Living With The Lakes: Challenges and Opportunities

Annex B
Environmental Features, Processes, and Impacts: An Ecosystem Perspective on the Great Lakes – St. Lawrence River System

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Environment Canada

LIVING WITH THE LAKES:

CHALLENGES

AND

OPPORTUNITIES

ANNEX B

ENVIRONMENTAL FEATURES, PROCESSES AND IMPACTS: AN ECOSYSTEM PERSPECTIVE ON THE GREAT LAKES - ST. LAWRENCE RIVER SYSTEM

PREPARED BY FUNCTIONAL GROUP 2
FOR THE PROJECT MANAGEMENT TEAM

International Joint Commission
Water Levels Reference Study

JUNE, 1989

PHASE 1 REPORT OUTLINE
IJC FLUCTUATING WATER LEVELS STUDY

MAIN REPORT

ANNEX A - PAST AND FUTURE WATER LEVEL FLUCTUATIONS

ANNEX B - ENVIRONMENTAL FEATURES, PROCESSES AND IMPACTS: AN ECOSYSTEM PERSPECTIVE ON THE GREAT LAKES - ST. LAWRENCE RIVER SYSTEM

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ACKNOWLEDGEMENTS

All of the members of FG2 have contributed to the group's activities during Phase I of the Water Levels Reference Study. It is simply not possible to describe all of these efforts in detail. What follows is a necessarily abbreviated list of significant contributions to the Study and to the preparation of this Annex. A list of the full membership of FG2 is in Appendix B-3.

Jean Thie (Environment Canada) served as Canadian Co-chair until July, 1988. His contributions to conceptualization and organization of FG2's activities, particularly in establishing a spatial perspective, were significant.

Because of the extensiveness of its inquiry into the coastal zone of the Great Lakes - St. Lawrence River system, FG2 divided itself into four groups: a terrestrial subgroup led by Tom Farrell and Pearl McKeen (Ontario Ministry of Natural Resources) and Chris Shafer (Michigan Department of Natural Resources), a wetlands subgroup chaired by Dieter Busch (U.S. Fish and Wildlife Service) and Gary McCullough (Environment Canada), an aquatic subgroup under John Gannon (U.S. Fish and Wildlife Service) and Janet Elner (Fisheries and Oceans Canada) and a data integration subgroup led by Ron Gelinas and Dell Coleman (Environment Canada) and by Frank Horvath (Michigan Department of Natural Resources). These subgroups were responsible for completing tasks identified in FG2's Plan of Study.

While the Annex was a collective effort of FG2, a number of members made substantial contributions to its preparation. Sections relating to the terrestrial environment were contributed by Ralph Moulton and Doug Brown (Environment Canada) and Frank Horvath. Robin Davidson-Arnott (University of Guelph) prepared the discussion of shore processes. Dieter Busch, Gary McCullough, and Bob Kavetsky (U.S. Fish and Wildlife Service) wrote the materials on wetlands. Mark Law (Ontario Ministry of Natural Resources, formerly with Environment Canada), Frank Horvath and Dell Coleman prepared the section on Geographic Information Systems. The discussions on the aquatic environment were prepared by John Gannon.

Several members, Doug Brown, Chris Shafer, Pearl McKeen, Bob Kavetsky, Gary McCullough, Dieter Busch, and, in particular, Mark Law, were principal organizers of FG2 workshops on coastal processes, coastal management, and wetlands.

Some FG2 members served as communication links with other groups, both in and outside of the Study, and helped provide a broader perspective on our work, Jody Rooney (U.S. Army Corps of Engineers) was our liaison to FG4. Chris Stewart (Environment Canada) and Don Williams (U.S. Army Corps of Engineers) facilitated the exchange of views with FG3. Chris Shafer, President of the Coastal States Organization, was a valuable link with both CSO and its member states in the Great Lakes basin.

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And finally, this Annex would not have come together were it not for the dedication of Madeleine Ward, who was responsible for typing the majority of the manuscript.

Robert Roden
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EXECUTIVE SUMMARY

The environment of the Great Lakes - St. Lawrence River system is a richly varying blend of land, water, and coastal wetlands. While much remains of what greeted the first European settlers of the region, this system has undergone substantial human-caused modifications, including intensive shoreline development, loss of half of the wetlands, and uncontrolled pollution of the Lakes, the St. Lawrence, and the connecting channels. Some of these abuses continue to the present day. However, there is also an element of hope in the increasing recognition of the need to protect and conserve this complex environment, which millions depend on for their livelihood and life-style. A number of conservation initiatives have made some progress towards stemming, and even reversing, the tide of human alteration and destruction of valued ecosystem components and their functions.

Water-level fluctuations, the subject of the 1986 Reference to the International Joint Commission, are integral to the Great Lakes - St. Lawrence environment, not an outside force imposed upon it. Fluctuations are especially important to coastal wetlands, the most productive and diverse natural component of this ecosystem. Variations in plant species, which in turn provide habitat for a multitude of animal species, are influenced substantially by both seasonal (within-year) and long-term (between years) changes in water levels. Life and landforms found throughout the Great Lakes - St. Lawrence coastal zone have evolved under conditions of fluctuating levels and continue to be shaped by them. From the perspective of the biophysical environment, fluctuations are truly a positive force. Indeed, levels comparable to the historical range are necessary to maintain the productivity, diversity, and areal extent of wetlands.

Erosion and recession of the shoreline occurs throughout much of the Great Lakes - St. Lawrence River coastal zone. For many shoreline types, the rate of long-term recession is largely independent of water-level fluctuations, although short-term increases and decreases in recession rates can result from water level rises or declines, respectively. For some shore types, recession rates are closely linked with water-level changes. The primary cause of shore erosion is the energy directed at the shoreline by wind-driven waves. The orientation of the shore and its composition are also important factors. As with many geomorphologic processes, shoreline recession is characterized by a tendency towards a state of "dynamic equilibrium" where changes in one set of causative factors are usually balanced out, especially over time, by corresponding changes in others. The flexibility of some portions of the shoreline to respond to natural shore processes has been reduced, and the processes themselves altered, by construction.

The aquatic component of the ecosystem, due in part to the mobility of many species and their independence from nearshore areas, is generally less affected by water-level fluctuations than are wetland components. However, many fish species, for example, have evolved under conditions of fluctuating levels and are well-adapted to them, especially during their reproductive cycles. Short-term changes in levels due to storms are probably more significant to the aquatic environment than longer-term changes. Water quality, degraded over years by watershed changes and waste discharges, is beginning to recover.

Considerable uncertainty exists regarding the future of the coastal zone environment of the Great Lakes - St. Lawrence system. The extent of continued human alteration is an ongoing factor. A related concern (because it may largely be a result of human activity) is the possible results of large-scale climate change. Although projected increases in temperature by themselves may be significant (leading to movement of plant and animal species, and with reduced ice cover in the Lakes, year-round shoreline erosion), climate change is also likely to result in a reduced net supply of water to the Great Lakes - St. Lawrence basin, leading to declines in lake levels and reduced flows in the St. Lawrence River and the connecting channels.

Any change in the existing water-level regime can be expected to result in some type of environmental change. Measures to address the adverse consequences of fluctuating water levels have the potential to cause environmental change which, for those measures directly affecting water levels and flows, may be significant and even irreversible. For decisions affecting the future, it is essential to have the best possible information available so that measures can be properly evaluated and their consequences well understood. The process of environmental impact assessment, developed and refined over the past twenty years, is an important element of the decision-making framework. Our ability to predict environmental impacts depends on our knowledge of the proposed measures (how, when, and where they would be implemented), the environment in which they would be applied, and the physical and biological processes at work in that environment. Analyses need to be performed, and results presented, in a manner which best communicates the significant information to decision-makers and to the public at large. With vast amounts of data and the variation in environments and processes throughout the system, environmental impact assessment (and, in fact, any type of impact assessment) is best performed and understood in a spatial context. Using state-of-the-art technology, Canadian and U.S. Geographic Information Systems (GISs) have been developed, and data and process models are being incorporated. The GISs will facilitate an integrated evaluation of complex and multi-faceted data sets and interrelated physical and biological processes. They can also be an excellent means of communicating results, or even of involving the interests in the actual analyses.

When all is said and done, the basic question posed by fluctuating water levels is whether humans will adapt themselves to the Great Lakes - St. Lawrence ecosystem, or continue to seek further changes in the ecosystem to suit their purposes. As long as society keeps looking for a solution outside itself (such as "full regulation"), other approaches, especially non-structural measures which have been recommended in previous studies, but which still face substantial obstacles to effective implementation, will not receive full consideration. Functional Group 2 is convinced, and the initial results of the Reference Study to date support a conclusion, that in a time of fiscal restraint and increasing environmental awareness, major new lake level regulation is years away, it if is attainable at all. It is our belief that the opportunity lies ahead for the human element of the Great Lakes - St.

Lawrence ecosystem to become more in harmony with its natural surroundings and to move towards a sustainable way of life for us all.

ANNEX B

ENVIRONMENTAL FEATURES, PROCESSES, AND IMPACTS: AN ECOSYSTEM PERSPECTIVE ON THE GREAT LAKES - ST. LAWRENCE RIVER SYSTEM

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SECTION 1

INTRODUCTION

The environment of the Great Lakes - St. Lawrence basin is truly a significant resource. The Great Lakes constitute the largest freshwater system in the world, containing 23,000 km^3, or almost one-fifth, of the world's fresh surface water. The basin supports numerous plant and animal species and a diversity of terrestrial, wetland and aquatic habitats. Vegetative communities in the basin range from Carolinian (true deciduous) to boreal and dune grass communities that are constantly adjusting to different environmental and water-level conditions. Over 200 species and subspecies of fish inhabit the lakes and channels, and productive coastal marshes support many of those fish and provide habitat for spectacular international migrations of many waterfowl species. The shores of the Great Lakes are physically rich, bearing evidence of geological events hundreds of millions of years ago, and geomorphological processes of the last 10,000 years, or even the last few hours.

The Great Lakes basin is also the home to 29,000,000 Americans and 10,000,000 Canadians. Many of these people depend directly or indirectly on the Great Lakes for employment, energy, transport, and pleasure. Human utilization of Great Lakes resources, however, is constantly changing. Commercial fishing is relatively less important today than in the late 19th century. On the other hand, recreational use of the Lakes, with a strong sport fishing component, has never been more important than it is today. For example, while only 33 of Ontario's 219 provincial parks are on the shores of the Great Lakes, they accommodate one-half of total park visitation. The Great Lakes unquestionably remain a vital resource, an environment in which many people choose to live, work and play.

While the environment of the Great Lakes - St. Lawrence River basin has been very accommodating of human demands over the past 300 years, there clearly are limits to the degree of change humans can impose upon this environment before serious environmental degradation occurs. Localized water quality problems, for example, were evident as early as the 1870's in Hamilton, and a typhoid crisis in Chicago in the 1890's prompted the diversion of the Chicago River away from Lake Michigan, the city's water source. Extensive deforestation, drainage of coastal wetlands, introduction of exotic species such as the sea lamprey and zebra mussel, industrial pollution and shoreline modification are examples of human impacts that have strained the capability of the Great Lakes environment to sustain historic resource uses and maintain the ecological processes and life support systems.

These and other problems have arisen because of our failure to look beyond short-term benefits to try to anticipate longer-term implications, both beneficial and adverse. While popular and political concern for environmental quality has grown immensely in the past two decades, action has focused on policy and regulations designed to reduce the worst abuses of pollution and resource exploitation. Ameliorating or mitigating, rather than avoiding, impacts has been stressed.

