CHANGES TO FISH HABITAT OF THE ST. MARYS RIVER: A RETROSPECTIVE ANALYSIS

A Thesis Submitted to the Committee on Graduate Studies

in Partial Fulfilment of the Requirements for the

Degree of Master of Science

in the Faculty of Arts and Science

TRENT UNIVERSITY

Peterborough, Ontario, Canada

Watershed Ecosystems M.Sc. Programme

June, 1993

Abstract

Changes to physical attributes of fish habitat in the St. Marys River are examined historically in relation to anthropogenic influences. Two types of habitat: the St. Marys Rapids and zones of aquatic vegetation are examined for changes in area and habitat suitability over time using the Instream Flow Incremental Methodology for rainbow trout and *Hydropsyche sp.* in the rapids and the Habitat Suitability Index model for northern pike in the aquatic vegetation. Evidence suggests that vegetation-based habitat has been lost because of structural changes in localised areas where physical stresses have been concentrated. More extensive losses in rapids habitat occurred. However, increased variations in habitat suitability in the rapids because of human influence are affecting habitat in the river. Habitat change is probably not the sole cause of reported fish community changes. Substantial natural change has occurred because of, for example, fluctuations in water levels. Human engineered changes in physical habitat would be difficult to reverse because of their magnitude and cultural importance. Fisheries management should therefore focus on enhancement of remaining habitat.

Acknowledgements

For their help, guidance, endurance, patience, and support in the preparation and completion of this thesis, I owe many people my gratitude, sincere thanks, and appreciation, especially:

To Dr. Tom Whillans, my supervisor and the reason I came to Trent, who took me on without knowing anything about me or my propensity for procrastination, for supporting me through a GLURF Research Grant, and for coming all the way from Ecuador to force me to defend.

To Dr. John Kelso who started this whole thing way back when in a boat probably somewhere on Thunder Bay, for funding me and allowing free access to the SSM office, and for believing in me all along.

To Dr. Ron Hall who was unfailingly encouraging and supportive and was the only one who didn't leave for the southern hemisphere before I finished.

To the staff at the GLLFAS, particularly Margo and Robert (and Caitlin) for their generosity, hospitality, and friendship, and to Marla for enduring endless questions and carrying out countless favours with characteristic good humour.

To the friends I made at Trent who made it all worthwhile: Marjorie, Dorothy, Vito, Cynthia & Alan, Frank, Doran Doran, and Temagami Man. Thanks to John too for all the love and healing.

Special thanks to Kathie whose warmth and friendship I have been lucky enough to experience, who helped keep the home fires (and home brews) at the Hotel Gillespie (and the Bolivar B&B) burning brightly, and who encouraged me to believe everything would turn out for the best in our uncannily similar but messed up lives. I had the time of my life, but I hope history really doesn't repeat itself.

Wish you were here, Dad.

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CHAPTER I

Introduction

1.0. Purpose

This thesis addresses changes in fish habitat of the St. Marys River (Ontario and Michigan) over the past two centuries. The purpose is fourfold:

a) to identify historical and current anthropogenic influences on fish habitat, including the nature and extent of habitat change;

b) to assess the implications of habitat change to the fish community;

c) to contribute to the growing set of comparable case studies on long-term ecosystem change, and

d) to provide a basis for rehabilitative plans and a baseline against which future changes in the St. Marys River can be measured.

Fish habitat is defined as the physical, chemical, and biological components of the areas upon which fish depend for their existence (Fisheries Act, R.S.C., 1985; Great Lakes Fishery Commission, 1987). This thesis focuses predominantly on changes to structural habitat and aquatic vegetation.

1.1. Background and Rationale

As the connecting channel between Lakes Superior and Huron, the St. Marys River is the first link in the Great Lakes chain (Figure 1.1). The St. Marys was and still is an important ecological corridor between the two upper lakes, providing a

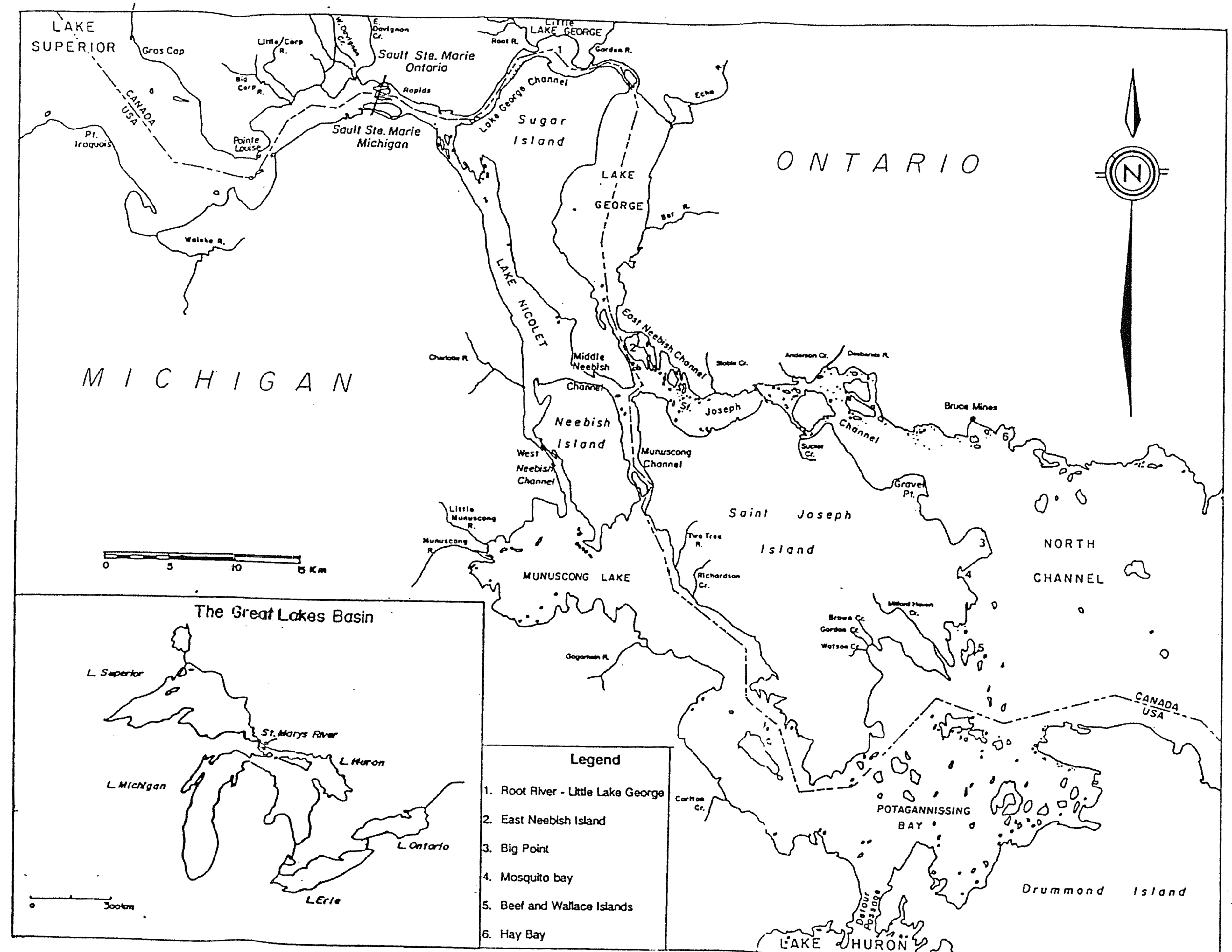


Figure 1.1. Map of the St. Marys River.

range of habitats for fish and wildlife. The river has also played an important role in the human history of the Great Lakes basin as a strategic waterway, power source, local water supply, and significant food source.

From the 1880's to the 1950's, the St. Marys River, particularly the Sault Ste. Marie area, experienced great growth in industry and population as commerce on the Great Lakes grew. Navigation and local industrial interests reshaped the rapids at the head of the St. Marys River through the construction of power canals, locks, and regulatory gates for controlling water levels and flows. Downriver, shipping lanes were dredged, drilled, and blasted to accommodate vessels of increasing draft, the spoil often disposed of in the river.

Development of the St. Marys River area led to degradation of water quality, one of the first concerns addressed by the newly formed International Joint Commission (IJC) in 1912. Bacterial pollution from passing vessels and untreated municipal sewage discharged directly into the river were blamed for the high incidence of deaths from typhoid fever (IJC, 1914). Water quality remained a concern as the nature of contamination expanded to include industrial chemical wastes in mid-century (IJC, 1951).

By 1972, the Great Lakes Water Quality Agreement (GLWQA) between Canada and the U.S. mandated the restoration and maintenance of the "chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem" (IJC, 1978, p.4). Certain areas, termed "Areas of Concern" (AOC), where water quality chronically did not meet GLWQA objectives, were later targeted by the IJC's

Great Lakes Water Quality Board for restoration of impaired 'beneficial uses'. Currently, there are 43 AOC's in the Great Lakes basin, most of which are harbours, river mouths, embayments, or connecting channels (Hartig et al., 1990), such as the St. Marys River.

Designation as an AOC obliges the governments of Canada/Ontario and the U.S./Michigan to ensure the preparation of a Remedial Action Plan (RAP) for the St. Marys River. A RAP is prepared in three stages:

I - describes environmental conditions of the AOC, identifies and demarcates the extent of impaired beneficial uses, and defines causes of the impairment;

II - identifies remedial measures, a schedule for their implementation, and the agencies responsible; and

III - describes procedures for monitoring and evaluating remedial measures once beneficial uses have been restored (OMNR/MDNR, 1991).

The Stage I document of the St. Marys River RAP has been prepared, but has yet to be accepted by the IJC; Stage II is in preparation.

The Stage I document of the St. Marys River RAP makes passing mention of losses to fish and wildlife habitat in the river, but does not clearly identify this as one of the impaired 'beneficial uses'. Although the RAP and others (e.g. Krishka, 1989; Kauss, 1991) generally assume that losses have occurred, little information exists on structural or biological habitat change in the St. Marys River other than in a broad, qualitative sense. Instead, the RAP document concentrates on chemical contamination as the reason for listing the St. Marys as an Area of Concern, devoting much effort to describing sources and composition of pollutants and water quality standards and legislation. The heavy emphasis on water quality issues in the RAP process has been criticised as too limiting for effective restoration of ecological integrity originally prescribed by the GLWQA (Hartig et al., 1990).

Past fisheries management strategies in the Great Lakes basin have also been limited in scope by concentrating predominantly on manipulating and predicting commercially important fish stocks. Managers relied on controlling mesh sizes, fishing seasons, and quotas, and on artificial propagation (Regier and Applegate, 1972). In recent decades, however, a shift towards ecosystem rather than single resource management has prompted recognition of the value of managing and protecting aquatic habitat *per se* as part of a healthy and functioning ecosystem. This acknowledgement has been validated in the form of policy (Canada Dept. Fisheries & Oceans (DFO), 1986; GLFC, 1987) and legislation (Canada Fisheries Act, R.S.C. 1985).

1.1.1. Retrospective Analyses

The ecosystem approach expected of RAP's and management of the Great Lakes demands a holistic perspective. This implies not only a thorough integration of current spatial information on ecosystemic patterns, but also of historical trends, influences on them, and their role in shaping the present and future ecosystem. To determine the nature of losses to habitat, or whether losses have indeed occurred, some knowledge of conditions prior to and following any change is essential. As

Francis et al. (1979) state:

> "Restoration [as part of a rehabilitative strategy] implies some shift toward earlier conditions. The nature of those early conditions and how they were integrated within an integral, functioning ecology can be 'backcasted' from a wide variety of kinds of information. Then we wish to understand the causal mechanisms that have produced the current ecological conditions in order to inactivate the degradative causal mechanisms or to redirect them toward rehabilitative goals, or introduce new mechanisms" (pp.16-17).

Although a relatively new approach in fisheries research, retrospective analyses of fish communities or environmental conditions affecting fisheries are becoming recognised as important contributions to ecosystem management (Minshall et al., 1985; Steedman and Regier, 1987; Petts, 1990; Petts et al., 1989).

In Europe, where the historical record is much longer and the cumulative effects of human habitation have been more intense than in North America, retrospective analyses, particularly of rivers, have become important tools for structural and biological rehabilitation (Petts, 1990).

Exploitation of the natural wealth of the Great Lakes - St. Lawrence River ecosystem has been the driving force in shaping the social and economic evolution of the basin in both Canada and the U.S. and has left the region with, not only a rich history, but a legacy of ecological change. A pivotal resource in the development of the area and the subject of several retrospective analyses has been the fisheries. Much of the initiative for these retrospective analyses arose from the Symposium on Salmonid Communities of Oligotrophic Lakes (SCOL) (Loftus and Regier, 1972). Studies, such as Christie (1973), Berst and Spangler (1973), Lawrie and Rahrer (1973), Pycha and King (1975), Richards (1976), Schneider and Leach (1979), Goodier (1981, 1982), Whillans (1979, 1985), Holmes and Whillans (1984), Martin (1984), McCullough (1985), Patch and Busch (1984), Bertrand et al. (1976), Holmes (1986), and Wilson (1990, 1991) have investigated aspects of historical change of the Great Lakes fisheries. The latter four dealt with Areas of Concern and contributed to the RAP process. Similar studies have been conducted on the fisheries of Canada's boreal region (Adams, 1978) and the U.S. northwest (Sedell and Luchessa, 1981), their rarity reflecting, in part, the paucity of historical information for those regions.

The theme common to all of these studies is change as a result of anthropogenic influences. Most have focused on community or stock transformations and fluctuations in abundance using information on the physical environment as supporting or corroborative evidence. Few have focused directly on habitat as the primary measure or on large river systems, such as the Great Lakes connecting channels.

1.1.2. The St. Marys River

The impetus for choosing the St. Marys River as the study area for this research came from a Department of Fisheries and Oceans (DFO) representative on the RAP Team, who considered the historical development of the river to have been important in shaping the present fish community, and therefore, of significance to rehabilitation initiatives. The initial thrust of the project was to investigate changes in the fishery, but a preliminary reconnaissance of the information available on the

St. Marys River revealed a fragmented and often solely qualitative record of the fish community, mostly a result of the lack of commercial fishing and attendant records after the early 1900's. Commercial navigation on the St. Marys, however, has resulted in a long (for North America) record of quantitative measurements of morphometric and hydrologic parameters, such as bathymetry, discharge, and water levels, which lend themselves more readily to retrospective analyses. The river is also relatively well-documented in maps, charts, and aerial photographs.

There is little argument that historically important fish species, such as whitefish (*Coregonus spp.*), walleye (*Stizostedium vitreum vitreum*), sturgeon (*Acipenser fulvescens*), and lake trout (*Salvelinus namaycush*), are no longer as abundant as they once were in the St. Marys River (Duffy et al., 1987; Kauss, 1991). Determining causality is an often difficult task as biological communities are likely to be cumulatively affected by successive perturbations (Petts et al., 1989).

Stresses identified as having had impacts on Great Lakes fish communities include: overfishing, introduction of exotics, nutrient and toxic contaminant loading, control of water levels, construction of canals, diversion, or entrainment, and the destruction of wetland and littoral zones through shoreline alteration, infilling, dredging, and wave action of shipping traffic (Regier, 1979).

Insufficient evidence exists to support or refute suggestions that overfishing, contamination, or any other stresses are responsible for the decline or lack of recovery of fish stocks in the St. Marys River. However, the quality of water flowing into the St. Marys is still high, Lake Superior water generally being considered to be in near pristine condition (Upper Great Lakes Connecting Channel Study (UGLCCS), 1989). Sediment and water contamination from industrial and municipal pollution is localised along the upper Canadian shoreline (UGLCCS, 1989). Fishing pressure has been confined to only a few commercial licenses operating at the extreme upper and lower limits of the river, subsistence fishing by native people on both the U.S. and Canadian shores, and sport fishing, all of which appear to be both localised and of low intensity (Krishka, 1989).

Possible explanations for the continuing depression of many of the historically abundant fish in the St. Marys include: the lack of recovery of many stocks in Lakes Superior and Huron, especially lake trout and lake whitefish, the introduction of exotic species, including parasitic sea lamprey (*Petromyzon marinus*) and the highly competitive Pacific salmonids, and loss of suitable habitat.

The influence of Lake Superior and Lake Huron fish communities on stocks within the St. Marys River is difficult to ascertain because little work has been done on stock identification in the area. Also, many fish are permanent residents of the river, and therefore, should not be directly affected by environmental conditions or fishing practices in these two Great Lakes. Declines in commercially valuable fish species in the St. Marys were noted in the mid to late 1800's (Milner, 1874), well before many of the exotic salmonids and the sea lamprey were recorded in the river. Thus, fishing pressures and habitat change remain as possible factors contributing to changes in the fishery.

At first glance, the St. Marys River does not appear radically altered from a natural state except in some localised areas, in particular at Sault Ste. Marie (SSM). The effects of those structural modifications, however, may have been more extensive by impacting areas of critical habitat or "centres of organisation" (Steedman and Regier, 1987; Regier et al., 1989). These are areas which perform several key functions, such as providing spawning and nursery habitat and a rich food source, the removal of which represents a significant loss of productivity to a system. Centres of organisation serve aquatic communities at both local and regional scales.

Both the St. Marys Rapids and coastal wetlands can be considered as centres of organisation. The former represents a single, discrete area in the upper river of historically highly productive fish habitat for salmonines and has been directly affected by river modifications, while the latter include many areas occurring mostly in the mid to lower river reaches, which are of significant value for the dominant percid and esocid community, and have undergone less direct alteration. Aquatic vegetation may be affected by the control of water levels and discharge in the river as well as by waves and currents produced from passing vessels (McNabb et al., 1986; Poe and Edsall, 1982; Williams and Lyon, 1991).

1.2. Objectives

The nature and extent of physical change to the St. Marys River, because of navigational restructuring and discharge regulation, raises the question of what kind of relationship has existed between the alteration of the physical environment and changes in the fish community. This thesis addresses that relationship by integrating the historical record of quantitative changes in fish habitat with semi-quantitative and anecdotal information on the fish community. The objectives are:

a) establish a time series index of suitable habitat for two significant species in the St. Marys Rapids using principles of the Instream Flow Incremental Methodology;

b) determine areal change in aquatic vegetation potentially occupiable as fish habitat;

c) use a Habitat Suitability Index Model to test whether there has been a change in suitability of aquatic vegetation habitat for fish; and

d) evaluate some of the implications of habitat change for rehabilitation of the St. Marys River fishery.

CHAPTER II

The Study Area

This chapter provides a brief description of the physical and cultural setting of the St. Marys River. A summary of ecological characteristics can be found in Kauss (1991), Edwards et al. (1989) and Duffy, et al. (1987). This is not intended to render a full account of the area, the following works contain more detail: Bayliss and Bayliss (1955); Heath (1988); Larson (1981); MacDonald (1978); and Osborne and Swainson (1986).

2.0. Boundaries

For the purposes of this study, the St. Marys River is considered as that area stretching from a transect between Point Iroquois, Michigan, and Gros Cap, Ontario, to that between Detour Passage, Michigan, and Bruce Mines, Ontario. This includes all of Potagannissing Bay and St. Joseph's Channel (Figure 1.1).

2.1. Physical Setting

Once a strait connecting Lakes Superior and Huron, the St. Marys became a river when crustal uplift of a sandstone ledge at Sault Ste. Marie elevated the head of the river above Lake Huron (Duffy et al., 1987). As with other connecting channels of the Great Lakes, the St. Marys has few tributary streams and a large headwater of high water quality (Edwards et al., 1989).

From Whitefish Bay, the river narrows quickly to form the St. Marys Rapids between the two cities of Sault Ste. Marie, Ontario and Michigan. The 6.1 m drop in elevation over the rapids constitutes most of the 6.7 m drop along the entire river length. Below the rapids, the river channel is split by four large islands and becomes more like a series of connected lakes and embayments. Sugar, Neebish, and Drummond Islands belong to the United States and St. Joseph Island to Canada. Three quarters of the river's flow passes through Lakes Nicolet and Munuscong, one quarter passes through Lake George (Duffy et al., 1987; Great Lakes United, 1988).

The Canadian side of the river is characterised by hilly, rocky shores of the Canadian Shield, sand beaches, and small pockets of emergent aquatic macrophytes in protected areas. The U.S. side has a gentler slope and generally flatter terrain, the more protected shoreline supporting greater expanses of emergent aquatic macrophytes (Great Lakes United, 1988).

Table 2.1 summarises some current morphometric, hydrologic and water quality parameters for the St. Marys River.

2.2. Cultural Setting

2.2.1. Early Settlement

The strategic location of the St. Marys River combined with its rich fishery are the two most important factors to have shaped the human history of the river. Archaeological records indicate that the first people to arrive in the St. Marys River

Table 2.1. Summary of current morphometric, hydrologic, and water quality characteristics of the St. Marys River study area.

Morphometry[1]	
Length (km)	112
Total Shoreline Length[2] (km)	397.5
Drop in elevation (m)	6.7
Drop at SSM Rapids (m)	6.1
Hydrology[3]	
Drainage basin area (km^2)	210 000
Mean annual total discharge (dam^3)	
(1860-1920)	79.8×10^6
(1921-1990)	66.3×10^6
Mean annual discharge (m^3/s)	
(1860-1920)	2128
(1921-1990)	2155
Mean annual water level (m) (IGLD, 1955)	
(below SSM 1903-1990)	176.79
Water Quality[4]	
Total Phosphorus (mg/l)	0.001-0.031
Total Nitrogen (mg/l)	0.262-0.668
pH	6.7-8.4
Oxygen Saturation (%)	0-100 (>90)
Alkalinity (mg/l $CaCO_3$)	40
Conductivity (uS/cm)	85-188
Chlorophyll *a* (ug/l)	0.88

[1]Duffy et al., 1987.
[2]International Great Lakes Diversions and Consumptive Uses Study Board, 1981.
[3]Inland Waters Directorate, 1988, 1991.
[4]Kauss, 1991.

valley after the Wisconsin glaciation did so about 10 000 years ago, stopping along the shores of the river, especially at the rapids, to replenish food stocks with fish, game, and berries (Heath, 1988). Permanent settlements are believed to have been established there since about 300 BC (Hurley, 1990). Substantial faunal remains found on Whitefish Island (Rick, 1978) indicate continuous use of the area since 800 AD.

First contact with the native inhabitants of the area by European explorers is believed to have been made in 1618 by Etienne Brulé, an emissary of Samuel de Champlain. The Jesuits arrived in 1642, establishing a permanent mission at Sault de Sainte Marie in 1668 (Heath, 1988). From their *Relations* comes one of the earliest descriptions (c. 1670's) of the famed dip-net fishery at the St. Marys Rapids.

> "It is at the foot of these rapids, and even amid these boiling waters, that extensive fishing is carried on, from Spring until Winter, of a kind of fish found usually only in Lake Superior and Lake Huron. It is called in the native language *Atticameg*, and in ours 'whitefish,' because in truth it is very white; and it is most excellent, so that it furnishes food, almost by itself, to the greater part of all these peoples."
>
> "Dexterity and strength are needed for this kind of fishing; for one must stand upright in a bark Canoe, and there, among the whirlpools, with muscles tense, thrust deep into the water a rod, at the end of which is fastened a net made in the form of a pocket, into which the fish are made to enter. One must look for them as they glide between the Rocks, pursue them when they are seen; and, when they have been made to enter the net, raise them with a sudden strong pull into the canoe. This is repeated over and over again, six or seven large fish being taken each time, until a load of them is obtained." (Thwaites, 1899, pp. 129-131).

Similar descriptions of this fishery were recorded by later travellers and residents, such as Alexander Henry (1760's), Henry Schoolcraft (1820's), Anna Jameson (1830's), and Rev. John Pitezel (1840's) (Henry, 1969; Schoolcraft, 1851; Jameson, 1838; Pitezel, 1859).

The rapids, however, were not the only source of fish. Some of the significance of the river fishery is reflected in native place names along the St. Marys which evoke visions of a rich and bountiful ecosystem. Neebish Island, for example, was known as *Ashiganikaning* or "the place of bass" (Bayliss and Bayliss, 1938) and Bay Mills (in the upper river east of Point Iroquois) as *Ginozhaekaunning* meaning "the place of the pike" (Johnson, 1986).

2.2.2. Industry and Commerce

Fur trading companies, such as the Hudson's Bay Company (successor to the Northwest Company) and the American Fur Company, were the first to exploit the natural resources of the area on a grand scale. While using the twin Sault Ste. Maries as trading posts, both companies operated commercial fisheries (Nute, 1926; MacDonald, 1978). Whitefish (*Coregonus clupeaformis*) was the principal catch, but lake trout, and "pickerel" (walleye) were also taken (Nute, 1926).

By the early 1800's, SSM's importance in the fur trade was on the decline and its significance as a navigational route was increasing. Rising demand throughout the 19th and into the 20th centuries from the booming industrial heartland of the Great Lakes for Lake Superior iron ore, copper, and fish made the St. Marys River a waterway of great economic consequence (Heath, 1988; Larson, 1981).

The greatest obstacles to navigation in the river were the rapids at SSM, Sugar Island (Neebetung or Little Rapids), and West Neebish, and shallow channel depths which prevented the passage of larger ships and freight loads (Larson, 1981; Osborne and Swainson, 1986). Tackling these impediments to navigation led to the era of greatest activity and change on the St. Marys River. From the 1820's to the 1960's, the construction of locks, power canals, discharge regulating gates, and rail and road bridges at Sault Ste. Marie left the once famed St. Marys Rapids a fraction of its former size. River channels were widened and deepened, cutting through islands and rapids to permit successively larger vessels ply the Great Lakes route.

At the turn of the century, industry arrived to take advantage of hydroelectric power generated at the St. Marys Rapids. Union Carbide, the Northwestern Leather Company, Soo Woolen Mills, Algoma Steel, and the SSM Pulp and Paper Company (now St. Marys Paper) were all established within ten years (Bayliss and Bayliss, 1955). Only the latter two, those built on the Canadian side, still operate. The population of SSM, Ontario, grew from 780 people in 1881 to 43 088 in 1961 (Canada. Dominion Bureau of Statistics, 1933, 1962), and to 82 697 by 1980 (Acres, 1990). In contrast, SSM, Michigan, grew from 2 000 people in 1880 to 18 000 by 1950 (Bayliss and Bayliss, 1955), and by 1980 had dropped to 14 448 (Acres, 1990). Since then, the populations of both urban and rural areas within the St. Marys River valley have remained much the same.

The rich natural resources which attracted people and industry to the St. Marys River area were rapidly exploited. By 1909, commercial fishing in the middle reaches of the river was halted (Schneider and Leach, 1979) and by 1939 was banned in Potagannissing Bay (Michigan Department of Conservation, 1961) due to overfishing. Only the upper reaches near Gros Cap and the extreme lower end of St. Joseph's Channel are currently allowed any commercial fish harvesting (Krishka, 1989). Extensive cover of mature pine was cut, especially on the Michigan side, much of it rafted down the St. Marys, and some of the land adjacent to the river turned to agriculture (IJC, 1951; Bayliss and Bayliss, 1955).

A chronology of engineering, cultural, and fishery events in the St. Marys River is included as Appendix C.

2.3. The Fishery

The St. Marys River fish community has been described as being both a coldwater community in the upper river (Krishka, 1989) and a predominantly coolwater percid community in the lower river reaches below the St. Marys Rapids (Liston et al., 1980; Duffy et al., 1987).

