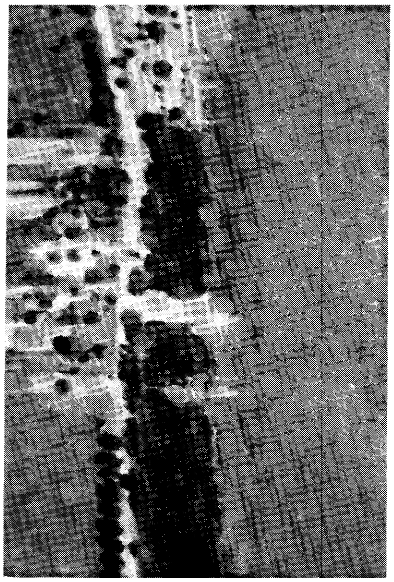
These results suggest that bank erosion processes during the winter may be more active on the St. Clair River than on the St. Marys River. The ice on the St. Clair River may be more mobile than that on the St. Marys River, possibly due to ship traffic. Ice-induced erosion may therefore be more active.

Wuebben (in press) reported that shore damage due to the lateral movement of ice induced by vessel passage is unpredictable, ordinarily infrequent, small, and difficult to measure. Damage is limited to times when the ice is mobile, and it occurs along the shore close to the navigation channel. During spring break-up, larger, more massive ice floes may push against and scrape the shore, but with warmer temperatures the ice is usually deteriorated and weak. A long reach of shoreline may be affected over a period of years, but only a small portion might be affected in any one year. The regulation of vessel traffic speed along affected areas when certain ice conditions exist may provide the best means of reducing ice damage.

Bank recession before winter navigation

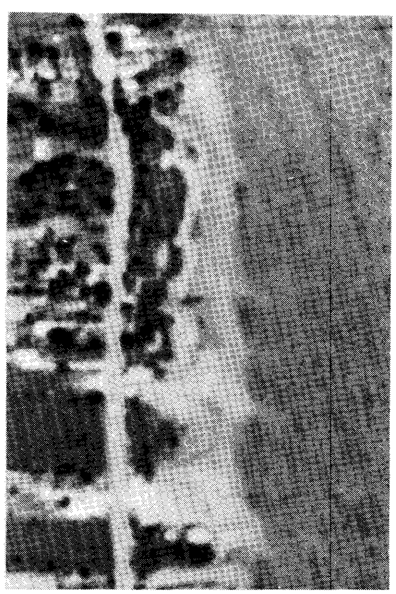
Using the observations made during the spring and fall surveys, I selected seven eroding reaches to estimate pre-winter-navigation bankline recession (Table A3). Between 1941 and 1977 recession varied from 40 feet at reach 5a to 139 feet at 12b. The amounts of recession from 1941 to 1970 at reach 12b appear to be extremely high, and the photographs clearly show that large-scale changes in the bankline have occurred along this reach (Fig. 11). In 1941 the crest of the riverbank was at the position shown in Figure 11a. The crest had receded to the position shown in Figure 11e by 1977. It appears that the water level had increased enough between 1941 (Fig. 11a) and 1957 (Fig. 11b) to inundate the low area shown in Figure 11a.

Most of the recession that occurred between 1941 and 1970 (Fig. 11) appears to have occurred between 1941 and 1957 due to this rise in water level. NOAA-NOS (1975) hydrographs for this period show high water levels on Lake Michigan and Lake St. Clair from 1943 to 1949 and from

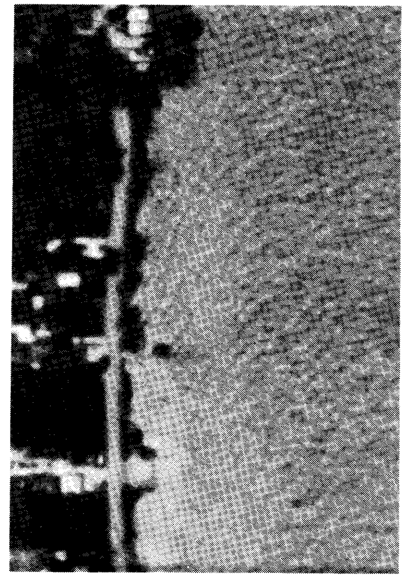


a. 1941.

b. 1957.



c. 1964.



d. 1970.

e. 1977.

Figure 11. Shoreline changes and recession at St. Clair River reach 12b.

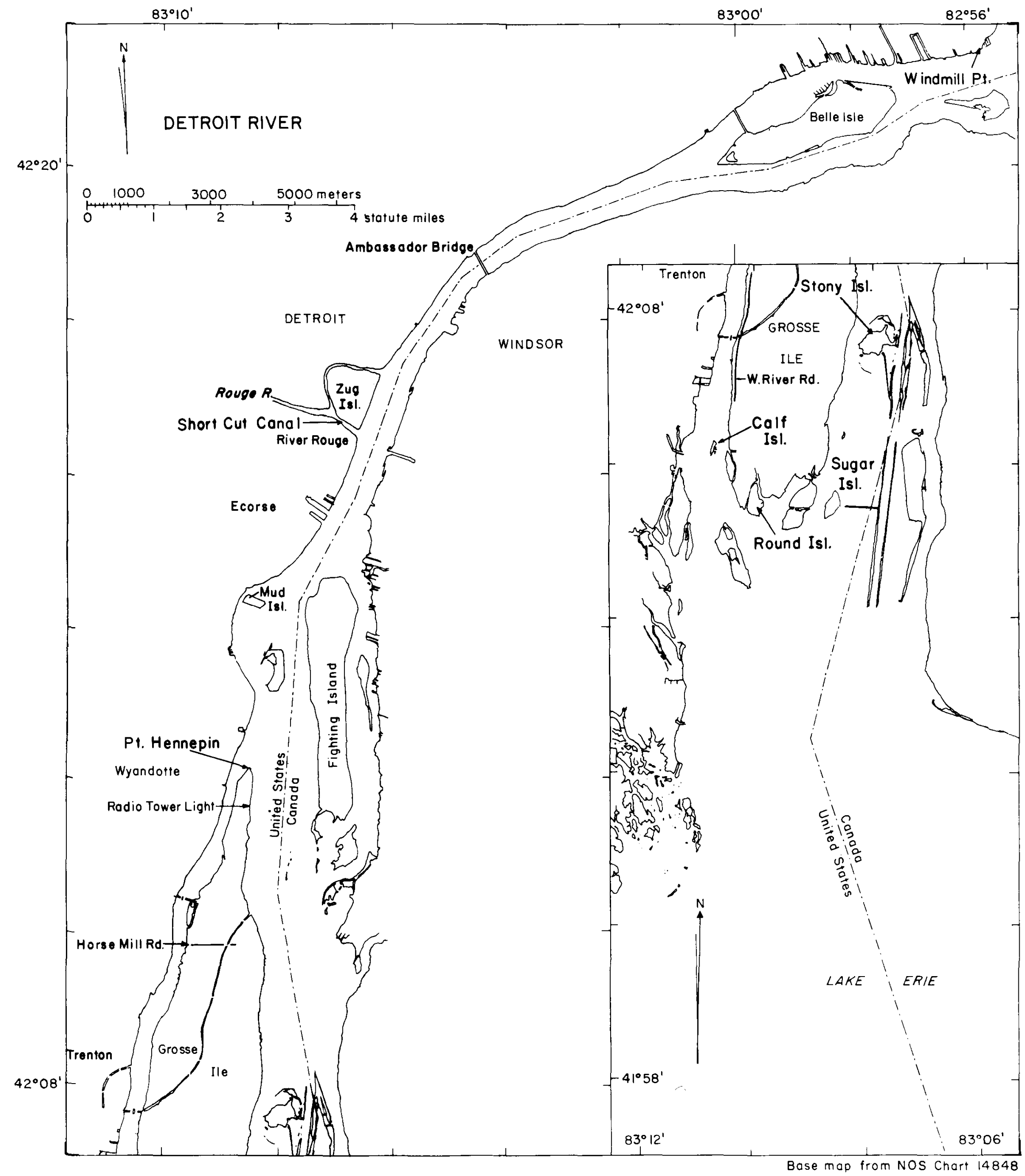


Figure 12. Map of Detroit River.

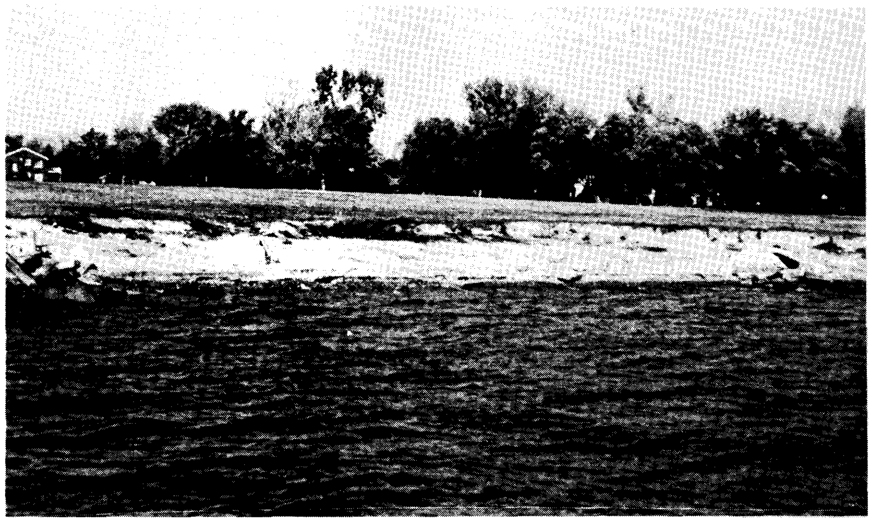
1951 to 1956. Record high water occurred in 1973 and 1974, which could account for the high recession between 1970 and 1977.

It is clear that the riverbank at the seven sites was receding prior to winter navigation. Judging from my field observations of nearshore hydraulic effects during ship passage, I feel that ship-induced erosion along the St. Clair River is minimal compared to that caused by water level fluctuations.

DETROIT RIVER

Bank changes

The initial boat survey of the Detroit River (Fig. 12) was done on 23 and 24 May 1977. The shoreline conditions and bank characteristics observed are shown in Figures C1–C3. I delineated partially vegetated and bare banks along 51 reaches (covering a total of 6.9 miles) at 23 sites (Fig. C1).



a. Detroit River reach 1a.

b. Detroit River reach 2a.

Figure 13. Slumped vegetation covering the low bank face.

The banks along 16 of these reaches appeared to be stable during this project (Table C1). Bank erosion along these reaches could begin if water levels were high for an extended period. Thirty-five reaches, about 5.6 miles or approximately 10.5% of the 53 miles of surveyed shoreline, were eroding. Of these 5.6 miles, only 1.1 miles border the navigation channel.

The reaches where erosion appeared to be most active are 5–10 around Zug Island, 19a around Calf Island, and 19g along the south side of Sugar Island. Along these reaches the effect of ship passage is either very small or nonexistent. The eroding reaches along Trenton Channel (14c and 15–18) are 120–1100 feet from the navigation channel. However, the hydraulic effect of ship passage in this channel is minimal because the ships are towed at low speed while in the channel.

The remaining eroding reaches that border the navigation channels (2a, 21g, 22, 23) are 300–1850 feet away. Observations made at sites 22 and 23 during ship passage show that nearshore hydraulic effects are too small to be apparent. I suspect that ship hydraulic effects are minimal at reach 2a due to the steep offshore profile and at 21g due to the relatively steep offshore profile (Gatto 1982) and the great distance from the channel (1750 feet).

As along the other rivers, most of erosion along the Detroit River was caused by undercutting at the waterline, with subsequent soil slides and falls along the faces of the banks. The vegetation on top of some of the banks simply slumped when the ground was not high enough for a bluff or bank face to form (Fig. 13). Surface erosion or groundwater sapping along the bank was not apparent during the field surveys.

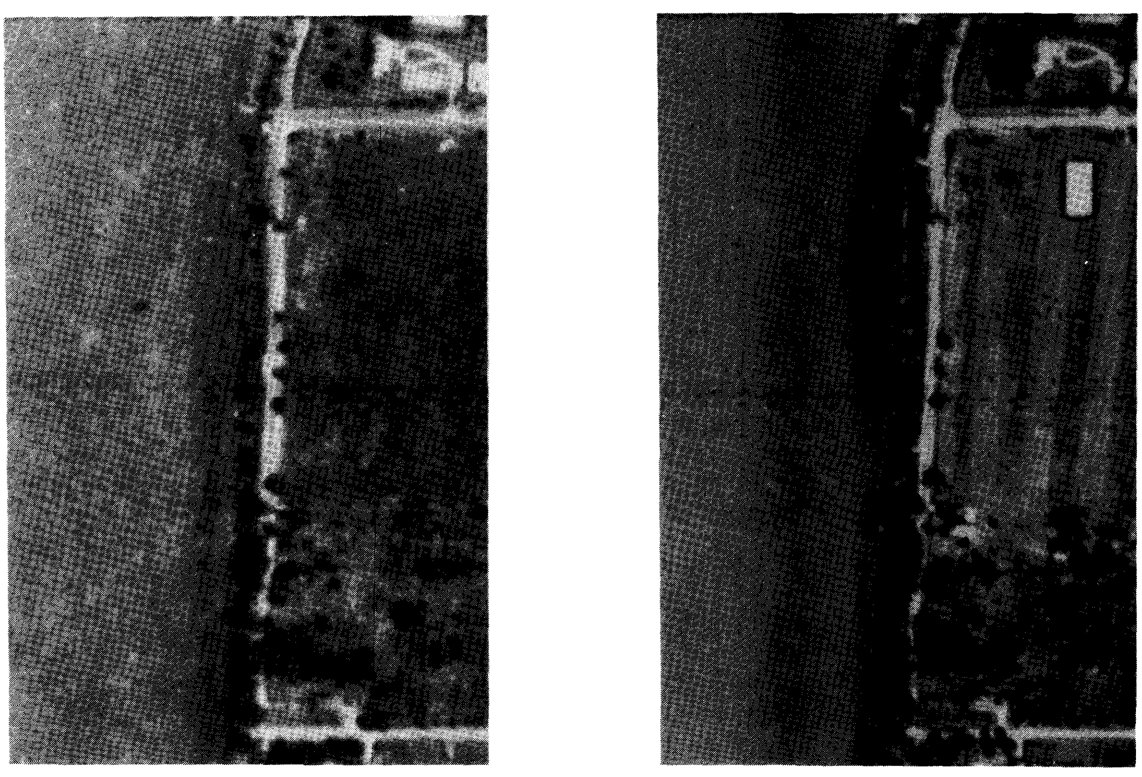
The degree of erosion rarely changed between winter and summer. Along site 2 erosion was greater between October 1979 and May 1980 than between May 1979 and October 1979 (Table C2). However, the degree of erosion at sites 22 and 23 reduced during the winter from the previous survey. I did not observe any other changes between successive intervals. Since 78% of the eroding reaches along the Detroit River do not border navigation channels, natural erosion processes related to water level fluctuations and man's trampling of the riverbanks are more significant in causing bank recession along the Detroit River than are the hydraulic effects produced during ship passage in the summer or winter.

Bank recession before winter navigation

I estimated the amount of historical bank recession at seven of the partially vegetated or bare reaches (Table C3). From 1937 to 1977 recession varied from an amount too small to be measured at reach 1a to 43 feet at site 23. Material was dumped along reach 1a between 1937 and 1970. From 1970 to 1977 there was not enough recession at reach 1a to be measured using the aerial photographs.

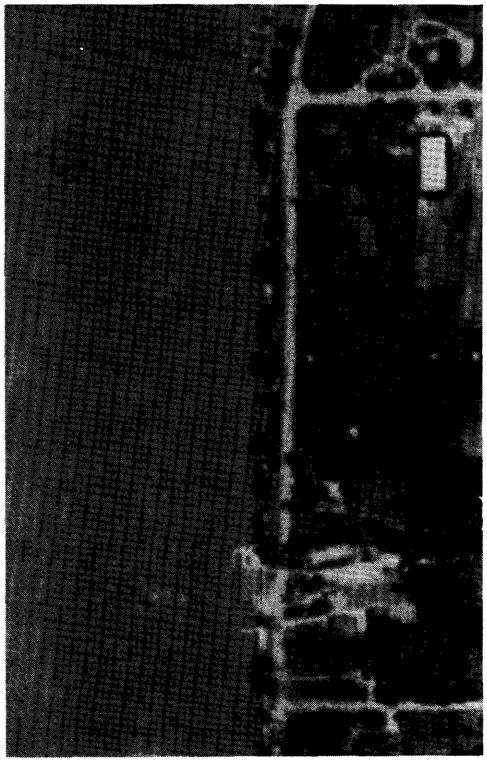
At reach 16f there was no major change between 1937 and 1940. Between 1940 and 1966 fill was dumped north of the reach, and the north end of the reach was straightened. Little observable change occurred between 1966 and 1970. Along the southern part of this reach, the bank receded less than 10 feet between 1970 and 1977.

Major changes along site 18 occurred between 1937 and 1977 (Fig. 14). The amount of recession was 26 feet from 1937 to 1970 and less than 10 feet from 1970 to 1977. Figures 14 a and b show a band of land along the river in 1937 and 1940.

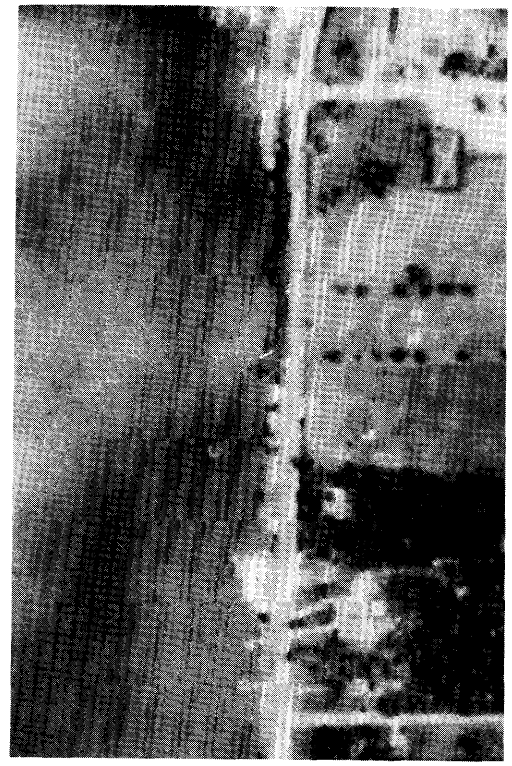


a. 1937. *b. 1940.*

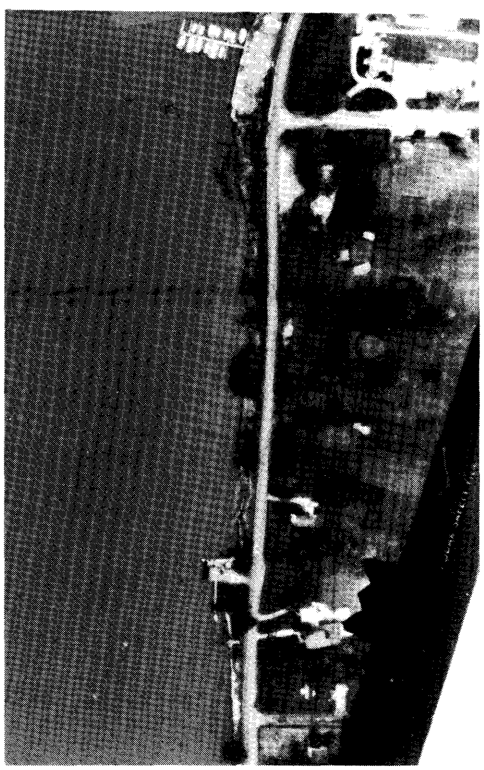
Figure 14. Shoreline changes and recession at Detroit River reach 18.



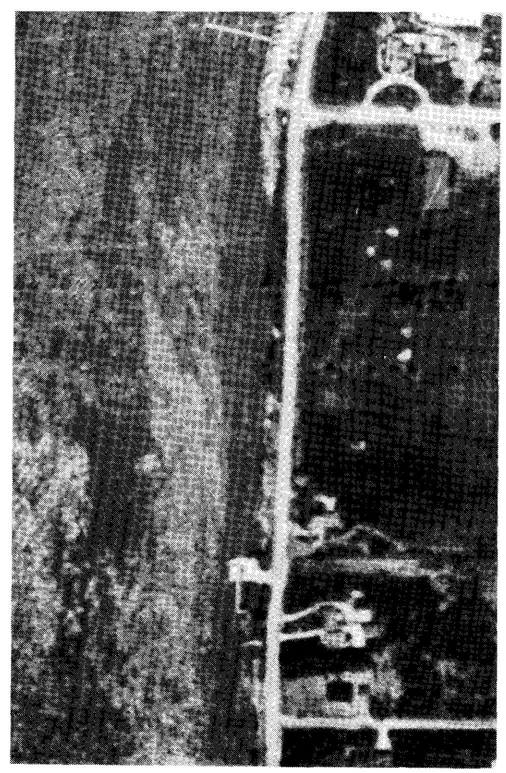
c. 1957.



d. 1966.



e. 1970.



f. 1977.