Few would question the desirability of sustaining indefinitely the benefits we presently derive from utilization of Great Lakes resources, or of leaving our grandchildren the same options for managing these resources we presently enjoy. If we are serious about sustainability, we must alter our mindset about the Great Lakes as both a resource and a hazard, and accept some of the basic principles of sustainable development set forth in documents such as the "World Conservation Strategy" (International Union For The Conservation of Nature and Natural Resources, 1980) and the "Brundtland Commission" report (World Commission on Environment and Development, 1987).

These reports argue for the maintenance of "essential ecological processes and life support systems on which human survival and development" ultimately depend. In a Great Lakes context, lake-level fluctuations, nutrient cycling, and flushing of embayments may be several of many important processes integral to the maintenance of productive, genetically diverse and resilient environments.

These documents also argue that we must see ourselves as part of an ecosystem, and better appreciate the ecological processes which bind humanity and environment. Processes key to the functioning of an ecosystem must be recognized, and human activities adapted to accommodate them. This perspective runs counter to a widely-held view of particular environmental processes as problematic to human activities, and that these processes should be modified to accommodate these activities. It begs for a change in thought not unlike that forced on the world by the "Copernican Revolution", namely that while we are a part of the environment, we are not necessarily the centre of it.

In Phase I of the IJC Water Levels Reference Study, Functional Group 2 (FG2) has applied an ecosystem perspective to describing: various terrestrial, wetland and aquatic environments of the Great Lakes - St. Lawrence River system; how these environments function, including known interrelationships between water levels and flows and these environments; and what is presently known about the environmental impacts of potential human responses to fluctuating water levels. This has required an assessment of current understanding of key environmental processes, professional judgement of FG2 members, and the initiation of numerous studies to address some important information gaps. A series of workshops on coastal processes, coastal management, and wetlands were organized to draw on the experiences and judgement of experts outside the membership of FG2. Conceptual models and analytical tools, including geographic information systems, have been developed or refined to further our knowledge of environment features, processes and impacts salient to the Great Lakes - St. Lawrence River system.

This Annex is viewed by FG2 as an interim or progress report. Some tasks have been completed, but some studies initiated by the Group will not be completed for several months. Some time will be necessary to assess the results of these studies and incorporate them into the ongoing activities of the Reference Study.

On the basis of its work to date, Functional Group 2 is convinced that substantial additional modification of the Great Lakes - St. Lawrence River system is neither justified nor prudent as a strategy to attempt to control the natural physical processes. In fact, there are substantial questions about whether an artificial change in lake levels will accomplish all that might be expected in relief for particular interests, whether the true environmental costs might outweigh the expected local benefits, and, indeed, whether the amount of control that can be achieved will resolve much at all over the long term. We must begin to think in terms of decades, rather than the immediate future.

In the following sections, we will describe in some detail the terrestrial, wetland and aquatic environments of the Great Lakes-St. Lawrence River system, the important processes which keep these environments functioning, and how the effects of fluctuating water levels and potential human actions on these environments can best be measured and evaluated. We will also discuss the extent to which we must learn more before evaluation of impacts can be done in a meaningful way. This learning process has begun and needs to be pursued vigorously in Phase II of the Reference Study. Finally, there is a series of conclusions based on our collective investigations during Phase I of the Study.

SECTION 2

EXISTING ENVIRONMENT OF THE GREAT LAKES - ST. LAWRENCE RIVER SYSTEM

2.1 INTRODUCTION

The Great Lakes-St. Lawrence River system is an extensive, physically and biologically diverse, and significant environmental resource. This system can be considered a series of lakes connected by channels, including the St. Lawrence which is the system's outlet to the Atlantic (Figure B-2-1). The system also can be considered to comprise an interrelated and interdependent set of terrestrial, wetland and aquatic environments, all of which can be found on both the lakes and connecting channels. In this and subsequent sections, the terrestrial environment refers to the shorelands of the Great Lakes and connecting channels, rather than to the entire land area of the Basin.

Some 15,700 km of shore enclose the Great Lakes, with an additional 4,800 km of shore lining the connecting channels. A diversity of shore types, from erosion-resistent bedrock to highly erodible cohesive bluffs is found on the Great Lakes. The world's largest lake sandspit complex, Long Point on Lake Erie, was recently declared a biosphere reserve by the United Nations.

Wetlands are highly productive biological environments at the land-water interface. Wetlands were once extensive along the Great Lakes shore, particularly the lower lakes. Some 50% of the original wetlands have been lost (USFWS, 1988). Presently, about 170,000 ha of wetland remains, about 63 percent of which is found on Lakes St. Clair and Erie.

The Great Lakes, themselves, occupy about 244,000 km^2 of the 766,000 km^2 of the basin, ranging in size from Lake Superior, (82,100 km^2), to Lake Ontario, (19,000 km^2). The lakes contain a variety of aquatic habitats, from deep, cool, oxygen-rich oligotrophic basins to shallow, warm eutrophic embayments. These habitats support numerous fish species and the many organisms upon which fish depend.

To appreciate more fully the quality, extent and distribution of existing terrestrial, wetland and aquatic environments of the Great Lakes - St. Lawrence River system, an historical perspective on human development and use of this system is helpful. Prior to European settlement, it is thought that human impacts were generally minimal because of the relatively small population and the lifestyle of native inhabitants. Agricultural land clearances were small and fishing was undertaken primarily in connecting channels and tributaries. In contrast, succeeding generations of European immigrants have had a major impact on the Great Lakes - St. Lawrence River system because of agricultural and industrial practices, settlement patterns, and other factors.

As settlement progressed westward and northward through the Great Lakes basin in the 1800s, impacts on terrestrial, wetland and aquatic environments were undoubtedly substantial. Deforestation for agricultural purposes was

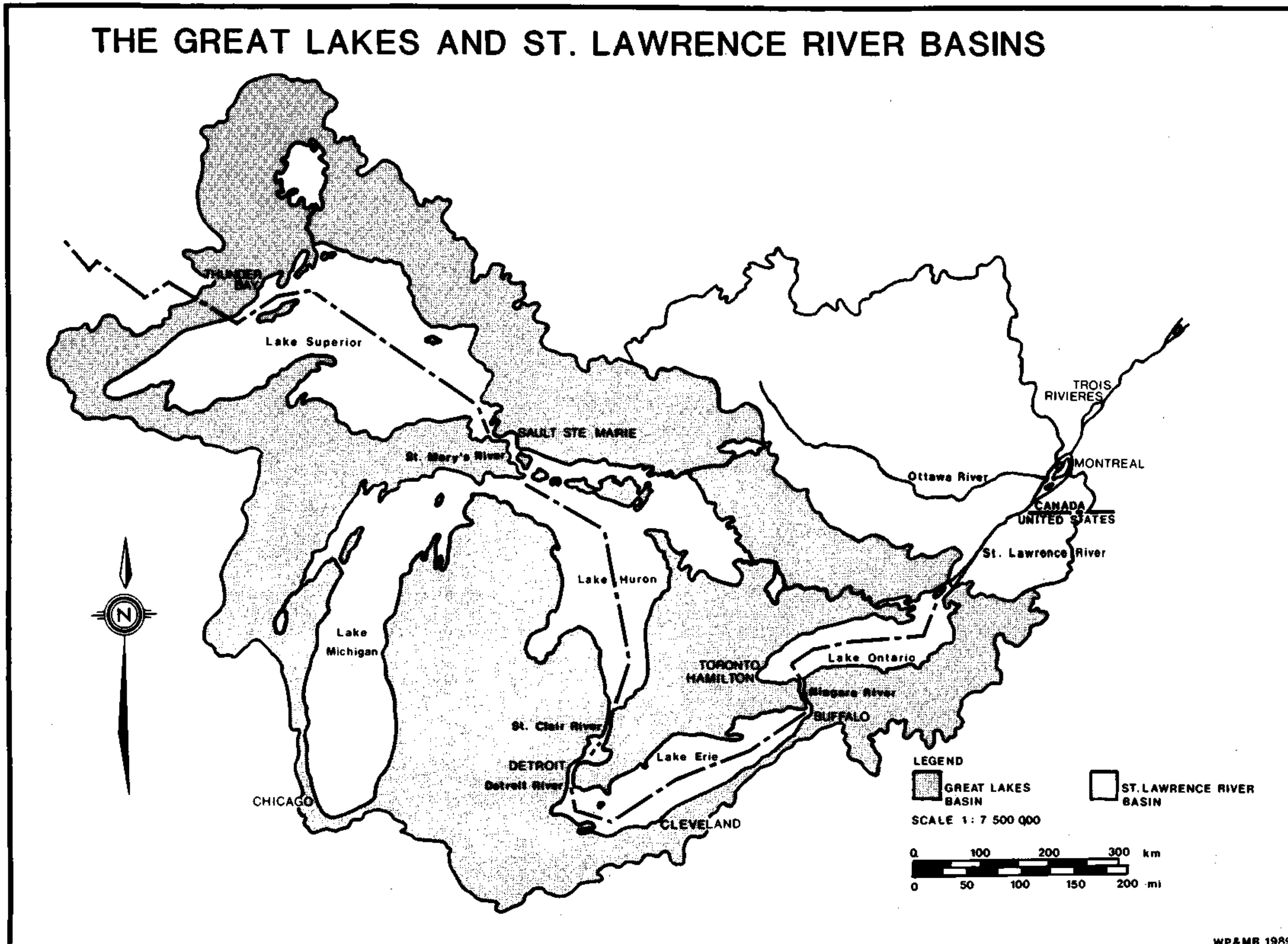


FIGURE B-2-1: GREAT LAKES AND ST. LAWRENCE RIVER BASINS extensive and much draining of coastal and inland wetlands, also for agriculture, occurred. Nutrient release from soils and soil erosion must have been extensive, especially in tributaries and embayments. Access to fish-spawning habitat in streams was cut off by construction of numerous dams. As waterborne transport was important in these early days, population growth concentrated at river mouths and around natural harbours. Urbanization and industrialization of many of these population centres, with little or no treatment of domestic and industrial wastes, resulted in degradation of the quality of water and aquatic habitat. Uncontrolled harvesting of fish, fur-bearers and other wildlife, in addition to loss and impairment of habitat, extirpated some species and stressed the populations of others.

By 1900, evidence of degraded terrestrial, wetland and aquatic environments was widespread. Outbreaks of typhoid fever and cholera were reported in a number of Great Lakes communities. While attempts were made to address some forms of degradation, the quality and quantity of many habitats continued to decline and new threats emerged, for example, those posed by a rapid increase in the production of synthetic chemicals in the 1950s and 1960s. Reversing these trends has become a priority of governments through the 1970s and 1980s.

2.2 EXISTING GREAT LAKES SHORE (TERRESTRIAL) ENVIRONMENT

DESCRIPTION OF SHORE TYPES

The physical characteristics of the shoreline result from the development of the Great Lakes region since the last ice age. The shores range from high bluffs of clay, till, shale and rock, through lower rocky shores and sandy beaches, to low marshy clay flats. The northern shores of Lakes Superior and Huron and the Thousand Islands area of the St. Lawrence River consist primarily of sedimentary and igneous rock which are highly resistant to erosion. The remainder of the shores however, are mainly composed of glacial sediments and are susceptible to erosion, primarily through wave action.

There are a number of specific shoreline types found throughout the Great Lakes and which are discussed throughout this Annex. This typology is based primarily upon the physiographic nature of the shoreline, which includes relief, composition, geology and erosion rates. The shore types are:

- **Bluffs** of variable heights, composed of glacial tills and lacustrine deposits consisting of clay, silt, gravel and boulders. In general, these shores are retreating due to erosion. In some cases, **bluffs can be overlying bedrock.** This may have a degree of influence on their respective recession rates.