Of the more than 80 species now in the St. Marys (Appendix A), twelve have been introduced within the last one hundred years, only five species intentionally (Table 2.2). With the exception of Atlantic salmon (*Salmo salar*), most species introduced into the river are commonly caught in netting surveys (Grimm, 1989). No species are known to have been eradicated from the St. Marys River system, although both the lake sturgeon and the lake herring (*Coregonus artedii*) have been placed on the list of threatened species in Michigan (Duffy et al., 1987).

Compared with other connecting channels of the Great Lakes, the St. Marys River supports a diversity of fish species intermediate between the St. Clair (90 species) and Detroit Rivers (60 species) (Edwards et al., 1989). In comparison with other large rivers in Canada, however, the St. Marys River supports a notably diverse

Table 2.2. Introduced fish species in the St. Marys River system and circumstances of their introduction.

Species	Year and Circumstances of Introduction	References
Rainbow trout	1897 - West Coast steelheads successfully stocked by Michigan	Mich. State Board of Fish Comm., 1909
Atlantic salmon	1897 - stocked by the State of Michigan until ~1914? 1972 - renewed stocking by Michigan	Mich. State Bd. Fish Comm., 1915
American eel	late 1880's - unknown when first appeared in the upper lakes, caught first in Lake Michigan in 1871; thought to have been transferred from natural distribution in lake Ontario to other lakes through accidental and intentional release	Emery, 1985
Brown trout	c.1895 - stocked by Michigan	Mich. State Bd. Fish Comm., 1987
Goldfish	c.1900 - accidental and possible intentional introduction into the Great Lakes system	Emery, 1985
Carp	early 1900's - first found in Georgian Bay in 1905; 1914 first commercial catch made in the North Channel; 1915 first seen in lake Superior	Berst and Spangler, 1973;
Rainbow smelt	1906-1921 eggs stocked five times in the St. Marys River by Michigan, considered unsuccessful; 1925 first reported in Lake Huron, increased rapidly in the 1930's	Emery, 1985
Sea lamprey	c.1940 - first reported in Lake Huron in 1937, in Lake Superior in 1946	Berst and Spangler, 1973; Lawrie and Rahrer, 1973
Alewife	c.1950's - first appeared in Lake Huron in 1933, South Bay of Manitoulin Island in 1951, and in Lake Superior in 1954;	Berst and Spangler, 1973
Pink salmon	c.1960's - accidentally introduced into Lake Superior in 1956, first reported in northern Lake Huron in 1969	Emery, 1985
Coho salmon	c.1967 - first recorded in Lake Huron in 1967 following stocking in Lake Michigan in 1966	Berst and Spangler, 1973
Chinook salmon	c.1970 - first introduced into Lake Michigan in 1967 and in Lake Huron in 1969	Berst and Spangler, 1973; Wells and McLain, 1973

fish community. The Mackenzie River basin fish community consists of 53 species, the Churchill River supports 39 species (Bodaly et al., 1989), the Moose River basin has 44 species of fish (Brousseau and Goodchild, 1989), and the Fraser River supports a total of 53 species, including exotics (Northcote and Larkin, 1989). The diversity of fish species in the comparatively short St. Marys River is attributed to the wide range of habitats available (Duffy et al. 1987).

Fish harvest records maintained by Canadian and American authorities from the 1870's to the 1910's, indicate that lake whitefish was the most important (in terms of quantities caught) commercial species in the river. Catches of lake trout were also large, but because most of the lake trout harvested were recorded either at Gros Cap or Detour, it is likely that most of the catch came from the open lakes rather than the St. Marys River itself. Major spawning grounds for lake trout were located in areas outside of the river (Goodyear et al., 1982a; 1982b). Sturgeon, walleye, northern pike (*Esox lucius*), lake herring, yellow perch (*Perca flavescens*), bass (no species mentioned), suckers, and occasionally muskellunge (*Esox masquinongy*), carp (*Cyprinus carpio*), and catfish (*Ictalurus spp.*) were recorded by commercial fishing operators in the St. Marys River. Most fish were taken either in the upper river near Gros Cap or in the lower reaches in Potagannissing Bay and near St. Joseph Island and Detour, with minor catches recorded from Lakes George and Nicolet (Canada Dept. Marine and Fisheries, 1887-1911; Mich. State Board Fish Comm., 1884-1914).

Notable declines in whitefish, walleye, lake trout, sturgeon, and muskellunge were observed by the late 1800's. The Michigan State Board of Fish Commissioners

(MSBFC) charted a decrease in the relative catch of whitefish in the St. Marys River from 1885 to 1893 although the number of nets had increased. Smaller sized whitefish were also observed by the late 19th century (Milner, 1874; MSBFC, 1895). In 1762, Alexander Henry reported that whitefish taken in the St. Marys Rapids weighed from 2.7 to 6.8 kg (6-15 lbs) (Henry, 1969). By 1885, however, a prominent native fisherman at the rapids claimed that whitefish averaged only 1.4 to 1.8 kg (3-4 lbs) (MSBFC, 1887). Creel census information from the rapids in 1985 and 1986 show the mean weight of whitefish to be 0.73 kg and 0.78 kg, respectively (Wurm, 1987). An increase in effort to catch the same (or less) quantity of fish and a decrease in the average size of fish caught are effects of overfishing (Regier, 1979; Regier et al., 1989).

Few historical or current records of sport fishing harvests exist. Brook trout (*Salvelinus fontinalis*) from the St. Marys Rapids, small creeks above the rapids, and the Root and Garden Rivers were important for tourism and sport in the 1800's (Ontario Dept. of Lands, 1860). By the 1920's, rainbow trout (*Oncorhynchus mykiss*) had become an abundant species in the rapids and, along with whitefish, supported much of the sport fishery. The introductions of pink (*Oncorhynchus gorbuscha*) and chinook salmon (*Oncorhynchus tshwatytscha*) in the 1960's, however, shifted the rapids' fishery to these exotic salmonids, particularly the pink salmon (Wurm, 1987; Krishka, 1989). The sport fishery in the lower river has remained centred on walleye, northern pike, lake herring, yellow perch, and smallmouth bass (*Micropteus dolomieui*) (Westerman and Van Oosten, 1939; MDNR, unpublished reports of

Conservation Officers, Wurm, 1987; Krishka, 1989).

Much of the information on the present fish community of the St. Marys River is fragmented among reports, both published and internal, conducted by different agencies at varying locations and times, and employing dissimilar methods. Comprehensive information is lacking on spawning and nursery grounds, stock identification, migration patterns, food habits, and population densities for most of the fish species in the river. The large size of the river combined with shipping traffic, swift currents, and the variety of habitats make it difficult to sample effectively and regularly.

CHAPTER III

Methods and Study Design

3.0. General

3.0.1. Data Collection

Data were collected in two stages over a two year period beginning in the spring of 1990. The first stage was an information reconnaissance to discover the quality and quantity of ecological information on the St. Marys River (Appendix B). These results were used to narrow the focus of the second stage of data collection. Whereas good continuous information on structural habitat exists, high quality, continuous biological data for the St. Marys River are scarce, not only because of the length of the historical period involved (fishery science needs changed radically), but also because of the peculiar situation of the river. Split between two countries and several agencies and having had no commercial fishery for a good part of its recorded history, the St. Marys River fishery has a much more fragmented documentation than many other areas on the Great Lakes, including the other connecting channels.

The hydrological record for the St. Marys River, however, is extensive, continuous, and spans at least 130 years. Measurements of discharge begin on a regular basis in 1860. Water levels have been measured above the St. Marys Rapids since 1871 (first continuous measurements) and since 1903 below the rapids. The most complete and detailed discharge and water level information comes from U.S.

sources.

The St. Marys River morphometry is relatively well documented with map and air photo coverage. The first hydrographic charts appeared circa 1790's and the first vertical aerial photography was taken in 1935 (Canada). Early maps and charts depict the entire river whereas current mapping is done separately by Canada and the U.S. and usually does not include all areas across the international border.

3.0.2. Verification of Sources

The accuracy of historical investigation depends on the nature of the historical record, the questions posed, and the availability of corroborating evidence (Hooke and Kain, 1982). The quality and quantity of existing information and the technology to retrieve and/or analyse information are the most significant limitations to retrospective ecological research.

Assessing the reliability of source material is a crucial step in historical analysis. Any recorded information must undergo some process of verification before being considered of use. Error can be introduced in the collection, transfer, storage, or analysis of information (Hooke and Kain, 1982).

Early accounts of environmental conditions are generally more suspect than later descriptions because the former are more difficult to corroborate. Rostlund (1952), however, suggests that accounts made by explorers, settlers, traders, and missionaries are most likely true descriptions of early environmental conditions and particularly of the early fisheries. Not only do many of the accounts agree, but "no glory was gained nor was any career advanced by saying that a catfish had been seen or that an Indian possessed fish nets" (Rostlund, 1952, p. 80). Problems, however, may lie in not what *has* been recorded, but what has *not*. In the St. Marys River, for example, while the whitefish fishery at the St. Marys Rapids is well documented, the remainder of the river fishery is much less well known, not because it did not exist, but because it was likely less spectacular and attracted less attention. Archaeological remains at Fort St. Joseph indicate a variety of fish species present, but there is little in the historical literature devoted to species other than those commercially important (Anonymous, n.d. a.). Moreover, the remains may be of fish that were caught elsewhere.

Trautman (1981) considered three criteria for assessing the reliability of statements made in the historical literature: a) where there is no evident reason for any embellishment of the facts; b) where the statements agree with ecological principles; and c) where the same statement is made by several authors.

Much of the anecdotal information collected on the St. Marys River was gleaned from published journals of early explorers or travellers, local and regional histories, annual reports, and from unpublished internal documents of various government agencies. In this analysis, two lines of evidence must have been present for qualitative information to be accepted. For quantitative data, where verification may not be available, e.g. water level values or catch statistics, the information was accepted based on Trautman's criteria and on whether the information is generally accepted by the research community. Water level and discharge values prior to 1900, for example, while not considered to have the same level of accuracy as those measurements taken this century, are accepted as "true" values because none other exist and they represent the best available estimates of the time.

3.0.2.1. Nomenclature and Units of Measure

An inescapable confusion of historical research is the often common occurrence of several names describing one place or species either within or between time periods. For example, walleye, known unofficially as pickerel, has been recorded as wall-eyed pike, doré, and pike-perch. Goodier (1982) found that fishermen often used pike and pickerel interchangeably. In 1859, the Superintendent of Fisheries for Upper Canada recommended that the word "pickerel" be inserted in the Fisheries Act instead of "pike" (Commissioner of Crown Lands, 1860). Often the species can be differentiated on the basis of seasons, methods or place of capture (habitat). To avoid confusion, names of fish species used in the thesis follow the standard of the American Fisheries Society nomenclature.

All units of measure are converted to metric, the original indicated in parentheses only if it is noteworthy. Landings of fish recorded in barrels are considered to be 91 kg (200 lbs) per barrel (Nute, 1926), 109 kg (240 lbs) fresh weight allowing 20% for shrinkage and wastage (Mich. State Board Fish. Comm., 1887). Discharge and water levels were converted from imperial measure.

3.1. Analysis

3.1.1. Structural Change of the St. Marys Rapids

Using SigmaScan (1988) and a digitizing tablet, areal change of the St. Marys Rapids was measured from 1:20 000 maps produced by the U.S. Army Corps of Engineers and its predecessors. The east and west boundaries of the area measured were held constant.

3.1.2. Habitat Modelling

Escalating conflicts within the last two decades between resource development and resource conservation and protection have made *a priori* impact assessment studies desirable and often compulsory. Concomitant has been an increasing need for a means of measuring and evaluating potential effects of development projects, particularly on aquatic ecosystems. A desire among researchers and managers for generic procedures for site specific assessments has focused attention on modelling ecosystem processes. Habitat modelling has become an increasingly popular focus for developing impact assessment strategies.

Models attempt to introduce order to otherwise seemingly chaotic relationships and to bring some level of simplicity to complex configurations. Habitat models generally seek to simulate and evaluate existing or potential habitat under varying environmental conditions for a particular species assuming a positive correlation between habitat and biomass.

The ability to predict standing crop or productivity by measuring and modelling a limited number of habitat parameters would be of great use to fishery managers. Thus, the inherent assumption of these models that habitat quality and quantity is reflected in the health and abundance of biota makes them seductive tools for managers.

Two models: the Habitat Suitability Index (HSI) and the Instream Flow Incremental Methodology (IFIM) are used in this thesis as a means of interpreting habitat change in the St. Marys River. The models can be used as frameworks for more refined habitat models at regional or local scales. In this analysis they are used to help in interpreting habitat change by providing an index or relative measure.

3.1.2.1. Habitat Suitability Index Models

Habitat Suitability Index (HSI) models have been developed as a means of evaluating the quality of existing or potential habitats for individual animal species. The models were developed using life history information from the literature combined with the opinions of those considered to have expert knowledge. They rely on suitability index (SI) curves which rate measures of individual habitat variables on a relative scale from least suitable (0) to optimum (1.0), combining scores for different life stages into a total HSI score.

The total score is meant as an index of the condition of a habitat and, while assumed to be correlated with carrying capacity, does not act as a measure of standing stock or as an indicator of species presence/absence. A low HSI score means that the habitat is poor and will most likely support limited populations, or none at all. As the HSI models were not intended to predict standing stocks, they employ only habitat characteristics and do not include any fish population measures, e.g. density, competition, or predation (Raleigh et al., 1984), although some researchers would consider these as part of the habitat.

A common criticism of HSI models, indeed of most habitat models, is their lack of universality (Shirvell, 1989). While they are developed using habitat preference information from as many locations as possible and are intended to apply over the North American range of a species, HSI's have been found to require extensive local calibration (Wesche et al., 1987; White, 1990). Habitat variables which limit a species' distribution and abundance may differ among regions (Bowlby and Roff, 1986; Portt et al., 1989), the differences not necessarily reflected in the HSI models (White, 1990). As well, in dynamic systems, such as streams and rivers, the potential outcome of the models may change over a relatively short time. Since the fluvial models rely heavily on channel morphology (and variables affected by morphology), SI scores could be altered by extreme events, such as storms. This can necessitate frequent habitat surveys to calibrate the HSI models.

Bowlby and Roff (1986) have claimed that HSI's are limited in scope and application because they do not account for habitat availability or accessibility, are not correlated with standing stock, rely heavily on assumptions and utilise SI curves which are often subjectively developed and interpreted (White, 1990), and do not account for dependencies among variables. The models provide only a snapshot of habitat conditions and thus neglect temporal change (White, 1990; Heggenes and

Saltveit, 1990). HSI models attempt to evaluate habitat *only*, regardless of whether it is occupied or available.

3.1.2.2. The Instream Flow Incremental Methodology

Stream discharge and morphometry affect the amount and quality of habitat available to aquatic organisms (Hynes, 1970; Minshall et al., 1985; Petts and Foster, 1985). Alteration of stream (or river) discharge by increasing or decreasing flows or by changing the pattern, frequency, or magnitude of high and low flows can have significant effects on biological communities (Reiser et al., 1989).

The IFIM was developed by the Cooperative Instream Flow Service Group of the U.S. Fish and Wildlife Service to be used as a quantitative tool for recommending instream flows (Bovee, 1982) which would satisfy both engineering and aquatic habitat needs (Gore and Nestler, 1988). The method is widely used in the U.S., particularly in the western states where water use conflicts are numerous (Armour and Taylor, 1991). The IFIM has also been applied in New Zealand (Scott and Shirvell, 1987; Irvine et al., 1987; Jowett and Richardson, 1990; Palmer, 1990;) and Quebec (Hayeur et al., 1990), predominantly in relation to hydroelectric development.

Although difficulties occur in using the IFIM (Armour and Taylor, 1991), the method has aided in the legislation of instream flows in the U.S. (Layher and Brunson, 1992). While the IFIM is not used extensively in Canada, Section 22(3) of the Fisheries Act (R.S.C. 1985) stipulates that adequate flows must be maintained for fish safety and spawning below any obstruction or dam.

The IFIM is a concept based upon hydraulic and biological principles, employing computer software equations (Gore and Nestler, 1988; Bowlby and Imhof, 1989). Of the different components to the IFIM described by Annear and Condor (1984) and Armour and Taylor (1991), the Physical Habitat Simulation (PHABSIM) is in most common use. PHABSIM uses computer software to model area of suitable habitat (expressed as a Weighted Useable Area) across different discharges (Bovee, 1982). A Weighted Useable Area (WUA) is obtained from the product of the habitat area and SI scores, usually for depth, substrate, and velocity for an indicator species and life stage(s):

$$WUA = A \times S_d \times S_s \times S_v$$

where: A = plan area of habitat,

S_d = suitability index for depth,

S_s = suitability index for substrate, and

S_v = suitability index for velocity.

As discharge is altered, the WUA changes and the relationship can be shown graphically. In this way, the IFIM is used to determine not only minimum acceptable flows for one or all life stages of a species, but a range of conditions under alternative flow regimes that might be negotiated in water use conflicts. The relative importance of different life stages and their differing habitat requirements can also be accounted for by weighting.

WUA over time can also be calculated using monthly or annual mean discharges and plotting WUA by month or year (Nestler et al., 1989; Milhous et al., 1990). The application of the PHABSIM model can be found in Bovee (1982), Milhous et al. (1981), and Gan and McMahon (1990) and of the habitat time series analysis in Milhous et al. (1990).

Originally designed for determining optimum (not just minimum) flows for fish, the IFIM is also being used for benthic macroinvertebrates (Gore and Judy, 1981; Peters et al., 1989; Gore, 1989; Jowett and Richardson, 1990; Weisberg et al., 1990). Instream flow analysis using benthic invertebrates may be more revealing as benthos are generally less mobile than fish species, and therefore, less able to seek alternative hospitable areas during periods of low flow. When high flows or spates occur, many benthic organisms can be swept away and the area must be recolonised. The importance of benthos as food items for many fish increases the usefulness of considering them in instream flow studies and habitat assessments.

Many of the criticisms levelled at the Habitat Suitability Index Models are also directed at the Instream Flow Model, particularly PHABSIM because it uses SI curves. The need to develop site-specific SI curves, the dubious and often unsubstantiated relationship between WUA and standing stock, and the lack of independent habitat variables are criticisms of the IFIM discussed by Orth and Maughan (1982), Annear and Condor (1984), Mathur et al. (1985), Scott and Shirvell (1987), and Armour and Taylor (1991). Gore and Nestler (1988) responded that the IFIM is a tool for blending fisheries information and values into water resource planning and is not intended as a replacement for research on fish populations or ecology. They also argue that the IFIM (and our knowledge of stream ecology) is inadequate to predict biomass using WUA/discharge relationships.

The Physical Habitat Simulation is applied to the St. Marys Rapids area as a means of illustrating on a relative scale the possible changes to habitat and habitat suitability for different organisms through time as a function of discharge.

Koshinsky and Edwards (1981) suggested applying the IFIM (or another habitat model) to the St. Marys Rapids to aid in resolving water use conflicts between fishery and hydroelectric interests. They presented an example of a habitat suitability index score based on a subjective determination of optimum discharge and area flooded, but did not pursue the model any further.

3.1.3. Applying the Instream Flow Model

Hydropsyche sp., a benthic macroinvertebrate, and rainbow trout are used here as indicator species in the instream flow analysis. Rainbow trout were chosen because the species was successfully introduced to the St. Marys Rapids almost a century ago and instream flow SI curves are available. Lake whitefish would seem an obvious choice for this analysis considering its historical significance in the St. Marys Rapids fishery. Unfortunately, no SI curves are available and too little is known about its habits and habitats, especially fluvial, to prepare curves with accuracy.

A lack of detailed information on the physical structure of the St. Marys Rapids, prompted reliance on a report prepared by the International Lake Superior

Board of Control (ILSBC) (1974). From ILSBC (1974), the area flooded and estimated mean water depths were obtained at four standard gate openings: 16, 4, 1, and ½. As the discharge at the 16 gate setting was known, it was possible to calculate the remaining three discharge values using the equation derived by the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data (1970):

$$Q = a\,(S.W.P - b)^{1.5}$$

where: Q = discharge,

$S.W.P.$ = Southwest Pier water level at International Great Lakes Datum 1955, and

a and b = equation constants which relate to the number of gates open.

As no constants are available for a ½-gate setting, the discharge was estimated using rating curves (Koshinsky and Edwards, 1981).

The rapids area was divided into five areas or cells. For each cell at each of the four discharges, the area flooded and mean depth were calculated. A WUA for each cell and each indicator organism was then obtained by applying the equation:

$$WUA = A \times SI_d$$

where A = area of the cell and

SI_d = suitability index for mean depth of the cell.

The WUA's were then summed and transformed into total % WUA to maintain a relative scale.

The relationship between discharge and total % WUA was derived from a line of best fit for each indicator organism and life stage. For comparison with the WUA estimates for each species, the relationship between total area flooded and discharge (no weighting factors included) was computed.

Time series of % WUA for each organism and life stage were prepared by generating % WUA from the line of best fit equations and known monthly or annual mean discharge over the rapids between 1915 and 1984. This time period was chosen because the area and structure of the rapids was relatively constant during this period (Figure 4.2) with the exception of the construction of the international road bridge in 1964. In 1985, a berm was built along the southern side of Whitefish Island and some excavation and alteration of the substrate took place which could have altered the WUA values. Mean depths derived from ILSBC (1974) would not be applicable prior to 1915 when the rapids extended farther on the U.S. side of the river.

SI values for substrate and velocity were not included because neither could be satisfactorily estimated. Substrate information for the rapids is not detailed, comprehensive or quantitative enough to apply to an SI curve. Velocity measurements are also difficult to estimate and could introduce substantial error to the WUA values. An estimate of mean velocity would be of little use in determining species suitability index values. For example, a mean velocity value would most likely result in a SI score of 0 for an organism which lives on or within the substrate, such as Hydropsychids. This could create a WUA which would not realistically reflect the actual species' distribution. Since velocity and water depth are dependent variables, it is assumed that using only depth as a weighting factor of area is sufficient to illustrate change.

3.1.3.1. *Hydropsyche sp.*

All benthic macroinvertebrate surveys in the St. Marys Rapids, have found high densities of the net-spinning caddisfly genus *Hydropsyche* (Trichoptera) (ILSBC, 1974; GLFC, 1979; Koshinsky and Edwards, 1981; Duffy, et al., 1987).

Hydropschids are important food items for rainbow trout, brook trout, and whitefish (Koshinsky and Edwards, 1981) and are known to be affected by changes in river discharge (Cellot et al., 1984; Munn and Brusven, 1987). As such, they represent a good indicator species for use with the IFIM. The SI curves used for this analysis were obtained from Peters et al. (1989) and are included in Appendix D.

3.1.3.2. Rainbow Trout

Intentionally introduced into the St. Marys River c. 1895 from a West Coast steelhead stock, the rainbow trout has become a mainstay of the sport fishery. A resident population of rainbow trout inhabitats the upper river, including the rapids, and there is also a run of spawning migrants (MDNR, unpublished data).

Both a Habitat Suitability Index model and instream flow curves (Appendix D) exist for rainbow trout (Raleigh et al., 1984), making it a good species to use in this analysis. Percent WUA versus discharge was calculated for four life stages:

adult, spawning, juvenile, and fry. All life stages were combined for a total rainbow trout habitat time series using the method described in the HSI model (Raleigh et al., 1984). As Raleigh et al. (1984) use the same water depth SI curve for spawning as for the embryo life stage, the latter was omitted from the analysis of individual life stages. The authors suggest that depth may not be as important a variable for the embryo stage provided that the eggs are kept moist and that the redds are submerged when the fry begin to hatch.

3.1.4. Aquatic Vegetation

3.1.4.1. Areal Change

Change in area with submerged and emergent aquatic vegetation along the Canadian shore from Gros Cap to Hay Bay (at Bruce Mines), including St. Joseph Island (Figure 1.1), was calculated from black and white air photos of five time periods: 1935 (National Air Photo Library), 1949, 1964, 1973, and 1981 (OMNR) (Table 3.1). Virtually complete coverage of the St. Marys River shoreline was available for all years except 1949. As prints cannot be made for the 1949 series because the negatives are under conservation at the Archives of Ontario, only those photographs that were available from the OMNR SSM District Office were used.

Table 3.1. Dates and scales of air photo coverage with corresponding annual mean water level (m).

Year	Dates(s)	Scale	Annual Mean Water Level
1935	27 Sep-08 Oct	1: 11 200	176.54
1949	Sep?	1: 15 840	176.38
1964	26 Jun-20 Aug	1: 15 840	176.16
1973	09 Jun-28 Jul	1: 15 840	177.17
1981	07 Jun-07 Jul	1: 15 840	176.77

Areas of aquatic vegetation were traced directly from air photos onto acetates. Four criteria were used to determine boundaries for aquatic vegetation:

1) areas of hydrophytic plants;

2) areas within stands of vegetation where open water is visible;

3) the outward limit of emergent or submerged plants; and

4) the upland limit of trees if no other boundary feature could be distinguished.

Existing areas of vegetation were identified with the help of maps, preliminary wetland assessment sheets, and a 1987 shoreline videotape from the OMNR (SSM District). Some areas were ground-truthed in the summers of 1990 and 1991. Identification of aquatic vegetation on historical photographs was based on vegetation that was seen in the field and related to recent (1981) photographs. Any additional sites were identified based on similarities in photo shade and texture to that of known areas.

The U.S. shoreline was not consistently available on Canadian air photo coverage. Information on current U.S. wetlands and aquatic vegetation and changes through time was obtained from Williams and Lyon (1991) and Herdendorf and Hartley (1979). As Williams and Lyon (1991) used different techniques and identification criteria, only general comparisons can be made between aquatic vegetation on the U.S. and Canadian shores.

Areas of submerged and emergent vegetation were calculated using a digitising tablet and SigmaScan (1988). All measurements were made in square metres to accommodate small areas and later converted to hectares.

3.1.4.2. Applying the Habitat Suitability Index

The HSI was applied to areas of aquatic vegetation potentially available as fish habitat in the St. Marys River as another measure of change over time. More important than suitability scores of the habitat for the individual year is the comparison among years. SI curves used for northern pike are included in Appendix D.

The northern pike, an important and abundant game fish in the St. Marys River, is used as an indicator species in the HSI predominantly because of its strong life cycle association with aquatic vegetation and its significance to the river fishery (Grimm, 1989; Liston et al., 1980; 1983)

3.1.4.2.1. Northern Pike

The Habitat Suitability Index Model for northern pike (Inskip, 1982) uses nine habitat variables to determine the total riverine HSI score. Total habitat suitability is determined by the lowest of the individual SI scores. Of the nine variables, five SI scores can be estimated based on current literature on the St. Marys River and one determined from the time series information gained from measuring the vegetated area. Two variables cannot be estimated: 1) the ratio of spawning habitat to summer habitat, because it requires knowledge of the extent and quality of vegetated bottom cover, and 2) the percent of pools and sluggish water to total area as the photography did not have sufficient resolution to measure this. The measure of total dissolved solids (TDS) is not included as it is not considered to be limiting in riverine systems which have a TDS of < 800 ppm (Inskip, 1982). In the St. Marys River, TDS is usually < 100 ppm (Liston et al., 1980; 1983). Table 3.2 lists the northern pike HSI variables and their usefulness in assessing historical trends in area of aquatic vegetation.

Total midsummer habitat was calculated by measuring the surface area of river up to about 6 m in depth on U.S. hydrographic charts (18' contour). According to Liston et al. (1980; 1983), the limit of vegetative growth is approximately at the 6 m depth in the St. Marys River. While northern pike are not limited by depth itself, they avoid the colder and deeper waters and are always found in conjunction with vegetation (Inskip, 1982). As temperature profiles for the river are unavailable, the limit of vegetational growth in the river was used as a surrogate measure of midsummer habitat.