Figure 14 (cont'd). Shoreline changes and recession at Detroit River reach 18.

This land had been inundated or eroded by 1957; this probably occurred during the 1941-1957 high water period. I observed little change between 1966 and 1977.

Except for site 23 most of the historical recession occurred before winter navigation. Judging from the historical data and observations from 1977 to 1979, I feel that shoreline erosion along the Detroit River is due mainly to natural processes related to water level fluctuations; the ship passage effects are minimal compared to natural processes.

ST. LAWRENCE RIVER

Bank changes

The initial boat survey of the St. Lawrence River from Lake Ontario to the U.S.-Canadian border near Massena, New York (Fig. 15), was made on 16 and 17 November 1977. I delineated partially vegetated or bare banks at 114 reaches (covering 10.9 miles) at 48 sites (Table D1, Fig. D1). During this project, erosion occurred along 8.6 miles of the riverbank at 59 reaches. This is 6.6% of the 130 miles of surveyed shoreline. Fifty-five reaches, about 2.3 miles of bank, appeared to be stable from 1977 to 1979. Erosion along some of these banks would probably begin if water levels were raised for an extended period.

The types of bank failure along most of the eroding banks were soil falls and slides of surface material along the face of the bank. There were localized slumping and flows along some of the high banks, such as along reach 35c (Fig. 16). Gully and rill erosion were apparent along the bank along reach 12.

Of the 59 eroding banks, five are not adjacent to the navigation channel (23a-c and 27a, b) and 22 are more than 2000 feet from the navigation channel. Two vary from 200 to 4200 feet from the channel. The remaining 30 reaches vary from 70 to 1950 feet from the channel. There does not appear to be a relationship between the degree of erosion and the proximity to the navigation channel. Sites 22, 23, 26, 34, 41, 42, 44 and 47, where erosion appears to be most active, either do not border the navigation channel or are 70-400 feet from it. Ship effects would be small along most of the eroding banks, either because the riverbed is steep or because the banks are far from the channel. The degree of erosion did not change between summer and winter (Table D2) or between any of the surveys. Since there was no winter navigation along the St. Lawrence River prior to or during this project, none of the erosion during that time can be attributed to winter navigation.

Historical bank recession

Aerial photographs were used to estimate historical bank recession along 10 partially vegetated or bare banks along the St. Lawrence River (Table D3). I did not see any bank changes along sites 5, 6 and 12. The measurements at these sites were less than the minimum measurable distance for the photographs and indicate that no detectable change had occurred. Detectable recession had not occurred along reaches 20a or 42.

Reaches 22, 26, 31b, 38 and 48 show that the most recession detectable on the photography occurred between 1968 and 1978. Field observations confirmed that these reaches were eroding during this project. The lack of detectable recession along reaches 5, 6f, 12 and upstream of reach 20a is due primarily to the change in bank material. Generally bedrock and coarse sediment occur along the shore upstream from Ogdensburg except along Carlton Island (site 6), which has finer-grained sediment. Also, upstream of Ogdensburg, the river level may be above the pool produced by the downstream dams, and water level fluctuations may not be as frequent or as large.

SUMMARY AND CONCLUSIONS

The intent of this study was to document where erosion was active along the riverbanks, to evaluate the degree of erosion based on repeated field observations, and to compare the degree of erosion to the proximity to the navigation channels, the bed topography and the observed ship effects. Using these field observations and the data collected from maps, charts and a historical analysis, I inferred possible relationships between winter navigation and bank erosion.

The degree of erosion assigned to a reach was based on field observations. This approach allowed me to detect only large-scale changes. Consequently, there may be additional reaches where erosion is active at a rate slow enough that I could not detect the resulting bank changes.

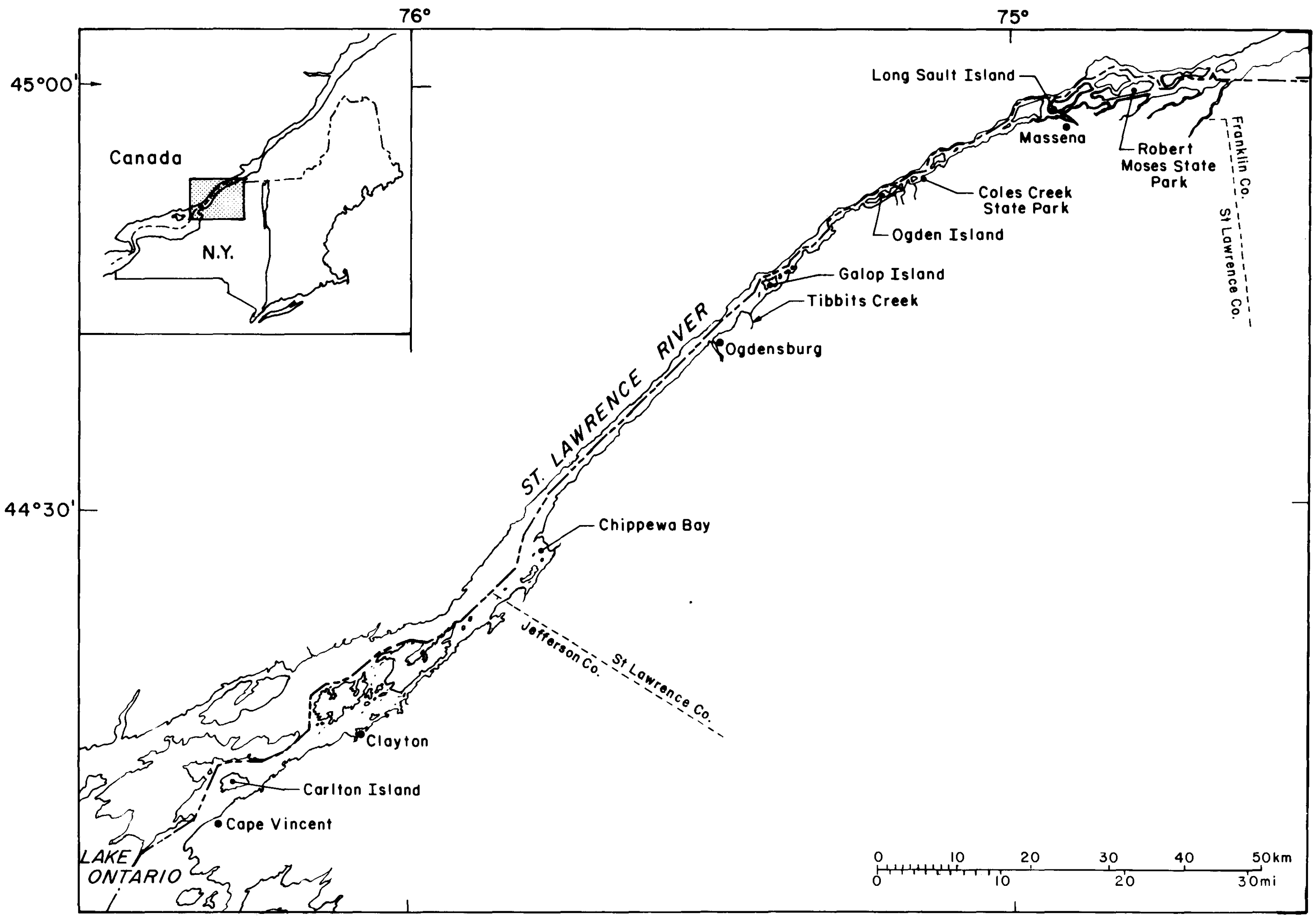


Figure 15. Map of St. Lawrence River.

Figure 16. Localized slumps and mudflows along St. Lawrence River reach 35c.

Three hundred forty-five miles of river shoreline were surveyed at least twice from May 1977 to May 1980 (Table 1). Most portions of the St. Marys, St. Clair and Detroit river shorelines were surveyed seven times, while most of the St. Lawrence River shoreline was surveyed four times. During these surveys I observed bank changes due to erosion along 21.5 miles of bank at 147 reaches; 10.2 miles at 140 reaches were stable during this project, but erosion had been active in the past. A rise in water level would probably reactivate erosion along many of these stable banks. The 287 banklines equal approximately 31.7 miles (9.2%) of the 345 miles surveyed.

The types of bank failure most frequently observed were soil falls (sloughing) and block sliding and slumping caused by undercutting and shallow washing. Rill and gully erosion and flows caused by failure in saturated soils, were rare.

Along the St. Marys River, 2 miles (38.5%) of the eroding bankline do not border the winter navigation channel. Approximately 4.5 miles (80.4%) of the eroding banks along the Detroit River are not adjacent to the winter navigation channel. Since there is no winter navigation on the St. Lawrence, the 8.6 miles of eroding bankline do not border a winter navigation channel. The erosion along approximately 15.1 miles (70.2%) of the total eroding banks on all the rivers could not be caused by winter navigation.

The analysis of historical aerial photographs shows that bank recession was active prior to winter navigation along the St. Marys, St. Clair and Detroit rivers and was active without winter navigation along the St. Lawrence River. Changes due to erosion at 29 of the 38 reaches analyzed were large enough to be detected and measured on the aerial photographs.

The results of the spring and fall surveys did not conclusively indicate whether or not bank erosion during the winter was more or less than that occurring during the summer. Along most of the reaches the degrees of erosion remained the same over the winter and the summer. However, along the few reaches where bank changes were observed over the winter, the number of times the degrees of erosion increased from the previous surveys equaled the number of times the degrees decreased (Table 2). Conversely, the degrees of erosion over the summer increased more times from the previous survey than they decreased. This suggests that the erosion continues during the summer more often than it continues during the winter.

It is clear from the field observations and measurements that drastic changes in nearshore hydraulics can occur during ship passage. Waves become larger, and river currents are reversed and increased. Riverbed sediment is rapidly resuspended and transported. However, most of the pre-passage conditions are re-established in

Table 1. Summary of erosion survey.

River	Distance surveyed (mi)*	Eroding reaches: Number	Eroding reaches: Distance (mi)*	Eroding reaches: Percentage of total surveyed	Potentially eroding reaches: Number	Potentially eroding reaches: Distance (mi)*	Potentially eroding reaches: Percentage of total surveyed	Eroding reaches not along winter navigation channel: Distance (mi)*	Eroding reaches not along winter navigation channel: Percentage of total surveyed
St. Marys	122	**29**	5.2	4.3	37	5.5	4.5	2	38.5
St. Clair	40	**24**	2.1	5.3	32	1.1	2.8	0	0
Detroit	53	35	5.6	10.6	16	1.3	2.5	4.5	80.4
St. Lawrence	130	59	8.6	6.6	55	2.3	1.8	8.6	100†
	345	147	21.5	6.2 (ave.)	140	10.2	3 (ave.)	15.1	70.2 (ave.)

* Mileages are approximate.
† No winter navigation along the St. Lawrence River.

Table 2. Number of times the degree of erosion increased or decreased from a previous survey.

River	Winter: Increase	Winter: Decrease	Summer: Increase	Summer: Decrease
St. Marys*	0	6	6	2
St. Clair*	8	1	1	3
Detroit*	1	2	1	0
St. Lawrence†	0	0	0	0
Total	9	9	8	5

* From three winter and two summer periods.
† From one summer, one winter and one year-long period.

10–15 minutes. Since the hydraulic effects of a fast-moving ship are greater than those of the same ship moving slower, ship speeds should be reduced to minimize ship effects.

The drastic hydraulic changes were observed along relatively few reaches, which are usually within 1500 feet of the navigation channel and have a gentle offshore slope. At most of the reaches, ship effects were barely detectable because the reaches are too far from the navigation channel and the offshore slope is too steep for the ship effects to reach the shoreline. Where the slope is steep, the effects of ships were minimal, even when the reach is within a few hundred feet of the navigation channel. In addition, only 29.8% of the eroding reaches border the winter navigation channel. It can inferred, then, that the contribution of winter or summer navigation to bank erosion is minor.

Alger (1977, 1978, 1979) and Wuebben et al. (1978a) pointed out that the rapid resuspension and transport of riverbed sediment during ship passage can disrupt nearshore equilibrium, which may eventually lead to undermining and erosion of the riverbank. They observed this rapid resuspension under ice-free conditions, but it probably occurs under an ice cover as well. Therefore, winter navigation could add to naturally occurring winter erosion processes. However, the effects from this would occur very slowly, only resulting in bank erosion after a long time. It would be very difficult to segregate and measure these additional erosive forces and the resulting erosion.

A far more definite relationship exists between bank erosion, water level stages and duration, and ship speed during ice-free seasons. The direct relationship between periods of high water and increased bankline recession along the Great Lakes is well established. The data from this investigation suggest that this relationship also applies to the Great Lakes connecting channels and the St. Lawrence River.

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Legend for symbols shown on survey maps shown in Appendices A-C.

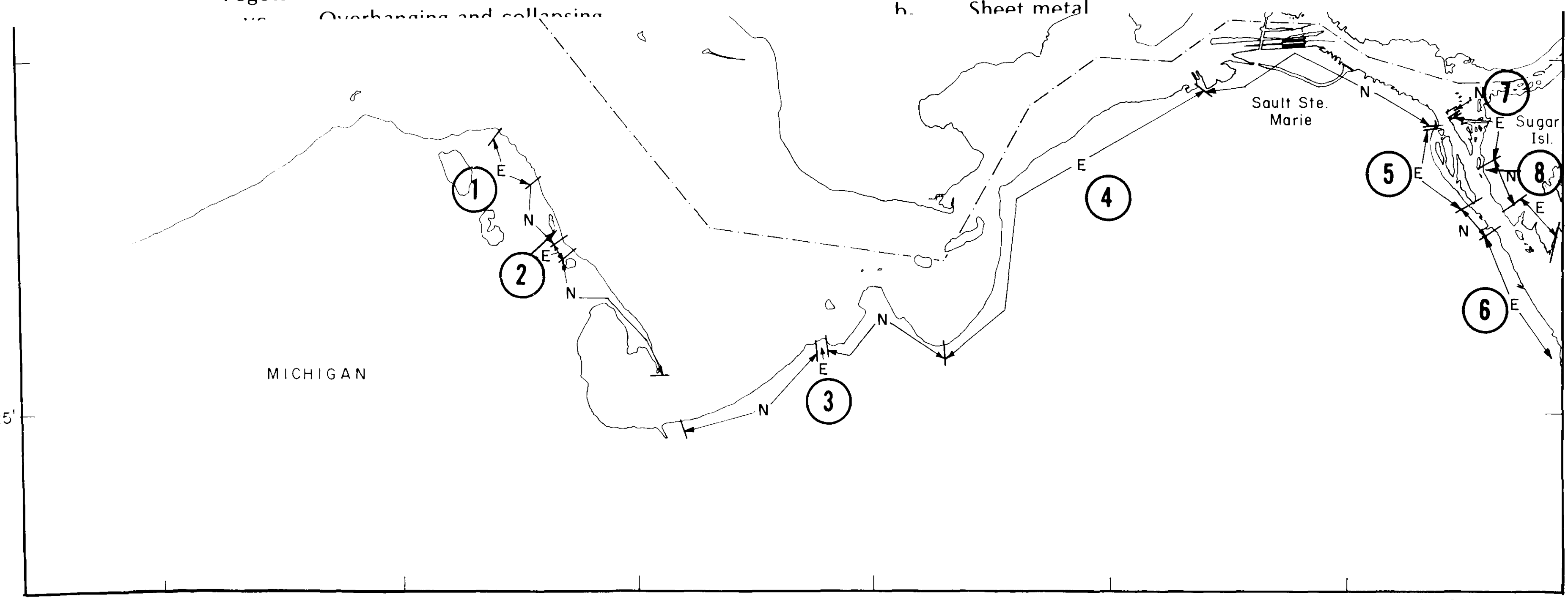
The delineations on the maps are generalized and show the predominant characteristics for a given reach at the time of the initial survey. The conditions at any particular site may be somewhat different than indicated.

Bank characteristics

E	Partially vegetated or bare
N	Completely vegetated and stable
Height	
h_1	< 1 ft
h_2	1-3 ft
h_3	4-10 ft
h_4	11-20 ft
h_5	> 20 ft
Slope	
s_1	< 45°
s_2	> 45°
Vegetation mat at bank crest	
[illegible]	Overhanging and collapsing

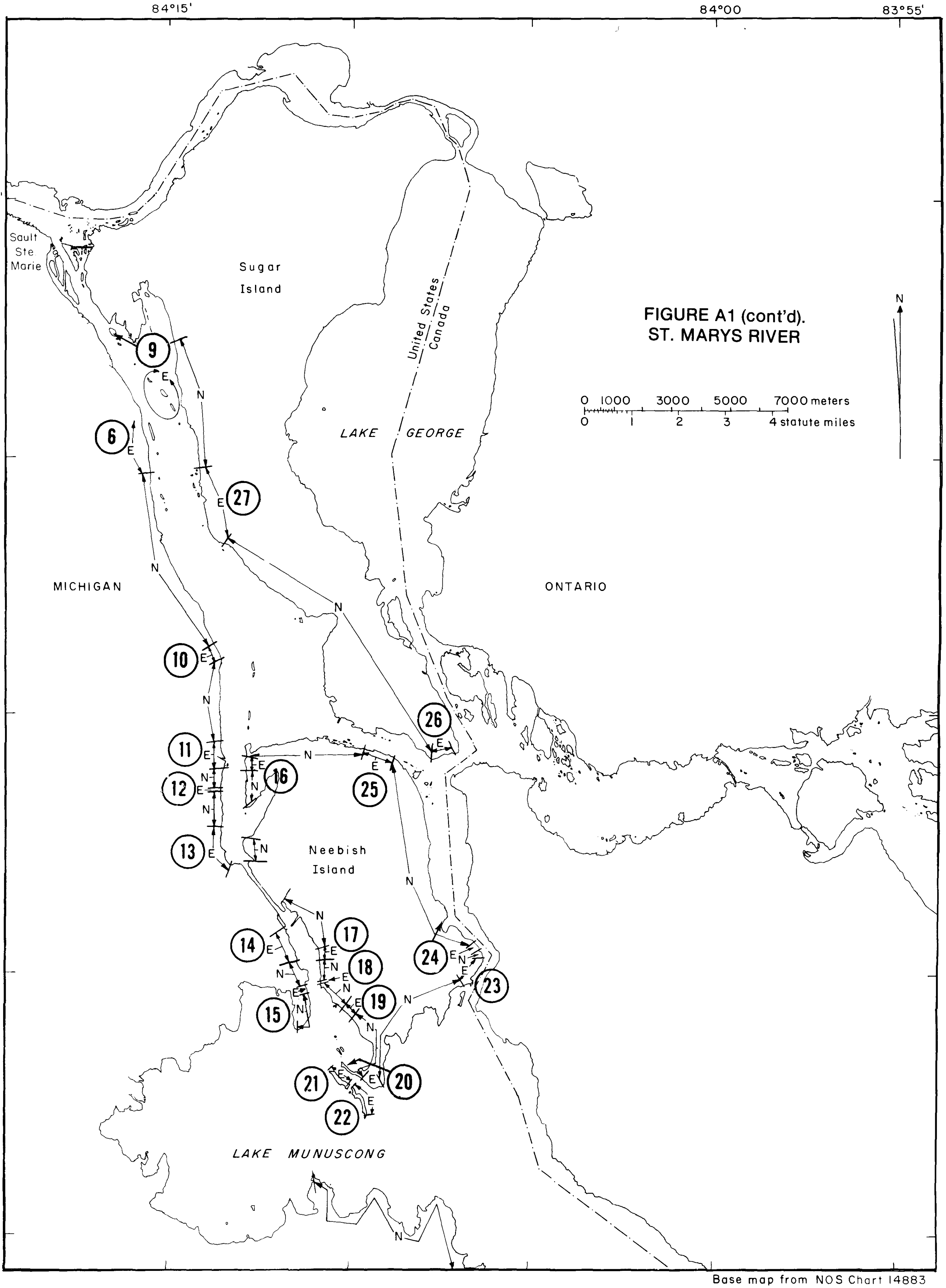
Bank protection

m	Mixed types (prefix)
s	Scattered types (prefix)
P	Protected
U	Unprotected
g	Gabions
tc	Timber cribs filled with boulders
gr	Groins
pc	Pile clusters
msp	Mixed combinations (usually bulkheads and riprap)
Bulkheads	
b_1	Timber
b_2	Sheet metal