- **Sand beaches**, which may be in equilibrium with natural forces, or which may be enlarging or eroding, depending on sand deposition patterns and sand supply. Commonly, sand beaches are fronting extensive dune systems, or else comprise a barrier to a wetland area. This type of shore can be described as a **barrier beach / dune complex.**

- **Wetlands**, which are low-lying areas, with characteristic vegetation, that are commonly protected from wave action by natural offshore barriers, or because of nearshore bathymmetry.

- **Rocky shores**, normally consisting of igneous or sedimentary rock that is eroding at a very slow rate as a result of freeze-thaw action and chemical weathering. These shorelines, except in areas where shale is present, are not eroding significantly.

- **Low coastal plain**, which can be described as any low lying land, usually meadow, or pasture, that slopes to the waterline and is not fronted by a beach and has no substantial bluff. Examples of this type of shoreline can be found in the connecting channels (e.g. the St. Lawrence River and St. Clair River).

- **Urban shorelines**, which usually are well armoured, except in those areas where public parkland exists. In many cases, road networks, residential areas, harbour structures, industrial areas, sewage treatment plants and other urban infrastructure are often located on or near the shoreline and can be subject to storm and flood damage.

LAKE BY LAKE DESCRIPTION

The following descriptions of the Great Lakes' shoreline are based primarily on a number of studies including the Great Lakes Framework Study (Great Lakes Basin Commission, 1975), The Coastal Zone Atlas (Haras and Tsiv, 1976) and The Great Lakes Environmental Atlas and Resource Book (Botts and Krushelnicki, 1987).

Lake Superior and St. Marys River Shores

The northern shoreline of Lake Superior is cut into the resistant rock of the Canadian Shield. As a result, the majority of the coast is characterized by low, resistant rock outcrops with few areas of sediment accumulation. The northwest and southeast sections of the coast have complex shorelines due to the erosion of relatively unresistant outcrops that has produced a series of large sheltered embayments. The remaining coastline is relatively straight with only small bays and headlands. Beaches are scarce, usually occurring in embayments, adjacent to river mouths.

The southern shore of Lake Superior is very similar, ranging from steep rock cliffs in areas such as the Pictured Rocks National Lakeshore area; to sandy beaches at Whitefish Bay; to low lying clay and gravel bluffs near Duluth, Minnesota; to the wetlands of Munuscong Bay, Michigan. A substantial baymouth bar encloses the harbours at Duluth, Minnesota and Superior, Wisconsin.

There are many islands in Lake Superior and the St. Marys River, with Isle Royale, and Sugar, St. Ignace and Michipicoten Islands being the largest. Major urban centres include the grain ports of Thunder Bay, Ontario and Duluth, Minnesota, and the border towns of Sault Ste. Marie, Ontario and Michigan.

Lake Michigan Shore

Perhaps one of the most impressive natural shore types of the entire Great Lakes is the long expanse of sand dunes along the eastern shore of Lake Michigan. These dunes extend from the Indiana border on the southern tip of the Lake almost to the Straits of Mackinac. They result from the prevailing westerly winds which cause an almost continuous washing and grading of shore materials. Wide sandy beaches are common along this shoreline, especially during periods of low water levels.

All shore types found along the Great Lakes are found along Lake Michigan's approximately 2,300 km of shoreline. Much of this is highly erodible bluff and dune along both the Michigan and Wisconsin shores. Most of the non-erodible shoreline exists in the northern section of the Lake along the Upper Peninsula of Michigan and Door County, Wisconsin.

Extensive coastal wetlands occur along Green Bay, Big and Little Bays de Noc, and along drowned river mouths of tributaries draining into the Lake.

Large urban sections of shore occur along the southwest shoreline and include the cities of Chicago, Illinois and Milwaukee, Wisconsin.

Lake Huron Shore

The Lake Huron shoreline is very diversified with rocky shores associated with the Precambrian shield covering the northern and eastern shores, exposed limestone dominating the shores of Manitoulin Island and the Bruce Peninsula; and glacial deposits of sand, gravel and till predominating in the southern and eastern portions of the shore.

Igneous or limestone rock comprises the majority of the shore from Sault Ste. Marie to Waubashene in southern Georgian Bay and most of Huron County in Michigan. Small sand beaches and wetland areas exist in embayments and river mouths.

The southern shore of Georgian Bay and southeastern shore of Lake Huron are characterized by long, wide beaches backed by dunes or bluffs at Ipperwash and Wasaga and high and low erodible bluffs with limited beach development through Huron and Lambton Counties in Ontario. Rock outcrops occur at Kettle Point.

The northwestern shore in Michigan is mainly rock and boulder with some high bank beaches extending landward into rolling uplands. The eastern shore is dominated by sandy beaches backed by low dunes and bluffs.

Saginaw Bay, a major embayment, consists of extensive coastal wetlands in the Inner Bay whereas the shoreline of the Outer Bay is mostly low sandy beaches backed by low dunes and bluffs.

There are many islands in Lake Huron ranging from very large islands like Manitoulin, St. Joseph, Cockburn, Bois Blanc and Drummond, to the many small islets in the "30,000 Islands" of eastern Georgian Bay.

St. Clair River, Lake St. Clair and Detroit River Shores

The shoreline of this region is generally low and consists of soft deposits of sand and clay. The shore of the St. Clair River consists of a sandy till bank 1.5 to 5 metres high, topped by clay deposits.

The islands of the St. Clair delta comprise almost one half of the shoreline of this region. The delta islands are very low and consist of broad marshes growing on sand deposits overlying a clay bed. Some marshes have been dyked and drained for agriculture.

The northern and eastern shores of Lake St. Clair are predominantly marshland on sand beds backed by low clay plains. Extensive areas of the shore have been dyked and drained for farming.

The south shore of Lake St. Clair consists of narrow sandy beaches backed by very low flat till plains. The western shore of Lake St. Clair is predominantly artificial fill for shoreline residential development.

The Detroit River shore consists generally of 1.5 - 5 metre high clay banks. This shore is heavily developed with many areas of fill and shore protection, and includes the cities of Detroit, Michigan and Windsor, Ontario.

Lake Erie and Niagara River Shores

The north shore of Lake Erie consists primarily of highly erodible deposits of glacial till, with some sections of clay and sand deposits. At the eastern end of Lake Erie, bedrock is exposed at or near the waterline in many locations. Except for the rocky portions of the eastern section, and the large sand spits at Point Pelee, Rondeau, and Long Point, most of the north shore of Lake Erie consists of soft eroding bluffs ranging from 3 to 30 metres in height. Extensive wetlands exist at creek mouths and behind sandspits. A large portion of these wetland areas at Point Pelee, Pelee Island and Rondeau have been dyked and drained for agriculture .

The southwestern shore of Lake Erie (Monroe County, Michigan) consists primarily of wetlands interspersed with artificial shore types in developed areas.

The Western portion of the Ohio shore is characterized by wetlands, low erodible bluffs and erodible plain while the eastern portion of the Ohio shore is mostly highly erodible glacial till and soft shale bluffs.

The Pennsylvania portion of the shore has bluffs ranging from 15 to 25 metres in height. In the western portion, the bluffs consist of silt, clay, and granular material with shale bedrock at or above water level. In the eastern portion the shale bedrock frequently rises to 10 metres above the lake level and the upper part of the bluff is composed of silt, clay and granular material. Sand and gravel beaches extend along the toe of the bluffs. A large sand spit, Presque Isle, occurs at Erie, Pennsylvania.

The southeastern shore of Lake Erie is characterized by erodible bluffs 10 - 15 metres high. The lower portion of these bluffs is shale overlain by unconsolidated material.

The Niagara River shoreline is composed of low banks in the upper portion of the river and a deep gorge cut through sedimentary deposits in the lower river below the Falls. Extensive filling has occurred in the Buffalo area.

The U.S. shoreline of Lake Erie is heavily developed with major urban areas occurring at Toledo and Cleveland, Ohio; Erie, Pennsylvania; and Buffalo, New York.

Lake Ontario Shore

The southwestern shore of Lake Ontario from the Niagara River to Hamilton consists of consolidated clays, silt and sand. In the Niagara region, 3 to 7 metre high bluffs predominate, while the shoreline in the Hamilton-Wentworth region is characterized by low-lying sandy beaches. A prominent sand bar closes off the western end of Lake Ontario and contains the heavily industrialized Hamilton Harbour. The northwestern shore from Burlington to Toronto consists primarily of shale outcrop, covered with glacial till. Cliffs along this shoreline range from 3 to 7 metres in height.

The western Toronto shoreline consists of low bluffs of sand, silt and clay with narrow sand and gravel beaches at the toe, while east of the Humber River the shoreline is low-lying but well protected by a seawall and breakwater. In the central part of the Toronto shoreline, sandy beaches form Toronto Island and close off Toronto Harbour. Extensive filling has occurred in the Toronto region with the creation of artificial headlands and spits. East of Toronto Island are the erodible Scarborough Bluffs which rise 90 metres above lake level.

From Scarborough to Presqu'ile Point the shoreline material is predominantly silty sand and boulder clay. Here the shoreline is mainly low bluff with beaches and marshes occurring at the mouths of rivers and creeks.

The eastern shore from Prince Edward County to the St. Lawrence River is mainly bedrock and therefore not readily erodible. Sand beaches and marshes occur in low-lying areas.

The south shore of Lake Ontario in New York consists generally of bluffs of glacial material ranging from 5 to 20 metres high. Narrow gravel beaches border the bluffs which are subject to erosion from wave action. Low marshes are interspersed among the bluffs in several places. The shore in the vicinity of Rochester and Irondequoit is marshy, with sand and gravel barrier beaches separating the marshes and open ponds from the Lake. The shoreline from Sodus Bay east to Port Ontario is a series of drumlins and dunes separated by marsh areas. The eastern shore consists of rock outcroppings interrupted by only a few pockets of beaches and marshes at the inner ends of deep bays.

St. Lawrence River Shore

The international reach of the St. Lawrence River flows over bedrock and consequently the shores are rocky and non-erodible through this reach. There are many small islands in the upper portion of the river.

Further downstream, between Cornwall and Montreal, the shore is generally low, within 5 metres of the low water plane. The shores are primarily clay with till outcrops. Rock outcrops occur at Montreal and wetlands are found in low-lying areas around Lac St. Francois. The Montreal - Cornwall section consists of three expansions: Lac St. Francois downstream of Cornwall, Lac St. Louis upstream of Montreal and the Laprairie Basin adjacent to Montreal Harbour. The Coteau and Beauharnois dams and the Lachine rapids separate Lac St. Francois, Lac St. Louis, and the Laprairie Basin, respectively.

The St. Lawrence River impacts on levels and flows on Lac Des Deux Montagnes and the Back Rivers that surround the Island of Montreal. Extensive dykes exist along these shores to protect low-lying urban development.

Downstream of Montreal the shoreline consists of clay banks overlain with sand and silt. The banks vary from a metre high in marshes around Lac St. Pierre to about 5 metres at Lanoraie. The river contains a series of islands between Montreal and Lanoraie, a deep section upstream of Sorel, a delta at the upper end of Lac St. Pierre, Lac St. Pierre itself and another deep section from the outlet of Lac St. Pierre to Trois Rivieres. The shores of Lac St. Pierre are marsh or low farmland. Downstream of Trois Rivieres the river deepens and water levels are predominantly affected by tides rather than by St. Lawrence River flows.