Table 3.2. Northern pike Habitat Suitability Index model variables and their use in historical evaluation of habitat change.

Variable	Historical Use
V_2 - Drop in water level during embryo and fry stages	Yes, based on historic monthly mean water levels.
V_3 - % of midsummer area with emergent or submerged aquatic vegetation or remains of terrestrial plants	Yes, using measurements of aquatic vegetation from historical air photos and an estimate of midsummer area from current hydrographic charts.
V_5 - Least suitable pH in spawning habitat during embryo and fry stages	Yes, assuming little or no change from current values.
V_6 - Average length of frost-free season	Yes, assuming little or no change from current values.
V_7 - Maximal weekly average temperature of the surface layer	Yes, using current values averaged from different sources.
V_9 - Stream gradient	Yes, assuming no change through time.

3.1.5. Summary of Methods

Table 3.3 provides a summary of the approach and methods used in this thesis. The analysis of changes to habitat is conducted on two very different centres of organisation (COG): the St. Marys Rapids and zones of aquatic vegetation, each of which is examined for areal changes over time. A habitat model for chosen indicator species is also applied to each COG to determine changes in habitat suitability over time and to identify the most important variables effecting change.

Table 3.3. Summary of methods.

Location	Indicator Species	Application	Purpose	Time Period	Variables
St. Marys Rapids	n/a	areal change through time measured from maps	document/illustrate absolute loss of area to the rapids	1855 - Present	-area
	Hydropsyche sp. Rainbow trout	IFIM	illustrate potential influence of changing discharge regime on habitat availability and suitability for indicator organisms in the rapids	1915 - 1984	-area -mean depth -discharge
Aquatic Vegetation (Canadian shoreline)	n/a	areal change through time measured from air photos	document changes in area; determine if any losses have occurred	1935, 1949, 1964, 1973, 1981	-area of submerged/ emergent veg.
	Northern pike	HSI	compare potential suitability of aquatic vegetation for fish habitat through time	1935, 1949, 1964, 1973, 1981	-water level -area of emergent/ submerged veg. -pH -frost-free season -temperature -stream gradient

CHAPTER IV

Results and Discussion

4.0. The St. Marys Rapids

4.0.1. Structural Change

The St. Marys Rapids area originally consisted of the rapids proper and a section known as the Belle Isle Cascades between St. Marys Island and the mainland (Fig. 4.1-A), on the north side. Between 1887 and 1915, a 50% reduction (Fig. 4.2) in the area of the St. Marys Rapids proper occurred as a result of endeavours to improve navigation and to generate hydroelectric power (Fig. 4.1-A to E and Table 4.1). Complete elimination of the Belle Isle Cascades (Fig. 4.1-A), an area considered to have supported a substantial fishery for native peoples (Hunter and Associates, 1979), occurred by the 1890's with the development of the site for a shipping lock and industry. If the Cascades are considerated when calculating percent change over time in the St. Marys Rapids, the area of rapids lost would be almost 60%.

This direct loss of area does not take into consideration the relative significance to overall productivity in the river. In 1788, the Deputy Surveyor General (Canada), John Collins, reported:

> "The North Shore immediately along the Rapid, consists of several small islands; the channel between them is shoal" (Ross, 1922, p. 45).

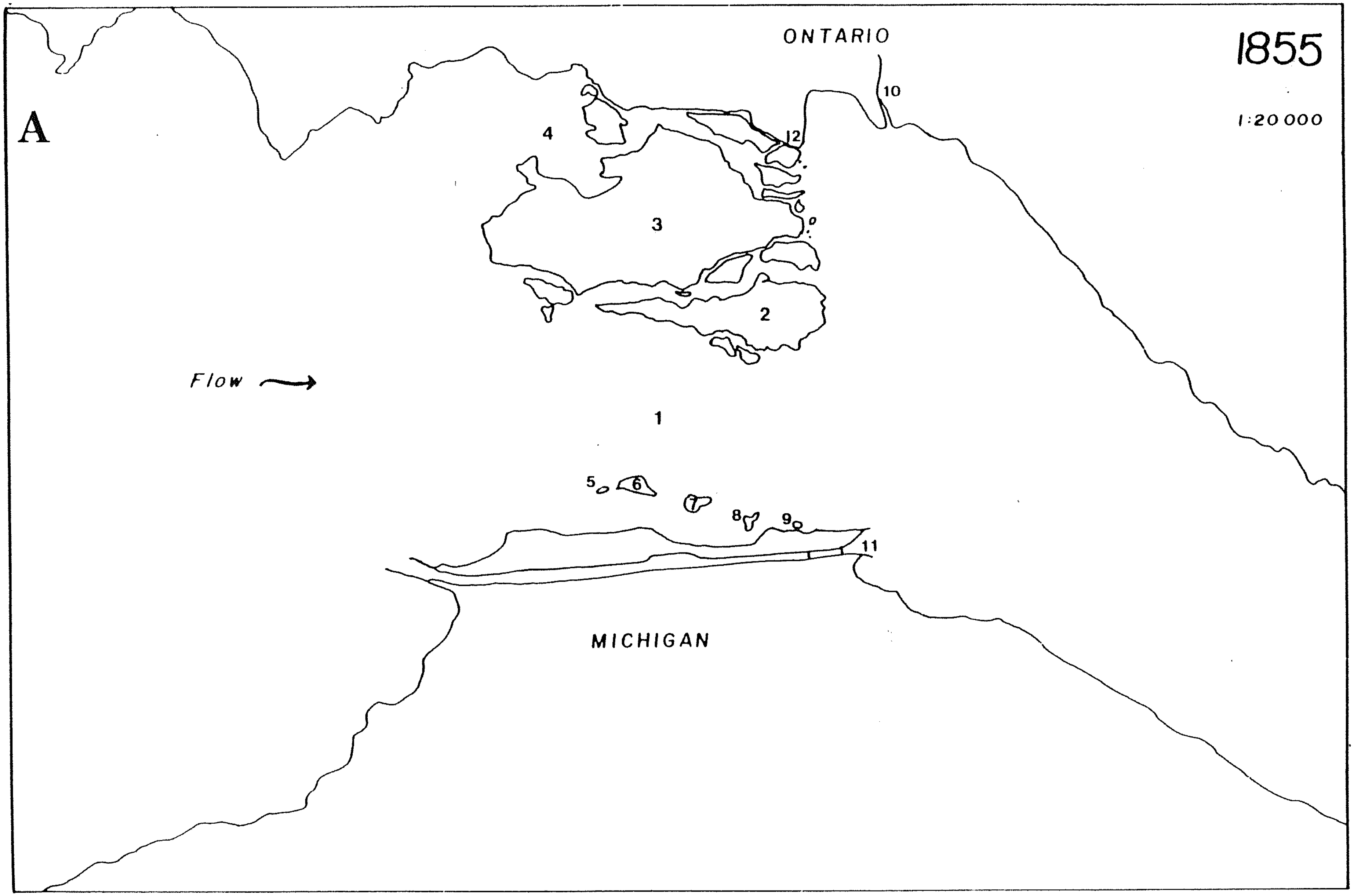
This brief statement describing the channels of the Belle Isle Cascades could indicate

Map Key

1. St. Marys Rapids
2. Whitefish Island
3. St. Marys Island (Belle Isle)
4. Belle Isle Cascades
5. Island No. 1
6. Island No. 2
7. Island No. 3
8. Island No. 4
9. Island No. 5
10. Fort Creek
11. St. Marys Falls Canal*
12. Site of the 1797 Northwest Co. lock
13. Algoma Steel Corp. Ltd.*
14. St. Marys Paper Co.*
15. International railway bridge
16. Great Lakes Power Co. Canal and Plant*
17. Canadian Locks and Canal
18. U.S. State Fish Hatchery
19. Weitzel Lock
20. Poe Lock
21. Edison Sault Electric Co. Power Canal and Plant*
22. Sabin Lock
23. Davis Lock
24. U.S. Water Power Plant
25. Compensating Works
26. Moveable Dam
27. New U.S. Hydro Electric Power House
28. MacArthur Lock
29. International road bridge
30. Berm

*Note: Many companies and places have undergone several name changes over the years; the most commonly known names are used here.

Figure 4.1-A to E. Structural changes to the St. Marys Rapids from 1855 to the present.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MICHIGAN
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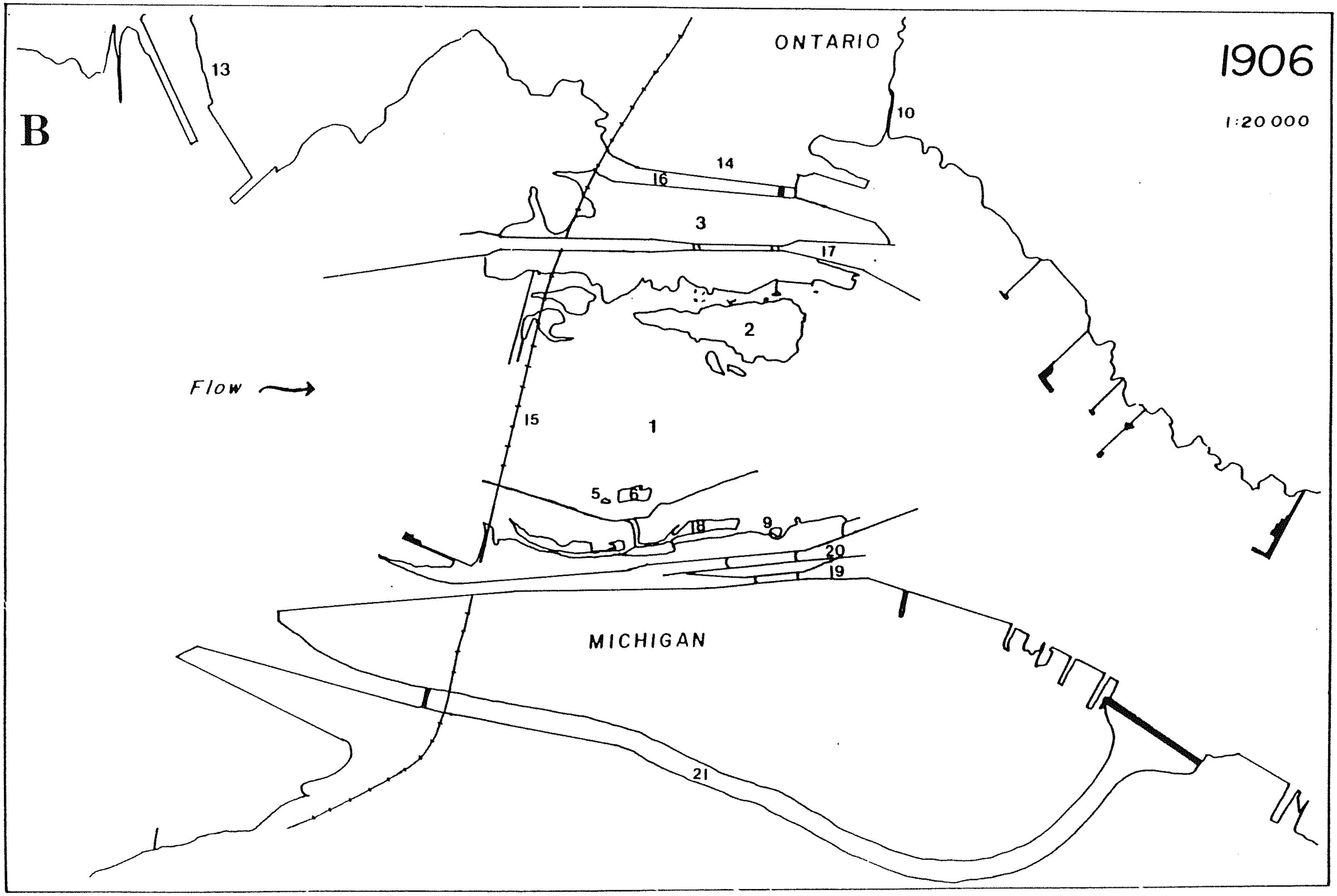
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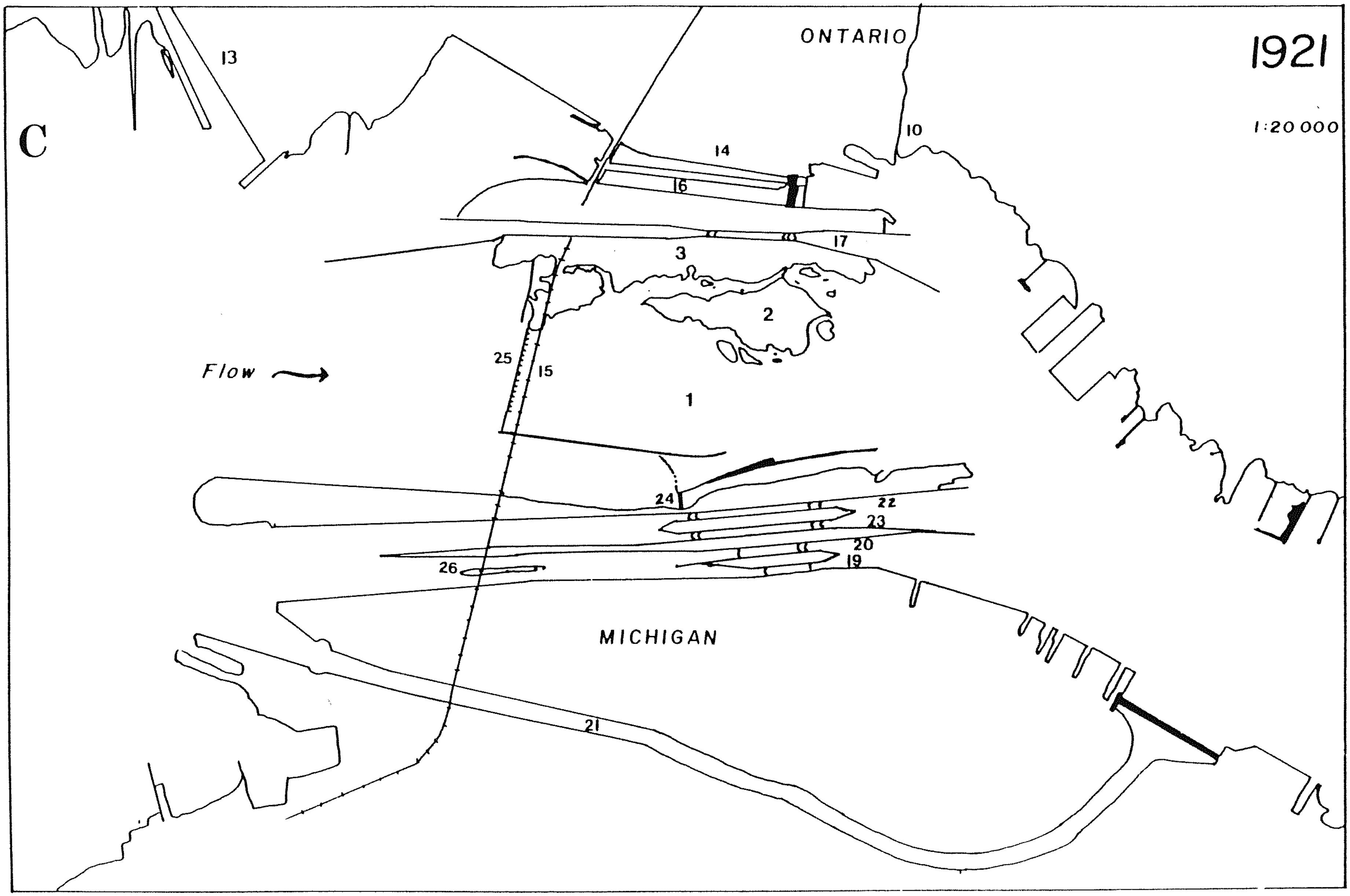
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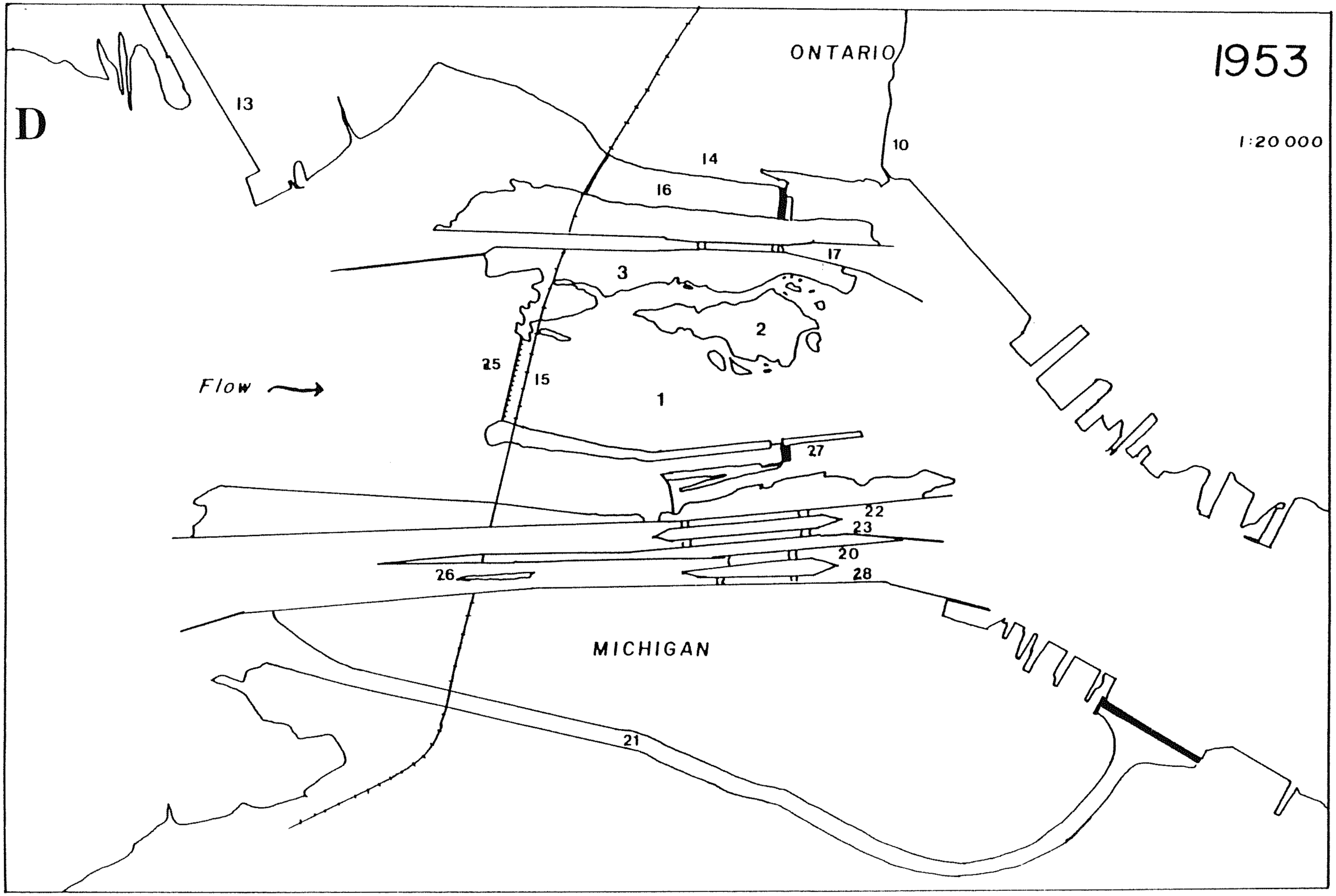
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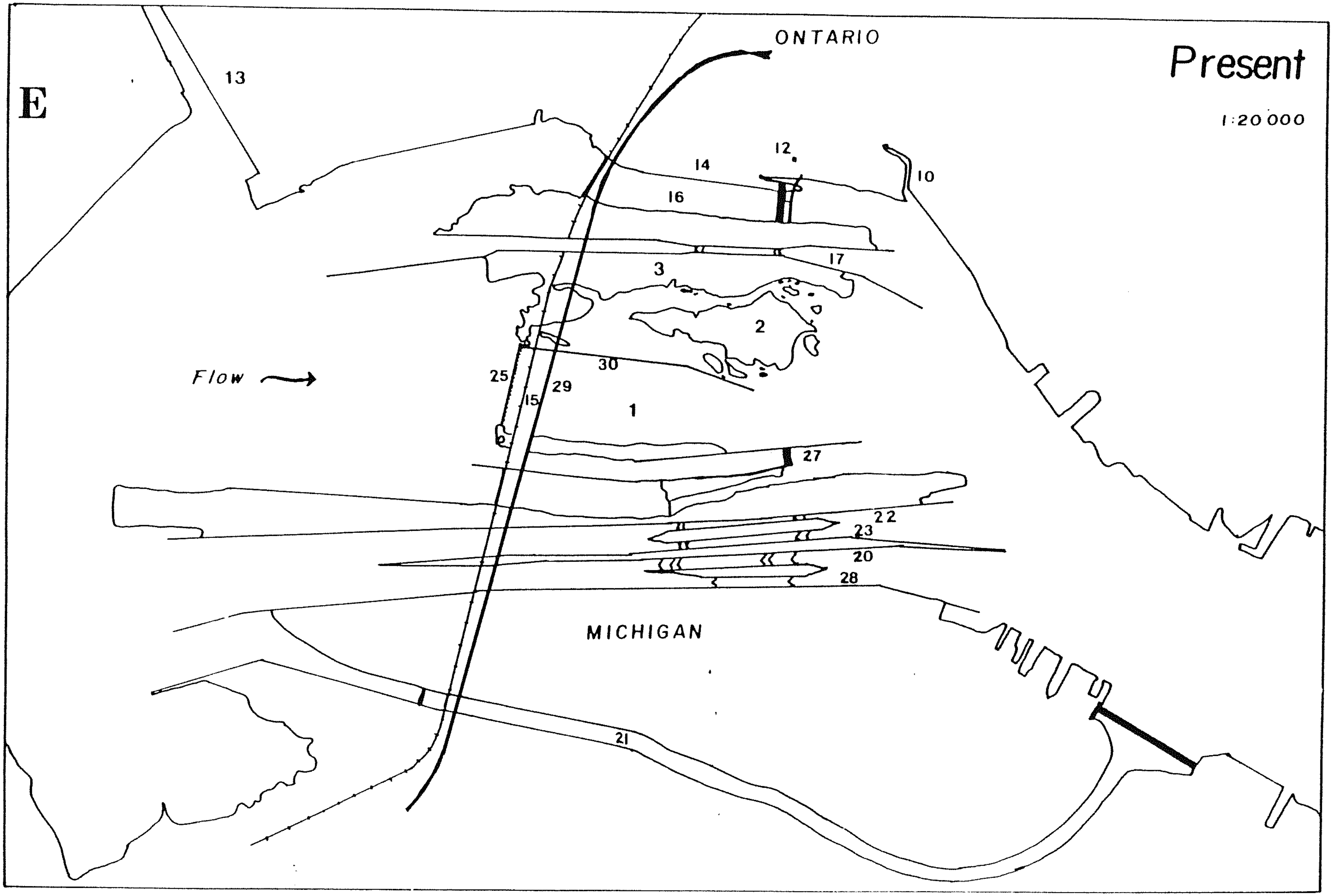
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Table 4.1. Chronology of events effecting change in the St. Marys Rapids Area. (Numbers refer to map series in Figure 4.1)

Year	Event	Map
1797	Northwest Co. lock is built for canoes on the Canadian shore; destroyed during the War of 1812. (12)	A
1855	Construction of the St. Marys Falls Canal navigation lock on the American shore is completed. Enlarged in 1872 and out of service by 1893. (11)	A
1881	Weitzel Lock on the American side is completed. (19)	B
1888	International railway bridge crossing is completed. (15)	B
1894	Fish Hatchery is constructed on Island No. 3; moved to Fort Brady site in 1909. (18)	B
1895	Canadian locks and canal are completed. (17)	B
1896	Poe Lock is built on American side and old St. Marys Falls locks destroyed. (20)	B
1901	Construction of the 16 gate Compensating Works is begun; interrupted by WWI. (25)	B
1902	Sault Edison Electric Co. Canal and Power House is completed. (21) Algoma Steel opens. (13)	B
1907	U.S. hydroelectric plant is constructed. (24)	C
1914	Davis Lock is completed. (23)	C
1916	Great Lakes Power Co. canal and plant on Canadian side is completed. (16)	C
1919	Sabin Lock is completed; Weitzel Lock now out of service. (22)	C
1921	Compensating Works completed, discharge regulation begins.	C
1943	MacArthur Lock replaces Weitzel Lock. (28)	D
c1950	New U.S. Power Plant is constructed. (27)	D
1954	Poe Lock is out of service.	D
1962	International road bridge is completed. (29)	E
1968	Poe Lock is reconstructed and enlarged.	E
1986	A berm is constructed on the Canadian side to increase water flows alongside Whitefish Island for improving fish habitat. (30)	E

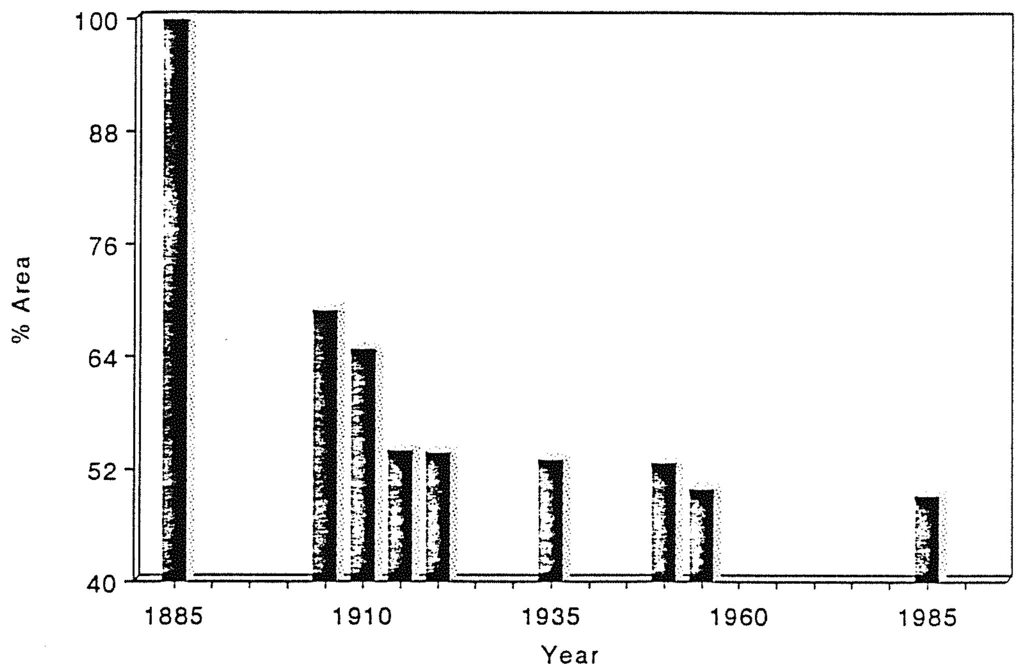


Figure 4.2. Percentage area remaining of the original St. Marys Rapids, 1885 - 1985.

a predominance of rocky or gravelly substrate suitable for fish, such as brook trout, slimy sculpin (*Cottus cognatus*), and longnose dace (*Rhinichthys cataractae*), and invertebrates, such as crayfish and Hydropsychidae. These species are present in the St. Marys Rapids and, with the possible exception of brook trout, are considered abundant (ILSBC, 1974; Koshinsky and Edwards, 1981) in what remains of the St. Marys Rapids. The loss of the Belle Isle Cascades, therefore, may represent more than an additional 10%.