eristics as observed on 25, 26 May 1977

Base map from NOS Chart 14884



Base map from NOS Chart 14883

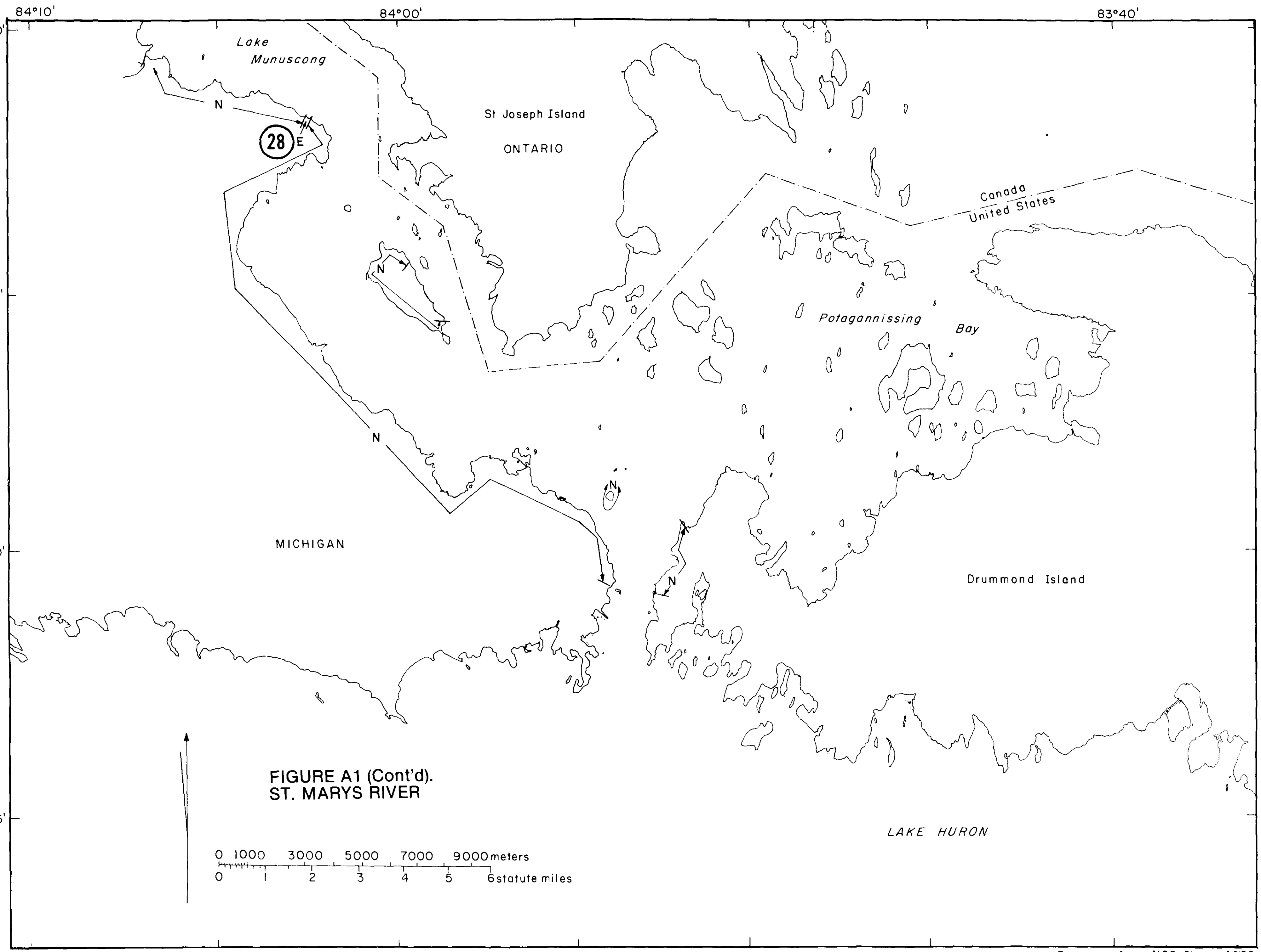


FIGURE A1 (Cont'd).
ST. MARYS RIVER

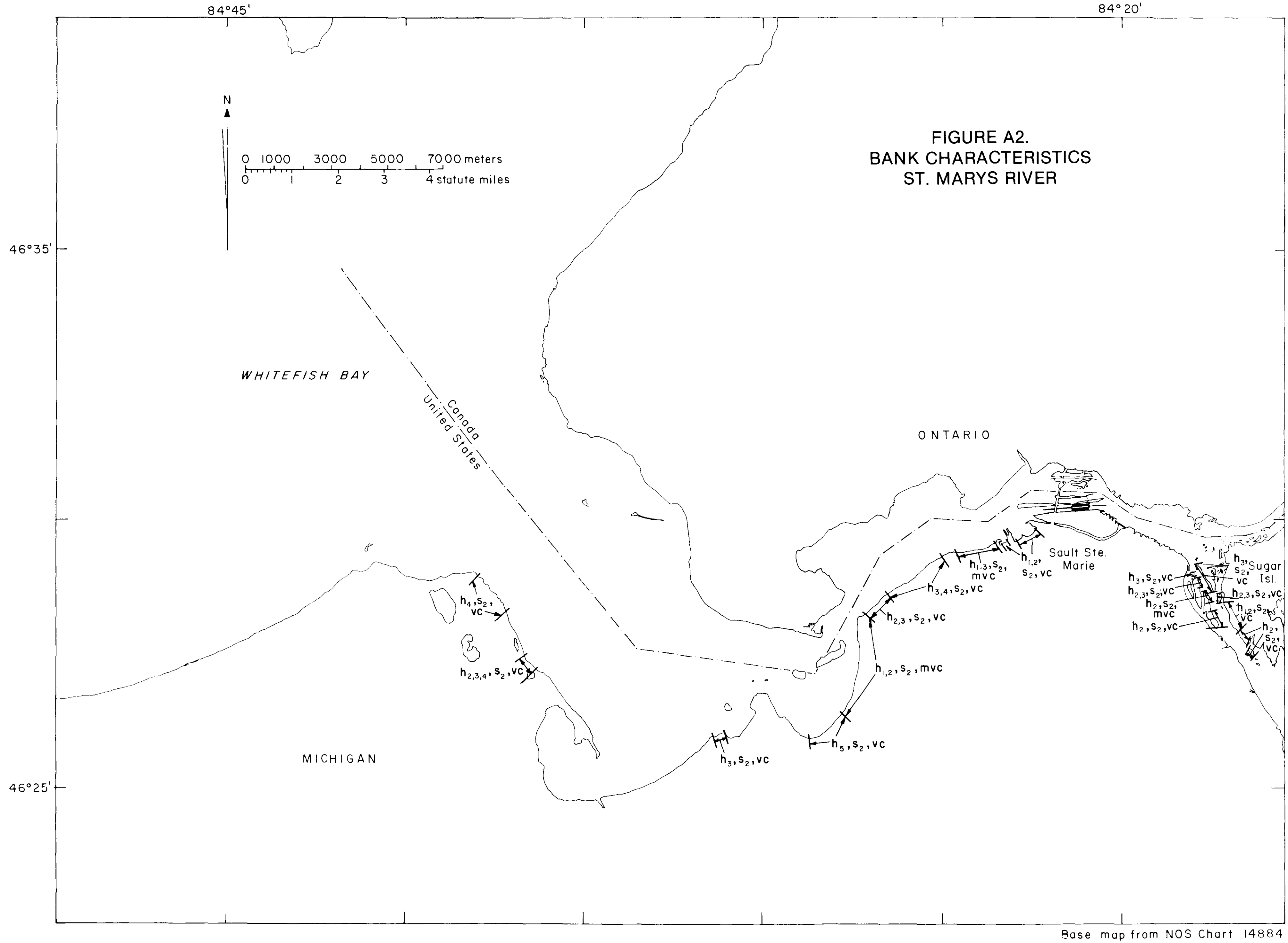


FIGURE A2.
BANK CHARACTERISTICS
ST. MARYS RIVER

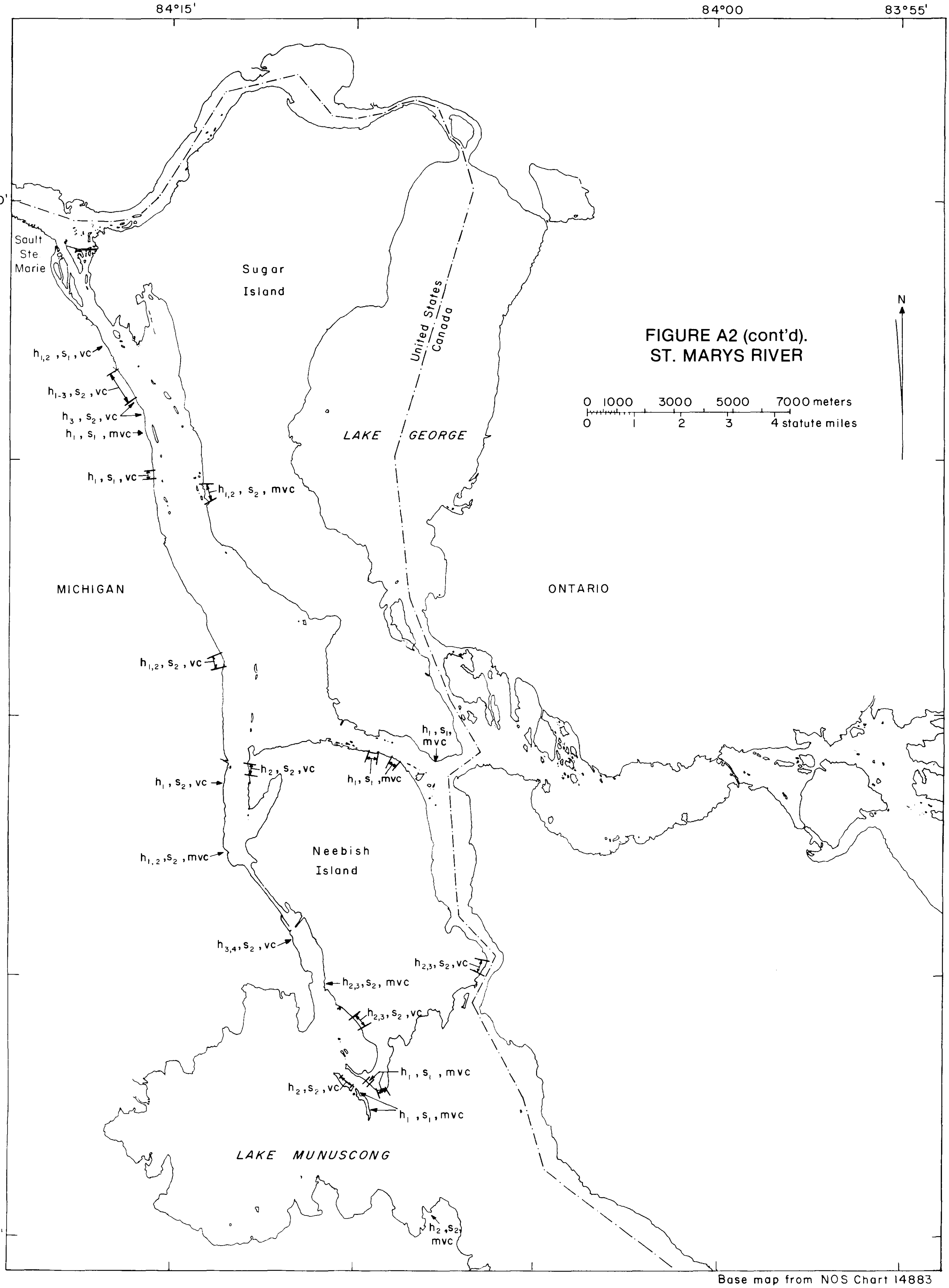


FIGURE A2 (cont'd). ST. MARYS RIVER

Base map from NOS Chart 14883

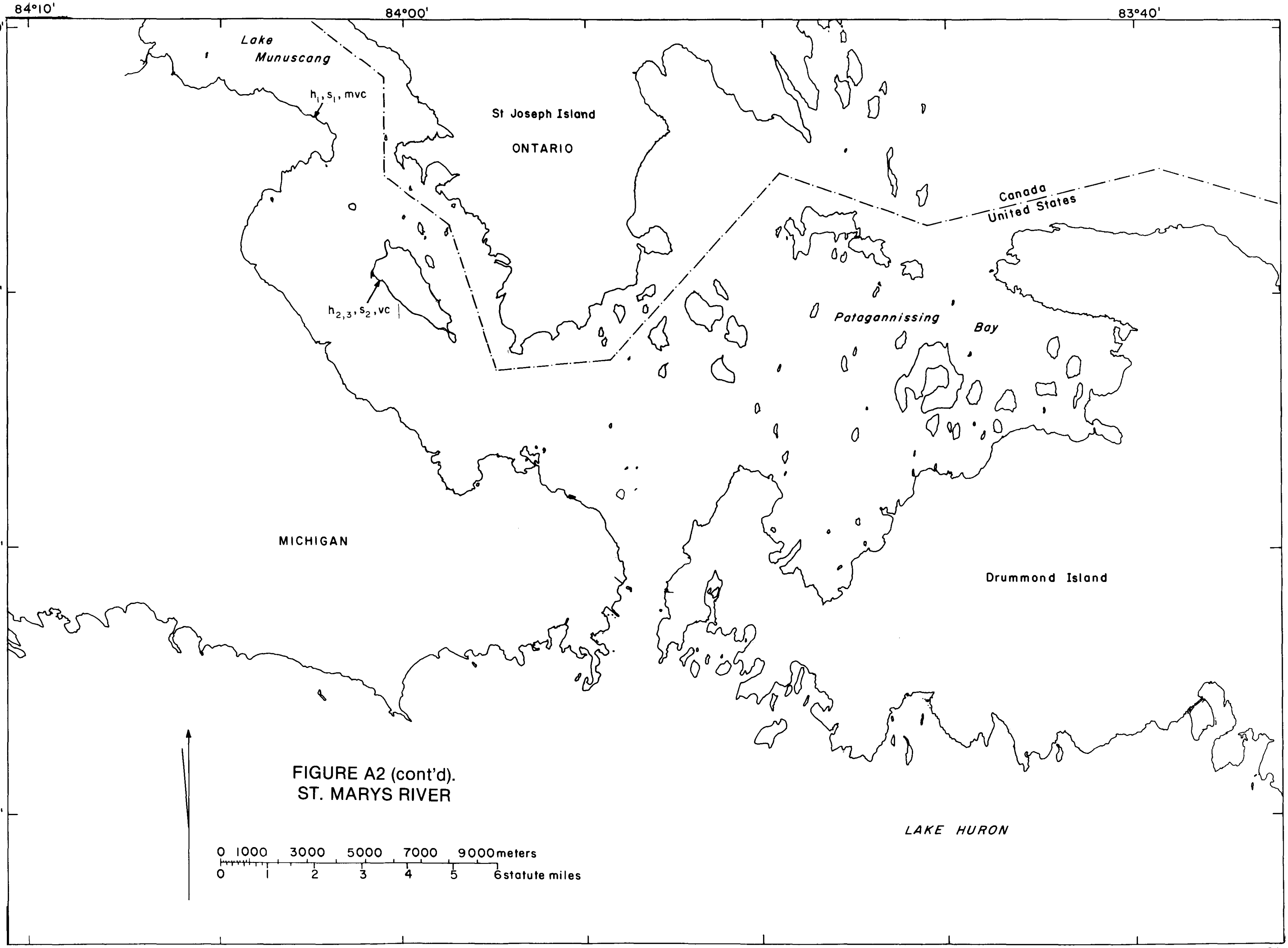


FIGURE A2 (cont'd).
ST. MARYS RIVER

Base map from NOS Chart 14882

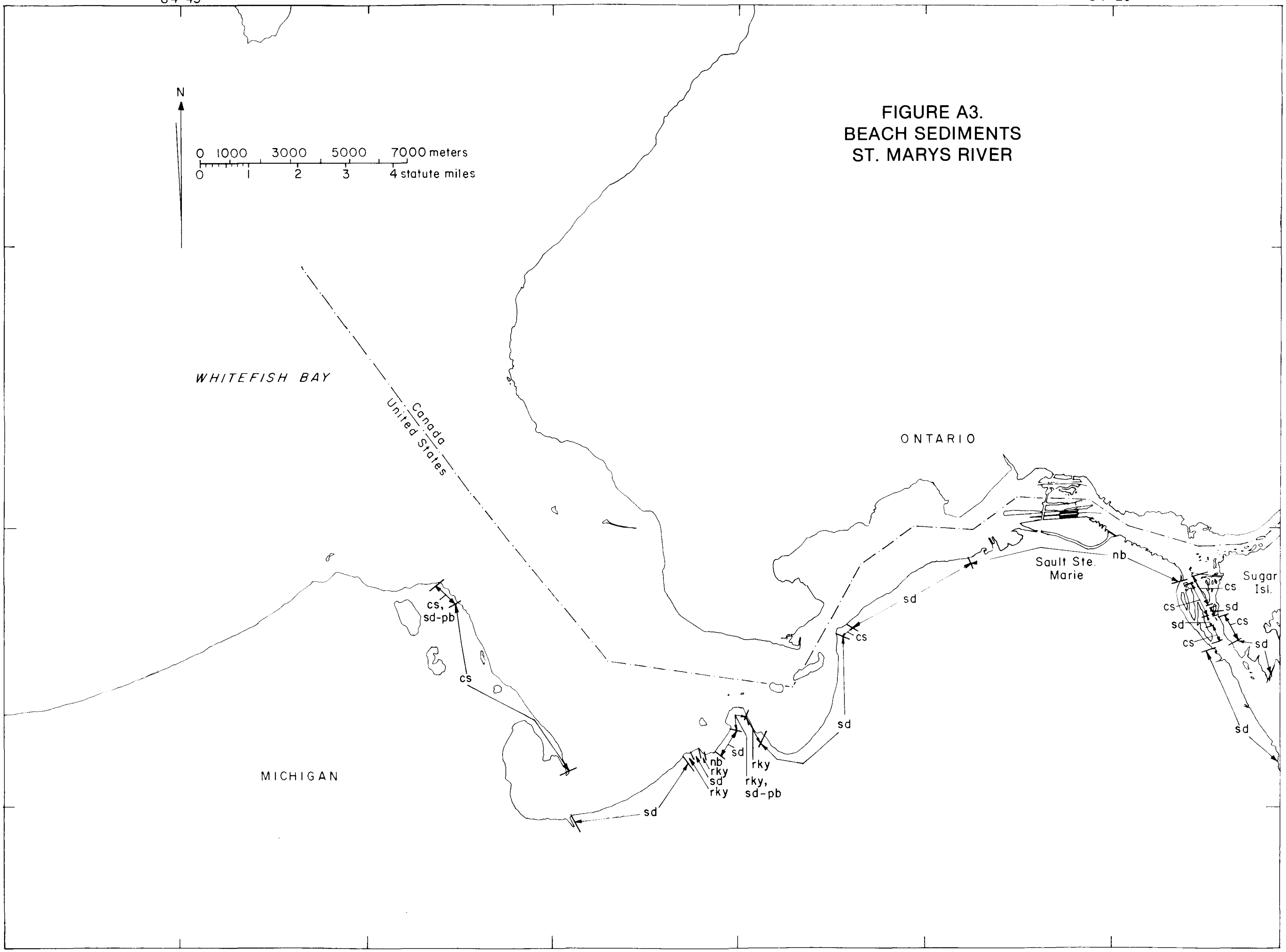
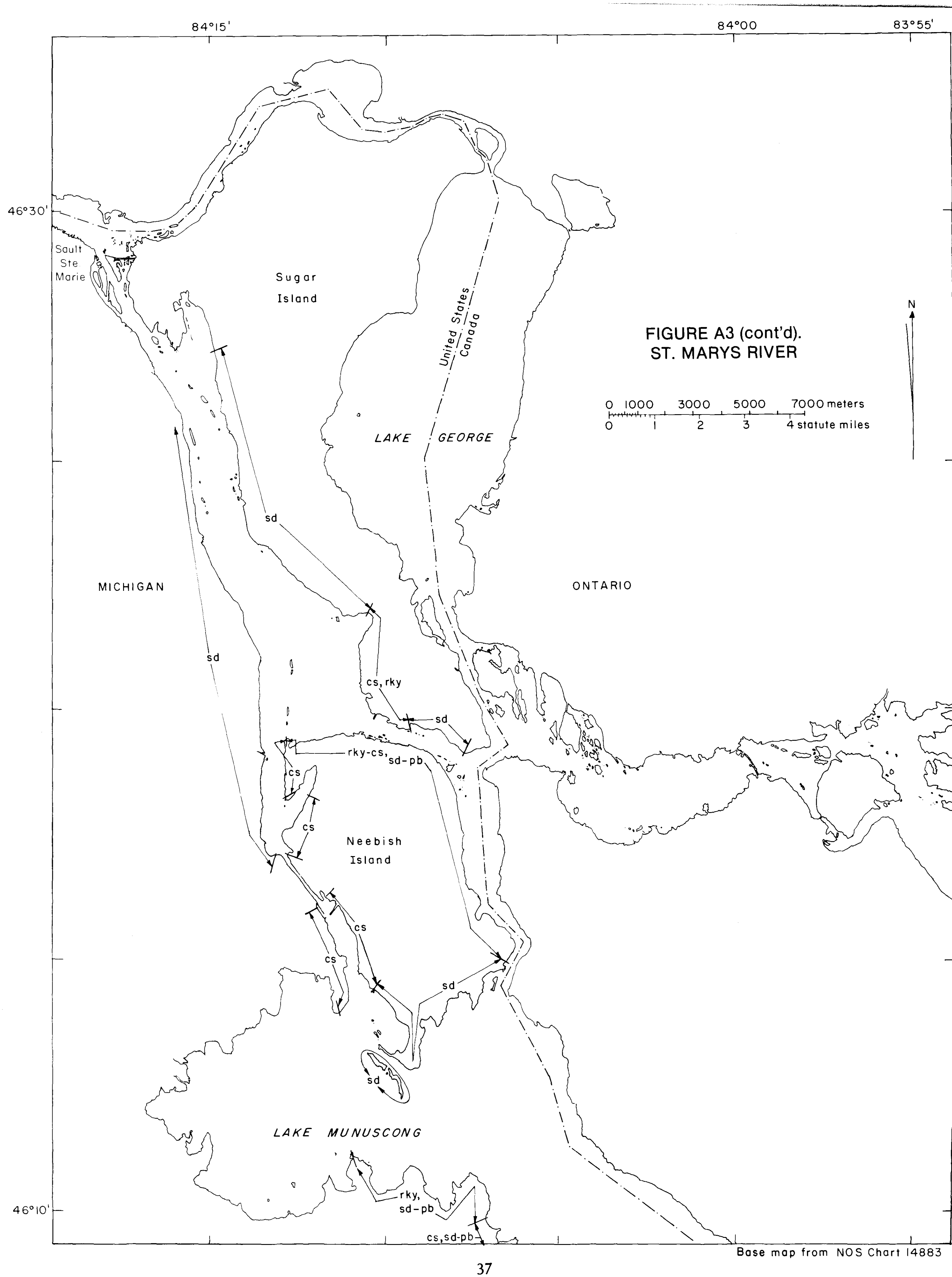