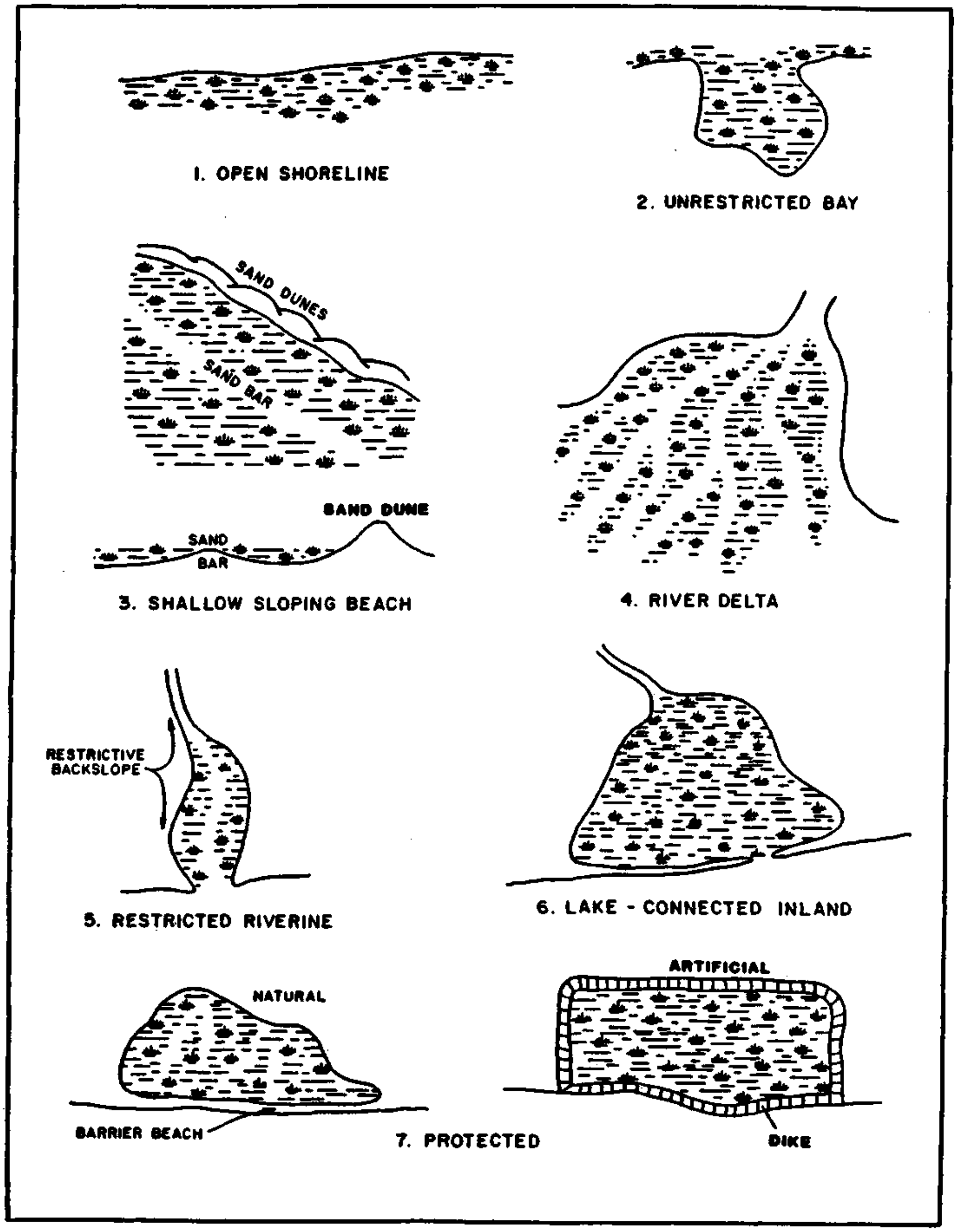
2.3 EXISTING GREAT LAKES WETLAND ENVIRONMENT

Wetlands (marshes, swamps, bogs and fens) are defined as lands where "the water table is at, near, or above the land surface long enough each year to support the formation of hydric soils and to support the growth of hydrophytes, as long as other environmental variables are favorable" (Cowardin et al., 1977). Coastal wetlands are the most productive and diverse component of the Great Lakes - St. Lawrence ecosystem. Productivity includes energy conversion and support of diverse flora and fauna. The productivity, biological composition, and size of the lower Great Lakes shoreline wetlands are a reflection of the long-term water-level regime. Coastal wetlands are the primary type of fish and wildlife habitat in the Great Lakes system and these areas and other shallow areas are where lake-level changes have the greatest ecological effect.

DESCRIPTION OF WETLAND TYPES

Descriptions of seven wetland types as presented in the Lake Erie Water Level Study (International Lake Erie Regulation Study Board, 1981) are given below and illustrated in Figure B-2-2. Each wetland type is described by its

FIGURE B-2-2: GREAT LAKES WETLAND TYPES



Source: ILERSB, 1981

physical and vegetational features. Although each wetland is unique, water level changes have resulted in the following general vegetation changes in the different wetland types:

- **Open shoreline wetlands** usually exist as a hydrophytic vegetation fringe adjacent to the shore. That fringe has expanded inland or lakeward in response to lake effects such as wave action. The dominant vegetation is usually emergent, but submergents can also be present and do not necessarily border on a shoreline. Examples of this wetland type are the north shore of the Inner Long Point Bay on Lake Erie and sections of the Detroit River shoreline in the vicinity of Fighting Island.

  Long-term lowering of the lake level has resulted in a corresponding shift of the vegetative fringe. The amount of lakeward shift depends on the bottom slope. A shoreward zone of vegetation is usually left dry. The lakeward shift of vegetation has terminated wherever the water became too deep for rooted plants to survive or the substrate was unsuitable. During long-term lake level rise, there commonly has been a shoreward shift of the vegetational fringe. Die-offs have occurred in water that has become too deep, but this has been offset to some degree by pioneering vegetation on the inshore side of the old fringe that has become inundated. When the backslope was too steep, high water levels have eradicated emergents in open shoreline wetlands.

  No shoreward shift can occur if alternate land use has already taken place (e.g. perimeter roads or highways, cottage or suburban development, agriculture or industry). In many cases, such development has been the standard and much wetland has been lost. The same caveat also holds for each of the examples following.

- **Unrestricted bays** are characterized by a marshy fringe along a bay shoreline, but these sites are afforded some protection from such lake effects as wave action. Depending on its size and depth, the whole bay could be vegetated. Submergents can be a part of those vegetative communities. This wetland type also includes typical open shoreline areas that are sheltered by an island or peninsula. Examples of this wetland type are the undiked section of the Ruhe Marsh of the Detroit River, and Bald Head Beach Marsh (Wellers Bay) and Black River Bay on Lake Ontario.

  Water-level changes have had effects on this wetland type similar to those described under "open shorelines". For wetlands located in an already shallow bay, lowering of water levels has created a condition encouraging dense emergent growth. A rise in the lake level has thinned out intolerant vegetation, and, when the backslope of the site was gentle, there has been inshore establishment of pioneer vegetation, as long as that natural terrain was available for wetland development. If the backslope was steep and the water level too high, there has been no inland pioneering and the vegetation has been eliminated.

- **Shallow sloping beach** wetlands are areas with very gentle to almost flat slopes on sand substrates. Very small variations in lake levels have had widespread effects on vegetation zones. Sand bars, if present, provide some wave protection. The large sand spit formations of Lake Erie, Long Point, Presque Isle, Point Pelee, and Pointe aux Pins, constitute most of this wetland type.

  A lowering of lake levels has usually produced extensive areas of dense emergents in this wetland type. At extreme low levels, large sections of completely dry substrate have been evident. High levels tend to produce a more open wetland. Vegetation that cannot adapt dies off. When high water-levels have been maintained for long periods, plant associations changed, with much of the area supporting extensive beds of submergents and floating-leaved aquatics. Because of the gentle slope of the landform, slight fluctuations resulted in vegetative shifts over large areas.

- **River deltas** are low islands and shallow zones formed by sedimentary deposits at a river mouth. The normally gentle slope allows the extensive shifting of vegetation zones when water levels fluctuate. The only wetlands identified as this type are the large St. Clair River delta along the northern edge of Lake St. Clair and the mouth of the Salmon River on eastern Lake Ontario.

  Low water levels have caused a lakeward shift of vegetation zones, while higher water levels usually shift vegetation zones landward. Diking to manage wetlands has increased during low water periods (e.g., Walpole Island Delta). Diking has prevented the natural shifting of vegetation zones over much of the wetland. Many of the remaining undiked areas have a steep backslope (dikeface), and, therefore, vegetation zones cannot shift landward, although the lakeward shifting of vegetation is still possible.

- **Restricted riverine** wetlands are characterized by marsh vegetation bordering a river course. The extent of the vegetated wetland is often restricted by a steep backslope on the landward side and the deeper water of the river channel on the other. The Grand River Marshes, the Portage River Marshes and the Sandusky River Marshes of Lake Erie are examples of restricted riverine wetlands.

  Spring flooding occurs more on riverine wetlands than others. These wetlands are partially or wholly protected from lake disturbances, but spring and early summer flooding have been intensified by high lake levels, and greater interspersion of vegetation and open water has resulted. With lower lake levels, the wetlands have tended to a drier state during summer and fall, except during short-term rises in the river levels.

- **Lake-connected inland wetlands** are typified by the presence of a barrier beach or ridge that restricts the outlet to the lake and also provides protection from wave action and other disturbances. Such wetlands can have a definite steep backslope or a gradual slope permitting some shifting of vegetation zones with changes in water regime. This type of wetland will have a connection to the lake, but a stream or groundwater discharge from its drainage basin could also contribute to its water supply. The Big Creek/Holiday Beach Marsh and Hillman Creek Marsh on Lake Erie, and Oshawa Second Marsh, Deer Creek Marsh and Sandy Creek Marsh on Lake Ontario are examples of this wetland type.

Because they tend to be situated in bowl-shaped basins, lake-connected inland wetlands have tended to develop toward a more "closed state" during extended periods of low water. The presence of a barrier beach has prevented the lakeward shifting of the wetland and there has been a greater dominance by emergent vegetation, especially in a marsh with no feeder stream. In cases where the outlet to the lake has closed because of lower lake levels, stagnation has increased due to the reduced water circulation. High lake levels have eliminated all or a good portion of the emergent vegetation, especially if the wetland backslope is steep, or the water increase extreme. In instances with a more gentle wetland backslope and a less severe increase in water level, a more typical shift of vegetation zones has occurred.

- **Protected wetlands** include both diked wetlands and those separated from the lake by an unbroken natural barrier beach or ridge. The natural wetlands and some of the diked wetlands obtain their water from inland groundwater discharge, streams, and, at times, from the lake, when the wetland floods during storms. There is some seepage of water through dikes, which can be magnified by extremes in lake levels.

The diked, managed wetlands of the eastern Lake St. Clair and western Lake Erie shorelines and Cranberry Marsh, Port Bay, Beaver Creek and Red Creek Marshes on Lake Ontario are examples of protected wetlands.

Lower lake levels have led to lower water levels in the naturally-protected marshes, encouraging denser emergent growth. In the diked marshes, lower lake levels have necessitated more pumping to alleviate effects, and have thereby increased management costs to the owners. High lake levels have produced high water levels in both the natural and diked marshes due to seepage from the water pressure differential on the dike. Overtopping of dikes and barrier beaches during storms has caused increased flooding. During high water years, managed diked marshes have required less pumping time to maintain water levels conducive to productive interspersion of vegetation and open water. However, extreme high levels have resulted in breaching of dikes and costly repairs.