Over a 65 year period, the state of Michigan suffered the loss of almost its entire portion of the rapids from the construction of locks and power canals. Figure 4.3-A to C illustrates the change in a portion of the rapids on the U.S. side over a period probably of fewer than fifteen years. The photo series depicts how the site of a productive and popular fishing ground was completely destroyed by the construction of the Chandler-Dunbar power house and canal. Interestingly, a spokesman for the Chandler-Dunbar Power Co., in hearings with the International Waterways Commission (IWC) regarding the outflow of Lake Superior, stated:

> "In the design of these works we have carefully kept in mind the necessity that we should be able to preserve the natural flow of the rapids, to pass the water on in exact quantities, and at such seasons as it would pass on were we not there at all" (IWC, 1913, p.143).

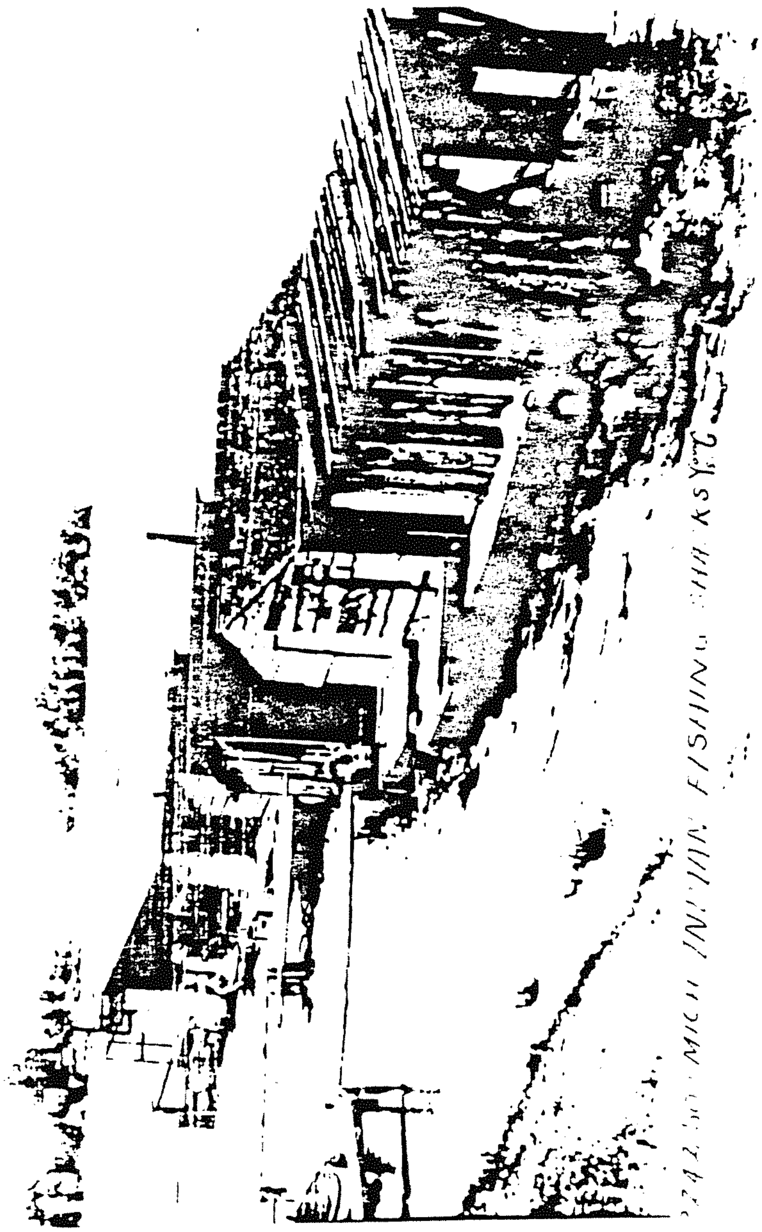
Further loss of rapids area may have come from the isolation of the main rapids area (now downstream of the Compensating Works) from the shoals upstream. While these shoals still exist, they were dredged for navigation purposes (U.S. Army Corps of Engineers, 1886; Canada Dept. of Public Works, n.d.) and possibly altered

Figure 4.3-A to C. Photographic series of the U.S. side of the St. Marys Rapids depicting the change as a result of the Chandler-Dunbar power house and canal from approximately 1895 - 1910. The building in the background with a peaked roof is the Fish Hatchery.

Photo A courtesy of the SSM Museum, SSM, Ontario.
Photos B and C courtesy of the Bayliss Public Library, SSM, Michigan. Reproduced by Materna Studios, SSM, Michigan.

A

FISHING IN THE RAPIDS SAULT STE. MARIE, CANADA



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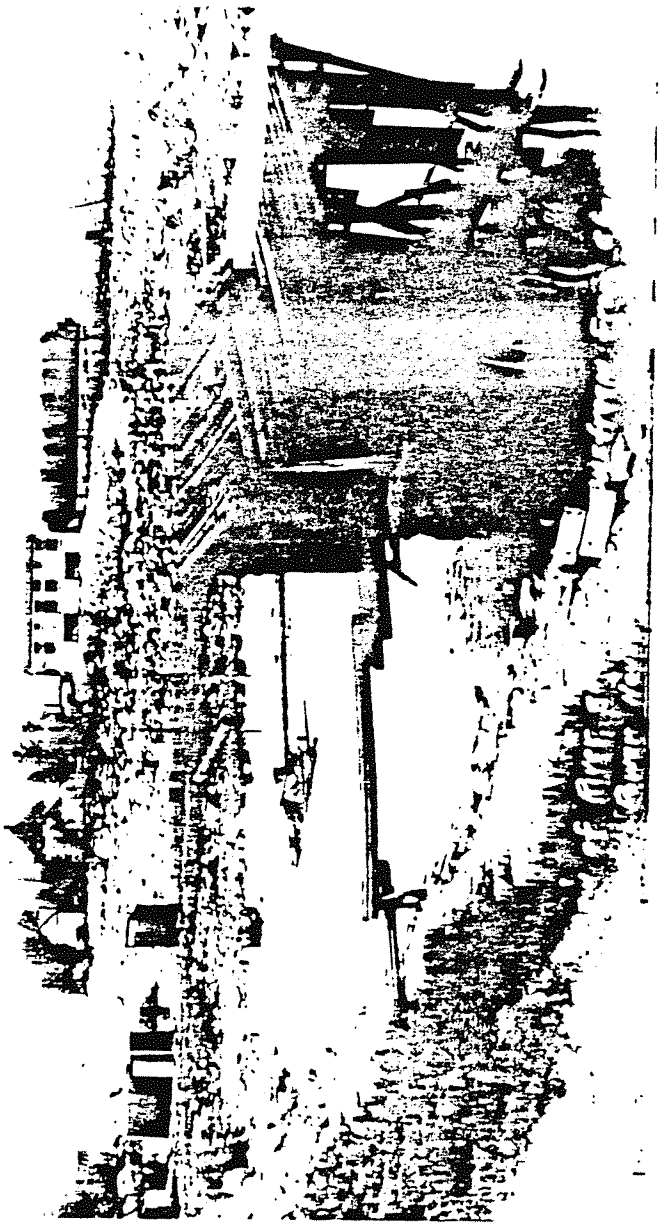

at the time of construction of the locks and Compensating Works. Damage to the shoals as productive habitat may also have occurred by isolating the area from the main rapids, creating difficulties for migrating fish, such as lake whitefish and lake trout.

4.0.2. Discharge Regulation

Water use conflicts arising from the use and diversion of water from the St. Marys Rapids for hydroelectric purposes and the need to maintain adequate levels in Lake Superior for navigation led to the construction of the Compensating Works across the head of the rapids. Completed in 1921, this series of 16 regulatory gates designed to "compensate" for power canal diversions allowed for complete control of the St. Marys River discharge (Figure 4.4). After regulation began, the mean annual discharge over the rapids dropped dramatically and both the frequency and amplitude of low and high discharges increased (Figures 4.5 and 4.6). Once the sole conduit of Lake Superior's outflow, the rapids now convey less than 50% of the total discharge, sometimes less than 10%.

The current plan of operation for the control of Lake Superior discharge gives priority for water to (1) navigation, (2) the St. Marys Rapids fishery, and (3) power generation (Krishka, 1989). In the years prior to 1921, however, concern for flows over the rapids centred only on having enough water for the passage of logs (IWC, 1913).

With regulation, gate settings depended on water needs of the power

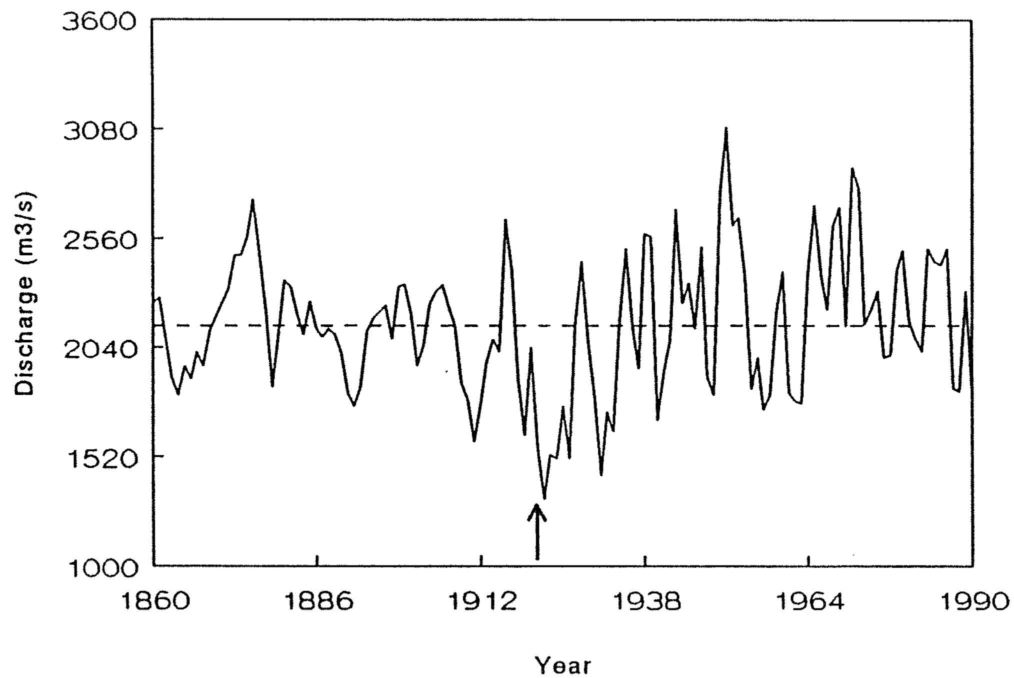

Figure 4.4. Mean annual discharge (m^3/s) of the St. Marys River, 1860 - 1990, measured at Southwest Pier gauging station below SSM. Arrow indicates the beginning of discharge regulation.

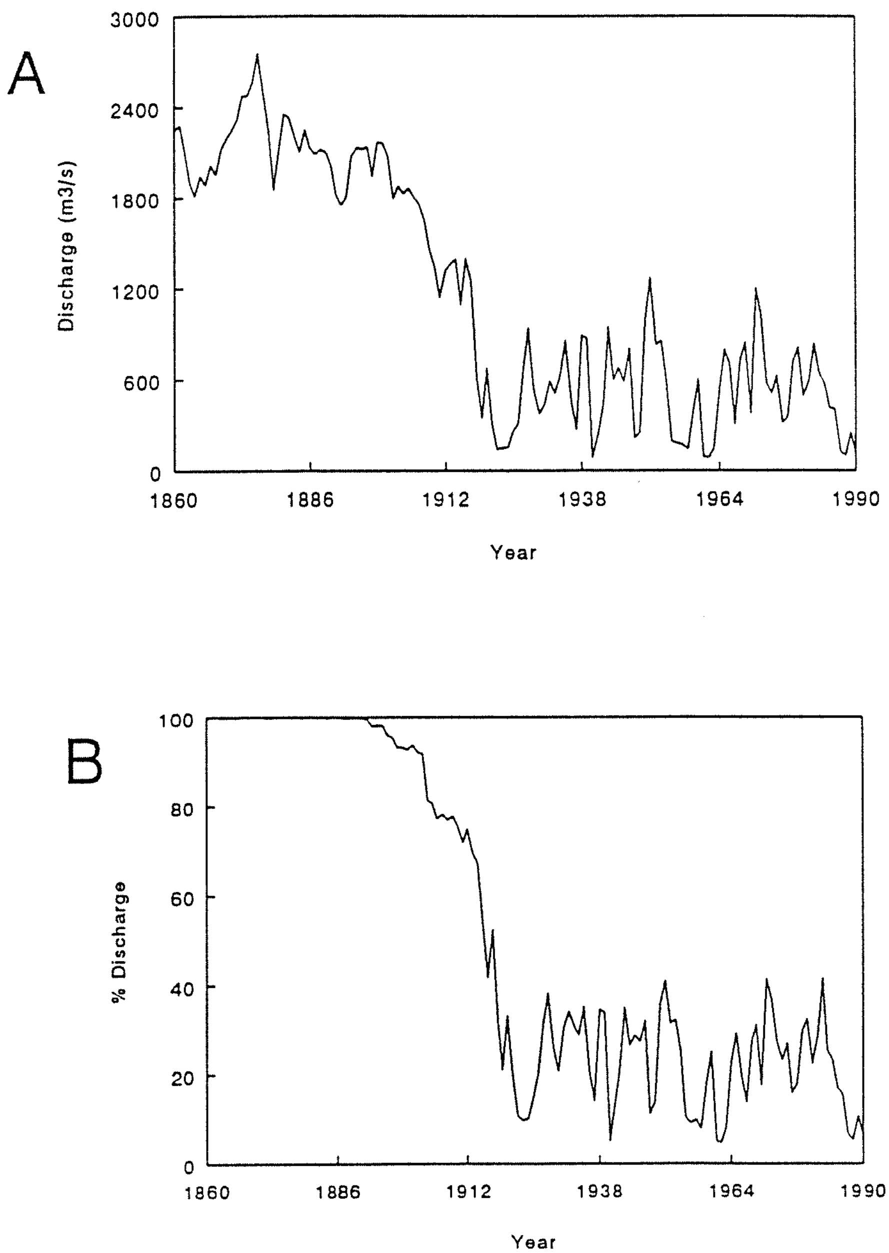

Figure 4.5. (A) Mean annual discharge (m^3/s) over the St. Marys Rapids and (B) mean annual discharge over the St. Marys Rapids as a percent of the total mean annual discharge of Lake Superior, 1860 - 1990.

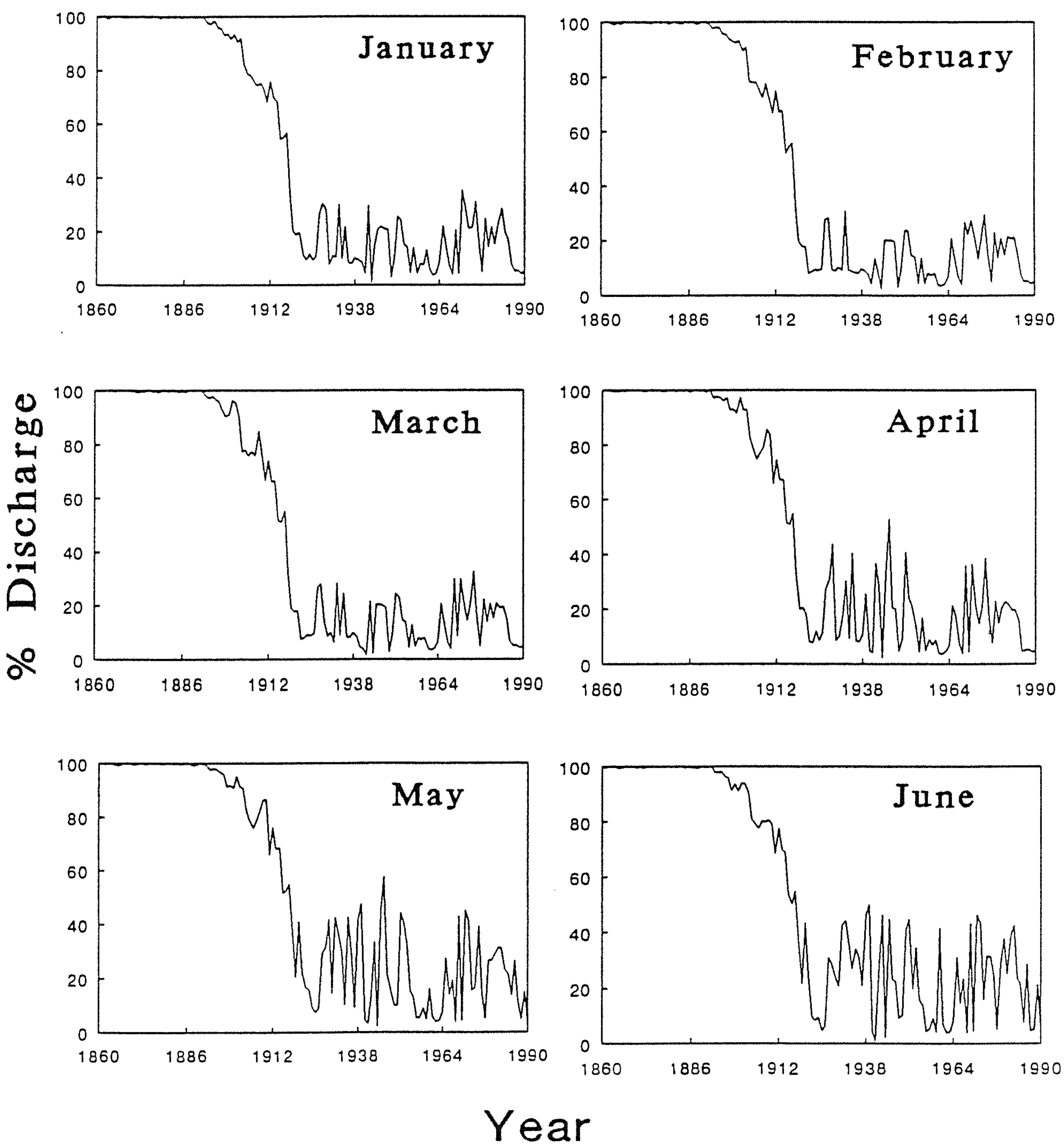

Figure 4.6. Mean monthly discharge over the St. Marys Rapids as a percent of total mean monthly discharge of Lake Superior, 1860 - 1990.

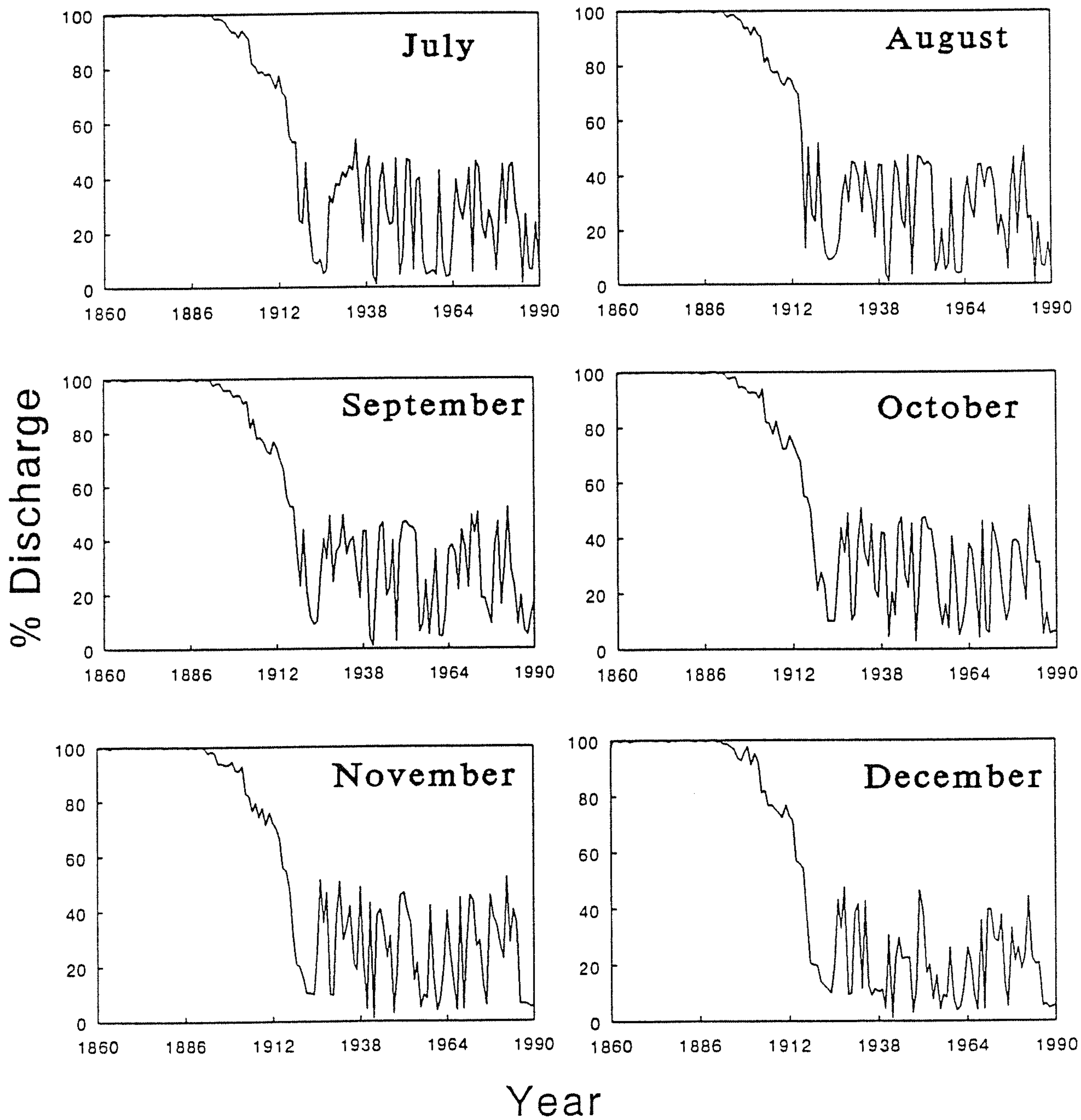

Figure 4.6. continued

companies and maintaining the level of Lake Superior. Since 1943, a minimum ½ gate setting has been maintained, although there were prior short periods when the rapids were dry during attempts to maintain Lake Superior levels (Hough et al., 1981).

Since the potential for hydroelectric power generation was realised in the rapids, there has been argument and negotiation over the distribution of the St. Marys River discharge among power companies. The frequency of high and low flows over the rapids was a concern for both power companies and agencies responsible for maintaining the fishery. The decline of the river fishery was considered by many anglers and some resource managers to have been the result of discharge regulation. In reply to complaints from the Izaak Walton League of America regarding the poor fishery, the Stream Control Commission of the Michigan Dept. of Conservation stated:

> "Some of us are more inclined to think that the seasonal and occasional regulation of the flow of the river as a result of the regulating locks operated by the federal government, for the purpose of maintaining a uniform level in Lake Superior, is much more liable to be a contributory cause to the difficulty.
>
> It has been observed apparently by some, that when flow stops down through the middle of the stream as it has at times, that fish are caught in pools on the rapids and expire there." (Mich. Dept. of Conservation, 1937)

During World War II, several letters expressing concern over the effects of rapidly changing water levels on young and small fish were sent to the Dept. of Conservation. It was at that time, when the Compensating Works were under the direction of the Dept. of War, that all of the gates were closed for a few months. The Dept. of Conservation was of the opinion that the changing water levels were detrimental to aquatic life, but that more evidence was needed (Mich. Dept. Cons., 1943).

Of note is that occurrences of the rapids running dry were not always the result of discharge alteration, as reports of no water in the rapids were made before 1855, when the first major engineering work was begun. Strong winds from the east were reported to cause part of the rapids to dry (from Collins' report in 1788 in Ross, 1922) and the current at Fort Brady (SSM, Mich) to reverse (Foster and Whitney, 1850). Wind-driven seiches on Lake Superior or Lake Huron were a probable cause (A. Ruffman, President Geomarine Associates, pers. comm, June 1992).

> "In the summer of 1834, an extraordinary retrocession of the waters took place at the Saut Ste. Marie. The river here is nearly a mile in width, and the depth of water over the sandstone rapids is about two and a half feet. The phenomenon occurred about noon. The day was calm, but cloudy. The water retired suddenly, leaving the bed of the river bare, except for the distance of about twenty rods, where the channel is deepest and remained so for the space of an hour. Persons went out and caught fish in the pools formed in the depressions of the rocks. The return of the waters is represented to have been sudden, and presented an imposing spectacle. They came down like an immense surge - roaring and foaming; and those who had incautiously wandered into the river-bed had barely time to escape being overwhelmed." (Foster and Whitney, 1850, p. 50-51)

4.0.3. The Instream Flow Model

The IFIM assumes that stream organisms respond to a set of physical conditions which, if known, can be used to predict habitat suitability, but not biomass, under varying flow conditions (Gore and Nestler, 1988). Application of the IFIM to the St. Marys Rapids was intended only as a tool to compare and evaluate the potential effects of the discharge regime on the rapids' inhabitants.

All estimates of useable area for the target organisms are most likely overestimates since only one weighting factor was used. Newcombe (1981) used only depth and velocity variables to determine instream flow suitabilities for salmonids and suggested that the use of only one variable may be sufficient. Also, while substrate and velocity variables are usually considered to be more important in determining habitat suitability for benthic invertebrates, abundances have been found to decrease with increasing depth (Cellot et al., 1984; Jowett and Richardson, 1990).

For comparison with the WUA for the target organisms, an estimate of only useable area (UA) over time was prepared (Figure 4.7). This shows the change in wetted area of the rapids with discharge and does not include any suitability factors.

Figure 4.7 (A) shows that, most of the time, greater than 70% of the rapids area was under water and potentially available as aquatic habitat, with the greatest area occurring in the months of highest discharge: August to October (Fig. 4.7-B). The decade of mean monthly %UA's is an example of how UA fluctuated on an annual cycle (Figure 4.7 - C).