FIGURE A3.
BEACH SEDIMENTS
ST. MARYS RIVER

Base map from NOS Chart 14884


84°15'
84°00
83°55'
46°30'
46°10'
Sault Ste Marie
Sugar Island
United States
Canada
LAKE GEORGE
FIGURE A3 (cont'd).
ST. MARYS RIVER
0 1000 3000 5000 7000 meters
0 1 2 3 4 statute miles
N
MICHIGAN
ONTARIO
sd
cs, rky
rky-cs, sd-pb
cs
Neebish Island
LAKE MUNUSCONG
rky, sd-pb
cs, sd-pb
Base map from NOS Chart 14883

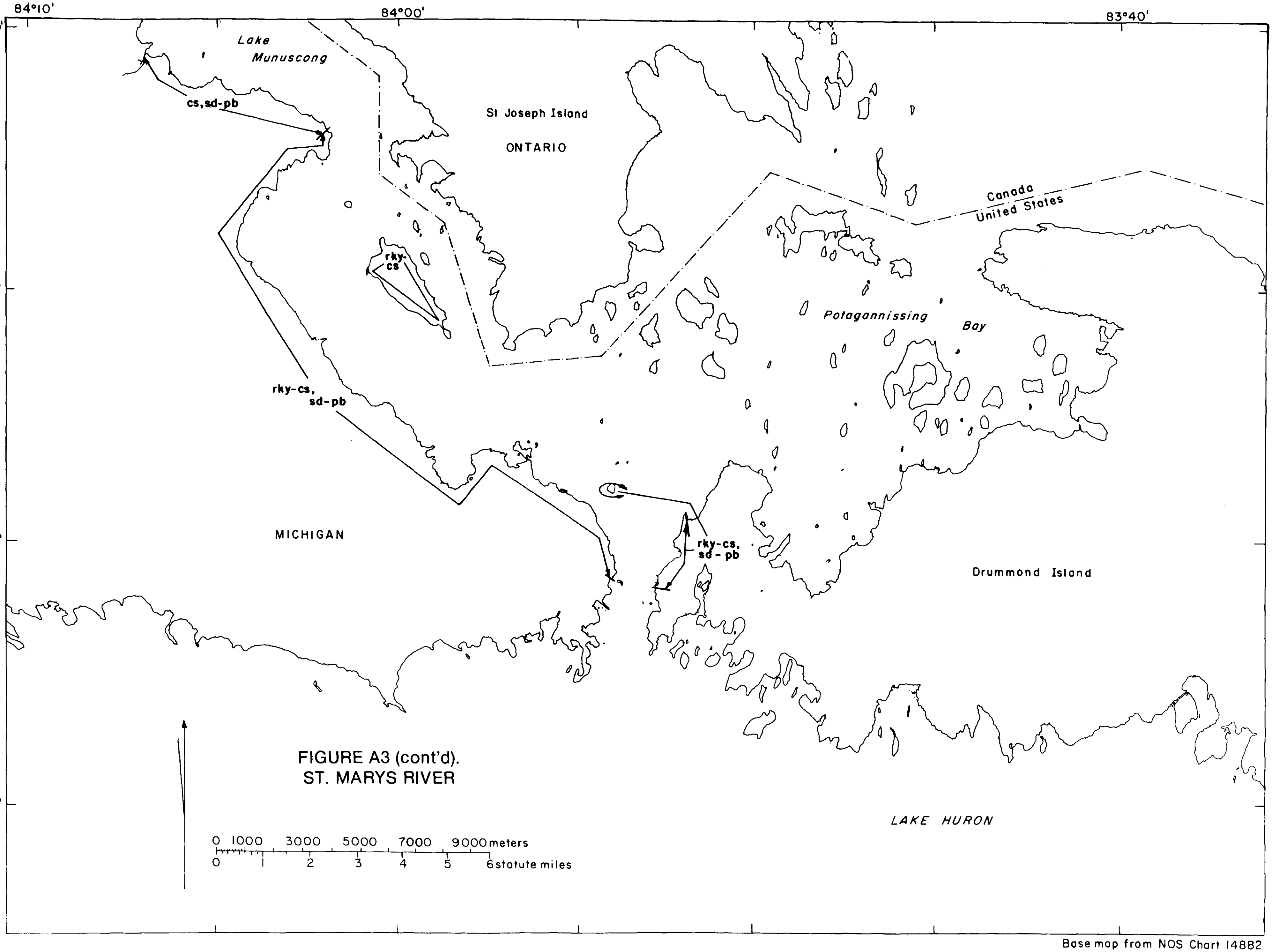


FIGURE A3 (cont'd).
ST. MARYS RIVER

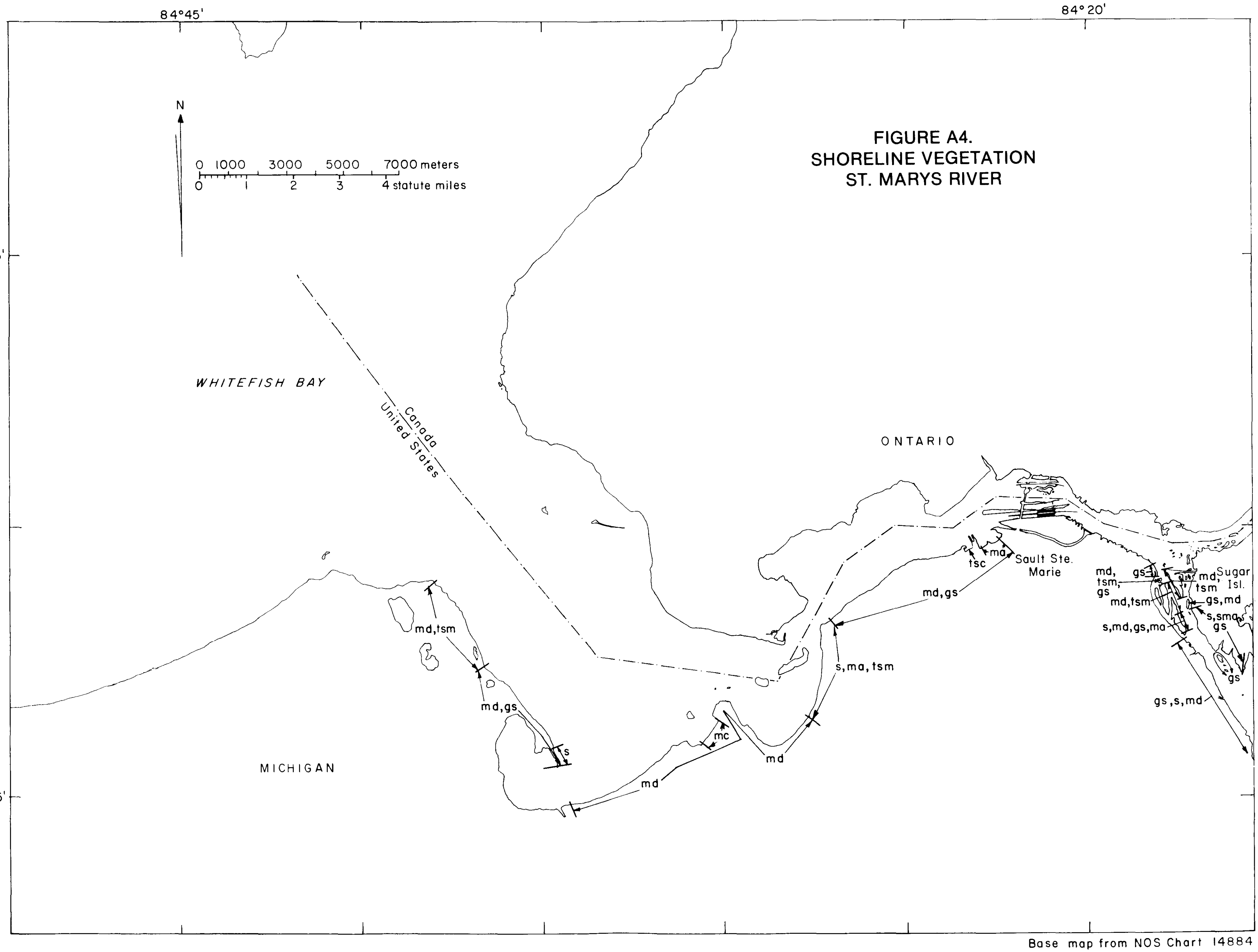
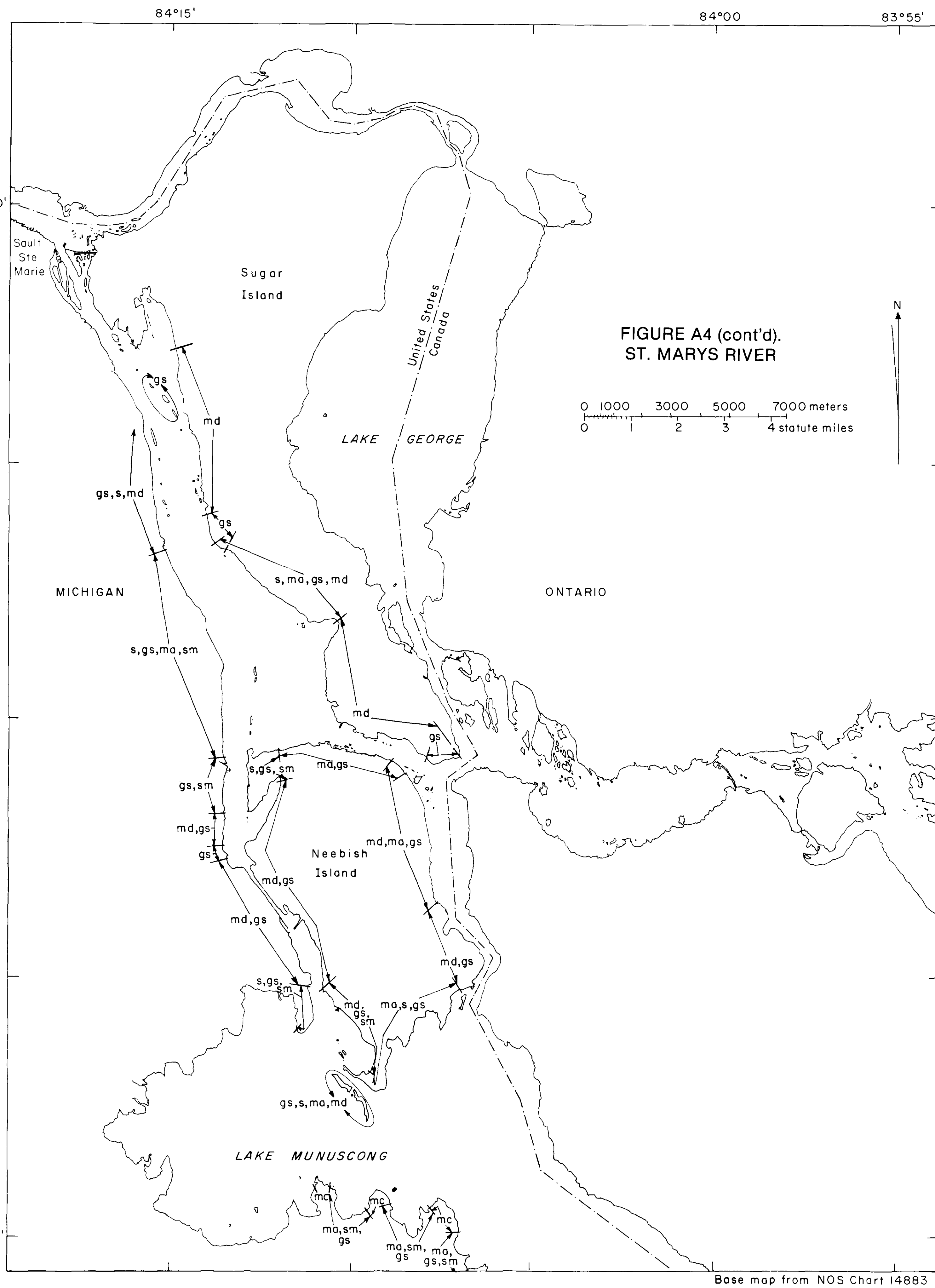


FIGURE A4.
SHORELINE VEGETATION
ST. MARYS RIVER


84°15'
84°00
83°55'
46°30'
46°10'
Sault Ste Marie
Sugar Island
United States
Canada
LAKE GEORGE
FIGURE A4 (cont'd). ST. MARYS RIVER
0 1000 3000 5000 7000 meters
0 1 2 3 4 statute miles
N
gs
md
gs,s,md
gs
s, ma, gs, md
MICHIGAN
ONTARIO
s,gs,ma,sm
md
gs
s,gs, sm
md,gs
gs,sm
md,gs
gs
md,ma,gs
Neebish Island
md,gs
md,gs
md,gs
s,gs, sm
md, gs, sm
ma,s,gs
gs,s,ma,md
LAKE MUNUSCONG
mc
mc
mc
ma,sm, gs
ma,sm, gs
ma, gs,sm
Base map from NOS Chart 14883

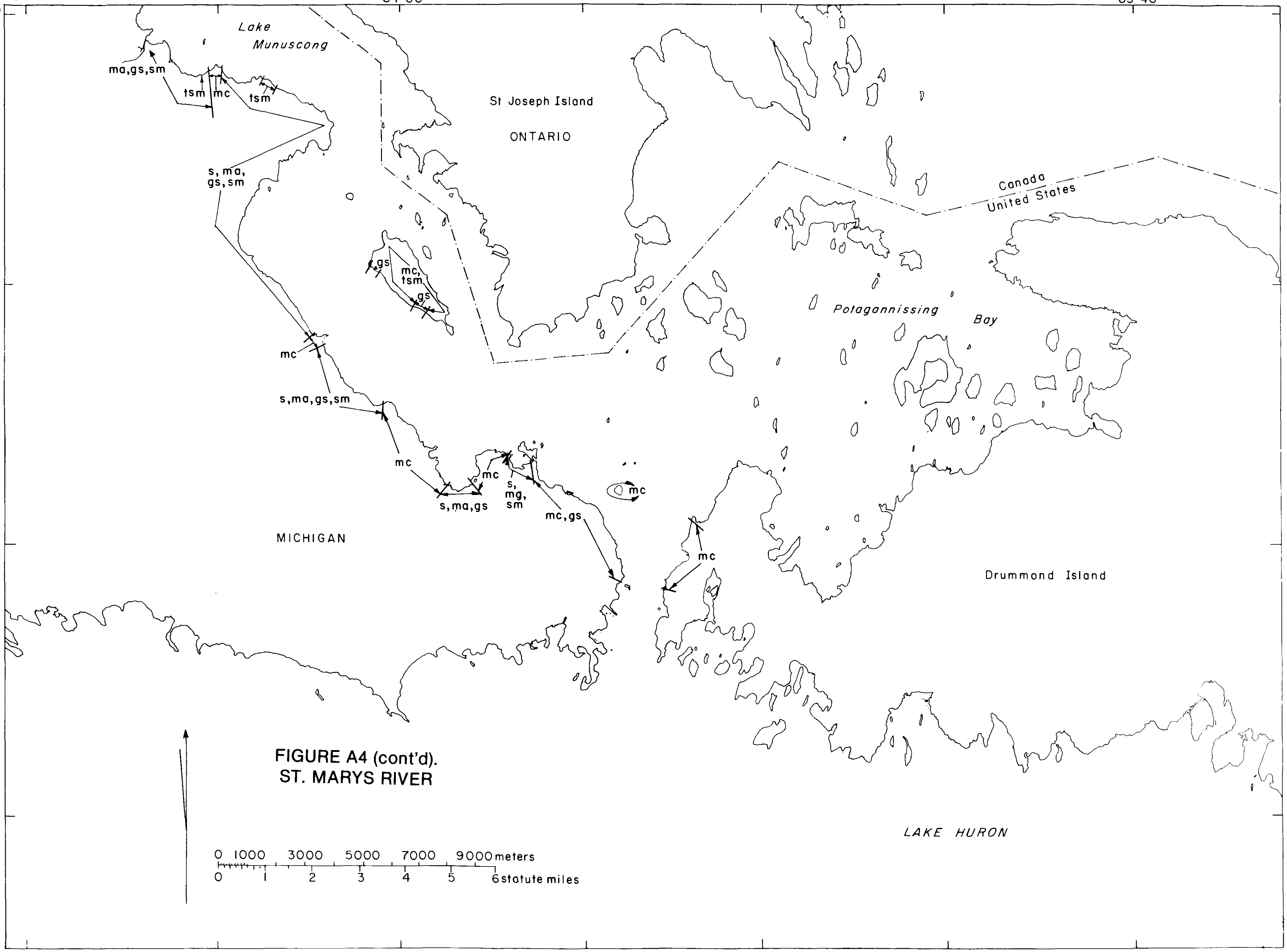
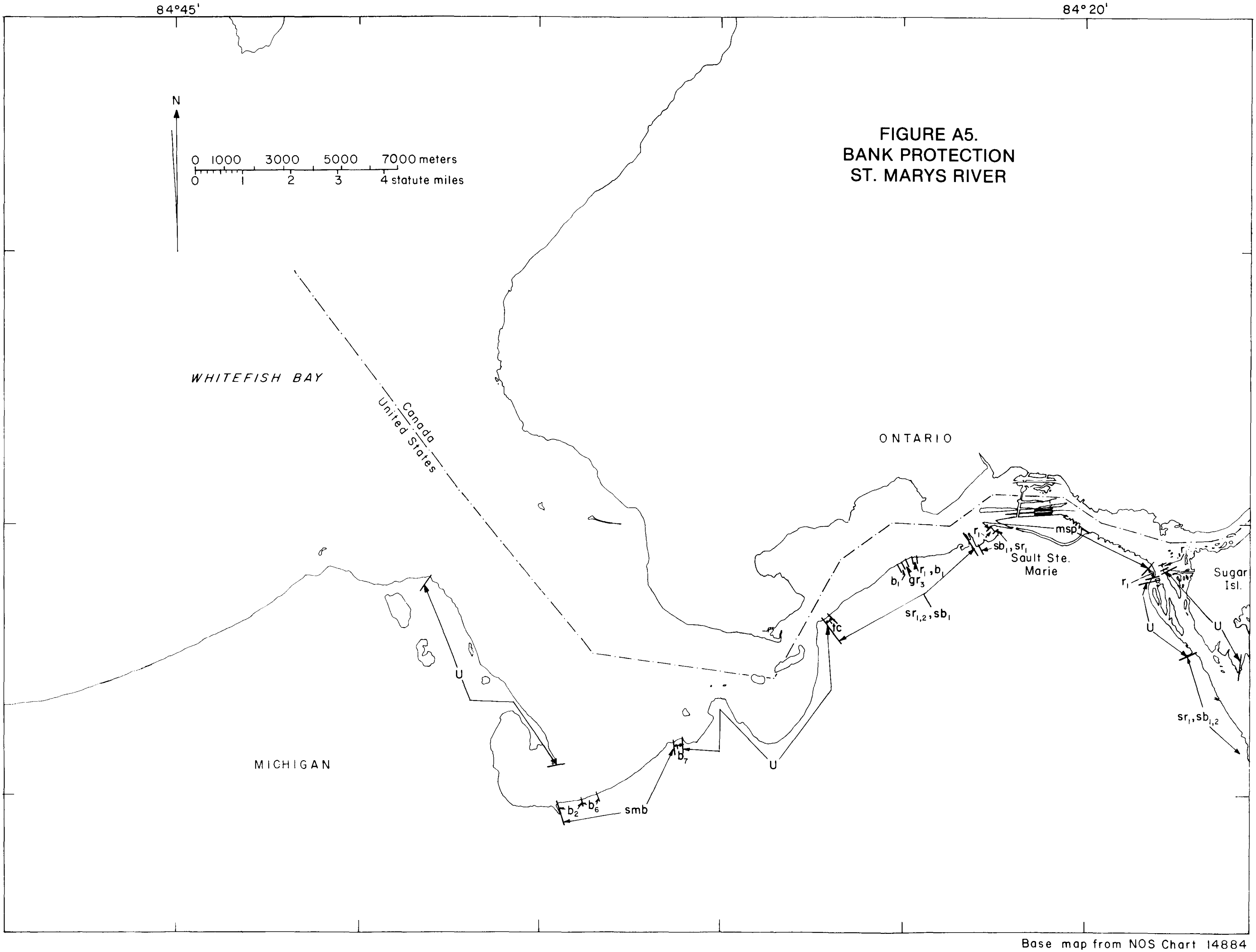