INVENTORIES: AMOUNT AND DISTRIBUTION OF SHORELINE WETLANDS

Compilation of various reports, primarily the Lake Erie Water Level Study (International Lake Erie Regulation Study Board, 1981) and Herdendorf et al. (1981a), indicate an approximate total of 170,000 ha of wetlands along the shoreline of the Great Lakes. The freshwater portion of the St. Lawrence River in the Province of Quebec (from Lake St. Francis downstream to Cap Tourmente) contains a total of 37,735 ha of wetland habitats (Lands Directorate, 1986). Table B-2-1 presents a breakdown of the lower Great Lakes wetlands by wetland type (International Lake Erie Regulation Study Board, 1981) and Table B-2-2 provides an estimate of the U.S. wetland acreage. Figures B-2-3 to B-2-9 present the distribution of shoreline wetlands. Figures B-2-3 and B-2-5 do not show Canadian wetlands on Lake Huron and Superior. However, Figures B-2-10 and B-2-11 present the location of some important Canadian wetlands on these Lakes.

VALUES AND ECOLOGICAL FUNCTIONS

Great Lakes coastal wetlands are highly productive, diverse communities which interface between terrestrial and aquatic environments and are often more significant, in terms of ecological functions performed and resources produced, than inland wetlands (Glooschenko, 1985). About 14% of all Ontario wetlands evaluated have been classed as provincially significant (Glooschenko, 1985), while 28% of Lake Ontario wetlands, 85% of Lake Erie wetlands and almost all Lake St. Clair wetlands are provincially significant (Glooschenko et al., 1989). The most obvious and unique feature of these wetlands is their characteristic vegetation, which provides a diverse community structure offering cover and food for the animal components of the system. Because of the ability of this vegetation to slow the flow rate of water passing through, wetlands are valuable for erosion control, trapping sediments before they reach the open lake, and attenuating the force of waves to lessen their destructive power. The same vegetation provides a natural pollution abatement mechanism by serving as a filter for coastal tributaries through the reduction of the quantity of nutrients and toxic pollutants being washed into the Great Lakes.

During the past decade, considerable research was carried out regarding the function and value of wetlands. Important general sources include Messman et al.,(1977); Greeson et al., (1979); Tiner, (1984). In reference to the Great Lakes, significant contributions were made by Jaworski and Raphael, (1978); Tilton et al., (1978); Raphael and Jaworski, (1979); Jaworski, (1981); Herdendorf et al., (1981 a,b,c; 1986); Whillans et al., (1989); Glooschenko et al., (1989).

Wetland functions are those processes occurring in wetlands which are associated with the functioning of the ecosystem or with the hydrosystem. Examples of such functions are primary production and water storage. In contrast, wetland values are those wetland products or services which satisfy a human need.

TABLE B-2-1: WETLAND AREA OF THE LOWER GREAT LAKES BY WETLAND TYPE AND WATER BODY AREA IN ACRES

	1.Open	2. Unrestricted Bay	3. Shallow Sloping Beach	4. River Delta	5. Restricted Riverine	6. Lake-Connected Inland	7. Protected	Total
ST. CLAIR RIVER								
Canada	221					15		236
United States								
Total	221					15		236
LAKE ST. CLAIR								
Canada	2,788			16,824	28		12,563	32,203
United States	125			5,848	56	298	3,805	10,132
Total	2,913			22,672	84	298	16,363	42,335
DETROIT RIVER								
Canada	600	123			98		633	1,454
United States	125	135						260
Total	725	258			98		633	1,714
LAKE ERIE								
Canada	516	141	18,195		2,313	5,221	2,637	29,023
United States	2,005	1,618	374		1,569	510	18,236	24,312
Total	2,521	1,759	18,569		3,882	5,731	20,873	53,335
NIAGARA RIVER								
Canada								
United States	57	12				197	26	292
Total	57	12				197	26	292
LAKE ONTARIO								
Canada	1,114	6,353	534		6,035	4,484	590	19,110
United States	280	1,721		90	919	4,401	5,901	13,312
Total	1,394	8,074	534	90	6,954	8,885	6,491	32,422
ST. LAWRENCE RIVER								
Canada (Ont.)	6,910	3,965			1,917	1,333	23	14,148
United States	1,029	1,357			1,609	2,828	455	7,276
Total	7,939	5,322			3,526	4,161	478	21,426
TOTALS								
Canada	12,149	10,582	18,729	16,824	10,391	11,053	16,446	96,174
United States	3,621	4,823	1,374	5,933	4,153	8,234	28,423	55,586
Total	15,770	15,425	19,103	22,762	14,544	19,287	44,869	151,760

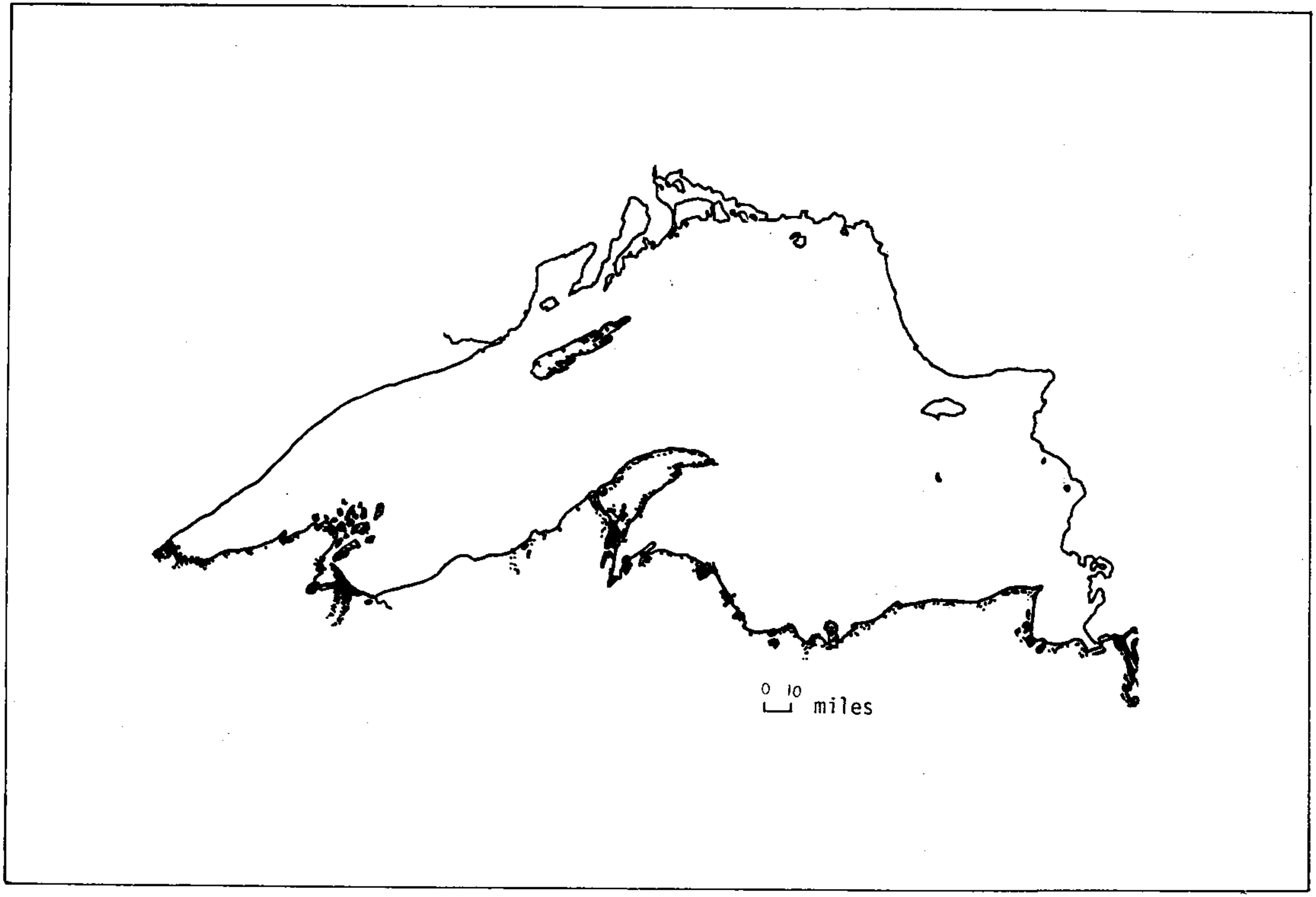
Source: ILERSB, 1981

TABLE B-2-2: COMPARISON OF UNITED SSTATES COASTAL WETLANDS FOR THE FIVE GREAT LAKES

Lake	No. of Wetlands	Percent of Total No.	Square Miles of Wetlands	Total No. of Acres	Percent of Total Area
Lake Superior and St. Marys River	348	25	103	66,175	22
Lake Michigan	417	30	189	121,230	40
Lake Huron, Lake St. Clair, and St. Clair River	197	14	110	70,245	24
Lake Erie and Niagara River	96	8	32	20,038	7
Lake Ontario and St. Lawrence River	312	23	32	20,797	7
TOTAL	1370	100%	466	298,485	100%