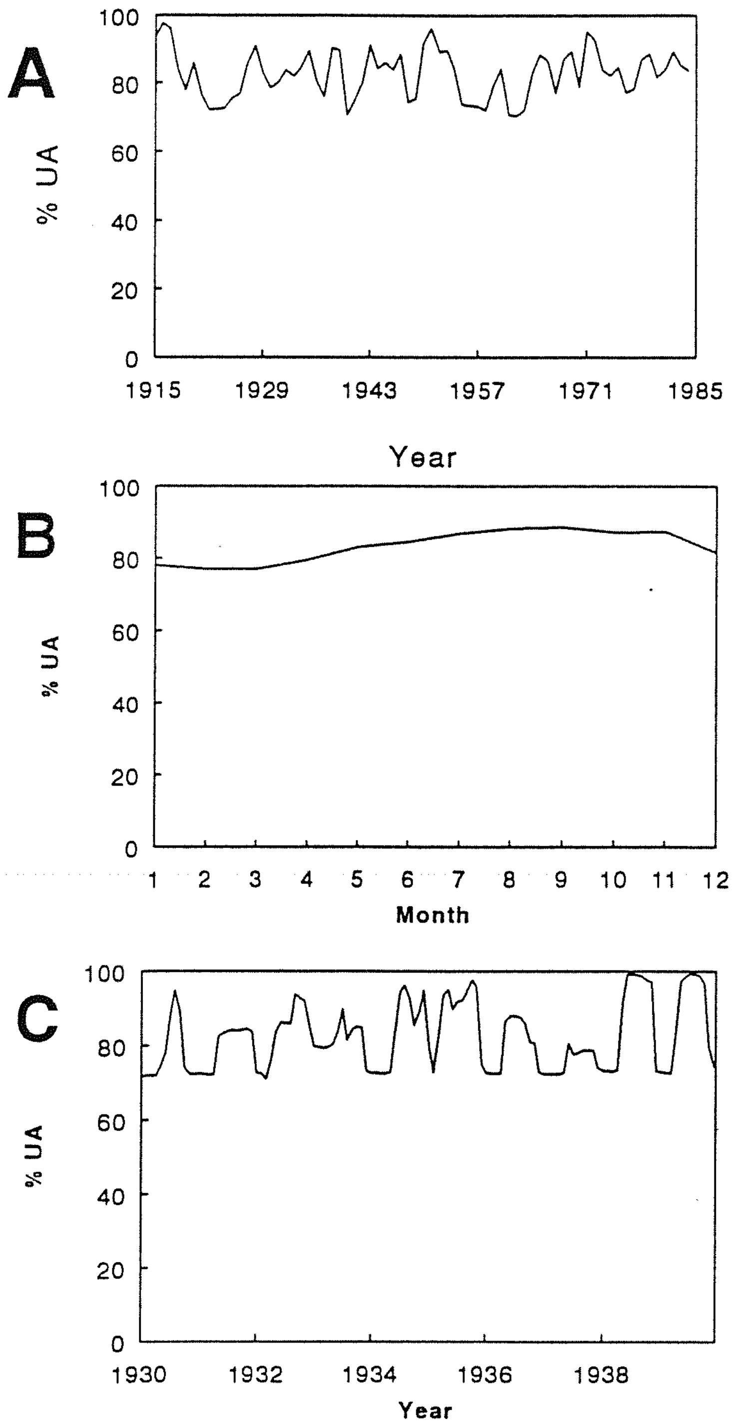

Figure 4.7. (A) Time series of percent area useable aquatic habitat (%UA), 1915-1984, (B) mean monthly %UA, 1915 - 1984, and (C) mean monthly time series, 1930 - 1939.

4.0.3.1. *Hydropsyche sp.*

Hydropsychids are collector-filterers which commonly cling to the hard substrate of swift flowing streams and rivers (Hynes, 1970; Merritt and Cummins, 1984). They are case-less, net-spinning caddisflies which depend on a swift current for oxygen.

The relationship between percent WUA and mean annual discharge (Q) (m^3/s) was found to be described by the equation:

$$\%WUA = 19.097 + 0.146\ Q - 0.000092\ Q^2$$

($r = 0.99$) (Figure 4.8). (r values for all equations in the IFIM are significant at $p < 0.05$).

The assumption that Hydropsychids potentially occupy the entire rapids area may have positively biased the WUA estimate. The most comprehensive survey of benthic macroinvertebrates in the rapids did not include most of the American side which is generally deeper with a substrate comprised of more flat slabs and bedrock, nor Whitefish Channel which was not always flooded (ILSBC, 1974). That study concentrated on the south side of Whitefish Island, venturing out as far as the international border only at the eastern edge of the rapids. The greatest densities of *Hydropsyche sp.* were found south of the western tip of Whitefish Island above the water's edge at a ½ gate setting (Koshinsky and Edwards, 1981). The benthic community on the American side of the St. Marys Rapids is largely undocumented.

Depth as a suitability weighting factor for Hydropsychids resulted in a %WUA ranging between about 40 to 80%. A 1 or ½ gate setting results in the loss of most

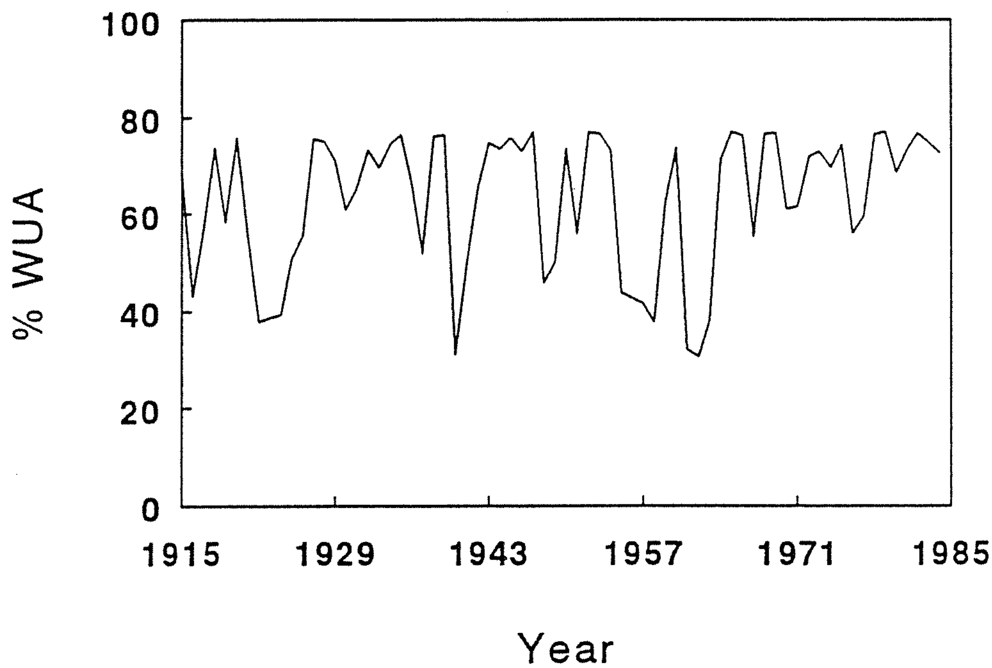

Figure 4.8. Annual habitat time series for *Hydropsyche sp.*, 1915 - 1984.

of the habitat along the south side of Whitefish Island. Hydropsychids are more likely to be found along riversides and in shallow water. This increases the variability in substrate and the availability of food although Hydropsychids have been found in the deeper mid-channel areas of large rivers (Cellot et al., 1984). It is conceivable, therefore, that the rapids in their entirety once supported Hydropsychids. In the 1870's, Smith (1874) found "great numbers of larvae and pupae and subimagos of *Hydropsyche*" (p. 708) along with molluscs, Diptera, Ephemeroptera, and Chironomids in the stomachs of whitefish taken from the St. Marys Rapids.

Since the eradication of most of the American side of the rapids with its channels and islands, the Canadian Whitefish Island area is probably the most productive part remaining in the rapids. Any reduction in discharge which reduced wetted area around Whitefish Island was probably not compensated for by any increase in suitability along the U.S. side. Not only is habitat dewatering a significant influence on abundance of net-spinning caddisflies, but the reduction in current velocity in the open channel may also lead to declines in abundance (Weisberg et al., 1990).

The mean monthly % WUA for the whole period (1915-1984) and for one decade (Figure 4.9-A & B) shows that on average approximately 60 to 70% of the area was suitable for Hydropsychids over the years. The higher WUA values correspond to the critical periods of caddisfly oviposition, incubation, and hatching. Hydropsychids deposit egg masses from May to September and are thought to have an incubation and hatching period of 8 to 11 days (Merritt and Cummins, 1984).

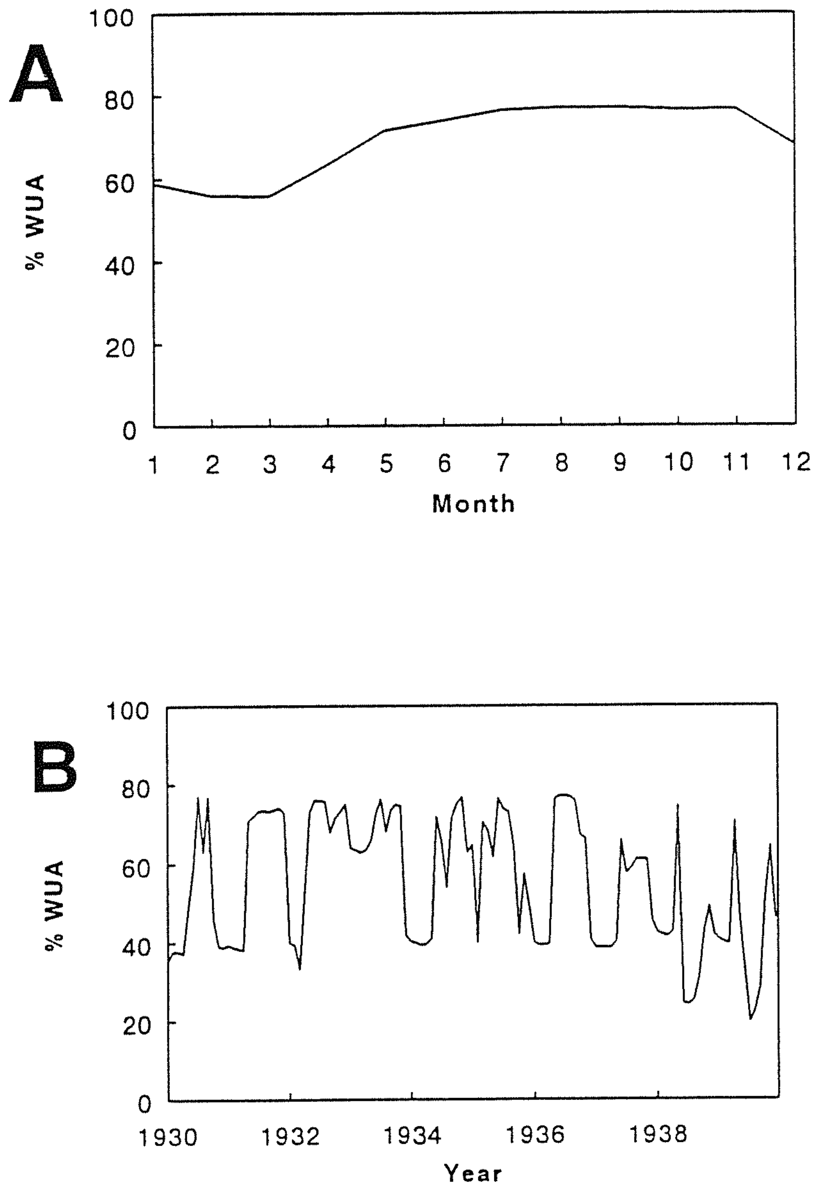

Figure 4.9. (A) Mean monthly %WUA, 1915 - 1984, and (B) monthly habitat time series, 1930 -1939, for *Hydropsyche sp.*

Emergence usually occurs from May until October (Cellot et al., 1984). The ten year mean monthly cycle (Figure 4.9-B), however, shows that values as low as 20% WUA can occur in periods of low water. Should velocity and perhaps substrate be added to the equation, the overall %WUA could drop even further.

Fluctuations in the abundance of Hydropsychids may be more significant than direct effects of discharge on the fish themselves (Irvine et al., 1987). Fish in the St. Marys Rapids may not be limited by space regardless of discharge, especially if nearby habitats are not fully exploited or the rapids is used only as a feeding ground. Whitefish, for example, although it is unclear whether or not they actually spawn in the rapids (Koshinsky and Edwards, 1981), are found there almost all year, and congregate during their fall spawning season. Other areas of the river are known spawning grounds for lake whitefish (Goodyear et al., 1982; Behmer et al., n.d.).

4.0.3.2. Rainbow Trout

Intentionally introduced into the St. Marys River around 1895, the rainbow trout has become a mainstay of the sport fishery. Within 10 years of its introduction, there were reports of 2 to 4 kg-sized fish (MSBFC, 1909) and rainbow trout of 5 kg and more were reported in later years. A 6 kg rainbow trout measuring 80 cm in length was taken in 1923 at the foot of the rapids (Sault Daily Star, 1923).

A summary of results of the IFIM for rainbow trout, including applicable figure references are presented in Table 4.2.

Table 4.2. Summary of results of the IFIM for rainbow trout.

Life Stage	Equation of the Line of Best Fit	r value*	Figure
Adult and Juvenile	$\%WUA = -106.026 + 28.27 \ln Q$	0.99	4.10-A
Spawning	$\%WUA = 8.833\ Q^{0.334}$	0.98	4.10-B
Fry	$\%WUA = 69.25\ e^{(-0.0024Q)}$	0.97	4.10-C
Combined	$\%WUA = -6.74 + 0.211\ Q - 0.000093\ Q^2$	0.97	4.11

*r values significant at $p < 0.05$

The habitat time series for individual and combined life stages of rainbow trout shows much more variation in %WUA than the Hydropsychid caddisflies. WUA for adult trout ranged from 20 to almost 100% and spawning stage trout 40 to 100%. The habitat time series for rainbow trout fry, however, is the reverse image of the adult. The use of mean depth measured across the width of the rapids has negatively biased the fry suitability score. Fry prefer shallower, more sheltered areas (Raleigh et al., 1984; Waite and Barnhart, 1992) which, in the case of the St. Marys Rapids, would include the slower current and increased cover afforded by Whitefish Island and Channel. In years of low discharge, the %WUA for fry increased while that for the other life stages decreased. Adult and spawning stage rainbow trout %WUA are similarly affected by discharge, the adult stage responding more to the lower discharges. The combined life stage %WUA estimate (Figure 4.11) shows a range of values from a low of near 10% of the total area to fully 100%.

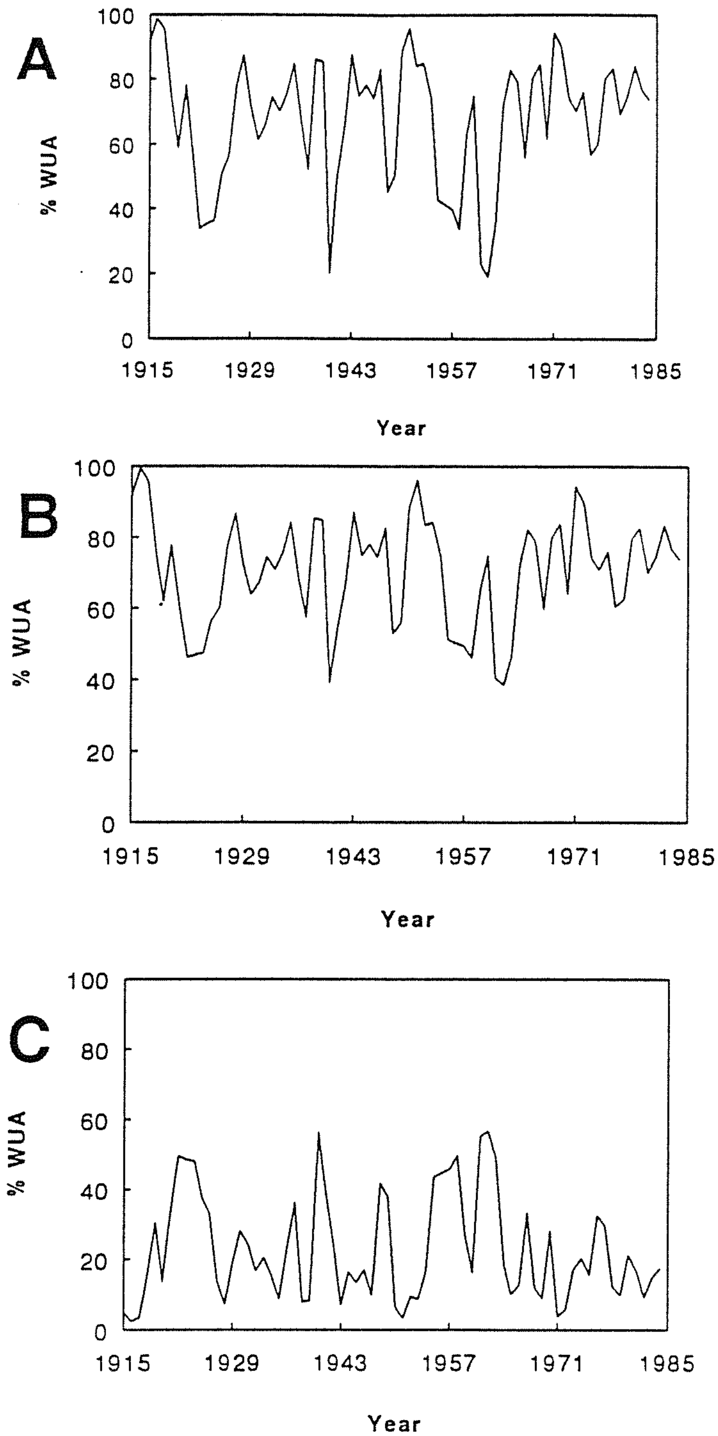

Figure 4.10. Annual habitat time series for rainbow trout at (A) adult and juvenile, (B) spawning, and (C) fry life stages, 1915 - 1984.

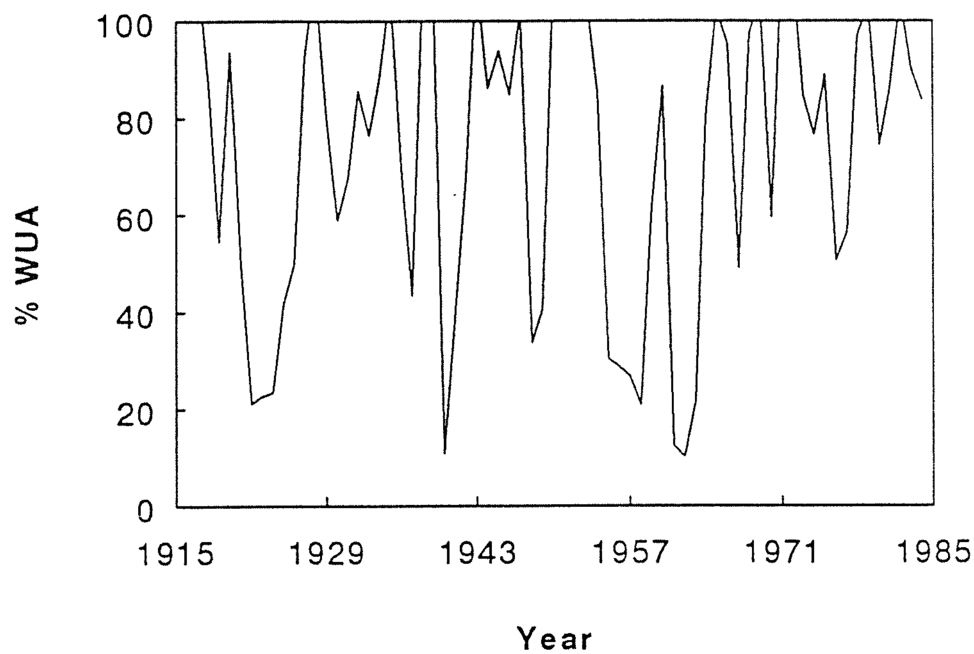

Figure 4.11. Annual habitat time series for combined life stages of rainbow trout, 1915 - 1984.

Suitability curves are usually prepared for species in stream habitats as few instream flow studies are done on large rivers. Preparation of site-specific curves is the most accurate way of determining WUA estimates, the lack of which is a criticism of many studies. Waite and Barnhart (1992) used four different curves, including those of Raleigh et al. (1984) that are used in this study, for comparing WUA of rainbow trout juveniles and fry. They found that velocity was the main source of differences in WUA although they also cite another study in which SI curves for depth were the main cause of variation in estimates of WUA. Interestingly, however, all curves in the Waite and Barnhart (1992) study resulted in the same shape of WUA estimate, only the magnitude was different. The Raleigh et al. (1984) curves were intermediate between those developed by Bovee (cited in Waite and Barnhart, 1992) and curves developed on site.

Although the exact dates of rainbow trout spawning in the St. Marys Rapids are unknown, it is believed that most spawn in June with a possible fall run as well (pers. comm. A. Dupont, OMNR, SSM District). Figure 4.12 illustrates that %WUA generally increases for adults and spawning stage (including embryo) rainbow trout within the annual cycle as spawning begins, but decreases for fry. The increase in discharge in the late summer and fall months results in a lower SI score for fry from increased water depths. If velocity was included as a weighting variable, the WUA estimate for fry could be even lower in the summer and fall months because of the higher discharge.

More than the occurrence of low flows, increased fluctuations in mean

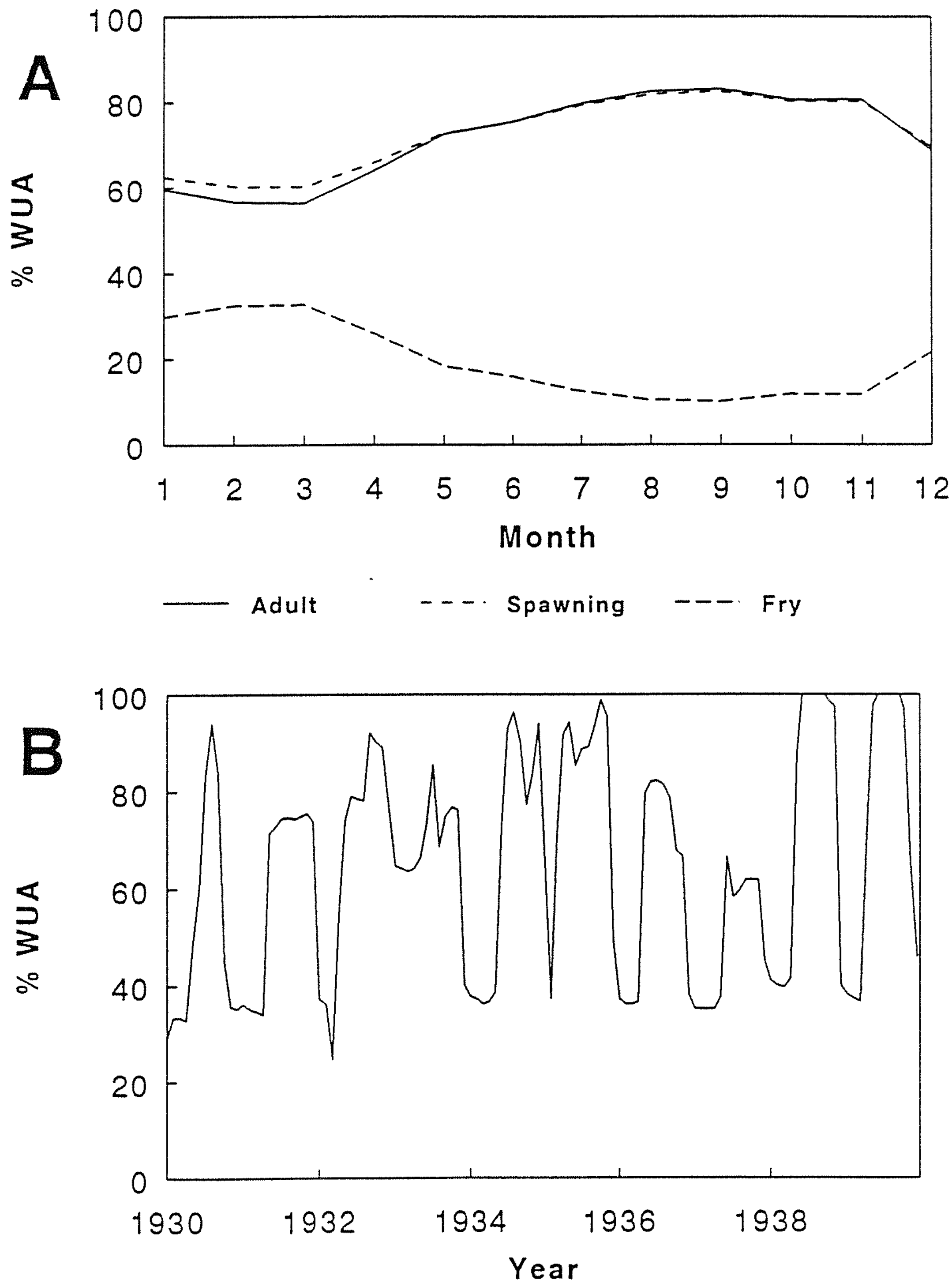

Figure 4.12. (A) Mean monthly % WUA for adults, spawning stage, and fry, 1915 - 1984 and (B) monthly habitat time series for adult rainbow trout, 1930 - 1939.

monthly and annual discharges as a result of discharge regulation may be responsible for imbalancing the rapids system and creating a habitat of unpredictable and varying suitability. Nelson (1986) found that large daily flow fluctuations generally led to poor yearling crops of brown trout (*Salmo trutta*). He concluded in his study that stream discharge was the most important factor in determining standing crops of trout because of the wide seasonal and annual variations in flow due to stream regulation. Despite the lack of historical daily discharges for the St. Marys River, the mean monthly and annual flows illustrated in Figures 4.5 and 4.6 show how widely the discharge can fluctuate.

However, as mentioned previously, habitat for species such as the rainbow trout, may not clearly be limited directly by changes in flow of the St. Marys Rapids. Food, spawning substrate, cover, temperature, or competition for space may also play important roles (Binns and Eiserman, 1979; Bowlby and Roff, 1986; Irvine et al., 1987).

4.1. Aquatic Vegetation

The St. Marys River wetlands are similar in form to other coastal wetlands of the Great Lakes having a zone of submerged vegetation farthest from shore, followed by emergents and then a zone of scrub-shrub and forest swamp (Smith et al., 1991; Williams and Lyon, 1991). The emergent/submerged vegetation communities are the major primary producers in the St. Marys River system. Emergents contribute 3 times more to primary production than submerged plants, and 20 times more than phytoplankton and periphyton combined (UGLCCS, 1988). Typically, stands of emergents in the St. Marys River are dominated by hardstem bulrush (*Scirpus acutus*), bur reed (*Sparganium eurycarpum*), and spike rush (*Eleocharis smallii*). Submerged vegetation on the U.S. side is dominated by two charophytes (*Chara globularis* and *Nitella flexilis*) and quillwort (*Isoetes riparia*) (Liston et al., 1986; McNabb et al., 1986; Duffy et al., 1987). Pondweed (*Potamogeton sp.*) and water celery (*Vallisneria americana*) are commonly found submerged plants in Canadian wetlands (OMNR, unpublished data).

While little is known regarding the overall contribution of Great Lakes coastal wetlands to fish production (Smith et al., 1991), aquatic macrophytes are known to play a significant role in determining community structure or abundances of some species (Durocher et al., 1984; Killgore et al., 1989). Forty-four species of fish in the St. Marys River depend to varying degrees on aquatic vegetation habitat for some of their needs (Jaworski and Raphael, 1978; Duffy et al., 1987). Many of these are forage fish, but the northern pike, yellow perch, muskellunge, walleye, smallmouth bass, and largemouth bass (*Micropterus salmoides*) are important game species using areas of aquatic vegetation for spawning, rearing, feeding, or shelter.

4.1.1. Areal Change and Water Levels

While the areal extent of emergent and submerged aquatic vegetation available as fish habitat has fluctuated from year to year, predominantly in response to changing water levels (Figure 4.13 and 4.14, Table 4.3), there has been little absolute loss of area from 1935 to 1981 as a result of human occupation or influence. The total area of aquatic vegetation along the Canadian shore changed with fluctuations in mean annual water level, ranging from a low of 1111 ha (1981) to a high of 2418 ha (1964), a difference of 1307 ha. Mean annual water levels ranged from 176.16 m to 177.17 m, a difference of 1.01 m (Figure 4.15).

Table 4.3. Area (ha) of emergent and submerged vegetation along the Canadian shore of the St. Marys River for each air photo series year and mean annual water level (m). The 1949 air photo series is incomplete (inc).