FIGURE A4 (cont'd).
ST. MARYS RIVER

0 1000 3000 5000 7000 9000 meters
0 1 2 3 4 5 6 statute miles

Base map from NOS Chart 14882


84°45'
84°20'
46°35'
46°25'
N
0 1000 3000 5000 7000 meters
0 1 2 3 4 statute miles
FIGURE A5.
BANK PROTECTION
ST. MARYS RIVER
WHITEFISH BAY
Canada
United States
ONTARIO
MICHIGAN
Sault Ste. Marie
Sugar Isl.
U
smb
b2
b6
b7
tc
sr1,2, sb1
b1
gr3
r1, b1
sb1, sr1
r1
msp
sr1, sb1,2
Base map from NOS Chart 14884

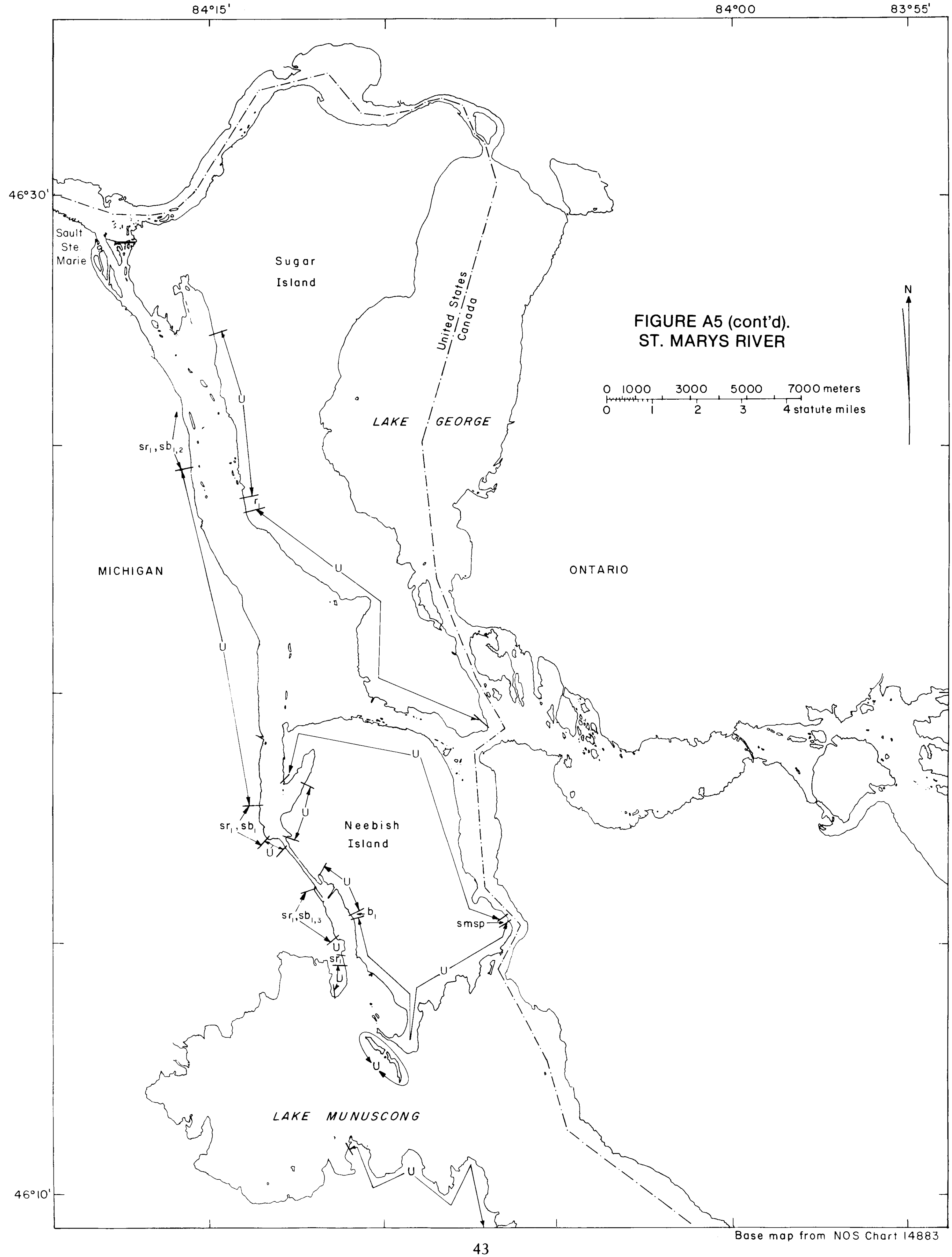


FIGURE A5 (cont'd).
ST. MARYS RIVER

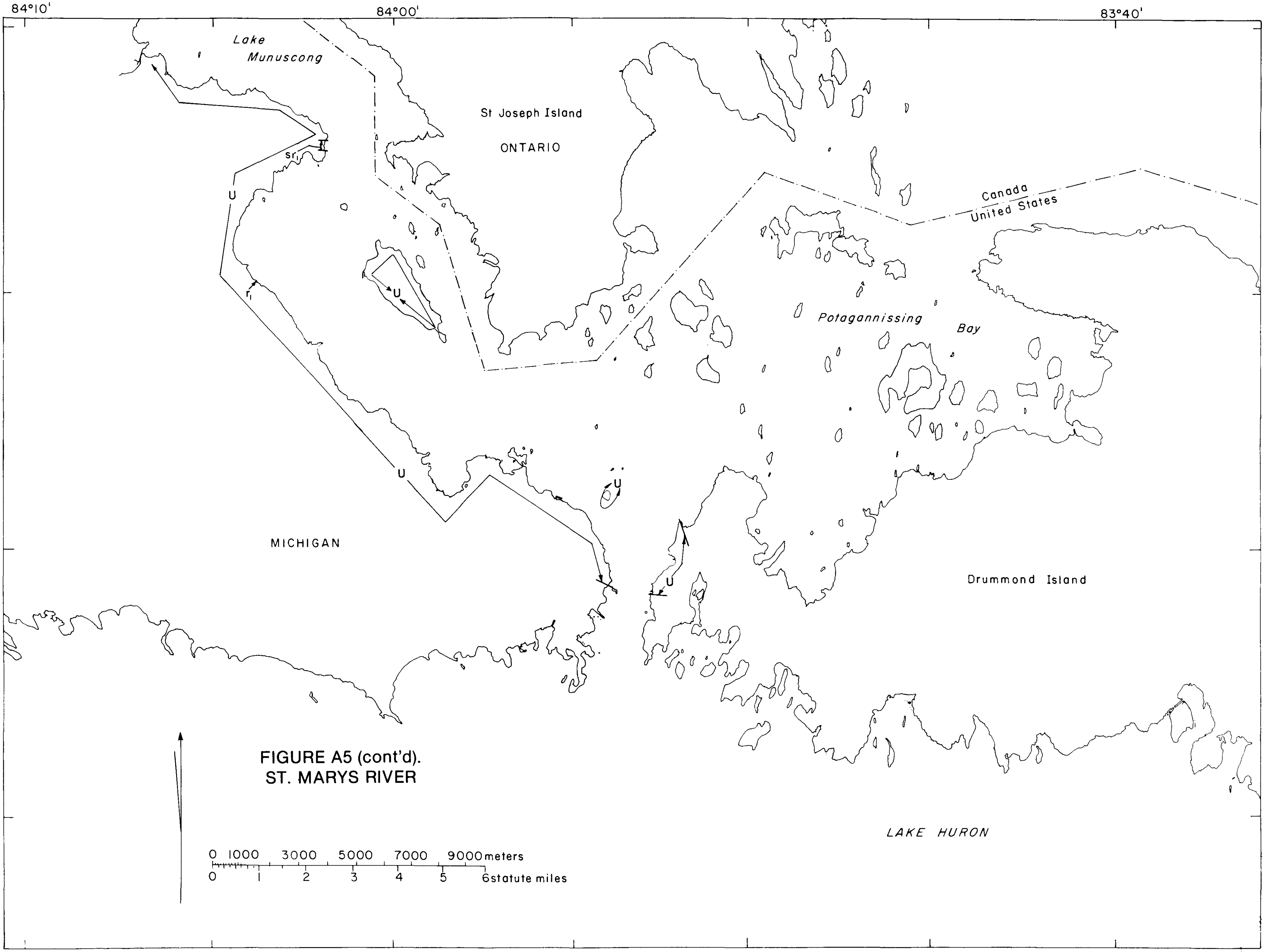
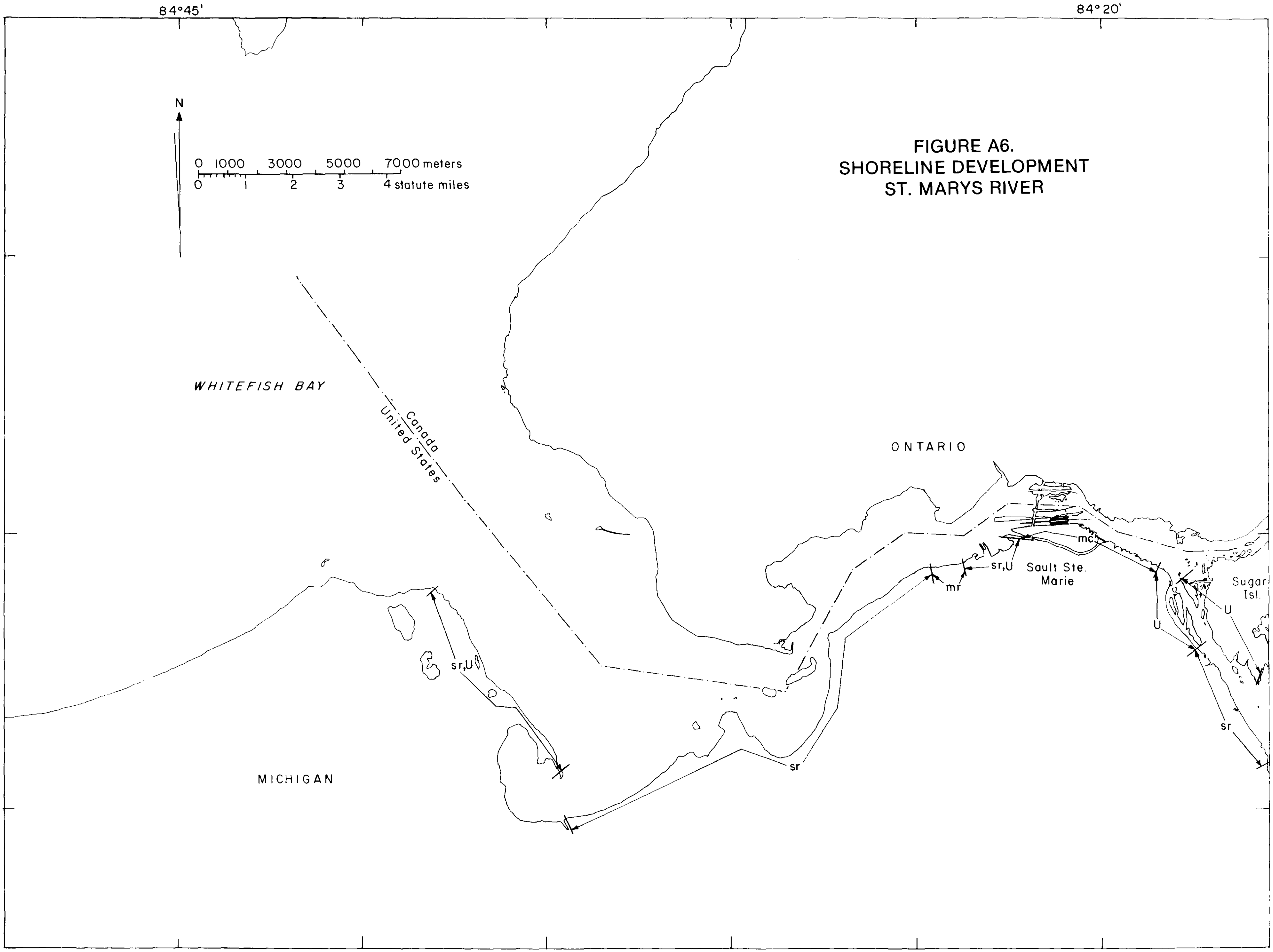


FIGURE A5 (cont'd).
ST. MARYS RIVER

Base map from NOS Chart 14882



Base map from NOS Chart 14884

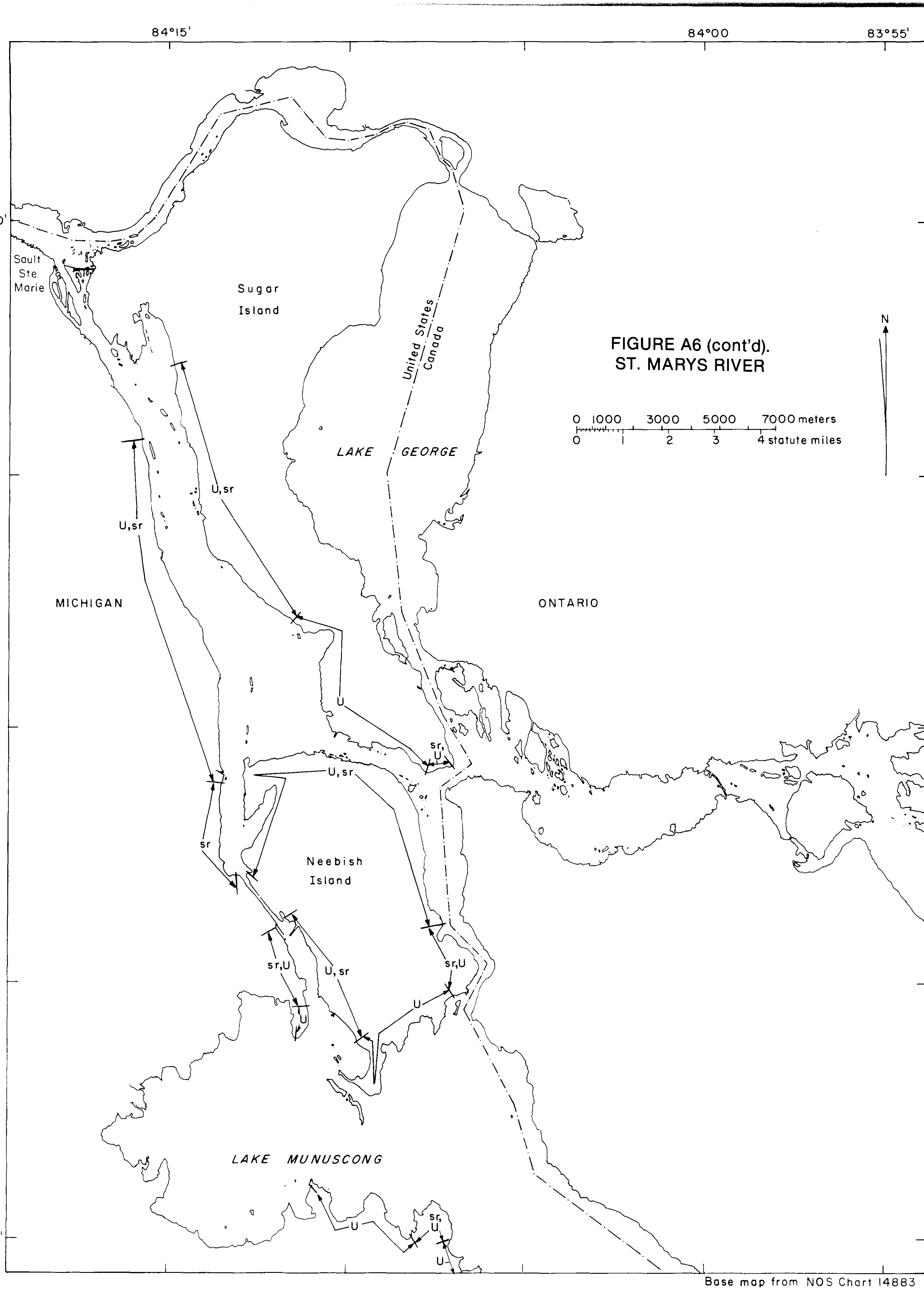


FIGURE A6 (cont'd).
ST. MARYS RIVER

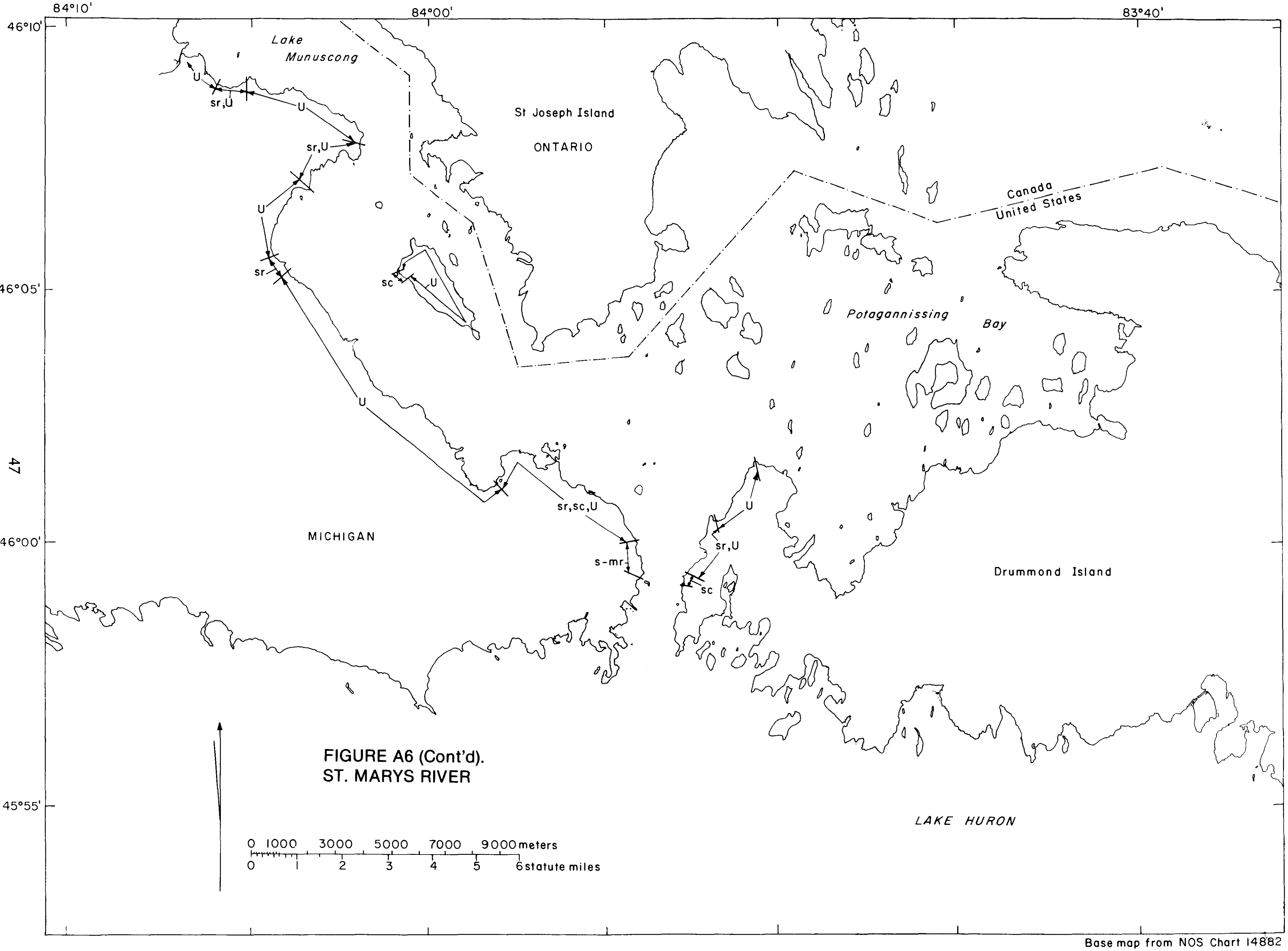


FIGURE A6 (Cont'd).
ST. MARYS RIVER

Table A1. Erosion and approximate lengths of reaches with partially vegetated or bare banks, St. Marys River.