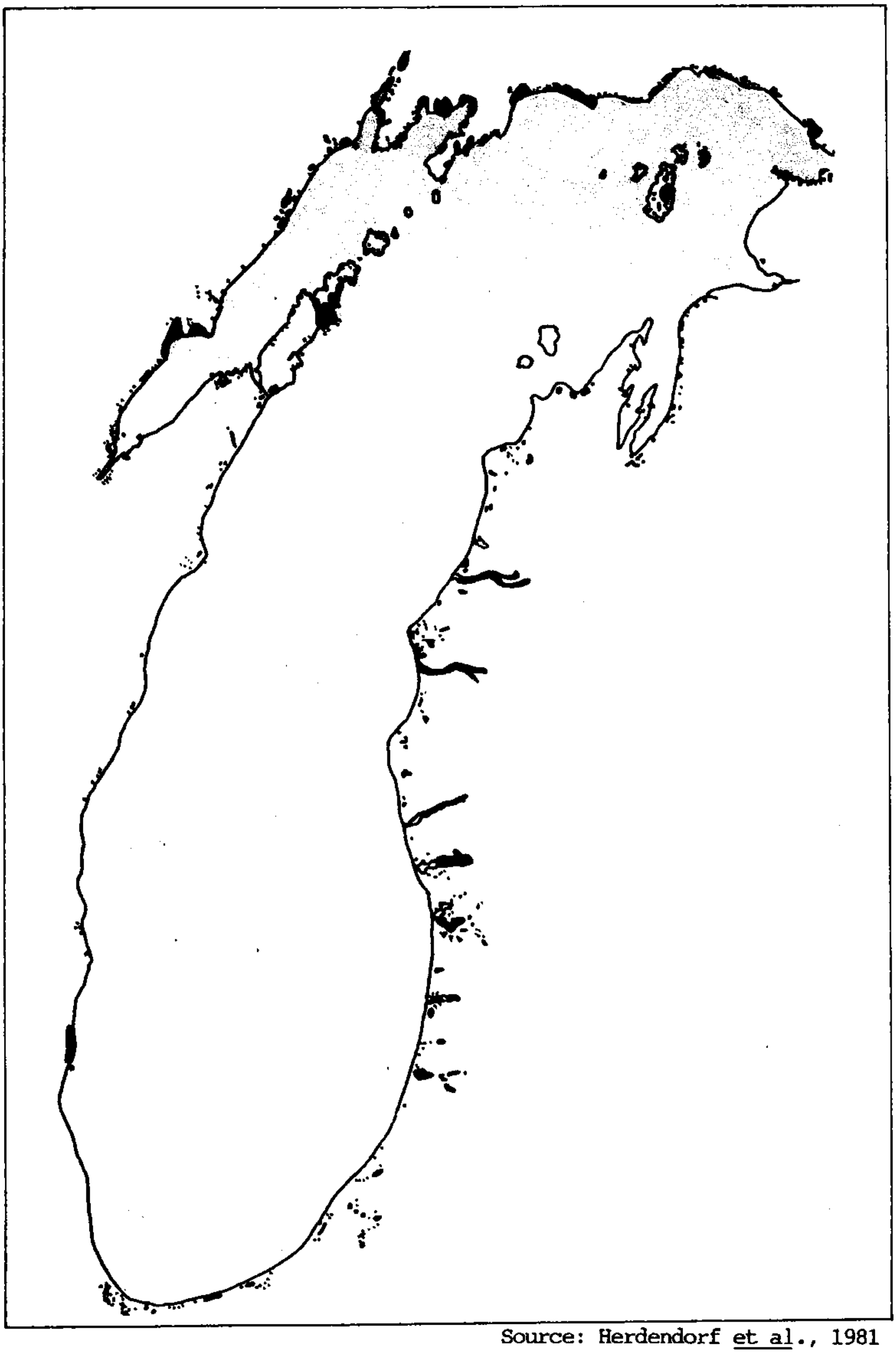
Source: Herdendorf et al., 1981

FIGURE B-2-3: COASTAL WETLANDS OF LAKE SUPERIOR



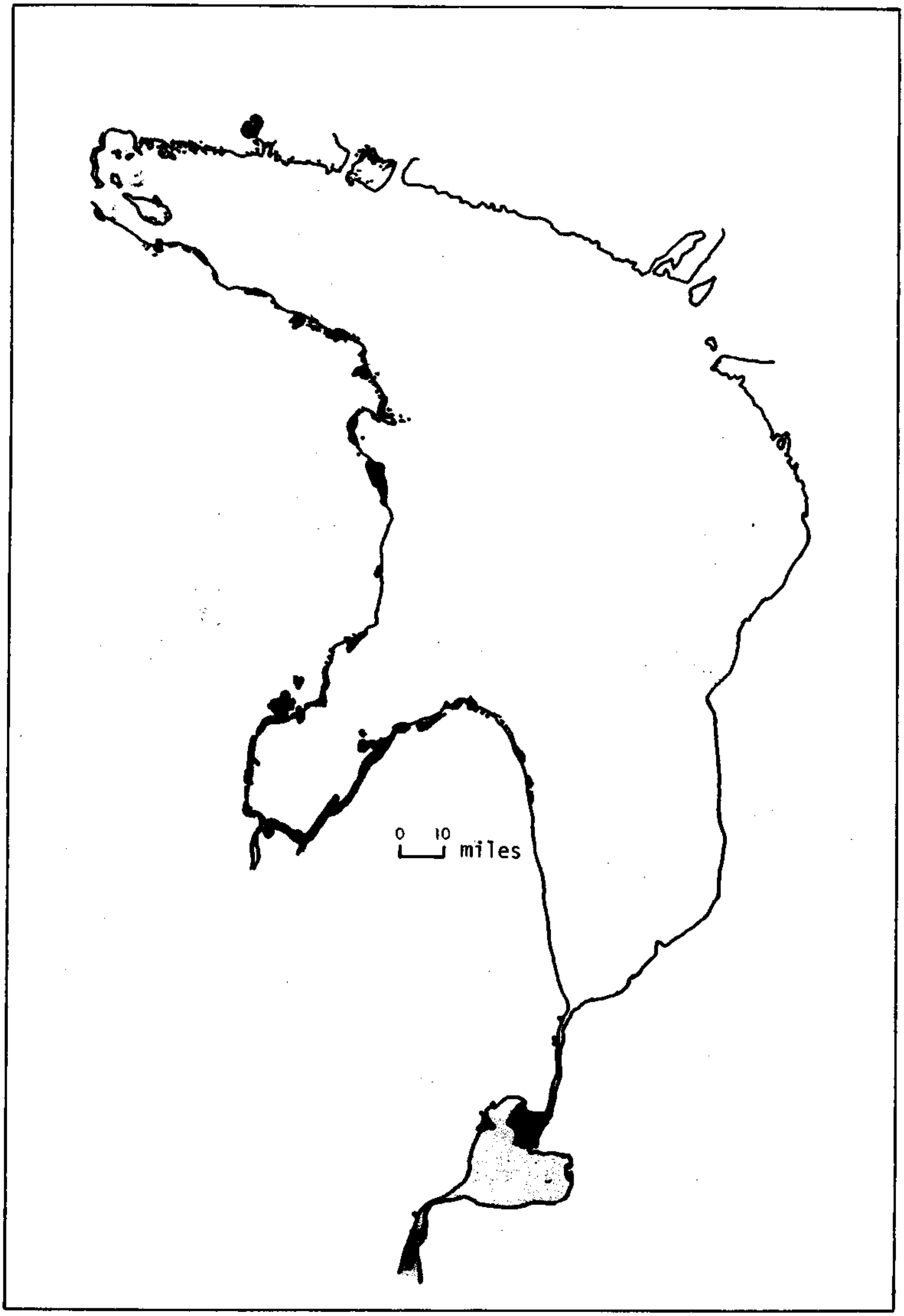
Source: Herdendorf *et al.*, 1981

FIGURE B-2-4: COASTAL WETLANDS OF LAKE MICHIGAN



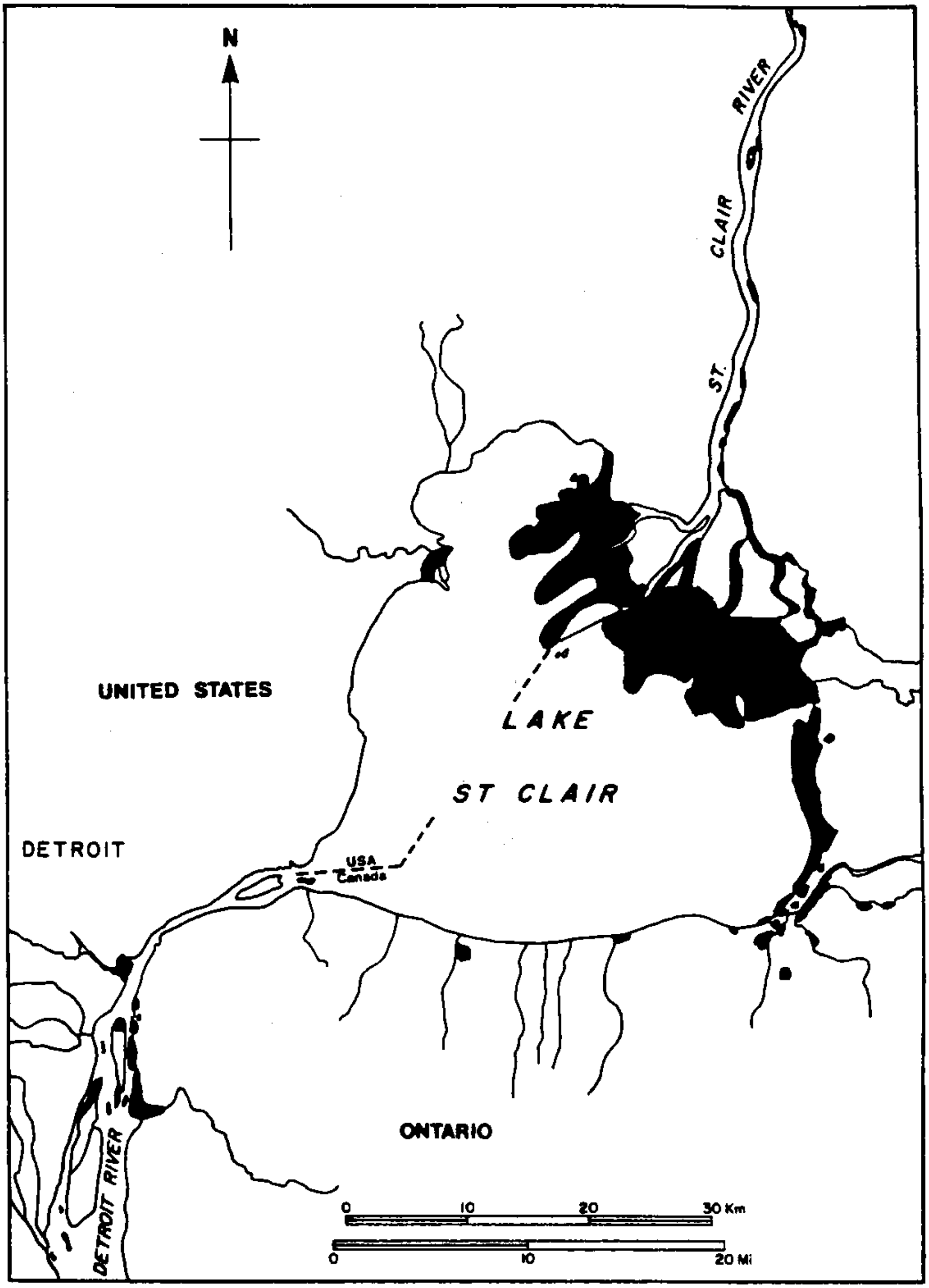
Source: Herdendorf et al., 1981

FIGURE B-2-5: COASTAL WETLANDS OF LAKE HURON



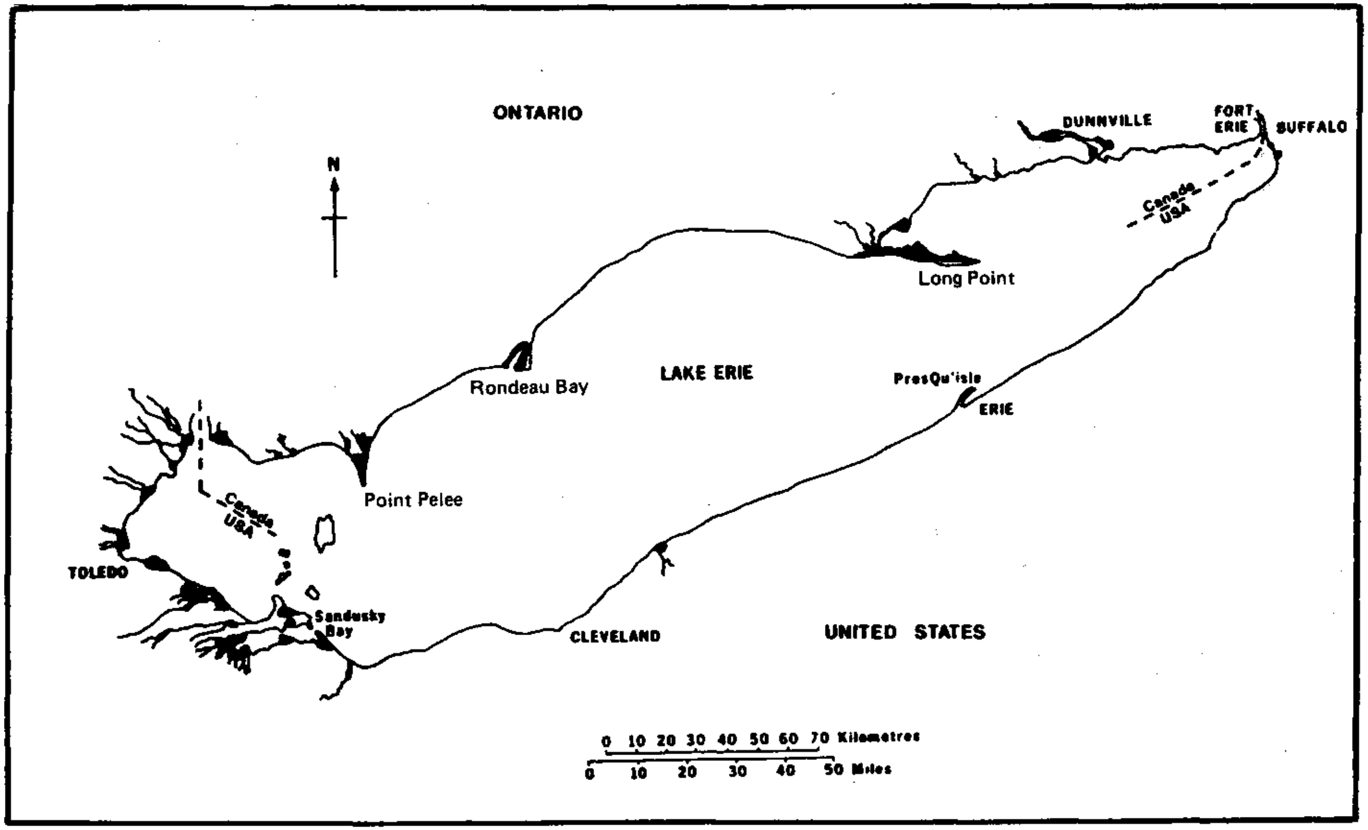
Source: Herdendorf et al., 1981

FIGURE B-2-6: COASTAL WETLANDS OF LAKE ST. CLAIR



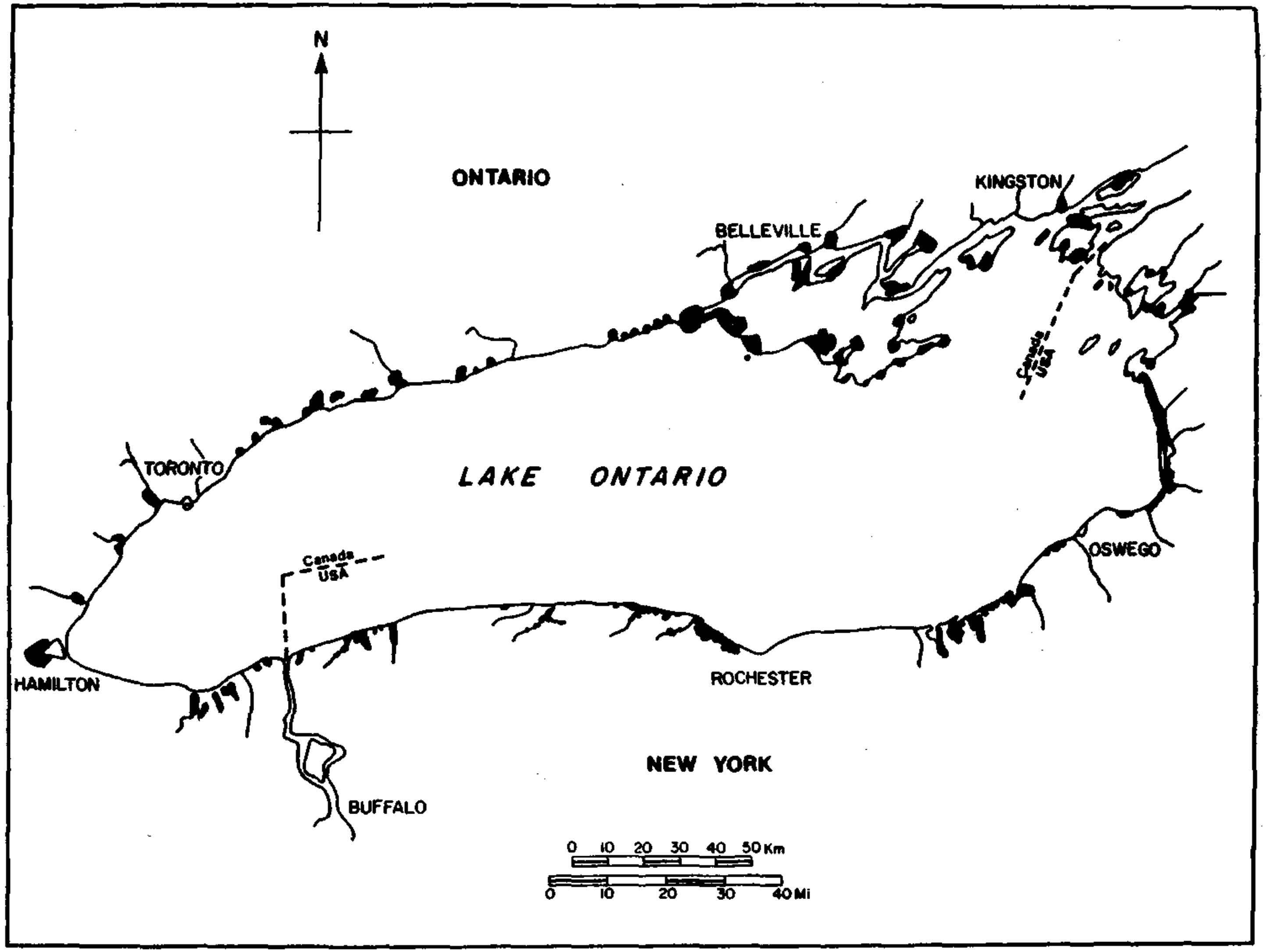
Source: ILERSB, 1981

FIGURE B-2-7: COASTAL WETLANDS OF LAKE ERIE



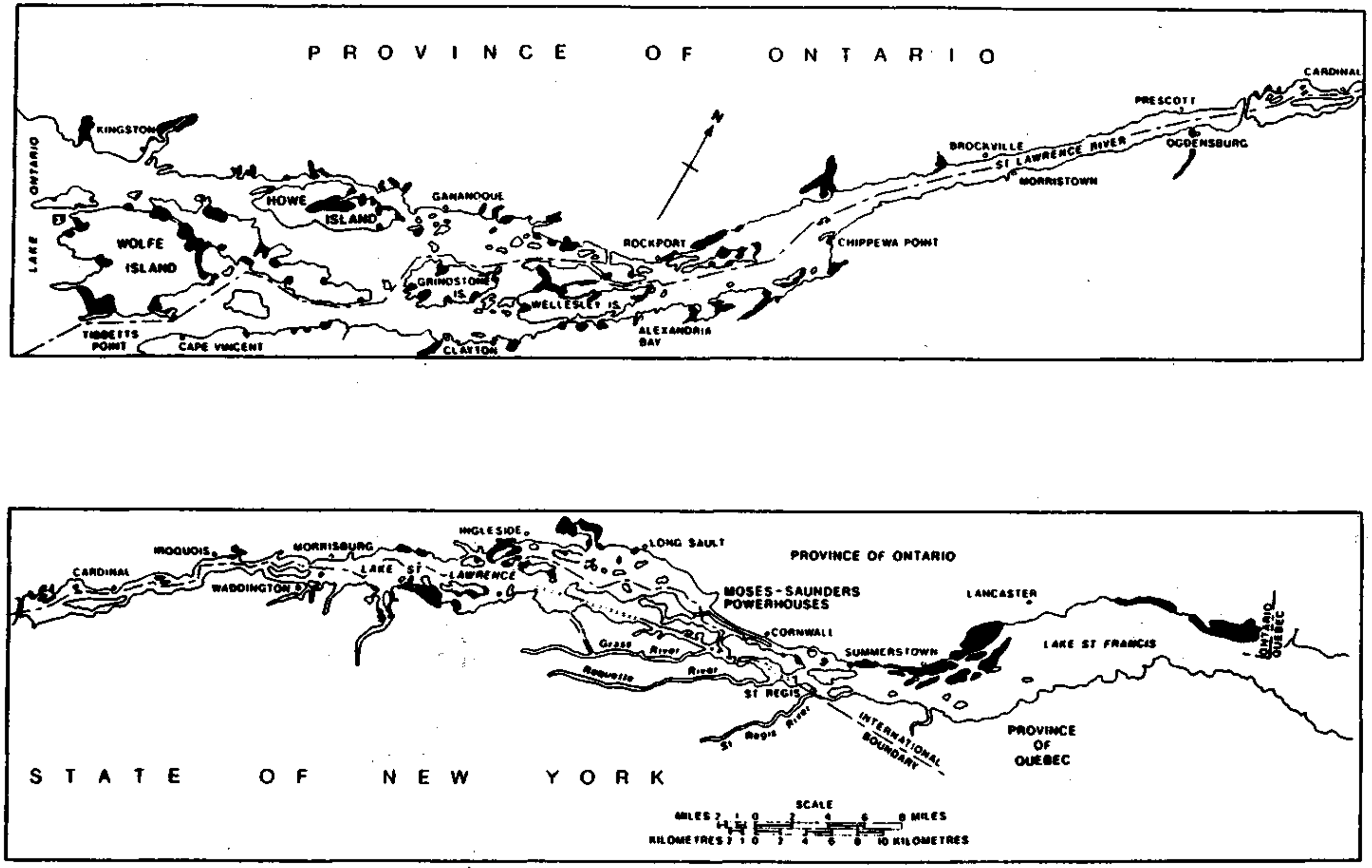
Source: ILERSB, 1981

FIGURE B-2-8: COASTAL WETLANDS OF LAKE ONTARIO



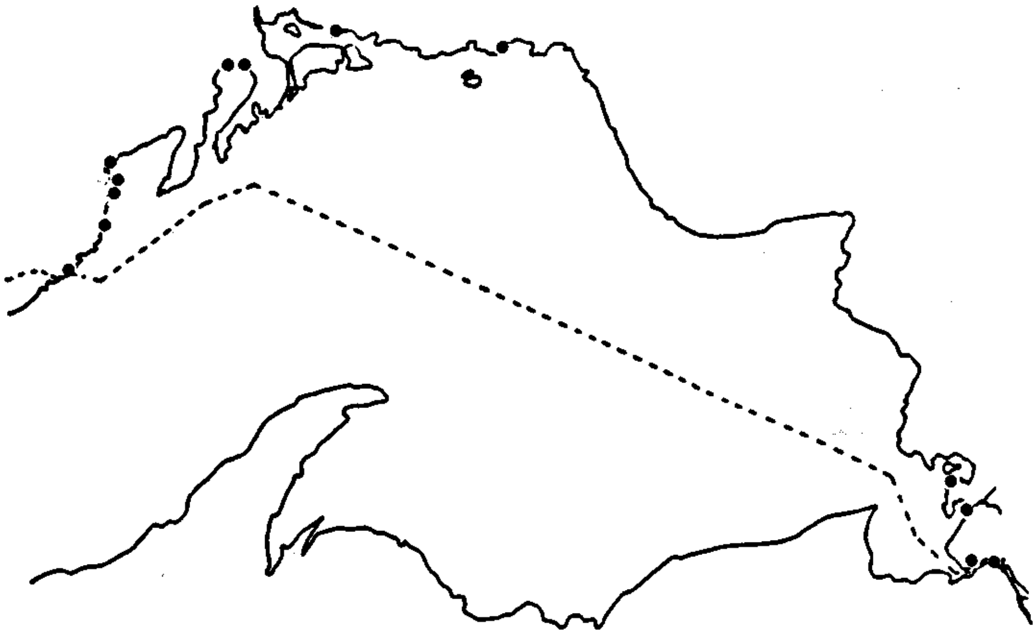
Source: ILERSB, 1981

FIGURE B-2-9: COASTAL WETLANDS OF THE INTERNATIONAL PORTION OF THE ST. LAWRENCE RIVER



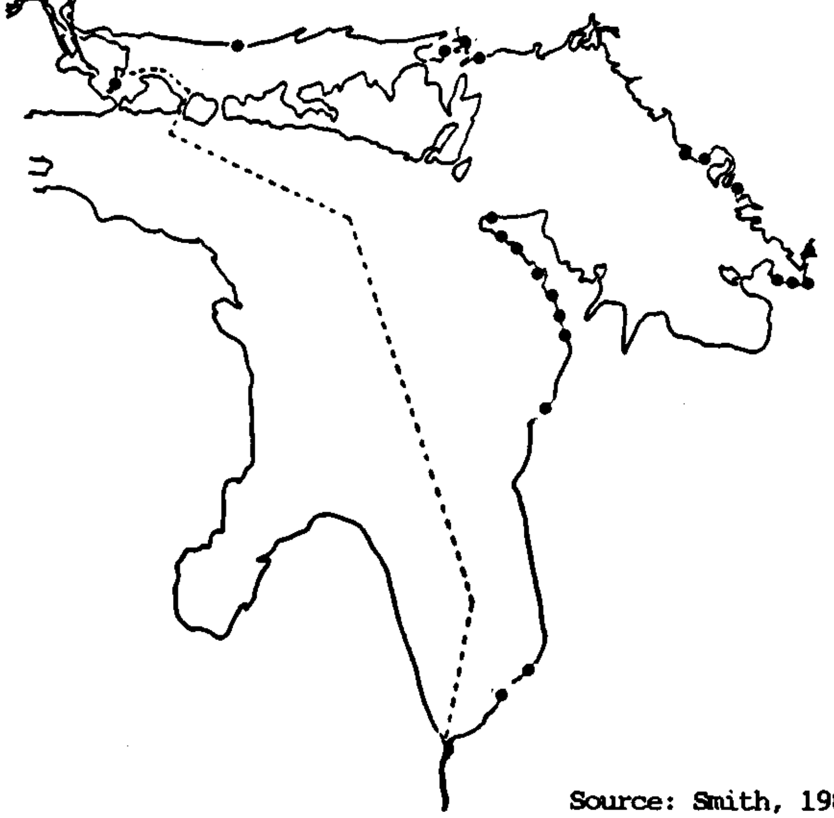
Source: ILERSB, 1981

FIGURE B-2-10: IMPORTANT WETLANDS - NATURAL HERITAGE AREAS - IN LAKE SUPERIOR, ONTARIO



Source: Smith, 1987

FIGURE B-2-11: IMPORTANT WETLANDS - NATURAL HERITAGE AREAS IN LAKE HURON, ONTARIO



Source: Smith, 1987

In response to Section 404 and other permitting authority, the U.S. Army Corps of Engineers (Reppert and Sigleo, 1979) developed the following list of wetland functions and services:

a. Natural biological functions

   1. net primary productivity
   2. food chain (web) support

b. Habitat for aquatic and wetland species

c. Aquatic study areas, sanctuaries and refuges

d. Hydrologic support functions:

   1. shoreline protection from wave attack
   2. storage of storm and flood waters
   3. water purification through natural filtration, sediment trapping, and nutrient cycling/uptake
   4. groundwater recharge

e. Cultural or auxiliary values including consumptive and nonconsumptive recreation as well as aesthetic value.

PRIMARY PRODUCTION AND DIVERSITY

Although shoreline wetlands are the most productive areas of a lake, the transfer of products from a wetland to the lake's secondary production is dependent on the physical nature of the water passageway. The operation of such a passageway is often affected by the water level.

Primary production of lake-influenced wetlands is dependent on a number of factors including seasonal temperatures, substrate, water levels and nutrients in the water. Although information concerning the levels of primary production of the wetlands for each of the Great Lakes is not available, it seems that primary production may show a general increase downstream in the system. For example, Edwards et al. (1988) calculated the estimated primary production of each of the Great Lakes' connecting channels. The international reach of the St. Lawrence River, which is the furthest downstream and receives most of its waters directly from Lake Ontario, was found to have the highest primary production of all the connecting channels, with the levels of production generally decreasing upstream. Since the nutrient rich waters that bathe the wetlands of the St. Lawrence River also bathe the wetlands of Lake Ontario, and the other connecting channels receive their water from the upstream lakes, similar levels of production rates could be expected, although morphometric factors such as exposure complicate comparison.

A rather detailed spatial and temporal comparison of the primary production of two Lake Ontario wetlands indicates significant differences. The difference in production between sites (Sage Creek versus Campbell) are explained by the differences in the dominant plant species. However, plant dominance is probably related to geomorphological conditions at the two sites. The difference in the level introduction at the same sites between years (1974 and 1980) is probably related to variations in water levels, temperature, and/or light intensity. Busch and Lewis (1984) found that water-level variations caused a major shift in the size of specific plant communities/species in these marshes. Geis (1979) reported that hydroperiod may be the most important variable in defining the extent, species composition, and stability of Great Lakes wetlands. Therefore, calculations that try to estimate total primary production of the wetlands for a lake system from a very limited number of study sites, have a strong chance for error due to the spatial and temporal variability in primary production of wetlands.