River Section	Year (Water Level)				
	1981 (176.77)	1973 (177.17)	1964 (176.16)	1949 (176.38)	1935 (176.34)
Upper river to Lake George	548	516	666	inc	827
St. Joseph Channel	94	217	339	inc	297
St. Joseph Island	469	918	1413	inc	1088
TOTAL Canadian Shore	1111	1651	2418	inc	2212

Williams and Lyon (1991) found an inverse relationship between water levels and emergent vegetation along the U.S. shore of the St. Marys River. A similar relationship between increasing water levels and decreasing areas of aquatic vegetation is seen in Figure 4.13 and some areas in 4.14 for the Canadian shore. The U.S. study found the greatest response to changing water levels in emergent class

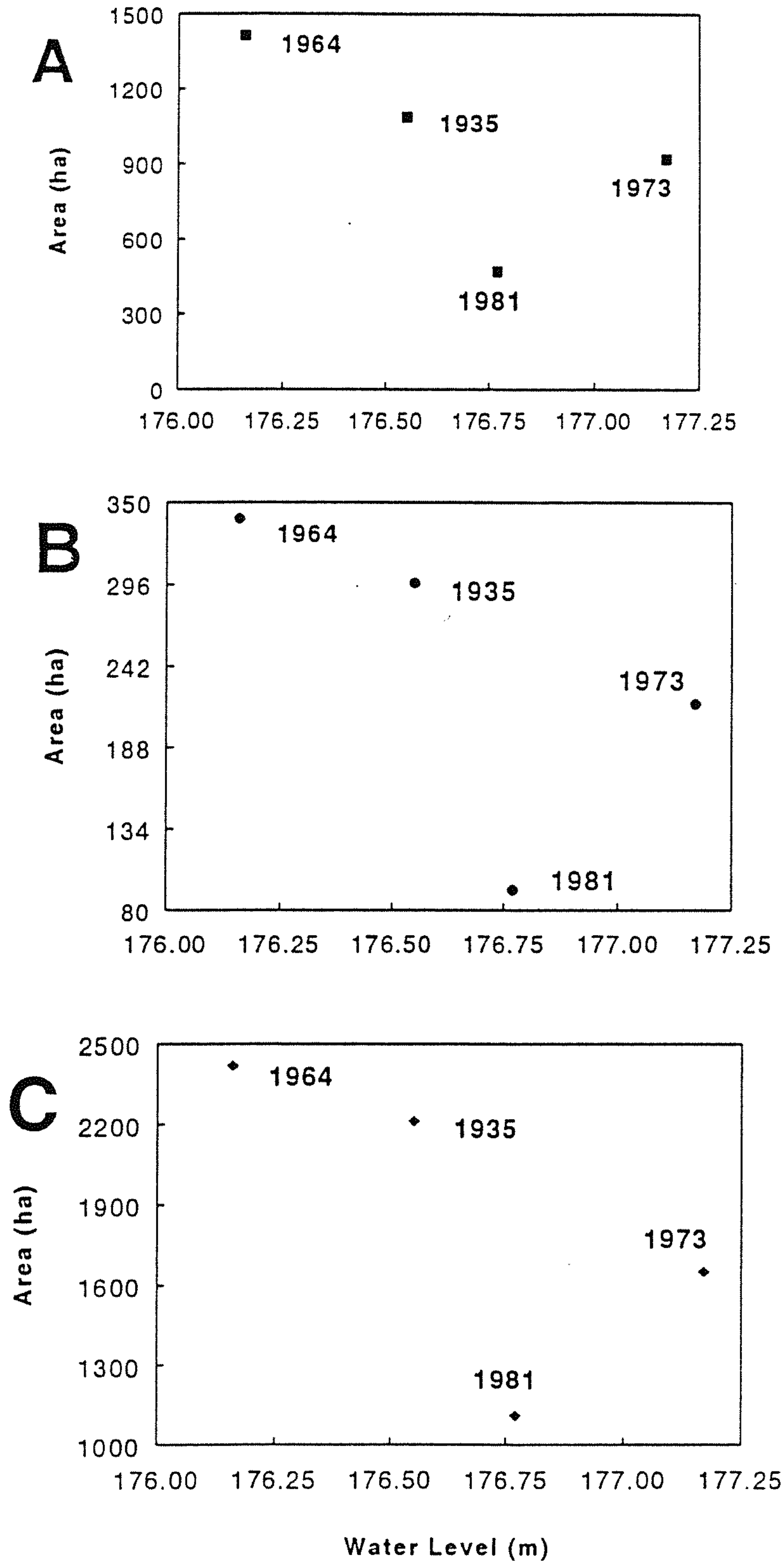

Figure 4.13. Area of emergent and submerged aquatic vegetation (ha) at mean annual water levels (A) St. Joseph Island, (B) St. Joseph Channel (from East Neebish Island to Hay Bay), and (C) the total Canadian shoreline.

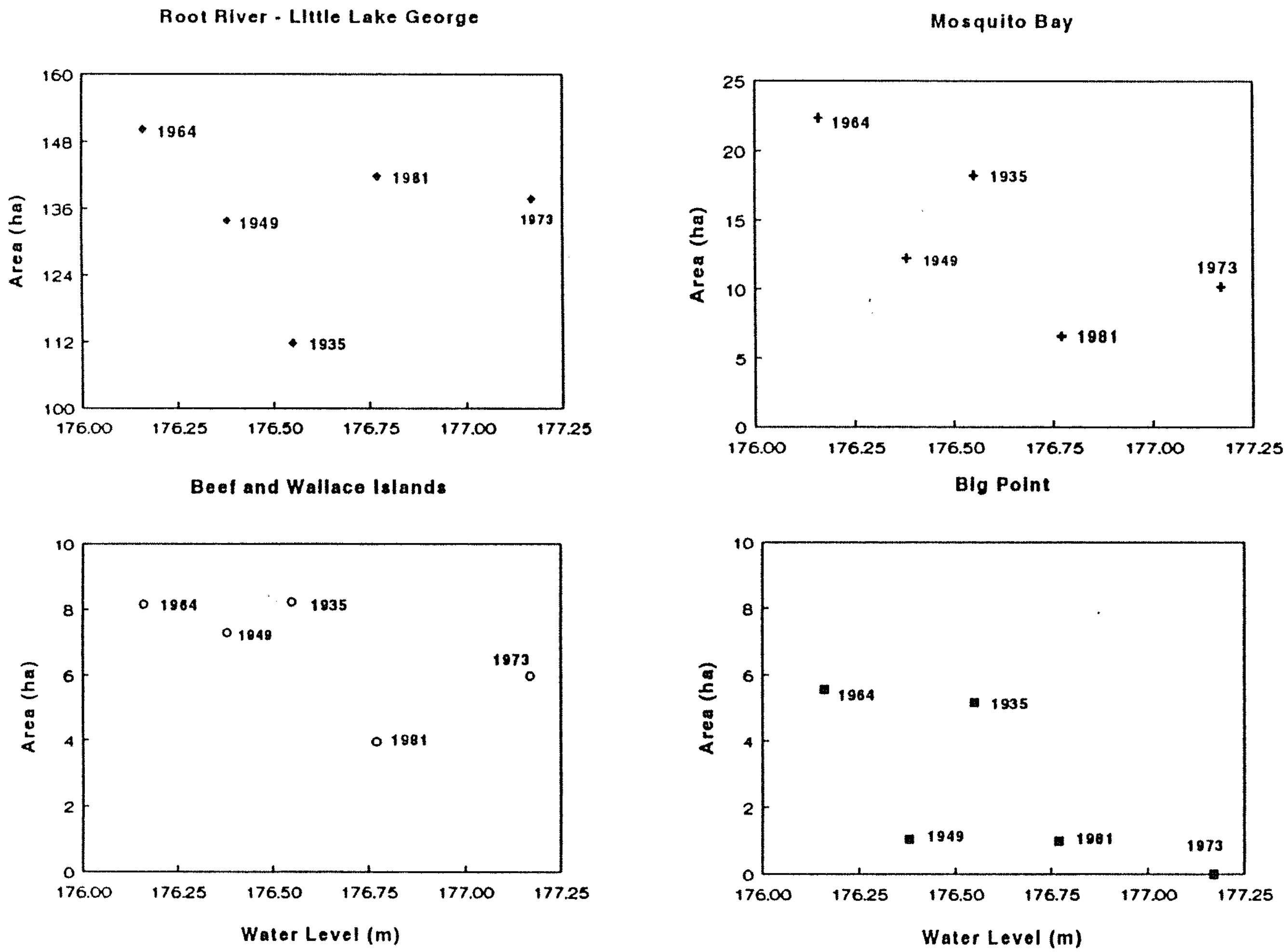

Figure 4.14. Area of emergent and submerged aquatic vegetation (ha) for specific locations in the St. Marys River for all years of air photo coverage.

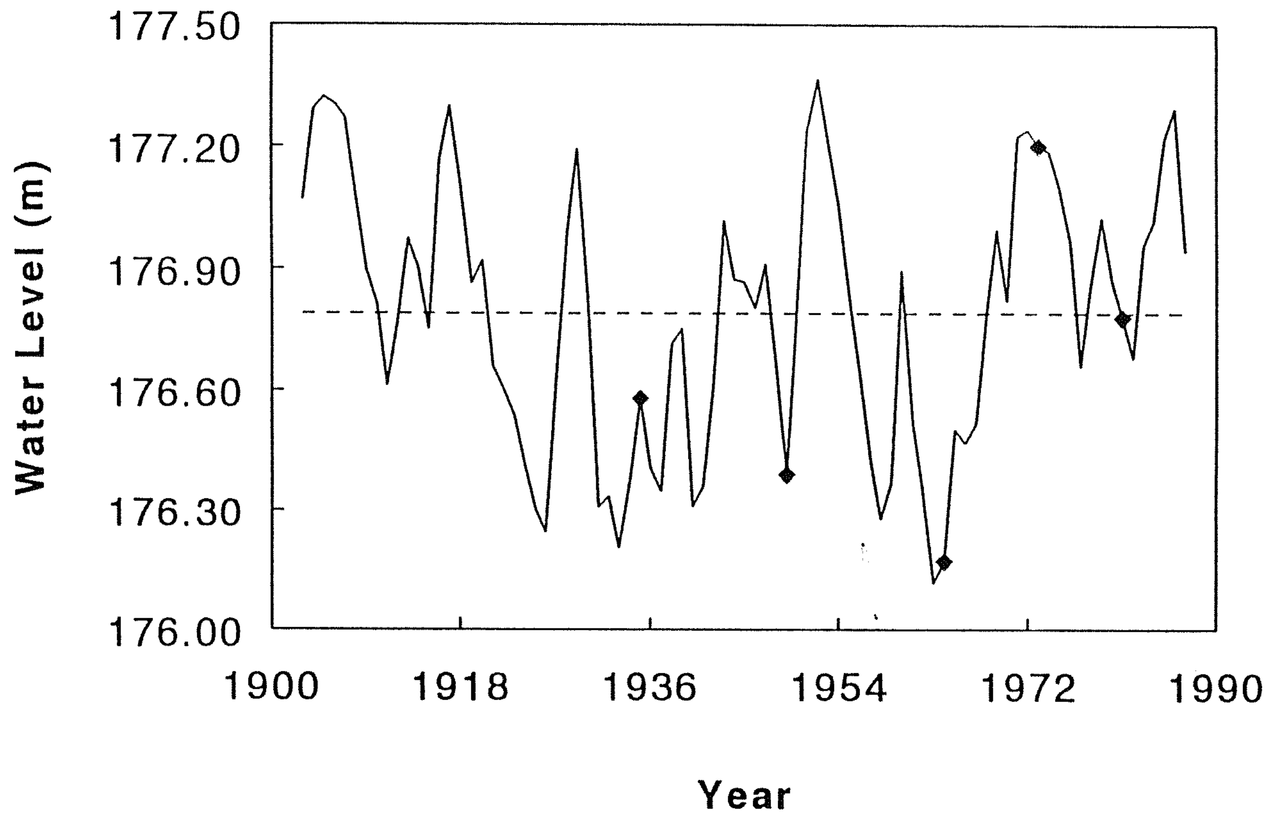

Figure 4.15. Mean annual water level below SSM, 1908 - 1988, markers indicate years of air photo coverage.

vegetation, whereas there was little change in total wetland area over time (1939-1985) (Williams and Lyon, 1991).

Most Great Lakes coastal wetlands, including those of the other connecting channels, are considered to be maintained in a state of early vegetational succession by what is termed 'pulse stability' (Herdendorf and Raphael, 1986; Williams and Lyon, 1991). Exposure to short and long-term water level fluctuations imposed by the actions of the Great Lakes prohibits advanced stages of succession and the eventual transformation of wetland to terrestrial environment (Herdendorf and Raphael, 1986).

The St. Marys River wetlands, however, tend to be disrupted less often by pulse events causing rapid changes in water levels. Williams and Lyon (1991) found that the negative relationship between areas of emergent vegetation and water levels on the St. Marys, while significant, to be less strong than for coastal wetlands on Lakes Michigan, Huron, and Erie. They suggest that the wetlands, or areas of emergent vegetation, may exhibit advanced successional growth due to greater protection from wind and wave action. Duffy et al. (1987) claim that within the past three decades, the plant communities of the St. Marys River wetlands have remained relatively stable in composition and distribution, the dominant species being hardy and long-lived.

It is unfortunate that no photographic record exists of the St. Marys River shoreline prior to discharge regulation for comparison with post-regulation photos. Of the five years of aerial photography analysed for aquatic vegetation, the annual mean water level for three years was well below the mean for the period on record (1935, 1949, 1964), only one year was significantly higher (1973), and one close to the mean level (1981) (Figure 4.15). While the greatest change in water level (among years surveyed) occurred between the years 1964 and 1973 (1.01 m in 9 years), this did not correspond to the greatest difference in area of aquatic vegetation (Table 4.3). Examining just the annual mean water levels it would seem that the area of aquatic vegetation in 1981 should have been higher than for 1973 since the water level had decreased. Between these years, only one year fell below the mean annual water level for the period on record (Figure 4.15). Continuous high water can cause significant die back of emergents within three to five years of flooding (Keddy and Reznicek, 1986). Emergent vegetation along the shore of the St. Marys River had little opportunity to reestablish, a circumstance which probably continued into the mid-eighties.

With the exception of the 1950's, the years following discharge regulation were predominantly low water years until the 1970's. During this time, the large stands of emergent vegetation had the opportunity to take hold in the river. Periodic high water levels would have served to maintain some diversity in plant communities along the water's edge and to curb some of the growth of woody plants and *Typha sp.*.

There can be only speculation regarding the area, species composition, and reaction to water levels of aquatic vegetation prior to discharge regulation. Travellers to the area wrote little of the lower river, but a few descriptions exist. In the early 1800's, Anna Jameson remarked: "we coasted along the south shore of St.

Joseph's [Island], through fields of rushes, miles in extent" (Jameson, 1838, p. 164). Bayliss and Bayliss (1938) cite John Bigsby's account of the area while he was with the British Boundary Commission. Going up St. Joseph Channel he described

> "the main [shore]...as a line of dark lofty cliffs, while the St. Joseph side is a marsh. Narrow as this strait is, it contains eighteen islets.... As the islets approach St. Joseph, they lower and have marshy coves." (p.83)

Although the record of water levels for the St. Marys River below the rapids does not reach beyond 1903, the pattern of fluctuations can be compared to a station in Lake Huron, such as Mackinaw City (Figure 4.16) which has a longer record of water level observations. Prior to the 1920's, water levels were generally higher, a trend which began in the early 1800's according to Bishop (1990). This may not have meant that more submerged vegetation existed. Periods of lower than normal water levels help establish plant species in deeper areas of the waterbody (Keddy and Reznicek, 1986). These events may have been necessary to allow for the growth of emergent stands, such as occurred in the mid 20th century. It is likely that there is presently more aquatic vegetation because of the four decades of mostly low water which promoted growth of shoreline plant communities. Recent high water years which have flooded these areas may have created more submerged vegetation.

Fluctuating water levels, however, are not the sole forces acting on aquatic vegetation stands in the St. Marys River. The scouring and eroding action of ice and ship traffic on the outward edge of plant communities are also important, although not well understood (Poe and Edsall, 1982; Williams and Lyon, 1991). Vessel traffic

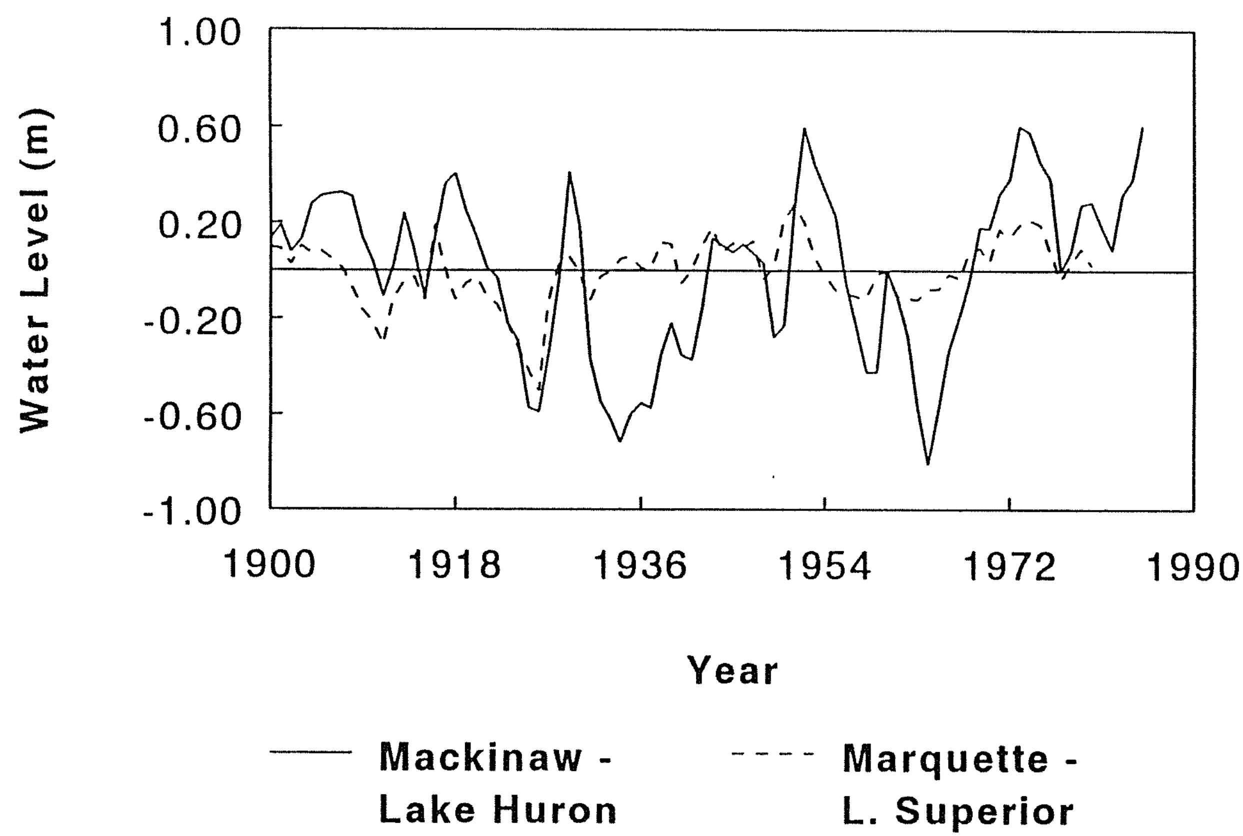

Figure 4.16. Variation (m) in mean annual water level from the mean on record for Mackinaw City, Lake Huron, and Marquette, Lake Superior, 1900 - 1985.

during ice cover creates more erosion of vegetation than when no ice is present (Poe and Edsall, 1982). Effects of ship passage on vegetation stands depend on the site characteristics and not necessarily ship size and speed, although McNabb et al. (1986) found that ship passage generally enriches wetlands through the influx of river sediments. McNabb et al. (1986), however, did not address frequency of passages in their investigation of the hydrologic effects of ship-passage on wetlands of Lake Nicolet.

It would appear from descriptions of early travellers to the St. Marys River area and the few air photos taken in the 1920's of the SSM area that the only real losses of aquatic vegetation occurred prior to regular air photo coverage and were confined to the Canadian shoreline at SSM and perhaps at Bruce Mines, both urban centres.

Early accounts of the area describe the shore at SSM, Ont. to have been low, wet, marshy ground. Describing the land on the Ontario side of the St. Marys Rapids in 1788, John Collins states:

> " The shore on the side opposite to the present forts is mostly low and wet and of that which is dry there is but a small proportion of it good land, the remainder is rocky; but the dry ground altogether is of no great extent for at 600 or 700 yards back from the shore the land falls into swamps and savannahs, and this for the most part is the case all the way between this and Lake George." (Ross, 1922, p. 45).

Another account c. 1815 describes much the same landscape:

> "The Canadian village is a straggling line of fifteen log-huts on a marshy ground...(Anonymous, n.d. b)

Low altitude, oblique aerial photography from 1927/28 shows remnants of this marshy ground where infilling and construction had not yet occurred (Figure 4.17). Today, the city's waterfront has changed considerably (Figure 4.1) and no longer supports the original swaths of aquatic vegetation.

The loss of what would only have been a small fraction of the total aquatic habitat of the St. Marys River may have been more important to overall productivity than loss of another, even larger, area of aquatic vegetation. The SSM shoreline vegetation may have provided important functions of refuge and food production for fish that had no other local wetlands options. Downstream, more opportunities were available if a similar area of habitat had been lost. The significance of the rapids as a centre of organisation could have been diminished with the loss of this peripheral habitat, helping to sever its vital connection with the river. Koshinsky and Edwards (1981) suggested that alterations to the rapids aided in the cessation of its contribution to the productivity of the St. Marys River.

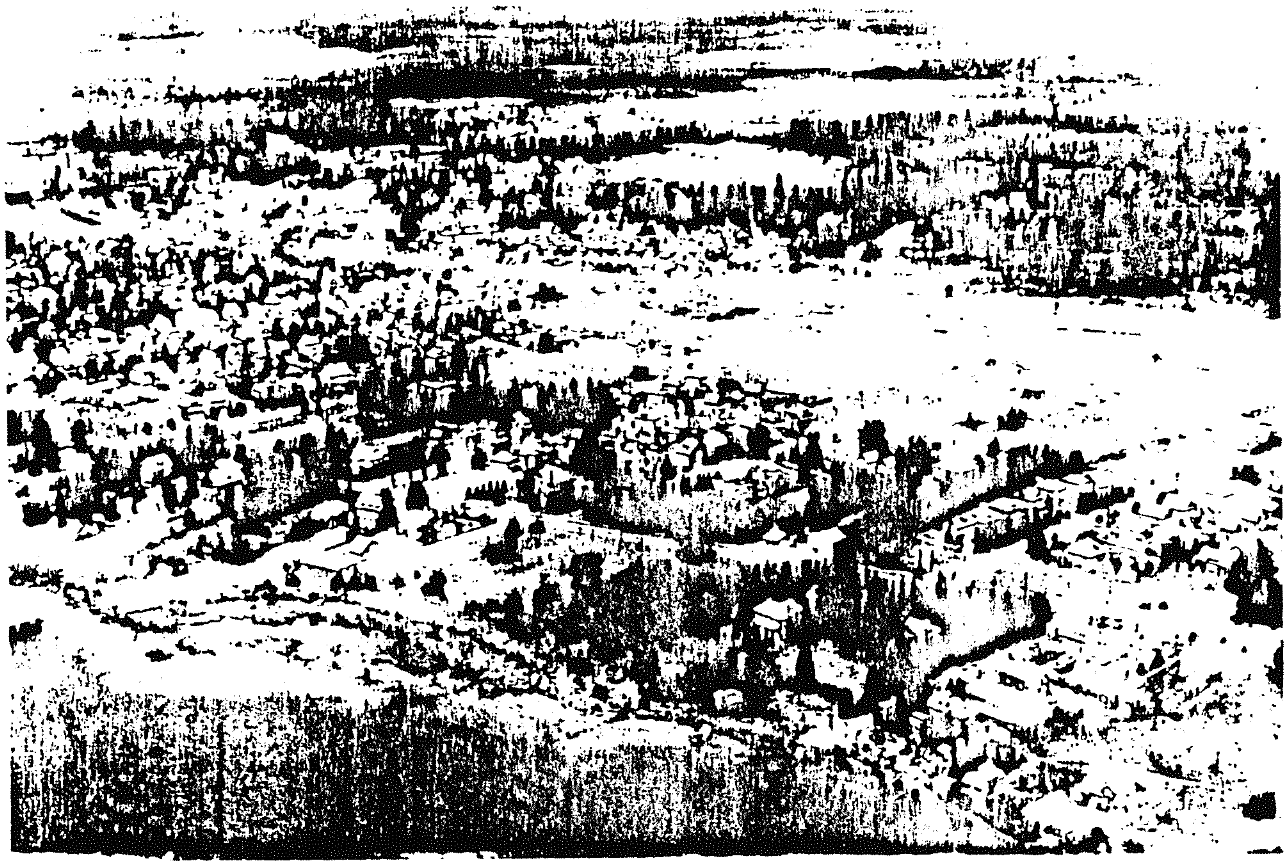

Figure 4.17. Oblique aerial view of SSM, Ontario, in 1927 showing the vegetated shore.

4.1.2. The Northern Pike Habitat Suitability Index Model

The results of the northern pike habitat suitability index are presented in Table 4.4.

Table 4.4. Habitat Suitability Index scores for northern pike.

Variable	Year	Value	SI Score
Drop in water level during embryo and fry stages (m) (V_2)	1981	increase	1.0
	1973	increase	1.0
	1964	increase	1.0
	1949	increase	1.0
	1935	increase	1.0
Percent of midsummer area with emergent and/or submerged aquatic vegetation (V_3)	1981	≤5	0.3
	1973	≤8	0.4
	1964	≤10	0.5
	1949	inc	inc
	1935	≤8	0.4
Least suitable pH in spawning habitat during embryo and fry stages (V_5) (Edwards, et al., 1989)	1981	6.7-8.4	1.0
	1973	6.7-8.4	1.0
	1964	6.7-8.4	1.0
	1949	6.7-8.4	1.0
	1935	6.7-8.4	1.0
Average length of frost free season (days) (V_6) (Duffy, et al., 1987)	1981	110	0.95
	1973	110	0.95
	1964	110	0.95
	1949	110	0.95
	1935	110	0.95
Maximal weekly average summer temperature (C) (1 to 2 m deep) (V_7) (Liston, et al., 1983)	1981	21-24	1.0
	1973	21-24	1.0
	1964	21-24	1.0
	1949	21-24	1.0
	1935	21-24	1.0
Stream gradient (m/km) (V_9)	1981	0.05	1.0
	1973	0.05	1.0
	1964	0.05	1.0
	1949	0.05	1.0
	1935	0.05	1.0

Interpreting the results as outlined in the model leads to a conclusion that habitat suitability was lowest in 1981 and highest in 1964 (Table 4.4) because the ratio of the area of aquatic vegetation measured from the air photos to the total midsummer area of aquatic vegetation calculated from hydrographic charts was highest in 1964 and lowest in 1981. The total HSI score for northern pike is equal to the lowest suitability score of the variables in the model. The actual score should most likely be reversed so that the year of highest suitability would correspond to the year of lowest measured aquatic vegetation. This is not necessarily a fault of the model but rather a result of measuring vegetation from aerial photographs, where years with lower annual water levels reveal more vegetation than years of high water levels.

Low water levels result in increased growth of emergents, whereas high water conditions usually cause a die-back of emergent vegetation and an increase in growth of submerged and floating-leaved plants (Keddy and Reznicek, 1986). This would mean that in years of high water levels, the amount of habitat for fish species, such as the northern pike which prefer submerged vegetation (Holland and Huston, 1984), would actually increase. Northern pike are particularly vulnerable to changes in water levels as they tend to spawn in very shallow water (Inskip, 1982).