Site	*Reach*	*Degree of erosion**	*Approximate length (ft)*	*Approximate distance to navigation channel (ft)†*	*Remarks***
1		NAE	4000		NR_1
2	a	NAE	400		NR_1
	b	NAE	2000		NR_1
3	a	NAE	200		$NR_{1,3}$
	b	NAE	300		P, $NR_{1,3}$
4	a	NAE	7000		$NR_{1,3}$
	b††	NAE	1000		
	c	NAE	300		
	d	NAE	50		R
	e	NAE	200		
	f	NAE	200		
	g	NAE	200		
	h	NAE	300		
	i	NAE-ME	400	1700	P
	j	NAE	50		
	k	NAE-ME	600	1850	
	l	NAE	500		$NR_{1,3}$
	m	NAE	600		$NR_{1,3}$
5	a††	NAE-ME	1000	80	R, NR_2
	b	NAE-ME	4500	80-550	NR_2
6	a	NAE-ME	600	450-650	
	b	NAE	100		
	c	NAE-ME	200	750	P
	d††	NAE	300		P
	e	NAE-ME	700	750	
	f	NAE	200		
7	a	NAE-ME	3800	80	
	b	NAE-ME	1100	250-650	
8	a	NAE	300		
	b	NAE-ME	1400	550	
9	a	NAE-ME	1000	750	
	b	NAE-ME	400	750	
10	a	NAE	100		
	b	NAE	200		
	c	NAE	200		
11	a	NAE	100		
	b††	NAE-ME	400	1350***	
	c	NAE-ME	300	1250	
12		NAE	400		
13		NAE	1200		
14		NAE	500		P
15	a	NAE	200		
	b	NAE	500		
16	a	NAE-ME	300	500	
	b	ME-E	300	500	
	c	NAE-ME	2100	400-850	
17		NAE	1400		P,R
18		NAE-ME	300	650	P
19		NAE-ME	1500	3200	NR_1
20	a	NAE-ME	1700	500	
	b	NAE	1100	500-950	
21	a	E	600	350	
	b	E	200	850	
	c	E	800	650	
22	a	E	900	750	
	b	E	1000	750	

Table A1. (Cont'd).

Site	Reach	*Degree of erosion**	*Approximate length (ft)*	*Approximate distance to navigation channel (ft)†*	*Remarks***
23	a	NAE	200		R
	b††	NAE	600		
24	a††	NAE	200		
	b††	NAE-ME	300	700	
25		NAE-ME	400	350	
26		NAE	3000		R
27	a††	ME	400	450	
	b††	NAE-ME	400	350	
	c	NAE	200		
28		NAE	700		
		37-NAE	29000 ft stable		
		29-ME or E	27600 ft eroding		
			56600 ft total		

* Range in the degree of erosion from 1977 to 1980.

† Distances not given for sites or reaches that show no apparent erosion (NAE).

** R: Revegetating (no evidence of erosion; bank appeared stable and vegetation was partially established).

P: Protected (since previous survey, bank protection was built or under construction).

NR: Not revisited: 1) Too far from the navigation channel to be affected by ship-induced effects.
2) Boat inoperative; no access.
3) Bank appeared stable during previous survey.

†† Profile and scarp data for this reach is reported in Alger (1977, 1978, 1979), Wuebben et al. (1978a, b) or Wuebben (in press).

*** The navigation channel from sites 11 to 22 is not used during the winter after an ice cover has formed.

Table A2. Summary of the range in the erosion observed along the reaches at each site, St. Marys River.

Site number	Number of reaches	*25, 26 May '77 to 20, 21 Oct '77*	*20, 21 Oct '77 to 22, 23 May '78*	*22, 23 May '78 to 2, 3 Nov '78*	*2, 3 Nov '78 to 17, 18 May '79*	*17, 18 May '79 to 5, 6 Oct '79*	*5, 6 Oct '79 to 27, 28 May '80*	Remarks
1	1	NAE	NAE	NAE	NR_1	-	-	NPS
2	2	NAE	NR_1	-	-	-	-	NPS
3	2	NAE	NAE	P	$NR_{1,3}$	-	-	NPS; VLB
4	13	NAE-ME	NAE-ME; $NR_{1,3}$	NAE-ME; P; $NR_{1,3}$	NAE-ME; P; $NR_{1,3}$	NAE-ME; $NR_{1,3}$	NAE-ME; R; $NR_{1,3}$	2BP at 4b
5	2	NAE-ME; R	NAE-ME; R	NAE-ME	NR_2	NAE-ME	NAE-ME	2BP at 5a
6	6	NAE-ME	NAE-ME; P	NAE-ME; P	NAE-ME	NAE-ME	NAE-ME	3BP and S at 6d
7	2	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NPS
8	2	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NPS
9	2	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NPS
10	3	NAE	NAE	NAE	NAE	NAE	NR_3	NPS; VLB
11	3	NAE	NAE	NAE-ME	NAE-ME	ME	NAE-ME	3BP and S at 11a
12	1	NAE	NAE	NAE	NAE	NAE	NAE	NPS; VLB
13	1	NAE	NAE	NAE	NAE	NAE	NAE	NPS; VLB
14	1	NAE; P	NAE	NAE; P	NAE	NAE	NAE	NPS; VLB
15	2	NAE	NAE	NAE	NAE	NAE	NAE	NPS; VLB
16	3	NAE-ME	NAE-ME	NAE-ME	NAE-ME	ME-E	ME-E	NPS
17	1	NAE; R	NAE; P; R	NAE; R	NAE; R	NAE; R	NAE	NPS
18	1	NAE; P	NAE; P	NAE; P	NAE; P	NAE-ME; P	NAE	NPS
19	1	NAE-ME	NR_1	NAE-ME	NR_1	NAE-ME	NAE-ME	NPS
20	2	ME	NAE-ME	NAE-ME	NAE-ME	NAE	NAE	NPS; uninhabited shores
21	3	E	E	E	E	E	ME-E	NPS; uninhabited island
22	2	E	E	E	E	E	ME-E	NPS; uninhabited islands
23	2	NAE; R	NAE; R	NAE	NAE	NAE	NAE	1BP at 23b
24	2	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME	3BP and S at 24a
25	1	NAE	NAE	NAE-ME	NAE-ME	ME	NAE	NPS
26	1	NAE	NAE	NAE	NR_1	-	NAE	NPS; VLB
27	3	ME	ME	ME	ME	NAE-ME	NAE-ME	2BP at 27a
28	1	NR_3	-	-	-	-	-	NPS; VLB

NAE: No apparent erosion (no fresh slide surfaces or slumps; no additional fallen trees or grass clumps).
ME: Minor erosion (isolated or scattered slide surfaces, slumps, fallen trees or clumps).
E: Eroding (many fresh slide surfaces along most of the reach).
R: Revegetating (no evidence of erosion; bank appeared stable and vegetation was partially established).
P: Protected (since previous survey, bank protection was built or under construction).
NR: Not revisited: 1) Too far from the navigation channel to be affected by ship-induced effects.
2) Boat inoperative; no access.
3) Bank appeared stable during previous survey.
NPS: No profiles or scarp survey.
VLB: Very low or indistinct bank.
BP: Number of bank profiles.
S: Scarp survey.

Table A3. Bank recession before and after winter navigation began, St. Marys River.

Site and reach	Distance from reference points to top of bank (ft) July 1939	June, July 1964	Oct 1977	Change in distance (ft)* 1939-64	1964-77	Total recession (38.2 yrs)	Reference point
1	133	111	76	-22	-35	57	NSR†
4b	2188	2154	2166	-34	< 8	37-<42	NSR
4i	788	728	701	-60	-27	87	NSR
4k	368	368	364	<13	< 8	<21	NSR
5a	1850	1821	1851	-30	< 8	30-<38	Bridge
6d	232	205	157	-27	-48	75	Building
7a	380	372	372	<13	< 8	<21	NSR
7b	189	179	165	<13	-14	14-<27	Building
8b	306	301	248	<13	-53	53-<66	Tree
9a	**	335	282	—	-53	53	Tree
11b	1200	1140	1076	-60	-64	124	NSR
23b	100	91	70	<13	-21	21-<34	Building
24b	1774	1703	1687	-71	-16	87	Road Intersection
27a	444	284	217	-160	-67	227	NSR

* MMD for 1939-1964 is 13 ft; MMD for 1964-1977 is 8 ft.

† NSR: No stable reference (no stable reference point nearby; the measurement was made from the intersection of lines drawn from the nearest stable reference points).

** Dredge material dump site (not present in 1939).

APPENDIX B: ST. CLAIR RIVER. The maps show the shoreline conditions and bank characteristics as observed on 23 May 1977. Refer to the legend in Appendix A for explanations of map symbols.

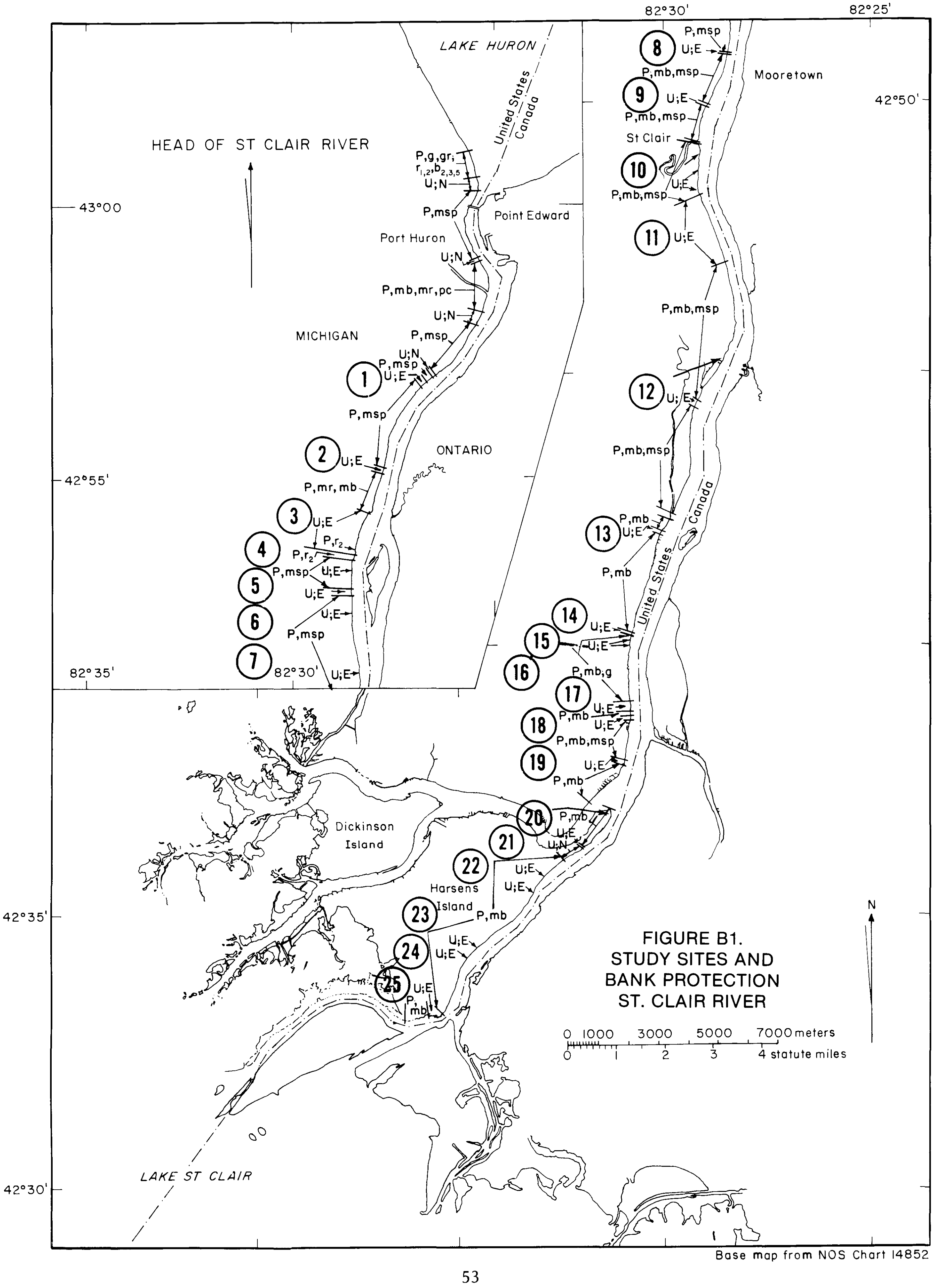


FIGURE B1.
STUDY SITES AND
BANK PROTECTION
ST. CLAIR RIVER

Base map from NOS Chart 14852

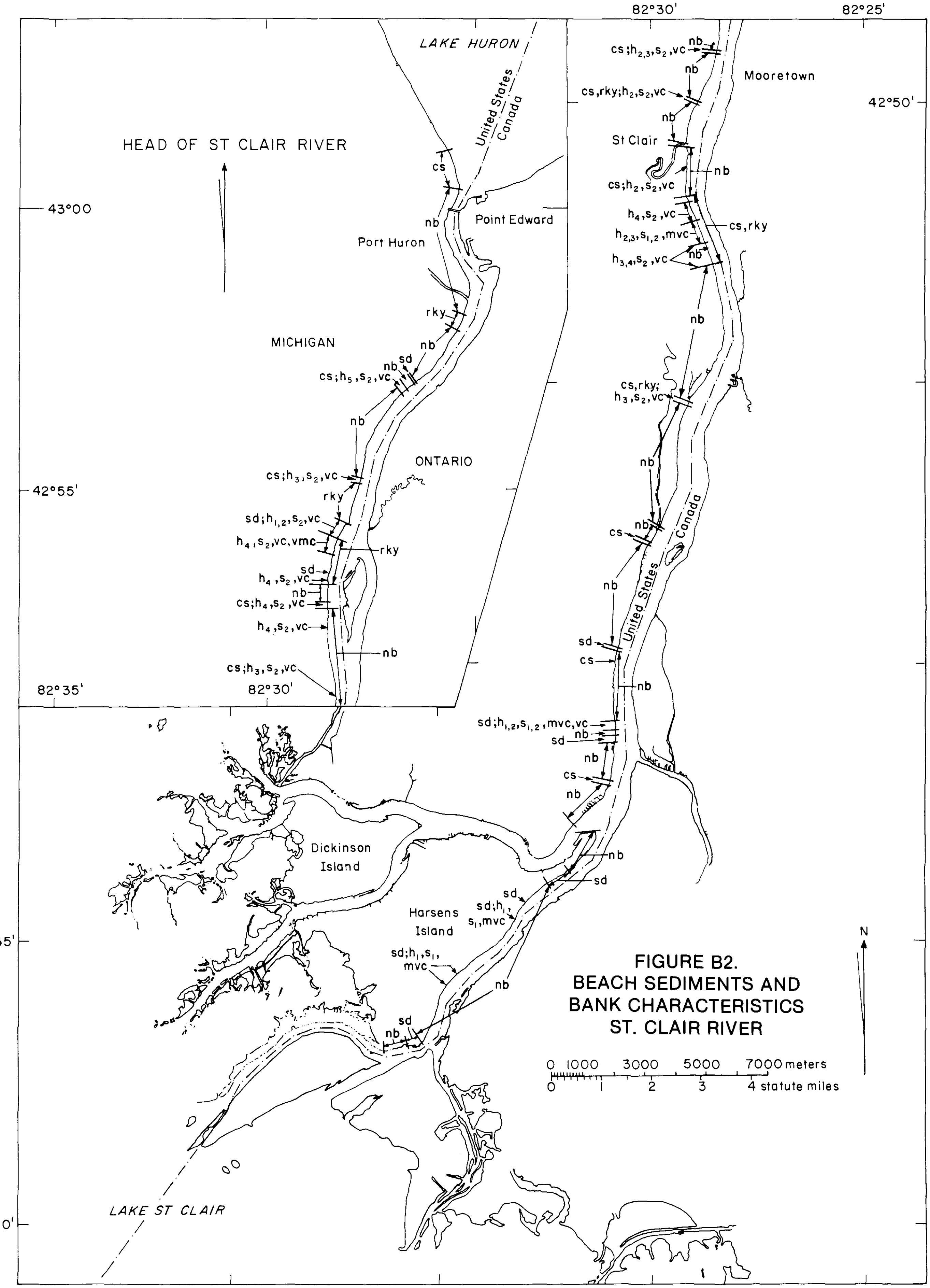


FIGURE B2.
BEACH SEDIMENTS AND
BANK CHARACTERISTICS
ST. CLAIR RIVER

Base map from NOS Chart 14852

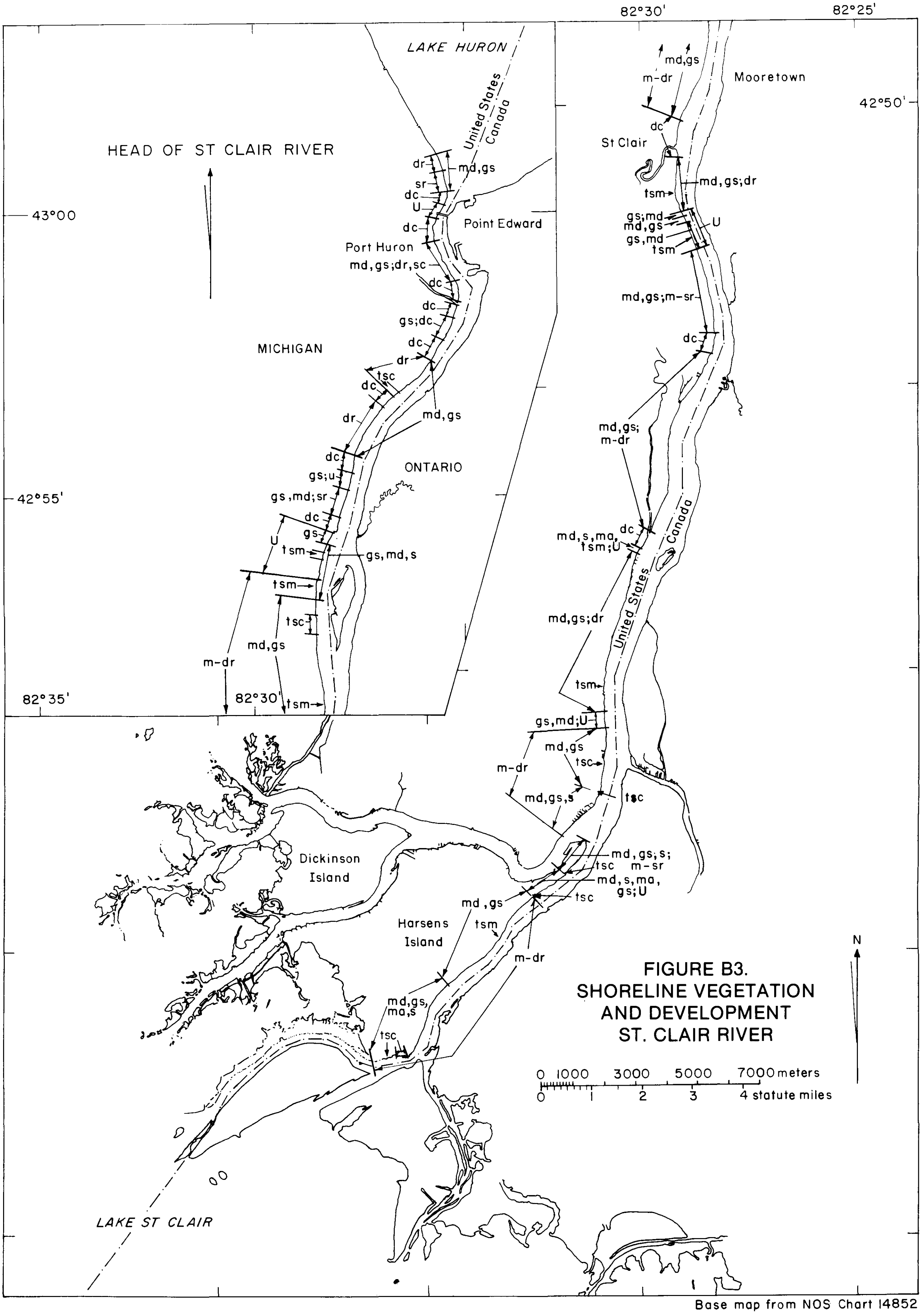


FIGURE B3.
SHORELINE VEGETATION
AND DEVELOPMENT
ST. CLAIR RIVER

Table B1. Erosion and approximate lengths of reaches with partially vegetated or bare banks, St. Clair River.