SECONDARY PRODUCTION AND HABITAT

Herdendorf et al. (1981 a,b) provided a comprehensive literature review of the fish and wildlife resources of the U.S. Great Lakes wetlands.

Herdendorf et al. (1981c) also described the resources of Lake Huron and the ecology of Lake St. Clair wetlands. The Lake Erie Water Level Study (International Lake Erie Regulation Study Board, 1981) presented a summary of the values and functions of the lower Great Lakes and Whillans et al. (1989) provided information for Lake Ontario. Glooschenko et al. (1989) described the values and characteristics of those Great Lakes coastal wetlands evaluated using Ontario's wetland evaluation system. (Environment Canada and Ontario Ministry of Natural Resources, 1984).

An important function of wetlands is fish and wildlife habitat. Many fish species are dependent on wetland habitat for parts of their life cycle, such as spawning and resting. Busch and Lewis (1982) reported 20 species that used a Lake Ontario wetland for spawning or as a nursery area. Herdendorf and Hartley (1980), using information from a number of sources, listed 24 species of fish that commonly spawn in wetlands. In addition, the wetlands are used for feeding. Herdendorf (1982) has noted that coastal wetlands are quite important for transfer of nutrients and energy via the export of young-of-the-year and forage fish. As much as 90% of the standing crop of Lake Erie coastal marshes is forage fish. The most definitive research on fish spawning and nursery use of Lake Ontario wetlands was conducted by Stephenson (1988). In the marshes that she studied, she found that 32 species, representing 89% of all the species present, used these shoreline marshes for these purposes.

The wetlands of the Great Lakes provide critical habitat for waterfowl, an international resource. In Ontario south of the extensive James Bay lowlands, the most critical wetland habitats for migrating waterfowl are associated with the shorelines of the lower Great Lakes (Dennis and Chandler, 1974; Dennis et al., 1984). The wetlands of Lake St. Clair, western Lake Erie and Long Point Bay on Lake Erie are examples of wetland areas of critical international importance. In addition, wetland habitat along the St. Lawrence River (shore swamp and tidal shore marshes) is also extremely important for waterfowl, including Greater Snow Geese, and shorebirds (Glooschenko and Grondin, 1988).

The North American Waterfowl Management Plan (United States Department of The Interior and Environment Canada, 1986), a U.S.-Canada document signed in 1986 and dedicated to the conservation of North American waterfowl, has identified the lower Great Lakes - St. Lawrence basin as one priority habitat area. One goal of the Plan is to protect 24,000 additional ha of breeding and migration habitat in the Great Lakes - St. Lawrence lowlands in Canada and 4,000 additional ha in the United States.

According to Hummel (1981), 42 bird species are totally dependent on Southern Ontario wetlands, 26 bird species are partially dependent, 16 mammal species are heavily dependent, and 20 reptile species are heavily dependent on these same wetlands.

Glooschenko et al. (1989) document the occurrence of endangered, threatened, and rare species for Canadian coastal wetlands. Use by rare birds is best documented, although a good deal of information exists on rare herpetofauna, fish and plants, including Great Lakes endemic plants. The wetlands of Lakes Erie and St. Clair are notable for many plant species rare in Ontario, some being at the northern edges of their ranges. Wetlands along Lake Huron and Georgian Bay possess a number of the plant species endemic to Great Lakes shorelines.