In Figure 4.18, the annual catch per trap net of northern pike from one commercial operation in Potagannissing Bay from 1909 to 1938 is compared to the corresponding mean annual water levels. The catches are considered to reflect the relative abundance of fish species in the bay at that time (Westerman and Van

Oosten, 1939). Higher catches of northern pike are recorded two to three years following periods of high water levels. Risotto and Turner (1985) state that the most appropriate lag time in the investigation of the effects of water levels on fishery yields depends on the time required for the fish to reach size at capture. In the St. Marys River, most northern pike caught in a 1987 fisheries survey in Potagannissing Bay were 1 to 4 years old (Grimm, 1989). This is by no means conclusive evidence as there is no significant correlation and confounding factors are numerous.

Other researchers have found positive correlations between high water level and year class strengths for largemouth bass (Miranda et al., 1984), walleye, and yellow perch (Kallemeyn, 1987). This relationship appears to result from an increase in area made available not only for spawning, nursery, and shelter, but for food production as well. Inundation of floodplain areas releases valuable nutrients from soils and vegetation (Risotto and Turner, 1985; Miranda et al., 1984). Northern pike, which spawn in areas of flooded emergent and submersed vegetation (Holland and Huston, 1984) may benefit from the increased habitat available in years of high water levels.

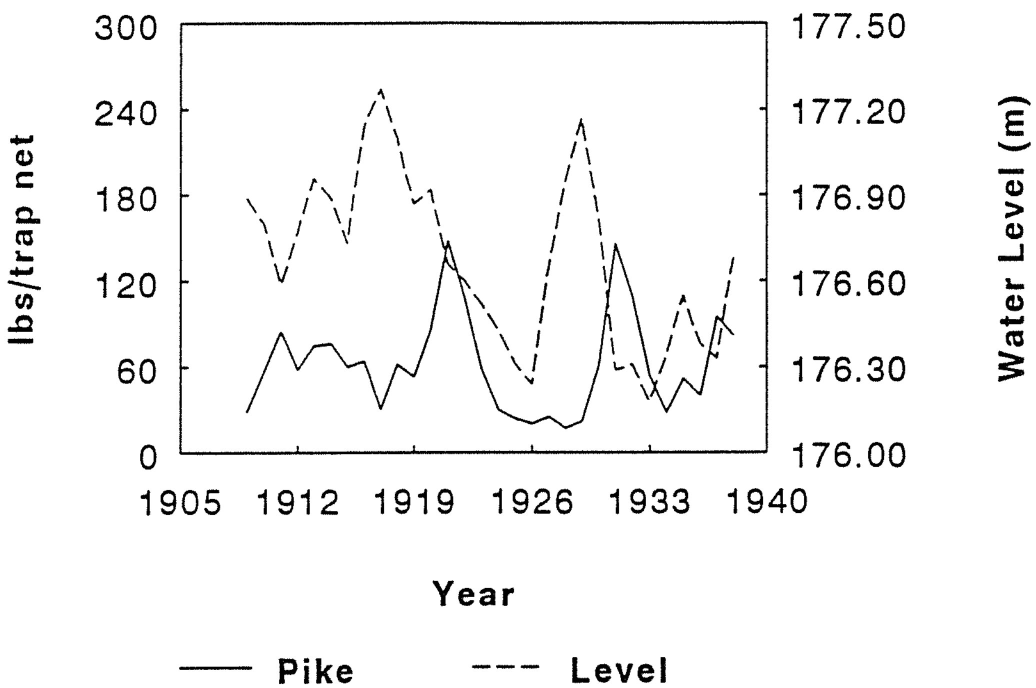

Figure 4.18. Annual catch of northern pike per trap net from one commercial fishing operation in Potagannissing Bay, 1909 - 1938, and corresponding mean annual water level (m).

4.2. Habitat Change - 1800 to the Present

The period of greatest structural change to the St. Marys River occurred from about 1885 to 1921, when most of the construction at the St. Marys Rapids took place and complete control of discharge was achieved. The changes were a result of the rise in industry and population in the SSM area and an increase in ship traffic through the river. The 1860's and 1870's were decades of less obvious change, but were the beginning of large scale projects to drill, blast, and dredge the river bed for navigation purposes. After the 1920's, only a few notable structural changes occurred, such as construction of the international road bridge, but the legacy of discharge regulation and modifications to the river may have continued to affect habitat (Figure 4.19).

For the St. Marys Rapids, the structural changes of 1885 - 1921 brought a 50% reduction in area accompanied by a marked decline in total discharge and followed by increased fluctuations in flows. The habitat suitability and Weighted Useable Area for fish and benthic macroinvertebrates using the rapids for all or part of their life cycle show that quality and quantity of habitat has varied with the changing discharges. WUA and discharge are usually, although not always, positively correlated. While increases in discharge flood more of the rapids area, thus providing more habitat, the overall suitability for some organisms and life stages, such as for *Hydropsyche sp.* and rainbow trout fry, decreases with the corresponding increase in water depths.

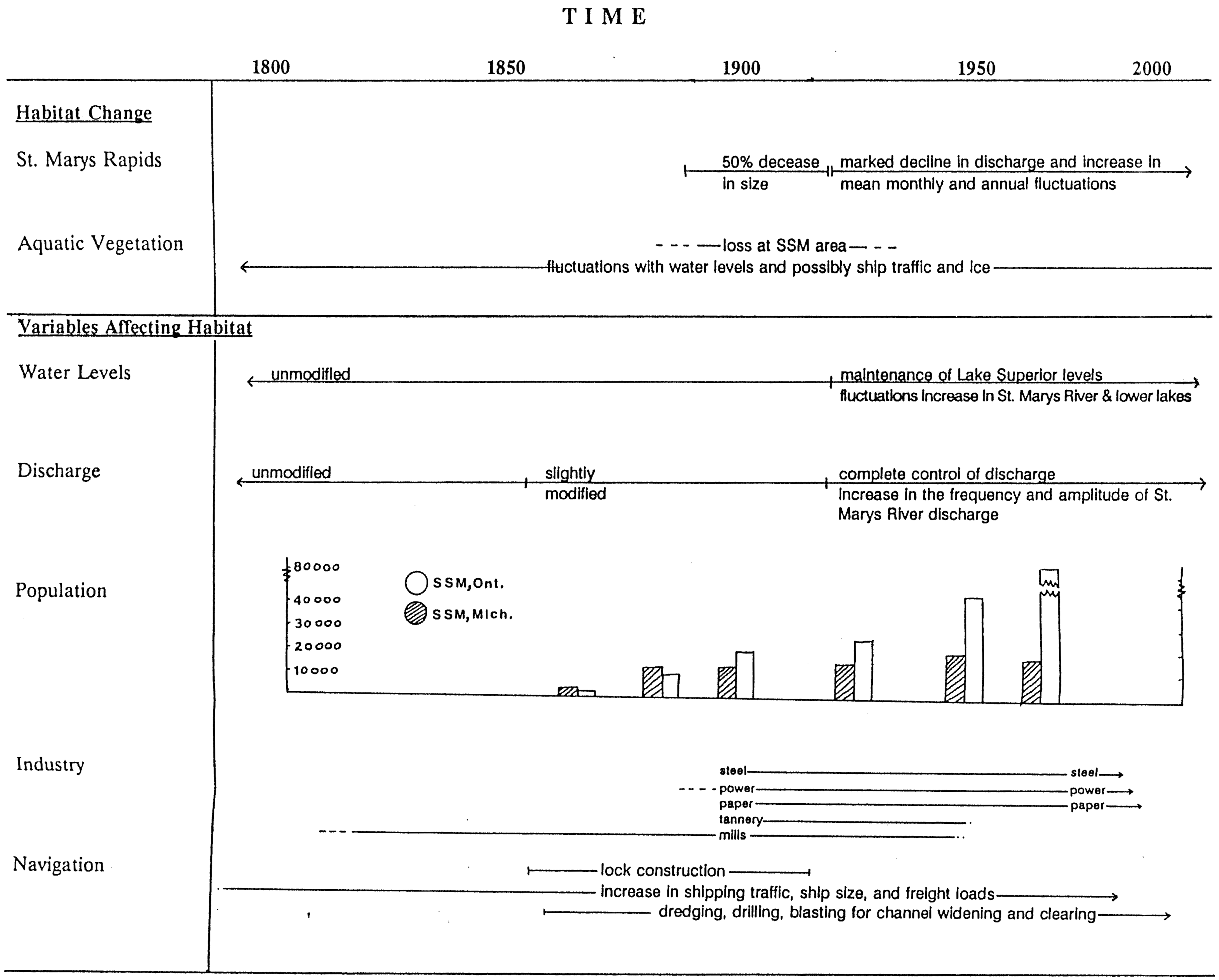

Figure 4.19. Time-scale of trends of habitat and variables affecting habitat in the St. Marys River.

It is unlikely that the frequency and magnitude of changing WUA's over time has been the sole cause of the decline of the rapids fishery. The St. Marys Rapids whitefish fishery is often cited as an example of a once prolific fishery reduced partly as a result of habitat change. While it is clear that the rapids have been reduced in size and discharge, those changes are probably not the cause of the whitefish decline. While the catch of whitefish from the rapids (Figure 4.20) fluctuated widely during the period of most intensive structural alteration, the same variation in catch was recorded in prior decades. This may be a result of differences in record keeping, but may also be a reflection of the stressed and declining whitefish stocks in Lakes Superior and Huron around the turn of the century (Berst and Spangler, 1973; Lawrie and Rahrer, 1973). Rainbow trout, another rapids inhabitant, also became more abundant in the years of great structural change to the rapids, although possibly remains below its potential. Other pressures, such as exploitation and competition from species introduced into the river and the open Great Lakes (for migratory species), may have played a more significant role in community change.

Disruption to the St. Marys Rapids system may also have occurred by the isolation of the rapids from shoals upriver and from most of the small shoal and rapids habitat once found along the north and south shores. The eradication of aquatic vegetation along the shore at SSM, Ontario, from urban and industrial expansion, aside from representing an actual loss of habitat, may have severed a link between the rapids and the rest of the river. The productivity of this zone of aquatic vegetation for spawning, shelter, and food production and its significance to seasonal

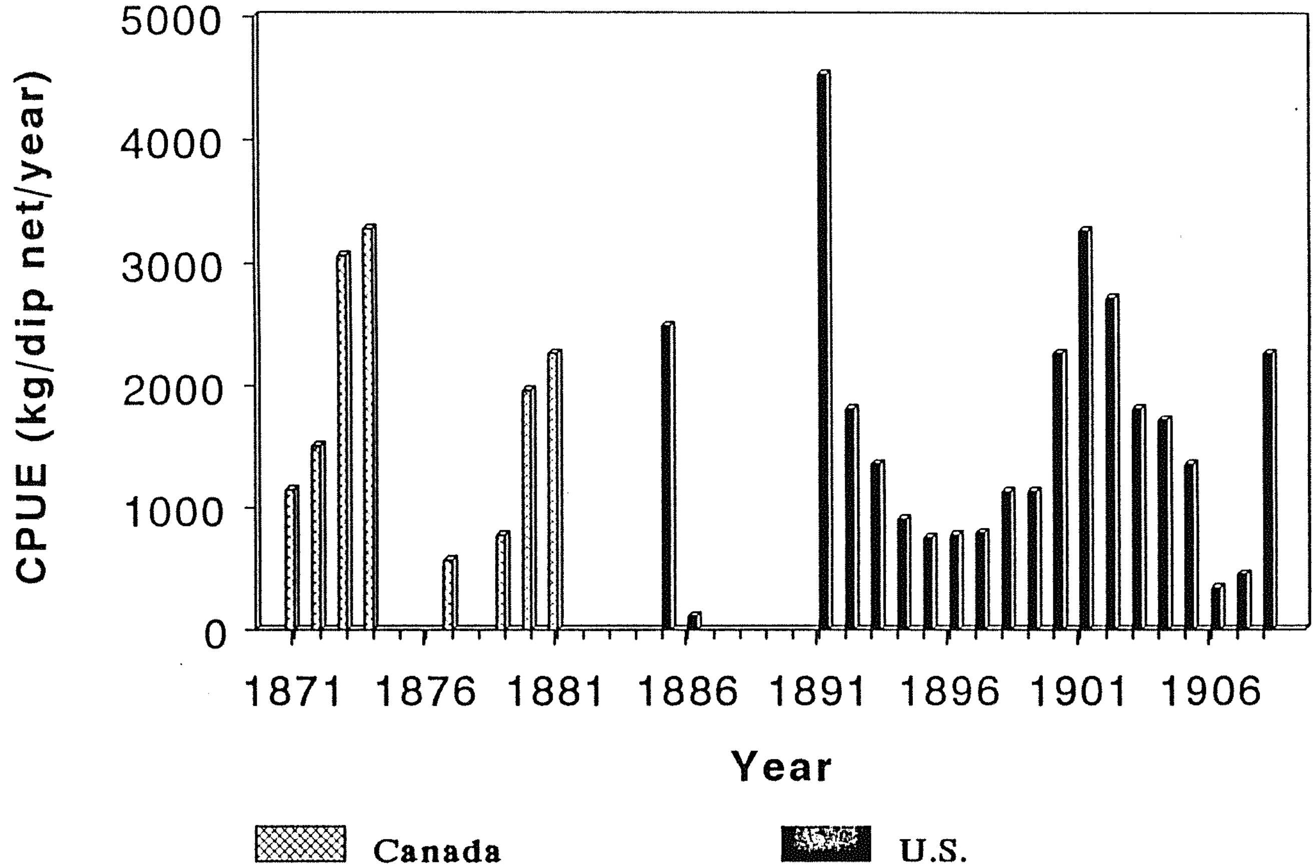

Figure 4.20. Catch per unit effort (kg/dip net/year) of whitefish from the St. Marys Rapids, 1871 - 1908.

and permanent residents of the rapids is unknown.

Areas of submerged and emergent aquatic vegetation found elsewhere along the river's shores have changed over time mostly in response to fluctuations in water levels. They have also possibly been affected by ship traffic and ice movement, although it is not clear to what extent. Habitat suitability for northern pike, a species strongly associated with aquatic vegetation, also appears to have been influenced by fluctuating water levels which affect the amount of habitat available.

In the early years of the last two centuries, the St. Marys Rapids experienced periods of activity and structural change. It might appear that with the turn of the next century, the St. Marys River is poised on the brink of another period of great change. The potential for the region to become more intensively settled and used as a recreational area is growing. In the last two decades, the increase in the number of residences built along the Canadian shore of the river is readily observed on air photos. What has saved the river from much of the same fate of the other connecting channels, e.g. from channelisation, industrial and urban growth, and widespread toxic substances contamination, has been its relatively remote location. As the southern lake and river shores fill up, however, the demand for the relatively unspoiled shore of the St. Marys will be great. The lack of publicly owned land along the shoreline makes the task of protecting the area more difficult.

Fish habitat of the St. Marys River has been degraded, and will unlikely ever be returned to the state of 200 years ago. This is not to say that the resulting fish community is "unhealthy", only different, and perhaps not as "desirable" as it once was. The assemblage of fish species in the river has had to adjust to successive and concurrent stresses, such as habitat change, exploitation, and introduced species, and will continue to undergo change imposed by events both within and beyond the river system. While the St. Marys is itself an ecosystem, it is also a corridor, a conduit of energy, information, and species between the two upper Great Lakes. What occurs to migratory stocks once outside the river could have great influence and should not be ignored.

4.3. Implications for Rehabilitation

If rehabilitation represents some return to an earlier functional state (not restoration), then our own perceptions of time and space scales can influence the direction and degree of rehabilitative efforts. Petts (1987) advises that time scales for recovery or adjustment of ecosystems to stresses imposed by river regulation are often ignored. The time needed for recovery depends on those variables which require the longest time to adjust. Petts (1987) suggests that channel substrate and form require the longest period of recovery of close to 100 years or more, while biological communities, such as benthos, vegetation, and fish, adjust in a relatively short time. Retrospective analyses, therefore, particularly of structural habitat, are important for providing the perspective necessary for rehabilitating systems and functions in the context of long term ecosystem change.

Rehabilitation has also been linked with a return to, or achievement of, a "desired state" which implies the need for human intervention and a knowledge of past conditions. Returning the St. Marys River to its physical state at the turn of the 19th century is clearly impossible. Many of the changes to habitat which have occurred are irreversible, e.g. the construction of locks, power plants, and Compensating Works at the rapids. Not only is a return to 19th century conditions impossible, it may also not be desirable. With or without perturbations altering physical structure, hydrologic regime, and biotic communities, the St. Marys River system would have undergone change as part of the natural trajectory of time. If natural functions are desirable, then prevention of natural change is not.

Regier et al. (1989) advocate a rehabilitation strategy in large rivers which addresses more than one issue or habitat feature. Centres of organisation, such as the St. Marys Rapids and coastal wetlands (or zones of aquatic vegetation), which provide critical habitat are crucial for maintaining flows of information in a healthy system and should be rehabilitated where warranted. In the sense of Regier et al. (1989), the St. Marys River itself is a centre of organisation in the Great Lakes basin. It is essential, therefore, to look at the St. Marys River not only as a single geographically defined area, but as a vital and codependent part of a larger entity.

Results from the empirical measurements and habitat models for indicator species used to investigate changes to habitat in the St. Marys River are evidence that habitat losses have been mostly restricted to localised areas where structural changes have been concentrated; i.e., the St. Marys Rapids/SSM area. However, changes associated with these losses of habitat, e.g. discharge regulation, affect the remainder of the river, particularly through alteration of the hydrologic regime.

In the St. Marys Rapids, the loss of 50% or more of area represents a drastic reduction in habitat, whether it was used by fish species directly (e.g. for spawning) or indirectly (e.g. as a food source) and is alone likely to have had a great impact on the community of the rapids and the river. The IFIM model, although applied to the period following most structural change to the rapids, indicates that the remaining habitat may be subject to fluctuations in discharge which create habitat losses and gains both in total area available and relative suitability.

Both the empirical measurements of aquatic vegetation and the application of the HSI model indicate that area of emergent and submerged vegetation changes predominantly with water level. Here too, the only absolute loss of habitat has been in the SSM area as a result of urban expansion. While the relative importance of this area of aquatic vegetation for biotic communities is unknown, it may have been significant both as local habitat and as a corridor linking the rapids with the rest of the river.

The results also indicate that, while important, loss of fish habitat or declines in suitability cannot be held solely responsible for the reported declines in fish abundances. Had the losses or modifications of habitat in the river been responsible for the decrease in fish populations, reports of poor fishing should not have occurred until the late 1800's to early 1900's, allowing for some lag time. As it was, complaints of reduced fishing success were documented prior to any substantial structural alteration of the river (Milner, 1874). This suggests that over exploitation of fish stocks, likely accelerated by improved fishing gear and techniques, started the path of decline. Also, some fish species increased in numbers, such as rainbow trout, while others with similar habitat requirements decreased, such as brook trout.

The cessation of commercial fishing by 1909 in the upper and mid-reaches of the St. Marys River, however, did not halt the reports of dwindling fish abundances, nor have some stocks, particularly migratory and game species, recovered to historic levels of abundance even to this day. If habitat alteration has not been severe, overfishing in the river has been curtailed, and water and sediment contamination is localised, the question remains as to what has prevented the recovery of the fish community. The answer may lie in events and processes affecting fish stocks outside the St. Marys River, in Lakes Superior and Huron, or in the cumulative effects of successive perturbations.

The RAP Stage II document, which is to set the agenda for rehabilitation in the St. Marys River, needs to be concerned with enhancing existing habitat rather than restoring lost habitat. Area lost from the St. Marys Rapids cannot be reclaimed, but the portion remaining and the periphery has the potential for improvement. The lost zone of aquatic vegetation at SSM, Ontario, however, is unlikely to ever be replaced now that the city's waterfront has been rebuilt for tourist attractions. In the lower river, areas of emergent and submerged vegetation require protection from complete or piecemeal destruction.

In order to manage fish habitat or the fish community of the St. Marys River or to plan for any rehabilitative strategies, much more information on the current condition of the river is needed. Research is needed to investigate the current role of the St. Marys Rapids in the river system. Information is also lacking on the fish community of the river as a whole, species abundances, stock identification, migration routes, and the interaction between the fish community of the river and of the adjacent Great Lakes. Research is needed to inventory habitats in the river and determine their relative importance to fish and other organisms. Comprehensive monitoring of change of habitat and biotic communities with regular surveys, although most likely impractical in terms of cost, would provide invaluable information for long term ecosystem planning. Most of these research needs should be addressed before the St. Marys River RAP completes the Stage II document. The RAP process is a unique opportunity to bridge the jurisdictional divide for St. Marys River rehabilitation, research, and long term management.

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APPENDIX A

FISH SPECIES - ST. MARYS RIVER

PETROMYZONTIDAE	
Petromyzon marinus	Sea lamprey
Lampetra lamottei	American brook lamprey
ACIPENSERIDAE	
Acipenser fulvescens	Lake sturgeon
LEPISISTEIDAE	
Lepisosteus osseus	Longnose gar
AMIIDAE	
Amia calva	Bowfin
CLUPEIDAE	
Alosa pseudoharengus	Alewife
Dorosoma cepedianum	Gizzard shad
SALMONIDAE	
Coregonus artedii	Lake herring
Coregonus clupeaformis	Lake whitefish
Prosopium cylindraceum	Round whitefish
Oncorhynchus mykiss	Rainbow trout
Salmo trutta	Brown trout
Salmo salar	Atlantic salmon
Salvelinus fontinalis	Brook trout
Salvelinus namaycush	Lake trout
Salvelinus fontinalis x namaycush	Splake
Oncorhynchus gorbuscha	Pink salmon
Oncorhynchus kisutch	Coho salmon
Oncorhynchus tshawytscha	Chinook salmon
OSMERIDAE	
Osmerus mordax	Rainbow smelt
UMBRIDAE	
Umbra limi	Central mudminnow

ESOCIDAE	
Esox lucius	Northern pike
Esox masquinongy	Muskellunge
CYPRINIDAE	
Carassius auratus	Goldfish
Couesius plumbeus	Lake chub
Cyprinus carpio	Carp
Hybopsis storeriana	Silver chub
Nocomis micropogon	River chub
Notemigonus crysoleucas	Golden shiner
Notropis atherinoides	Emerald shiner
Notropis cornutus	Common shiner
Notropis heterodon	Blackchin shiner
Notropis heterolepis	Blacknose shiner
Notropis hudsonius	Spottail shiner
Notropis stramineus	Sand shiner
Notropis volucellus	Mimic shiner
Phoxinus eos	Northern redbelly dace
Pimephales notatus	Bluntnose minnow
Pimephales promelas	Fathead minnow
Rhinichthys atratulus	Blacknose dace
Rhinichthys cataractae	Longnose dace
Semotilus atromaculatus	Creek chub
CATASTOMIDAE	
Catastomus catastomus	Longnose sucker
Catastomus commersoni	White sucker
Moxostoma anisuram	Silver redhorse
Moxostoma erythrurum	Golden redhorse
Moxostoma macrolepidotum	Shorthead redhorse
ICTALURIDAE	
Ictalurus nebulosus	Brown bullhead
Ictalurus punctatus	Channel catfish
ANGUILLIDAE	
Anguilla rostrata	American eel
CYPRINODONTIDAE	
Fundulus diaphanus	Banded killifish

GADIDAE	
Lota lota	Burbot
GASTEROSTEIDAE	
Culea inconstans	Brook stickleback
Gasterosteus aculeatus	Threespine stickleback
Pungitius pungitius	Ninespine stickleback
PERCOPSIDAE	
Percopsis omiscomaycus	Trout-perch
PERCICHTHYIDAE	
Morone chrysops	White bass
CENTRARCHIDAE	
Ambloplites rupestris	Rock bass
Lepomis gibbosus	Pumpkinseed
Lepomis macrochirus	Bluegill
Micropterus dolemieui	Smallmouth bass
Micropterus salmoides	Largemouth bass
Pomoxis nigromaculatus	Black crappie
PERCIDAE	
Etheostoma exile	Iowa darter
Etheostoma nigrum	Johnny darter
Perca flavescens	Yellow perch
Perca caprodes	Logperch
Stizostedion canadense	Sauger
Stizostedion vitreum vitreum	Walleye
SCIAENIDAE	
Aplodinotus grunniens	Freshwater drum
COTTIDAE	
Cottus bairdi	Mottled sculpin
Cottus cognatus	Slimy sculpin
Cottus ricei	Spoonhead sculpin
Myoxocephalus quadricornis	Fourhorn sculpin

Source: Duffy, et al., 1987.

APPENDIX B

INSTITUTIONS CONSULTED

A. Government Agencies

1. Ontario

   a. Department of Fisheries and Oceans
      Great Lakes Lab. for Fisheries and Aquatic Sciences, SSM
      Sea Lamprey Control Centre, SSM

   b. Environment Canada
      Canadian Parks Service, Sault Ste. Marie Canal Office
      Great Lakes Levels Board, Cornwall

   c. Ontario Ministry of Natural Resources
      Sault Ste. Marie District Office
      Maple District Library
      Queen's Park Library
      South Baymouth Office

   d. Ontario Ministry of Environment
      Sault Ste. Marie District Office
      Ontario Water Resources Commission, Toronto

   e. SSM Region Conservation Authority

   f. Corporation of the City of SSM
      Planning Department

   g. International Joint Commission, Windsor

2. Michigan

   a. U.S. Fish and Wildlife Service Library, Ann Arbor

   b. U.S. Army Corps of Engineers, Detroit District Office

   c. Department of Natural Resources
      Institute for Fisheries Research, Ann Arbor
      Newberry Office

   d. Great Lakes Fishery Commission, Ann Arbor

B. Public Libraries and Archives

1. Ontario

   a. National Archives of Canada (incl. map archives), Ottawa

   b. Archives of Ontario (incl. map archives), Toronto

   c. SSM Museum and Historical Society

   d. SSM Public Library

   e. Algoma University College Library

   f. National Library of Canada, Ottawa

   g. National Air Photo Library, Ottawa

   h. University of Toronto, Toronto
      Robarts Library
      Map Library
      Zoology Library

   i. University of Waterloo
      Dana Porter Library
      William B. Davis Library
      Map and Design Library

   j. Trent University
      Bata Library, CIHM Collection
      University Archives

   k. Royal Ontario Museum, Toronto
      Ichthyology Department Library
      Archives

2. Michigan

   a. State Archives of Michigan, Lansing

   b. State of Michigan Library, Lansing

   c. Michigan State University Library, East Lansing

d. University of Michigan, Ann Arbor
   Harlan Hatcher Graduate Library
   Engineering - Transportation Library
   Museums Library, General and Fisheries Sections
   Michigan Historical Library, (Bentley)

e. Lake Superior State University, SSM
   Kenneth J. Shouldice Library

f. Bayliss Public Library, SSM
   Historical Room

Appendix C. Chronology of engineering, cultural, and fishery events of the St. Marys River.