Site	*Reach*	*Degree of erosion**	*Approximate length (ft)*	*Approximate distance to navigation channel (ft)†*	*Remarks***
1	a	NAE	50		
	b	NAE	100		
	c	NAE	200		
	d	NAE	200		P
	e	NAE-ME	200	650	
	f	NAE-ME	500	650	P
	g	NAE-ME	100	650	
2	a	NAE	50		
	b	NAE-ME	50	450	
	c	NAE	1200		
	d	NAE-ME	100	250	
3	a††	NAE-ME	2000	300	
	b	NAE-ME	800	200	P, R
4	a	NAE-ME	100	150	
	b††	NAE-ME	100	150	
5	a††	NAE-ME	1200	200	
	b	NAE-ME	100	200	
6		NAE-ME	50	250	
7	a	NAE-ME	200	150	
	b††	NAE-ME	100	150	P
	c	NAE-ME	400	200	
8	a	NAE	400		R
	b	NAE	100		P
9	a	NAE-ME	100	200	
	b	NAE	100		
	c	NAE	100		
	d	NAE	100		P
10	a	NAE	50		
	b	NAE-ME	100	550	P
	c	NAE	50		
11	a	NAE-E	1000	250	
	b††	NAE-E	2000	200	
	c	NAE-E	200	250	
	d	NAE	100		
12	a	NAE	100		
	b††	NAE-ME	400	600	P
13	a	NAE	400		
	b	NAE	100		
	c	NAE	100		
14		NAE	200		
15		NAE	100		
16		NAE	100		
17	††	ME-E	800	350	
18		NAE	100		
19		NAE-ME	200	450	
20	a	NAE-ME	250	350	
	b	NAE	100		
	c	NAE	200		
21	a	NAE	200		
	b	NAE	200		
22		NAE	500		
23		NAE	300		
24	a	NAE	150		P
	b	NAE	150		
25	a	NAE	150		
	b	NAE	100		
		32-NAE	6050 ft stable		
		24-ME or E	11050 ft eroding		
			17100 ft total		

Table B1. (Cont'd).

* Range in the degree of erosion from 1977 to 1980.

† Distances not given for sites or reaches that show no apparent erosion (NAE).

** R: Revegetating (no evidence of erosion; bank appeared stable and vegetation was partially established).

P: Protected (since previous survey, bank protection was built or under construction).

NR: Not revisited: 1) Too far from the navigation channel to be affected by ship-induced effects.
2) Boat inoperative; no access.
3) Bank appeared stable during previous survey.

†† Profile and scarp data for this reach is reported in Alger (1977, 1978, 1979), Wuebben et al. (1978) or Wuebben (in press).

Table B2. Summary of the range in erosion observed along the reaches at each site, St. Clair River.

Site number	Number of reaches	23 May '77 to 18 Oct '77	18 Oct '77 to 20 May '78	20 May '78 to 30, 31 Oct '78	30, 31 Oct '78 to 19 May '79	19 May '79 to 4 Oct '79	4 Oct '79 to 29 May '80	Remarks
1	7	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME; P	NAE-ME; P	NPS; VLB
2	4	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE	NAE	NPS
3	2	NAE-ME	NAE-ME	NAE-ME; P	NAE-ME; R	NAE-ME; R	NAE-ME	3BP and S at 3a
4	2	NAE	NAE	NAE-ME	NAE-ME	NAE	NAE-ME	1BP at 4b
5	2	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME; P	3BP at 5a
6	1	NAE	NAE	NAE	NAE	NAE	ME	NPS
7	3	NAE-ME	NAE-ME	NAE-ME; P	NAE-ME; P	NAE-ME	NAE-ME; P	3BP at 7b
8	2	NAE	NAE	NAE; P	NAE; R	NAE; R	NAE	NPS; VLB
9	4	NAE	NAE	NAE; P	NAE	NAE	NAE-ME	NPS; VLB
10	3	NAE	NAE	NAE; P	NAE	NAE	NAE-ME	NPS; VLB
11	4	NAE-E	NAE-E	NAE-E	NAE-E	NAE-E	NAE-E	4BP and S at 11b
12	2	NAE	NAE-ME; P	NAE	NAE-ME	NAE-ME	NAE; P	1BP at 12b
13	3	NAE	NAE	NAE	NAE	NAE	NAE	NPS; VLB
14	1	NAE	NAE	NAE	NAE	NAE	NAE	NPS; VLB
15	1	NAE	NAE	NAE	NAE	NAE	NAE	NPS; VLB
16	1	NAE	NAE	NAE	NAE	NAE	NAE	NPS; VLB
17	1	ME	ME	ME	ME	ME	E	3BP and S
18	1	NAE	NAE	NAE	NAE	NAE	NAE	NPS; VLB
19	1	NAE	NAE	NAE	NAE	NAE	ME	NPS; VLB
20	3	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NPS; VLB
21	2	NAE	NAE	NAE	NR3	NR3	NAE	NPS; VLB
22	1	NAE	NAE	NAE	NR3	NR3	NAE	NPS; VLB
23	1	NAE	NAE	NAE	NR3	NR3	NAE; P	NPS; VLB
24	2	NAE	NAE	NAE; P	NR3	NR3	NAE	NPS; VLB
25	2	NAE	NAE	NAE	NR3	NR3	NAE	NPS; VLB

NAE: No apparent erosion (no fresh slide surfaces or slumps; no additional fallen trees or grass clumps).
ME: Minor erosion (isolated or scattered slide surfaces, slumps, fallen trees or clumps).
E: Eroding (many fresh slide surfaces along most of the reach).
R: Revegetating (no evidence of erosion; bank appeared stable and vegetation was partially established).
P: Protected (since previous survey, bank protection was built or under construction).
NR: Not revisited: 1) Too far from the navigation channel to be affected by ship-induced effects.
2) Boat inoperative; no access.
3) Bank appeared stable during previous survey.
NPS: No profiles or scarp survey.
VLB: Very low or indistinct bank.
BP: Number of bank profiles.
S: Scarp survey.

Table B3. Bank recession before and after winter navigation began, St. Clair River.

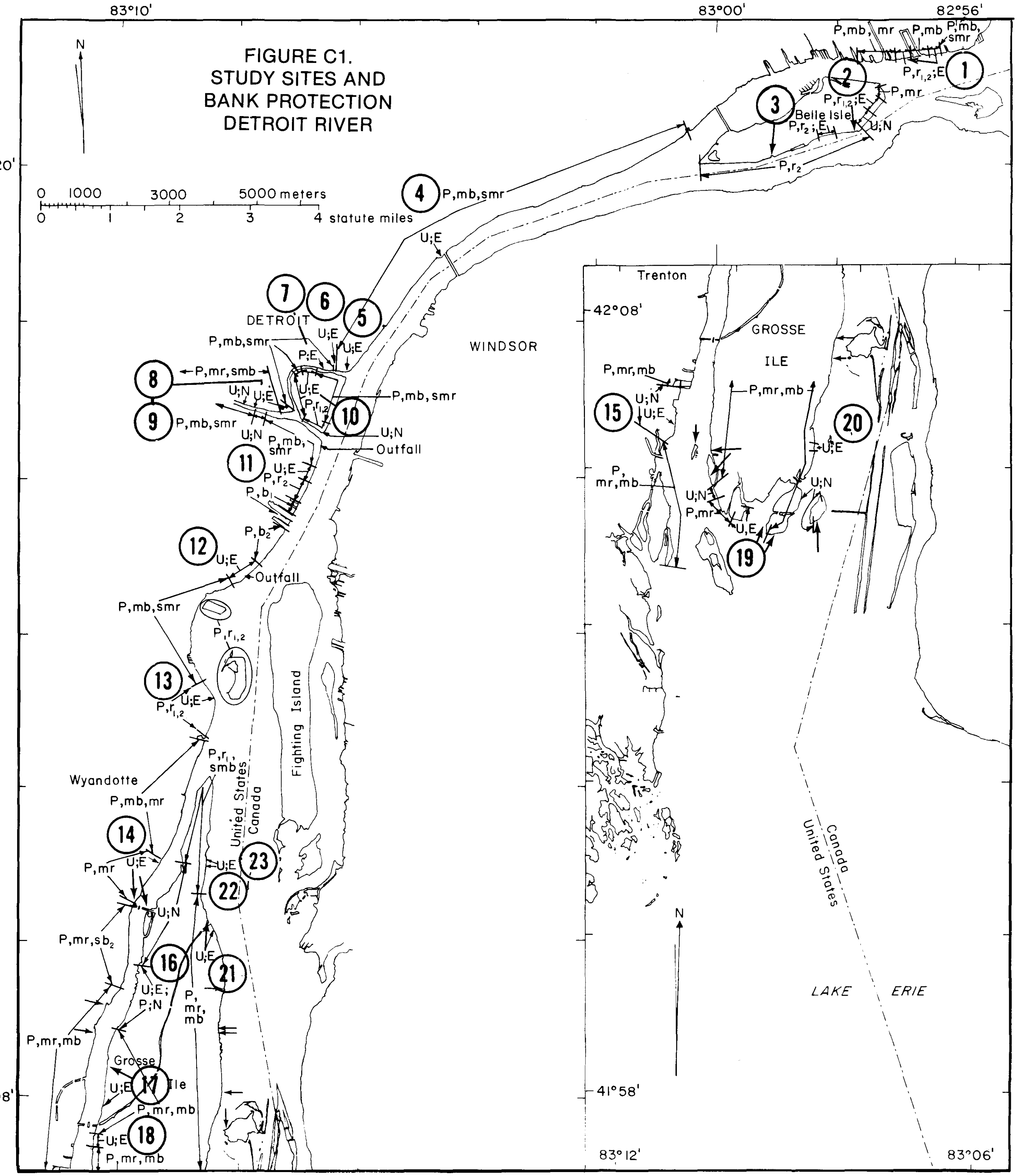
Site and reach	*Distance from reference points to top of bank (ft)*			*Change in distance (ft)**		*Total recession (36.2 yrs)*	*Reference point*
	Aug 1941	*May 1970*	*Oct 1977*	*1941–70*	*1970–77*		
3a	543	512	476	-31	-36	67	Chrysler Plant sign
4b	115	84	76†	-31	<10†	31-<41	Road
5a	72	51	32	-21	-19	40	Road
11b	535	500	478	-35	-22	57	Road
12b	173	50	34	-123	-16	139	Road
17	176	117	106	-59	-11	70	Road
20a	805	733	727	-72	<10	72-<82	NSR**

* MMD for 1941-1970 is 15 ft; MMD for 1970-1977 is 10 ft.

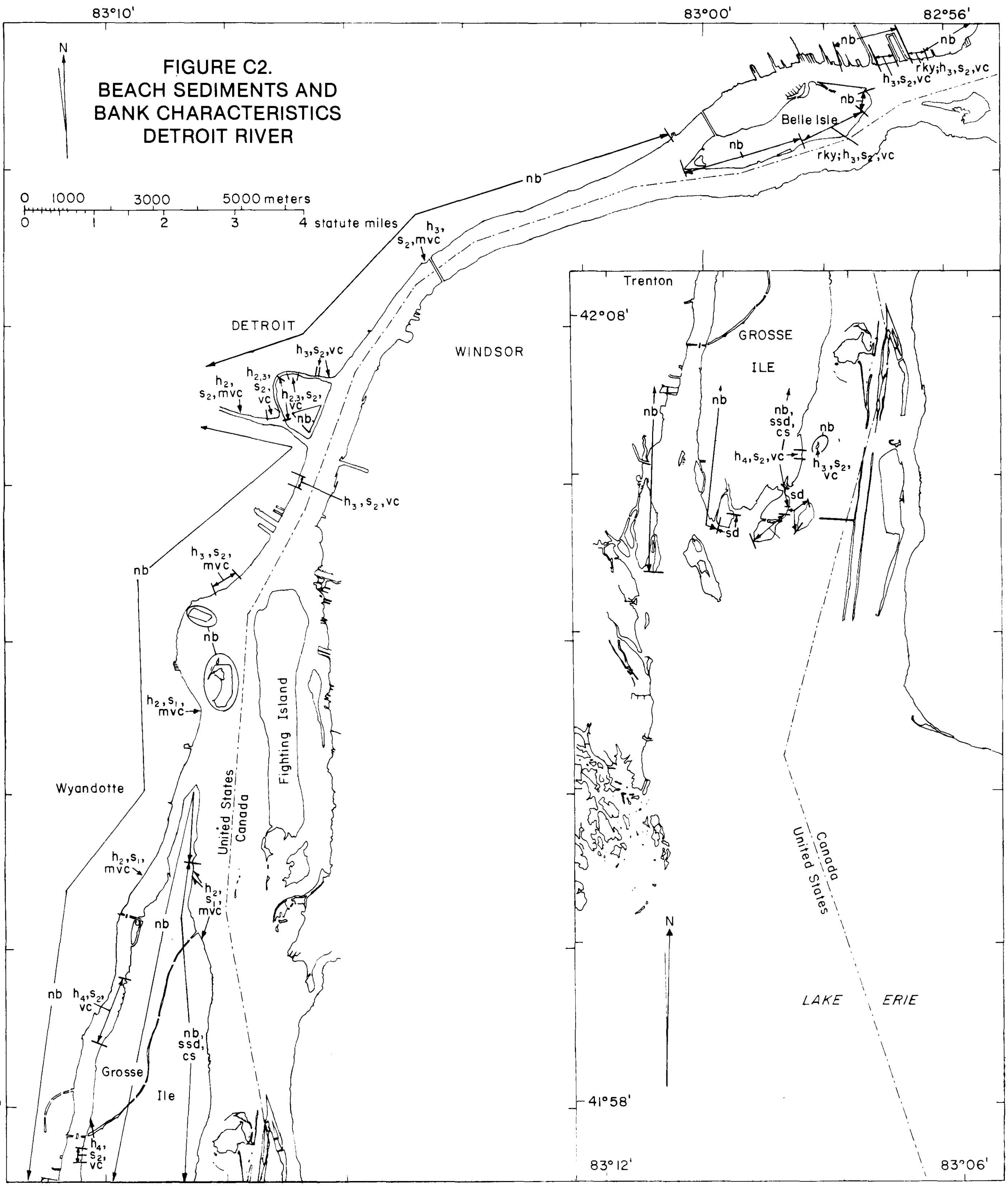
† Based on May 1978 photograph (site missed on 1977 photography).

** NSR: No stable reference (no stable reference point nearby; the measurement was made from the intersection of lines drawn from the nearest stable reference points).

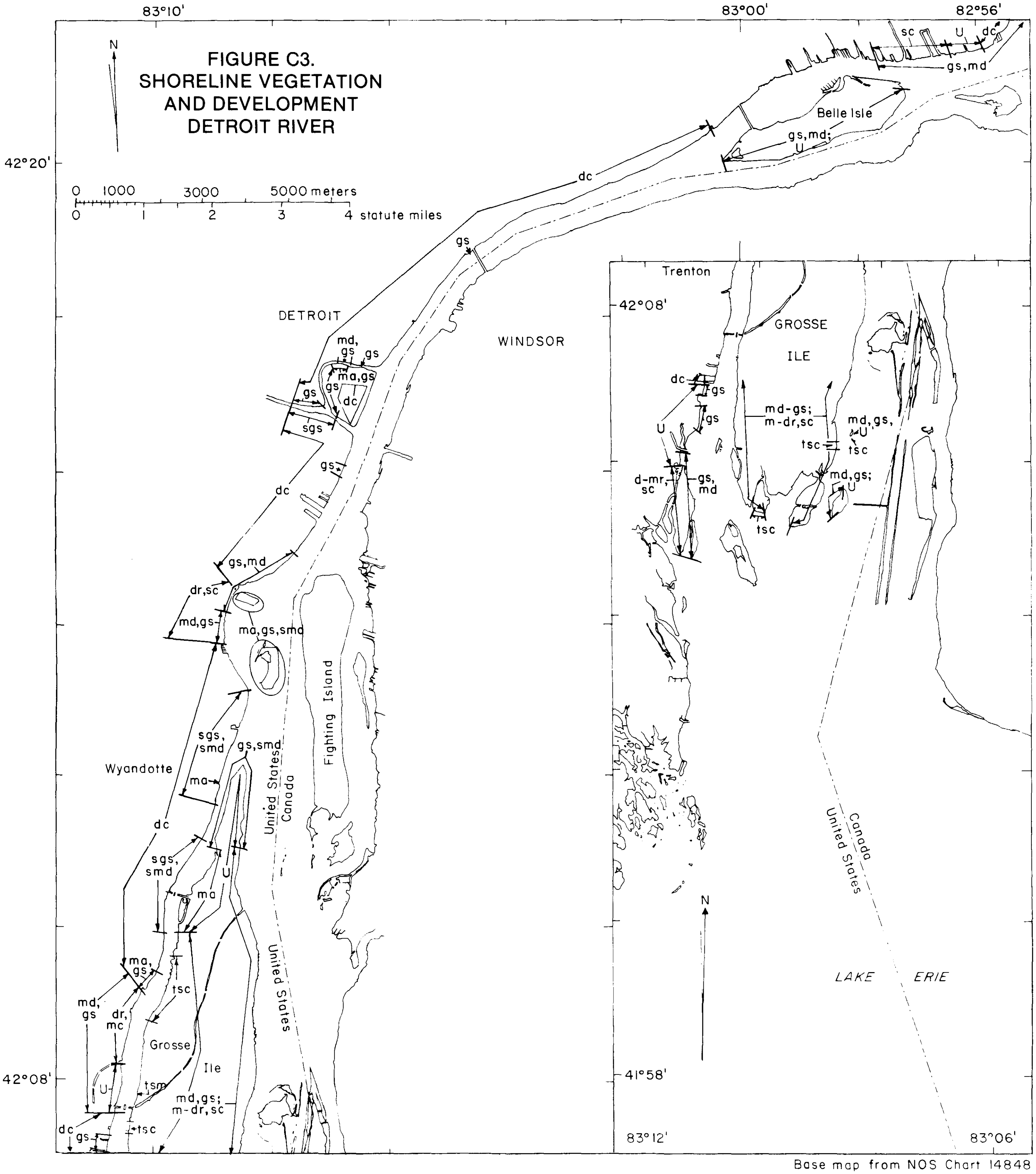
APPENDIX C: DETROIT RIVER. The maps show the shoreline conditions and bank characteristics as observed on 23, 24 May 1977. Refer to the legend in Appendix A for explanations of map symbols.



Base map from NOS Chart 14848



Base map from NOS Chart 14848



Base map from NOS Chart 14848

Table C1. Erosion and approximate lengths of partially vegetated or bare banks, Detroit River.