Date	Engineering	Cultural	Fishery
300 B.C.		first permanent residents in the St. Marys River Valley	fish are a staple food source for the native people and thousands converge on the St. Marys River in the fall to partake of the seasonally abundant runs of fish
1618		first contact between native inhabitants and a European, Etienne Brulé, occurred	
1642		first Jesuit missionaries reach the SSM area	
1668		Jesuits set up a permanent mission at SSM	one of the first descriptions of the dip net fishery at the St. Marys Rapids - whitefish plentiful
1760's		Alexander Henry, British fur trader is given monopoly of the fur trade in the Lake Superior region	whitefish from the St. Marys Rapids described as 6-15 lbs and are deemed better than those at Michilimackinac; dip net fishery described again, Alexander Henry says that one fisherman could take 500 fish in two hours from the rapids in autumn
1766/67			Alexander Henry reports that for some reason the fishing suddenly failed and famine resulted in the SSM area
1784		North West Company is formed to organise independent fur traders	
1797	first canoe lock and canal built on the Canadian shore for the fur trade; the lock was 38'long, 8' 9" wide, with a lift of 9' and had a cart track running alongside the 2580' canal to pull the boats through the canal; it was believed to have become a sluice for a saw mill since there is no mention of it after 1803 until its destruction in the War of 1812; the reconstructed lock now sits on the grounds of St. Marys Paper Co.		
1807			whitefish caught by Sault fishermen will not be taken until October 1st

Appendix C. Chronology of engineering, cultural, and fishery events of the St. Marys River.

Date	Engineering	Cultural	Fishery
1820		June 16th, Treaty of Sault de Sainte Marie negotiated between Lewis Cass and the native people gives the U.S. land from Ashmun Bay to Little Rapids (16 acres - the site of SSM, Michigan); the native people are given fishing rights in the St. Marys Rapids and a place of encampment on the ceded lands close to the fishing grounds	
1821		North West Company amalgamates with the Hudson Bay Company in SSM, Ont.	
1822	raceway and sawmill built on the American side of the rapids by the U.S. army		Schoolcraft describes much the same dip net fishery in the rapids as before
1820's			whitefish and brook trout are caught in great abundance in the St. Marys Rapids; whitefish are sometimes sold for as low as 2-3 cents each
1833		first Methodist mission originally planned for Sugar Island was changed to Little Rapids (Mission Point) 2 miles below Fort Brady because the native people decided the site on Sugar Island was too far from fishing at Little Rapids	
18??		American Fur Company (AFC) enters into a commercial fishing venture on the St. Marys River	Gabriel Franchère, the AFC representative at SSM, claims there are many pickerel and other fish in the St. Marys Rapids; mesh size usually used for whitefish is 6", for siscowet 5.5"
1834	rapids seen to run dry for one hour before the water came rushing back		

Appendix C. Chronology of engineering, cultural, and fishery events of the St. Marys River.

Date	Engineering	Cultural	Fishery
1835		Major Rains arrives on St. Joseph Island to build (unsuccessfully) a permanent settlement, including building a sawmill at the upper end of Milford Haven which preceded every other mill on the island by about 50 years;	description of fishing in St. Marys Rapids states that at every 3rd or 4th scoop of a dip net the catch is whitefish, trout, or sturgeon
1836/37			1836 Franchere reports that he would have more than 107 barrels of pickerel if the seine had not broken under the weight of the fish; 1837 a bad year for fishery, because of late season, only 170 brls of pickerel seined from SSM area; ordinary season prices $14/brl for siscowet, $12/brl for whitefish and trout, $8/brl for pickerel; 600 brls of whitefish and lake trout caught in the St. Marys River
1838	highest water known when Lakes Huron and Michigan rose 26" above ordinary high stage		
1838/39			fish yields for the AFC doubled and trebled (mostly as a result of a company reorganisation) and there was difficulty in selling them all
1841/42	in April 1842 a similar event occurred as in the summer of 1834 when the rapids ran dry, but twice in the same day; there was no ice on Lake Superior nor was there any wind at the time; a few years previously the current at the foot of the rapids near Fort Brady was observed to reverse and the water rose two feet or more	AFC fishing for profit ended although employees still fished; AFC failed a year later and the fishery was never reorganised	
1846	Lake Superior and all upper lakes considerably below former water marks		

Appendix C. Chronology of engineering, cultural, and fishery events of the St. Marys River.

Date	Engineering	Cultural	Fishery
1850's		1850 Robinson-Huron Treaty cedes Whitefish Island to the Batchewana Band of the Ojibwa	whitefish and trout caught in St. Marys Rapids, pickerel in Muddy Lake (Munuscong Lake), and herring caught by gill net or spear in the winter, possibly the summer as well; pike, gar, whitefish, bass, herring, sturgeon, and muskellunge caught in the vicinity of St. Joseph Island in season
1853	construction begins on the St. Marys Falls Canal and Locks on the U.S. side (the first ship canal and locks in the U.S.)		
1855	opening of the St. Marys Falls Canal; navigation between Lakes Superior and Huron through Middle Neebish and Lake George capable for 14' draft vessels		
1857		most fish seem to be consumed by local inhabitants with the surplus sent by steamers and schooners to Detroit mostly in fresh state	at the St. Marys Rapids fish taken in large quantities nearly all seasons of the year: 3-4 species of salmon-trout, whitefish, herring, and sturgeon taken in considerable numbers; herrings sold at $5-6/brl, trout at $9-11/brl in Detroit; fishing done by scoop nets or standing gill nets at the foot of the falls; opinion of Superintendent of Fishery (Ont) that the fishery could yield 2000-3000 brls/yr if operated by skilled men within regulations, but looks as if only 1000 brls are taken; St. Joseph Island fishery probably produces about 700-800 brls/yr of salmon-trout and whitefish taken from standing gill nets and hooks baited with small herrings;

Appendix C. Chronology of engineering, cultural, and fishery events of the St. Marys River.

Date	Engineering	Cultural	Fishery
1859		Superintendent of Fisheries for Upper Canada mentions decline of many fish species, mostly in Lake Ontario streams and recommend gear and season restrictions, more fish inspectors, greater penalties, and disallowing spears; Fishery Overseer for Lakes Huron and Superior cites overfishing occurring at Manitoulin Island, North Channel fishing grounds; new leasing system for fishing grounds under the Fishery Act (it was suspected that fierce opposition by independent fishermen led to the disappearance of the Fishery Overseer) brook trout is an important species for tourism and sport, the manager of the Chippewa House in SSM says he would have to close down without the brook trout fishery; problems with smuggling and poaching in Canadian waters;	catch lower than average as a result of unusually stormy weather causing a loss of nets and the failure of many fisheries; pound net in operation close to the boundary between Drummond Island and Tenby Bay (St. Joe's Is.) taking vast quantities of fish; scoop nets used almost all year in the St. Marys Rapids, 2 men in a canoe with one net can catch 2 brls of whitefish a day; brook trout plentiful in the Garden and Root Rivers as well as branches of the St. Marys Rapids and in small creeks above the rapids; concern over the possibility of a decline in brook trout from allowing netting, trolling, and spearing on spawning shoals; most people seem to think that any decline is from sawdust from mills but overseer thinks spearing and netting at stream mouths and the lack of fishways for dams; Native people take brook trout with spears and nets to sell to the Americans; last season about 40 fish averaging 1.75 lbs each sold for $0.30/lb;
1860's		Hudson Bay Company post at SSM closes	
1864			first pound nets used in the SSM area by Capt. Beau

Appendix C. Chronology of engineering, cultural, and fishery events of the St. Marys River.

Date	Engineering	Cultural	Fishery
1866			pound nets now regularly used, a Mr. Roach brought more from Lake Erie and fishes them in the St. Marys River for pike and pickerel several weeks in the spring before going to Whitefish Point
1869	first steam barge is launched at Cleveland allowing up to 230' length; previous designs of freighters were wooden hulled and had a maximum length of 175', the advancements having great consequence for the dimensions of the navigation system and the cargo capabilities of lake freighters		
1871			Fishery Overseer at SSM (Ont) reports whitefish of the St. marys Rapids are decreasing annually while they are as numerous as ever on the U.S. side; considers this strange since offal is thrown into the water on the U.S. side but not on the Canadian side; natives believe that the fish go over to the U.S. side to feed on the offal
1872	St. Marys Falls Canal and Locks enlarged		Canadian Fishery Overseer reports the St. Marys Rapids fishery is much improved; above and below the St. Marys Rapids the smallest whitefish found (YOY) 4 9/10", largest 6 1/10"; at the foot of the St. marys Rapids, natives take whitefish averaging 4 lbs, one specimen caught was 12 lbs; natives say that the whitefish of Lake Superior never descend to the rapids and those of the rapids never ascend to the lake; whitefish leave the rapids in August, there are then so few that hotels in the area must get them from Point Detour;

Appendix C. Chronology of engineering, cultural, and fishery events of the St. Marys River.

Date	Engineering	Cultural	Fishery
1875		grist mill built on the Canadian side to take advantage of the water power; later bought out by a syndicate in 1888 who ran out of funds trying to expand the operation; eventually taken over by F. Clergue and turned into a power plant in 1916	
1876-77	construction is begun on the Weitzel lock ice is seen to influence the river bed by moving boulders down and through the rapids at break-up	St. Joseph Island is opened to settlement in 1877 resulting in a large influx of people	
1878	1877/78 extremely low water stage in the river		Root River is suggested to be set apart for natural reproduction of fish as it is a spawning and nursery ground for the St. Marys River
1879	survey of the river revealed 27 shoals from Round Island to Sailor's Encampement which impeded navigation for drafts up to 16'		
1880's		lumber industry at its height, logs rafted down the St. Marys River frequently	angler's guide book lists the best fishing spots at SSM to be: Little Rapids, Root River, Silver Creek, and Hay Lake with June to October as the best seasons; the waters on the Canadian side are said to be best for trout, black bass, and perch; during cloudy wet weather, brook trout can be caught at the west end of the (U.S.) canal pier
1881	Weitzel Lock on the U.S. side is completed and is the largest lock in the world at the time		

Appendix C. Chronology of engineering, cultural, and fishery events of the St. Marys River.

Date	Engineering	Cultural	Fishery
1882	26 of the 27 shoals surveyed in 1879 removed by dredging, one remaining near Sailor's Emcampement could only be removed by drilling and blasting; work is begun on Middle Neebish Channel, test pits dug in the rapids there found most of the material easily excavated except in the lower part where blasting was necessary		
1883	Middle Neebish Channel begun to be cut to 19'; test pits dug at Sugar Island rapids (Little Rapids) in anticipation of moving the shipping route through Hay Lake (Lake Nicolet), the material was found to be readily dredged	first suggestion of a hatchery at SSM, Mich.	trout fishing not as good as before in the rapids because of overfishing especially on the U.S. side, but large speckled trout are still available
1884	channel of 16' draft completed from Lake Superior to Lake Huron	strong opposition to the use of pound nets from Canada	decrease in yield, very few fish caught after Nov. 1st;
1885		native people on the U.S. of the rapids are removed from their homes for the expansion of the lock system	large quantities of sturgeon and pickerel taken in pound nets; trout more abundant than in 1884, but whitefish about the same; on May 18th, crew of one canoe took 1115 lbs of whitefish from the St. Marys Rapids worth about $40 - $50; four days later another 5000 lbs landed by natives in the same way;

Appendix C. Chronology of engineering, cultural, and fishery events of the St. Marys River.

Date	Engineering	Cultural	Fishery
1885/86			mostly pound nets fished between Detour and SSM with a catch of whitefish, walleyed pike, sturgeon, and muskie in order of importance; John Boucher, oldest canoe fisherman on the St. Marys Rapids reports a marked decrease in the whitefish catch: on April 12, 1878 he caught 1800 whitefish with a dip net, on the 13th over 1300, the 14th about 100, and for 6 weeks after he caught about 1250 a day averaging 4 lbs each; this year in May and half of June the catch averaged 200 lbs/day of 3 lb fish; Canadians claim an increase in whitefish but claim that no improvement can be expected until the American stop setting pound nets below the rapids; muskellunge (*Esox mobilor*) most abundant in widenings of the river where they are caught in pound nets; second only in size to sturgeon and commands highest price of any lake fish;
1887	construction begun on the new Poe Lock	another sawmill built at Milford Haven since the one of 1835 long abandoned	Canadians claim an increase in whitefish except in the St. Marys Rapids blaming the American use of pound nets; Fishery Overseer from the St. Joseph Is. area reports a large increase in trout, but a decrease in sturgeon
1888	international railway bridge is completed construction of a Canadian lock and canal system is authorised	two more sawmills built at Two Tree River on St. Joseph Island	
1889			fishing as good as last year around St. Joseph Island

Appendix C. Chronology of engineering, cultural, and fishery events of the St. Marys River.

Date	Engineering	Cultural	Fishery
1903		few fish sold in Canada, most exported to the U.S.;	sturgeon decreased throughout most of the province, in the SSM area a change in the closed season resulted in a decrease in catch;
		about three illegal trap nets set near St. Joseph Is., one was seized and destroyed	prosperous year for SSM area fishery: increase in whitefish, lake trout, and other fish compared to previous year;
			good angling for muskellunge, pike (pickerel), bass, and trout in the Echo River
1904	cut through West Neebish Channel is begun May 16th, a 300' wide, 21' deep channel blasted "in the dry", rocks piled on land to either side	except for 3-4 tonnes of fish used for local consumption, all is exported to the U.S.;	still a decline in sturgeon;
		illegal small mesh net found in the Root River and destroyed	SSM area reports such a decline in whitefish catch that fishermen took their nets out of Lake Superior in September and fished no more after October 1st; decline of about 100 000 lbs of whitefish;
			all other species same as last year
1905		SSM, Mich. hatchery distributing brook trout, rainbow trout, lake trout, walleyed pike, landlocked salmon, and whitefish; small plantings are made in the St. Marys River, but most are for inland lakes and streams of the Upper Peninsula (MI);	good season, decrease in trout, increase in whitefish in the North Channel attributed to very calm weather in July and August and that fishing was done mostly in shallow waters;
			introduction of rainbow trout considered a success as a number of fish 5-9 lbs taken in the past 2-3 years; also a success with landlocked salmon although only a limited number were planted;
1906			rainbow smelt eggs planted in the St. Marys River to provide a food source for salmon and other fish, unsuccessful planting
1907	U.S. hydroelectric plant is constructed at the St. Marys Rapids		
1908	construction on the Davis Lock is begun, water supply to the SSM hatchery is cut off as a cofferdam is constructed		

Appendix C. Chronology of engineering, cultural, and fishery events of the St. Marys River.

Date	Engineering	Cultural	Fishery
1909	SSM hatchery more isolated as a result of lock building and land is expropriated for expansion	suggested that a longer closed season for whitefish and salmon-trout be implemented from Oct 15th - Dec 1st; also suggested that rainbow and lake trout be protected as much as brook trout; complaints from Canadians of poaching by Americans and that a patrol is needed southeast of St. Joseph Is.; St. Marys River (U.S.) is closed to commercial fishing from Bay Mills to downstream limit of Lime Island	brook trout still plentiful; whitefish and lake trout catch much larger this year attributed to leaving protected areas for better feeding grounds;
1910			brook trout plentiful in SSM district, best angling for years; bass not plentiful, maskinonge and sturgeon scarce, pickerel increasing in Lake Superior; rainbow trout in St. Marys River round weight of 6-12 lbs, spawn about May 1st
1911		SSM, Mich. hatchery moved to a site on the Fort Brady reservation Aug. 10th	bass increasing in St. Marys River, maskinonge increasing in Lake Superior, some in Echo Lake (one 35 lbs), and pickerel increasing in Lake Superior and St. Marys River
1912			rainbow trout becoming numerous in the St. Marys Rapids, but in a few instances are being wantonly destroyed during spawning season
1913	construction of the Sabin Lock is begun		maskinonge scarce in SSM district, pickerel increasing in lake Superior, sturgeon increasing slightly in lake Superior
1914	Davis Lock opens	Canadians complain that American poachers continue to trespass near St. Joseph Is.; continued call for closed season on rainbow trout to protect them the same as brook trout	rainbow trout abundant in St. Marys Rapids; lake trout also numerous

Appendix C. Chronology of engineering, cultural, and fishery events of the St. Marys River.

Date	Engineering	Cultural	Fishery
1915		fishing in St. Marys Rapids curtailed during WWI, expected to give rainbow trout a chance to increase	many rainbow trout in St. Marys Rapids are 9 lbs or more, one caught at 12 lbs 14 oz; bass plentiful east of SSM along north shore of Lake Huron; pike very plentiful in all bays of Lakes Superior and Huron; sturgeon very scarce, whitefish and trout holding in lake Superior but are not so plentiful in Lake Huron; herring plentiful in both Lakes Superior and Huron
1916	Great Lakes power canal and plant are completed on the Canadian side of the St. Marys Rapids		
1917			bass increasing in the St. Marys River and along the north shore of Lake Huron; rainbow trout increasing in St. Marys River
1919	Sabin Lock opens, Weitzel Lock now out of service		
1921	Compensating Works completed and discharge regulation begins	SSM, Ont. provincial fish hatchery opens	14 lb rainbow trout caught at the lower end of the St. Marys Rapids by rod and line, two others of 12 lbs also caught; 150 lb sturgeon, 6' in length taken in pound net at Hilton Beach (St. Joseph Is.)
1926	large ice blockade in the St. Marys River in the fall ("greatest of all")	Dominion Government of Canada withdraws from commercial fish culture in Ontario	
1929		SSM, Mich. hatchery closed, replaced by the American legion	
1931	West Neebish Channel cut again to 27'; coffer dams used to block water so that the work could be done dry; work begun July 1931 and finished August 5, 1932		

Appendix C. Chronology of engineering, cultural, and fishery events of the St. Marys River.

Date	Engineering	Cultural	Fishery
1932			winter fishing popular on St. Marys River, estimated that 30-35 families depend on winter fishing for income and food; mostly herring speared through the ice at night; 35 lb, 48" in length muskellunge taken in Munuscong Lake, 27.5 lb, 46.5" in length muskellunge taken at Six Mile Point;
1937		request by the Izaak Walton League of America for a stream survey in the St. Marys River to investigate the possible effects of pollution on fish breeding and feeding , claiming that fish in the river, and particularly Potagannissing Bay have been depleted reply from the Mich. Dept. of Conservation suggests that discharge regulation is the culprit for declining populations	concern is expressed by fishermen in Potagannissing Bay/Detour over the declining fishery of the area, controversy over the influence of commercial fishing on sport fish
1938			carp seen in Munuscong Bay every spring, entering several days in June; a spearing party of about 20 men caught 100 carp some weighing 35 lbs
1939			Potagannissing Bay closed to commercial fishing despite recommendations of the Westermann/Van Oosten report
1943	MacArthur Lock replaces Weitzel Lock.	Mich. Dept. of Conservation receives several letters of concern over the effects of rapidly fluctuating water levels on young and small fish; reply that operation of the gates is under the Dept. of War and that nothing can be done until the wartime emergency is over, believe however that changing water levels are detrimental to aquatic life	

Appendix C. Chronology of engineering, cultural, and fishery events of the St. Marys River.

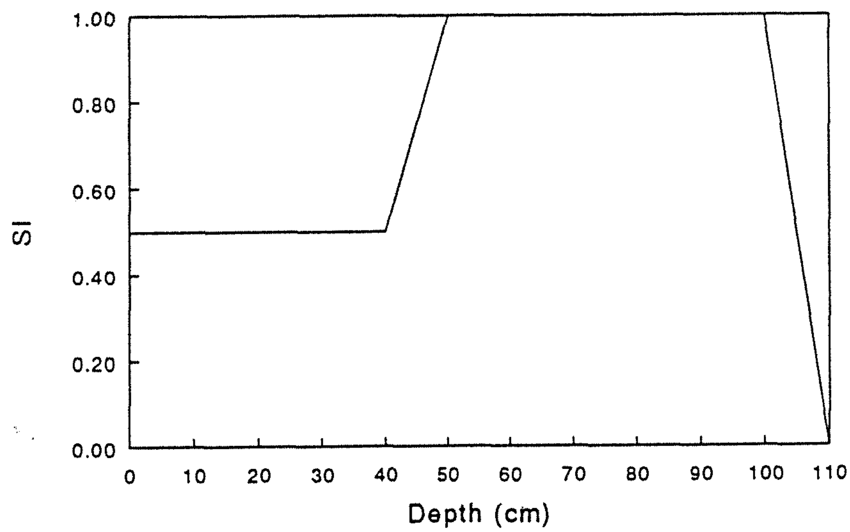
Date	Engineering	Cultural	Fishery
1947			July 10th, two women trolling in the upper St. marys catch a northern pike 25 lbs 6 oz, 45" in length
1949			fall season for rainbow trout in the St. Marys Rapids open Sep 23 - Nov 30 for hook and line
1950's	new U.S. hydroelectric power plant in the rapids is constructed		St. Marys River supports medium to large resident population of rainbow trout as well as a run of migrants; no straying from stocking locations recorded
1961			whitefish spearing reported to be back after a ten year hiatus due to a lack of fish; pike and perch are biting well in Munuscong Bay and Lake Nicolet
1964	International road bridge completed		
1972		Great Lakes Water Quality Agreement signed	
1978		Amending protocol to the GLWQA signed	
1985	berm built in the St. Marys Rapids along the south shore of Whitefish Island to help maintain water levels in Whitefish Channel		
1991		RAP Stage I document for the St. Marys River completed	

Sources: Various

APPENDIX D

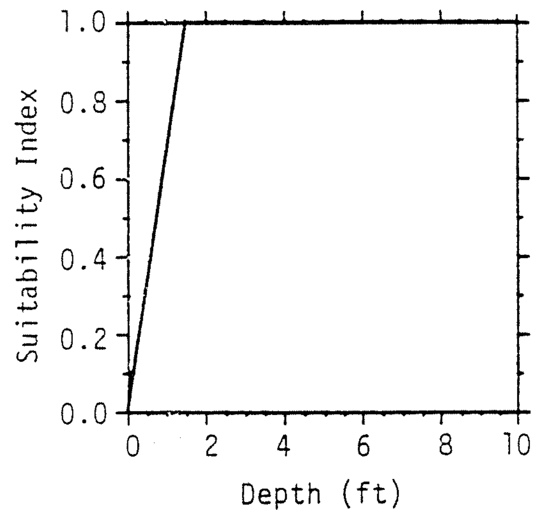
Habitat Suitability Index Curves

1. Instream Flow Depth Suitability Curve for *Hydropsche sp.* (Peters et al., 1989).



2. Instream Flow Depth Suitability Curve for rainbow trout.
(Raleigh et al., 1984)

x	y
0.0	0.0
1.5	1.0
10.0	1.0
100.0	1.0



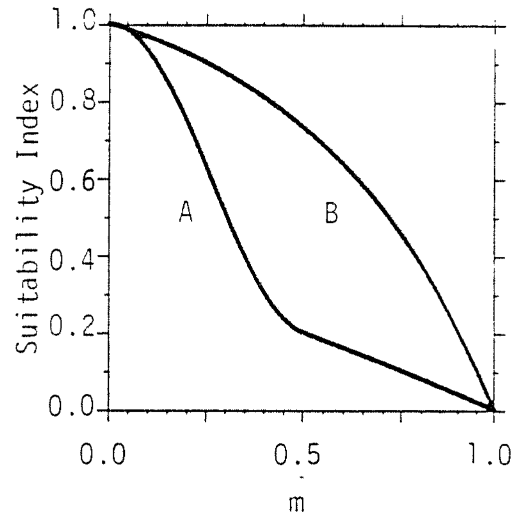
3. Habitat Suitability Index Curves for northern pike.
(Inskip, 1982)

V_2

Drop in water level during embryo and fry stages.

A. Embryo and early fry stages (until yolk sac absorbed).
B. Fry stage, after yolk sac absorbed.

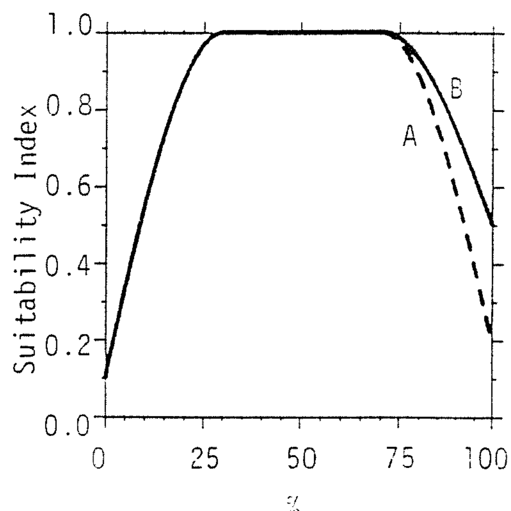
SI for V_2 = A or B, whichever is the lowest.



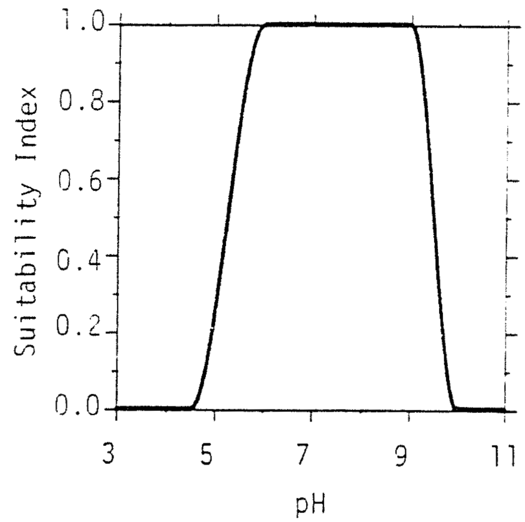
V_3

Percent of midsummer area with emergent or submerged aquatic vegetation or remains of terrestrial plants (bottom debris excluded).

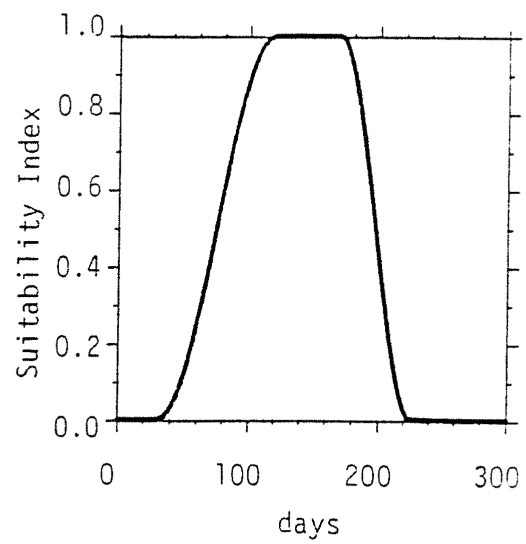
A. Max. depth < 3 m and lake ice-covered > 2 months.
B. Max. depth > 3 m or lake ice-covered ≤ 2 months, or both.

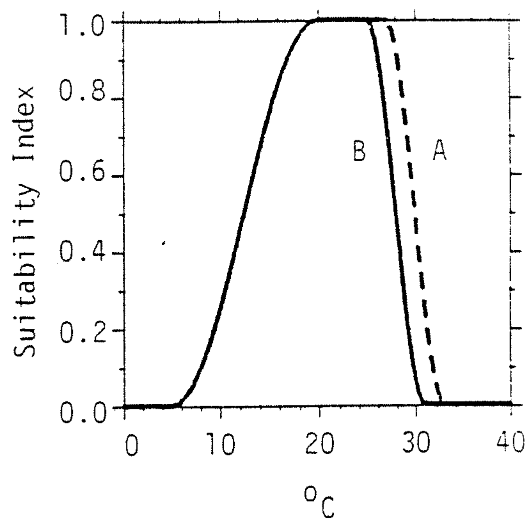


V_5 Least suitable pH in spawning habitat during embryo and fry stages.



V_6 Average length of frost-free season (average number of days between last spring occurrence and first fall occurrence of an air temperature of 0° C).



V_7	Maximal weekly average temperature of the surface layer (1 to 2 m deep). A. Stratified lake with ≥ 1.5 ppm dissolved oxygen in metalimnion. B. River, stream, unstratified lake, or stratified lake with < 1.5 ppm dissolved oxygen in metalimnion.	
V_9	Stream gradient.