Site	*Reach*	*Degrees of erosion**	*Approximate length (ft)*	*Approximate distance to navigation channel (ft)†*	*Remarks***
1	a††	NAE	200		P, NR_3
	b	NAE	1100		NR_3
2	a††	NAE-ME	300	300	
	b††	NAE	300		R
3	a	NAE	100		
	b	NAE	50		
	c	NAE	50		
4		NAE	200		NR_3
5		ME	50	***	NR_4
6		ME	150	***	NR_4
7		ME	50	***	NR_4
8		NAE-ME	1000	***	NR_4
9		NAE-ME	50	***	NR_4
10		ME	3800	***	NR_4
11		NAE	3000		NR_3
12		NAE	1400		NR_3
13		NAE	100		NR_3
14	a	NAE	50		
	b	NAE	100		
	c	NAE-ME	200	500	
15		NAE-ME	2000	***	
16	a	NAE-ME	800	450	
	b	NAE-ME	50	450	
	c	NAE-ME	50	450	
	d	NAE-ME	1000	450	
	e	NAE-ME	300	450	
	f††	NAE-ME	400	1100	
	g	NAE-ME	100	800	
17	a	NAE-ME	600	350	
	b	NAE-ME	800	450	
18	††	NAE-ME	1000	150	P
19	a	NAE-E	2500	***	
	b	NAE-ME	800	***	VLB
	c	NAE-ME	800	***	P
	d	NAE-ME	1100	***	VLB
	e	NAE-ME	2000	***	
	f	NAE-ME	2000	***	VLB
	g	NAE-ME	3000	***	
20	a	NAE-ME	700	***	
	b	NAE-ME	1500	***	P
21	a	NAE-ME	300	***	
	b	NAE-ME	1000	***	
	c	NAE-ME	100	***	
	d	NAE-ME	600	***	
	e	NAE	50		
	f	NAE	50		
	g	NAE-ME	100	1750	VLB
	h	NAE	150		P
	i	NAE	150		
22		NAE-ME	200	1850	
23		NAE-ME	100	1850	P
		16-NAE 35-ME or E	7050 ft stable 29500 ft eroding 36550 ft total		

Table C1. (Cont'd).

* Range in the degree of erosion from 1977 to 1980.

† Distances not given for sites or reaches that show no apparent erosion (NAE).

** R: Revegetating (no evidence of erosion; bank appeared stable and vegetation was partially established).

P: Protected (since previous survey, bank protection was built or under construction).

NR: Not revisited: 1) Too far from the navigation channel to be affected by ship-induced effects.
2) Boat inoperative; no access.
3) Bank appeared stable during previous survey.

VLB: Very low or indistinct bank.

††Profile and scarp data for this reach is reported in Alger (1977, 1978, 1979), Wuebben et al. (1978) or Wuebben (in press).

*** Not bordering the navigation channel.

Table C2. Summary of the range in erosion observed along the reaches at each site, Detroit River.

Site number	*Number of reaches*	*23, 24 May '77 to 17, 19 Oct '77*	*17, 19 Oct '77 to 21 May '78*	*21 May '78 to 30 Oct '78*	*30 Oct '78 to 20 May '79*	*20 May '79 to 3 Oct '79*	*3 Oct '79 to 30 May '80*	*Remarks*
1	2	NAE	NAE; P	NAE; P	NAE	NAE	NR3	1BP at 1a; VLB
2	2	NAE; R	NAE; R	NAE; R	NAE; R	NAE; R	NAE-ME	3BP and S at 2a; VLB 3BP and S at 2b; VLB
3	3	NAE	NAE	NAE	NAE	NAE	NAE	NPS; VLB
4	1	NAE	NAE	NAE	NAE	NAE	NR3	NPS
5	1	NR4	-	-	-	-	-	NPS
6	1	NR4	-	-	-	-	-	NPS
7	1	NR4	-	-	-	-	-	NPS
8	1	NR4	-	-	-	-	-	NPS; VLB
9	1	NR4	-	-	-	-	-	NPS; VLB
10	1	NR4	-	-	-	-	-	NPS
11	1	NAE	NAE	NAE	NAE	NAE	NR3	NPS
12	1	NAE	NAE	NAE	NAE	NAE	NR3	NPS
13	1	NAE	NAE	NAE	NAE	NAE	NR3	NPS; VLB
14	3	NAE	NAE	NAE	NAE	NAE-ME	NAE-ME	NPS
15	1	NAE-ME	NR4	-	-	-	ME	NPS
16	7	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME	S at 16a 2BP and S at 16f
17	2	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NPS
18	1	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME; P	NAE-ME; P	1BP
19	7	NAE-ME	NR4	-	-	NAE-E; P	NAE-E; P	NPS; some VLB
20	2	NAE-ME	NR4	-	-	-	NAE-ME; P	NPS
21	9	NAE-ME; NR4	NAE-ME; NR4	NAE-ME; NR4	NAE-ME; NR4	NAE-ME; NR4	NAE-ME; P	NPS; some VLB
22	1	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE	NPS
23	1	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE-ME	NAE; P	NPS

NAE: No apparent erosion (no fresh slide surfaces or slumps; no additional fallen trees or grass clumps).
ME: Minor erosion (isolated or scattered slide surfaces, slumps, fallen trees or clumps).
E: Eroding (many fresh slide surfaces along most of the reach).
R: Revegetating (no evidence of erosion; bank appeared stable and vegetation was partially established).
P: Protected (since previous survey, bank protection was built or under construction).
NR: Not revisited: 1) Too far from the navigation channel to be affected by ship-induced effects.
2) Boat inoperative; no access.
3) Bank appeared stable during previous survey.
4) Not along main navigation channel.

NPS: No profiles or scarp survey.
VLB: Very low or indistinct bank.
BP: Number of bank profiles.
S: Scarp survey.

Table C3. Bank recession before and after winter navigation began, Detroit River.

Site and reach	*Distance from reference points to top of bank (ft)*			*Change in distance (ft)**		*Total recession*	*Reference*
	July, Sept 1937	*Apr 1970*	*Oct 1977*	*1937–70*	*1970–77*	*(39.8 yrs)*	*point*
1a	615	800	800	Filled-in	<10	<10	Road
2a	73	66	61	<15	<10	<25	Road
2b	116	110	102	<15	<10	<25	Road
16a	58	41	31	-17	-10	27	Road
16f	348	379	373	Filled-in	<10	<10	NSR†
18	57	37	31	-26	<10	26-<36	Road
23	357	354	332	-21	-22	43	Road

* MMD for 1937–1970 is 15 ft; MMD for 1970-77 is 10 ft.

† NSR: No stable reference (no stable reference points nearby; the measurement was made from the intersection of lines drawn from the nearest stable reference points).

APPENDIX D: ST. LAWRENCE RIVER. The maps of bank characteristics, beach sediment, shoreline vegetation, bank protection and shoreline development were not prepared since much of this information is already available in the St. Lawrence-Eastern Ontario Commission (1977a) report.

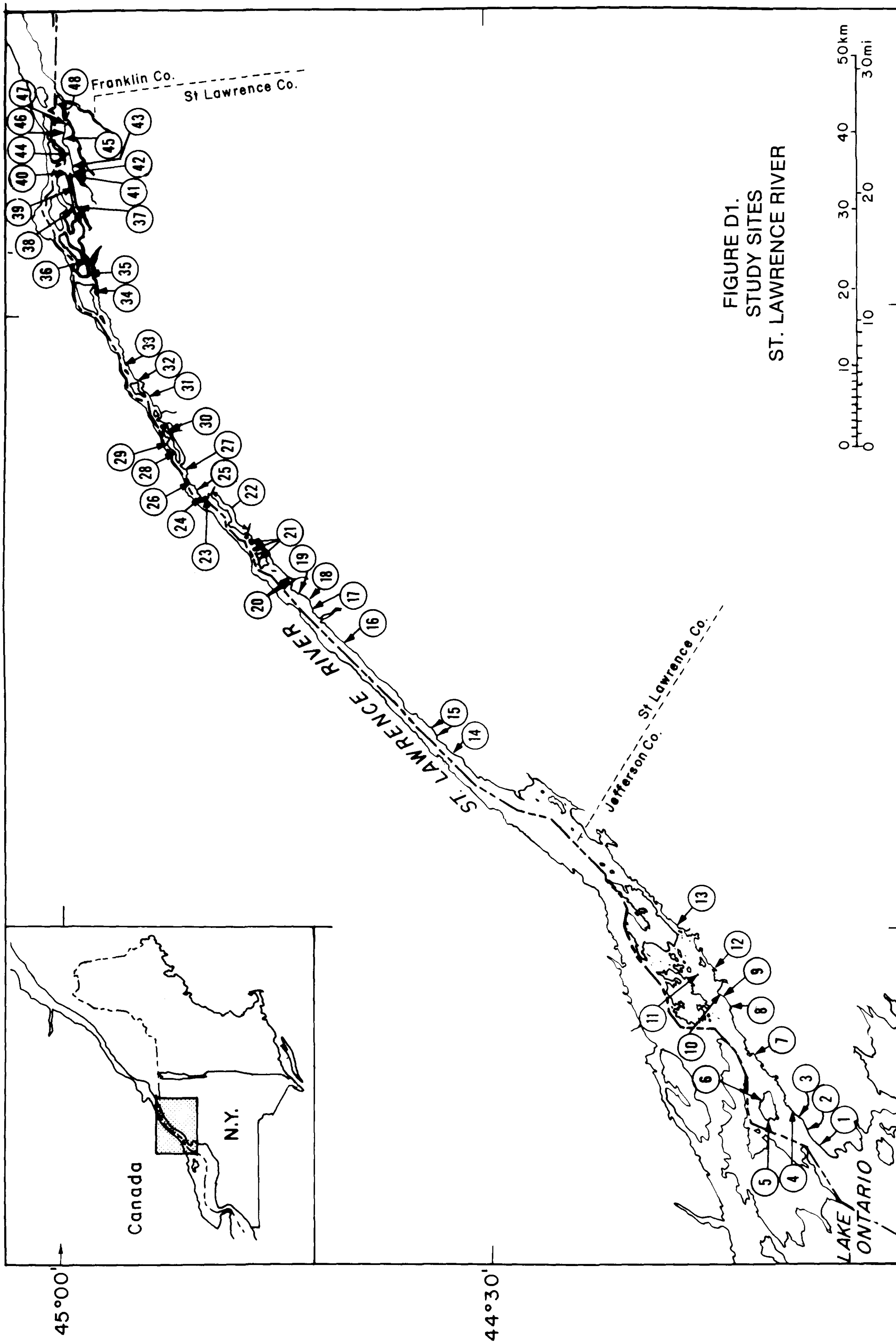


FIGURE D1.
STUDY SITES
ST. LAWRENCE RIVER

Table D1. Erosion and approximate lengths of partially vegetated or bare banks, St. Lawrence River.

Site	*Reach*	*Degree of erosion**	*Approximate length (ft)*	*Approximate distance to navigation channel (ft)†*	*Remarks***
1		NAE	200		
2		NAE	150		
3		NAE	500		
4		NAE	600		
5		NAE	1000		
6	a	NAE	100		
	b	NAE	100		
	c	NAE	100		
	d	NAE-ME	600	3000	
	e	NAE-ME	200	>3000	
	f	NAE-ME	300	>3000	
	g	NAE	300		
	h	NAE-ME	200	>3000	
	i	NAE-ME	150	>3000	
	j	NAE-ME	100	>3000	
7	a	NAE	400		
	b	NAE	300		
	c	NAE	300		
	d	NAE	50		
	e	NAE	50		
	f	NAE	1000		
8		NAE	500		
9	a	NAE	50		
	b	NAE	50		
	c	NAE	100		
	d	NAE	100		
10		NAE	100		
11		NAE	400		
12		NAE-ME	300	2700	
13	a	NAE	100		
	b	NAE	200		
14		NAE	50		
15	a	NAE	100		
	b	NAE	300		
	c	NAE	100		
16	a	NAE	200		
	b	NAE	400		
	c	NAE	50		
	d	NAE	50		
17	a	NAE	100		
	b	NAE	200		
18		NAE	500		
19		NAE	150		R
20	a††	NAE	300		
	b	NAE-ME	50	3200	
	c	NAE-ME	300	>3200	
	d	NAE-ME	50	>3200	
	e	NAE-ME	100	>3200	
	f	NAE-ME	100	>3200	
21	a	NAE-ME	100	250	
	b	NAE-ME	100	100	
	c	NAE-ME	300	100	
	d	NAE	150		R
	e	NAE	100		R
22		ME-E	20000	200-4000	
23	a	ME	800	***	
	b	ME	50	***	
	c	ME	50	***	

Table D1. (Cont'd).

Site	*Reach*	*Degree of erosion**	*Approximate length (ft)*	*Approximate distance to navigation channel (ft)†*	*Remarks***
24		NAE-ME	400	1950	
25	a	NAE-ME	100	2000	
	b	NAE-ME	800	2050	
	c	NAE-ME	1200	2300	
26	††	ME	2400	1550	
27	a	NAE-ME	300	***	
	b	NAE-ME	1000	***	
28		NAE-ME	500	1400	
29	a	NAE-ME	700	450	
	b	NAE	100		
30		NAE	500		
31	a	NAE-ME	200	3350	
	b††	NAE-ME	500	3550	
	c	NAE-ME	400	4950	
32		NAE	300		
33	a	NAE	100		
	b	NAE	100		
	c	NAE-ME	200	1650	
	d	NAE	200		
34	a	ME	400	350	
	b	ME	400	350	
	c	ME	300	350	
35	a	NAE-ME	150	200	
	b	NAE-ME	150	250	
	c	NAE-ME	400	250	
36	a	NAE-ME	100	100	
	b	NAE-ME	100	150	
	c	NAE	100		
	d	NAE-ME	600	150	
37	a	NAE-ME	400	100-350	
	b	NAE-ME	100	80	
38	††	NAE-ME	600	90-250	
39	a	NAE	100		
	b	NAE	100		
40		NAE	100		R
41		ME	500	70	
42		ME	800	170	
43	a	NAE	50		
	b	NAE	300		R
	c	NAE	50		
44	a	NAE-ME	50	500	
	b	NAE-ME	50	650	
	c	ME	100	350	
	d	NAE-ME	100	200	
	e	NAE-ME	300	350	
	f	NAE-ME	50	450	
	g	NAE	100		
	h	NAE	700		
45	a	NAE-ME	100	100	
	b	NAE-ME	600	250-650	
	c	NAE-ME	200	1000	
46	a	NAE	50	2000	
	b	NAE-ME	100	2400	
	c	NAE-ME	50	2500	
47		ME	1000	2000-3000	
48		NAE-ME	5000	1350-4200	
		55-NAE	12450 ft stable		
		59-ME or E	45250 ft eroding		
			57700 ft total		

Table D1. (Cont'd).

* Range in the degree of erosion from 1977 to 1980.

† Distances not given for sites or reaches that show no apparent erosion (NAE).

** R: Revegetating (no evidence of erosion; bank appeared stable and vegetation was partially established).

P: Protected (since previous survey, bank protection was built or under construction).

NR: Not revisited: 1) Too far from the navigation channel to be affected by ship-induced effects.

2) Boat inoperative; no access.

3) Bank appeared stable during previous survey.

†† Profile and scarp data for this reach is reported in Alger (1977, 1978, 1979), Wuebben et al. (1978) or Wuebben (in press).

*** Not bordering the navigation channel.

Table D2. Summary of the range in erosion observed along the reaches at each site, St. Lawrence River.

Site number	*Number of reaches*	*16, 17 Nov '77 to 16–18 May '78*	*16–18 May '78 to 27–29 Oct '78*	*27–29 Oct '78 to 1, 2 Oct '79**	*Remarks*
1	1	NAE	NR_3	-	NPS
2	1	NAE	$NR_{1,3}$	-	NPS
3	1	NAE	$NR_{1,3}$	-	NPS
4	1	NAE	$NR_{1,3}$	-	NPS
5	1	NAE	NAE	NR_3	NPS
6	10	NAE–ME	NAE–ME	NR_5	NPS
7	6	NAE	NAE	$NR_{3,4}$	NPS
8	1	NAE	NAE	NR_3	NPS
9	4	NAE	NAE	NR_3	NPS
10	1	NAE	NAE	NR_3	NPS
11	1	NAE	NAE	NR_3	NPS
12	1	NAE–ME	NAE–ME	$NR_{1,4}$	NPS
13	2	NAE	NAE	NR_3	NPS
14	1	NAE	NAE	$NR_{1,4}$	NPS
15	3	NAE	NAE	$NR_{1,4}$	NPS; VLB
16	4	NAE	NAE	NR_3	NPS
17	2	NAE	NAE	NR_3	NPS
18	1	NAE	NAE	NR_3	NPS
19	1	NAE; R	NAE; R	NR_3	NPS
20	6	NAE–ME	NAE–ME	NAE–ME	3BP+S at 20a; VLB at 20a
21	5	NAE–ME; R	NAE–ME; R	NAE–ME; R	NPS
22	1	ME–E	ME–E	ME–E	NPS
23	3	ME	ME	ME	NPS
24	1	NAE–ME	NAE–ME	NAE–ME	NPS
25	3	NAE–ME	NAE–ME	NAE–ME	NPS
26	1	ME	ME	ME	3BP+S
27	2	NAE–ME	NAE–ME	NAE–ME	NPS
28	1	NAE–ME	NAE–ME	NAE–ME	NPS
29	2	NAE–ME	NAE–ME	NAE–ME	NPS
30	1	NAE	NR_1	$NR_{1,4}$	NPS
31	3	NAE–ME	NAE–ME	NAE–ME	3BP at 31b; VLB at 31b
32	1	NAE	NAE	NR_6	NPS; VLB
33	4	NAE–ME	NAE–ME	NR_6	NPS; VLB
34	3	ME	ME	NR_6	NPS
35	3	NAE–ME	NAE–ME	NR_6	NPS
36	4	NAE–ME	NAE–ME	NR_6	NPS
37	2	NAE–ME	NAE–ME	NAE–ME	NPS; VLB
38	1	NAE–ME	NAE–ME	NAE–ME	3BP+S
39	2	NAE	NAE	NAE	NPS; VLB
40	1	NAE	R	R	NPS
41	1	ME	ME	ME	NPS
42	1	ME	ME	ME	NPS
43	3	NAE	NAE; R	NAE; R	NPS
44	8	NAE–ME	NAE–ME	NAE–ME	NPS
45	3	NAE–ME	NAE–ME	NAE–ME	NPS
46	3	NAE–ME	NAE–ME	NAE–ME	NPS
47	1	ME	ME	ME	NPS
48	1	NAE–ME	NAE–ME	NAE–ME	NPS

* No May 1979 survey.

NAE: No apparent erosion (no fresh slide surfaces or slumps; no additional fallen trees or grass clumps).

ME: Minor erosion (isolated or scattered slide surfaces, slumps, fallen trees or clumps).

E: Eroding (many fresh slide surfaces along most of the reach).

R: Revegetating (no evidence of erosion; bank appeared stable and vegetation was partially established).

NR: Not revisited: 1) Too far from the navigation channel to be affected by ship-induced effects.
2) Boat inoperative; no access.
3) Bank appeared stable during previous survey.
4) Not along main navigation channel.

Table D2. (Cont'd).

5) Shore recession no threat to roads or buildings.
6) Too foggy to navigate safely.

NPS: No profiles or scarp survey.
VLB: Very low or indistinct bank.
BP: Number of bank profiles.
S: Scarp survey.

Table D3. Historical bank recession, St. Lawrence River.

Site and reach	*Distance from reference points to top of bank (ft)* May, June 1959	*May 1960*	*May, June 1962*	*July, Aug 1966*	*Apr 1968*	*Oct 1977*	*May 1978*	*Change in distances (ft)** 1959-66	*1960-68*	*1962-68*	*1966-77*	*1968-77*	*1968-78*	*Total recession*	*Reference point*
5	690	-	-	688	-	691	-	<14	-	-	< 9	-	-	<23	NSR†
6f	433	-	-	430	-	432	-	<14	-	-	< 9	-	-	<23	NSR
12	277	-	-	277	-	280	-	<14	-	-	< 9	-	-	<23	Road
20a	-	1125	-	-	1132	1125	-	-	<15	-	-	<10	-	<25	Sidewalk
22	-	131	-	-	119	108	-	-	<15	-	-	-11	-	11-<26	Building
	-	257	-	-	250	240	-	-	<15	-	-	-10	-	10-<25	Building
	-	178	-	-	161	158	-	-	-17	-	-	<10	-	17-<27	Building
26	-	445	-	-	445	420	-	-	<15	-	-	-25	-	25-<40	Tree
31b	-	-	180	-	169	116	-	-	-	<15	-	-53	-	53-<68	Tree
38	-	-	462	-	-	454	424	-	-	<15	-	-	-30	30-<45	Road
42	-	-	444	-	456	-	460	-	-	<15	-	-	<10	<25	Road
48	-	-	803	-	-	790	744	-	-	<15	-	-	-46	46-<61	NSR

* MMD for the following intervals are: 1959-1966, 14 ft; 1960-1968, 15 ft; 1962-1968, 15 ft; 1966-1977, 9 ft; 1968-1977, 10 ft; 1968-1978, 10 ft.

† NSR: No stable reference (no stable reference points nearby; the measurement was made from the intersection of lines drawn from the nearest stable reference points).