WETLANDS AND WATER QUALITY

Wetlands affect the nutrient status of inflowing water. This occurs because of the filtering effect of litter, saturation of suspended load, adsorption of nutrients to sediments, precipitation of dissolved and suspended material to the sediment surface, bacterial denitrification, and biological uptake (Kadlec, 1981). Vegetation would not be cropped (human activities) in natural marshes, thus nutrient control attributable annually to new plant material would be relatively minor. Apparently, this only affects a small proportion of the uptake by plants.

More controversial has been the question of net nutrient export from a wetland, especially one connected closely with a Great Lake. Much of the nutrient retention by wetlands is attributable to storage in sediments (King, 1985). Sediment transport is related to wetland size and shape; more protected wetlands would export less, but as long as wetlands are sediment sinks, nutrients accumulate (Kaiser, 1985). Lake Ontario, especially, is subject to high water-level fluctuations (daily, seasonally, and long term) that affect all lacustrine wetlands. Nixon (1980) argues that tidal marshes undergo tide-influenced nutrient fluxes. Sager et al. (1985) support this for the Great Lakes, explaining that marshes import dissolved, oxidized forms of nitrogen, carbon and phosphorus and export dissolved, reduced and particulate forms.

The effect of wetlands on more persistent pollutants (metals) is of considerable interest, given the public concern about this subject in the Great Lakes basin. Much of the attention is directed to the influences of soil and sediment and uptake by roots or animals in close contact with the substrate. Organic soils were found to reduce the impact of metals such as magnesium, iron, and manganese in a swamp in Prince Edward County, Ontario (Creasy et al., 1981). Submerged plants in Lake Ontario marshes tend to have higher concentrations of metals than emergent plants (Murdock, 1981), the roots having the highest within-plant concentrations (Taylor and Crowder, 1983).

More important perhaps, is the effect of vegetation on sediment mobility and resuspension of contaminant-laden sediments. For example, in Second Marsh, Ontario, the late winter decomposition of emergent plants is associated with the loss of metals, presumably to the sediment (Greig, 1987). Metal concentrations in this and other Lake Ontario shoreline marshes are known to be elevated. Experiences elsewhere in Lake Ontario and the Great Lakes demonstrate the problem of sediment suspension that results from loss of aquatic vegetation (Hannah and Associates 1984; Hamilton Harbour Remedial Action Planning Committee, 1988). The seasonal benefits that were discussed with respect to nutrient uptake by vegetation could also apply to friction-related sedimentation of contaminants.

HUMAN USE OF WETLANDS

From the United States and Canadian research that has been done, it is evident that Great Lakes shoreline wetlands are used for a range of activities including sportfishing, waterfowl hunting, trapping furbearers, water supply, tree cutting, nature study, public school usage, hiking, snowmobiling, cross-country skiing, canoeing, and for privacy of individual marsh owners/residents (Bardecki, 1982; 1984). The relative economic values and percentage of engagement in such activities can be seen in Table B-2-3. This table compares figures from Jaworski and Raphael's (1978) Michigan wetland study, Kreutzwiser's (1981 a,b) study of a Lake Erie marsh and Bardecki's (1984) study which included lake marshes in Southern Ontario. Valuation of these different human consumptive and non-consumptive uses is not an exact science as can be seen by the variation in the data.

2.4 EXISTING GREAT LAKES AQUATIC ENVIRONMENT

OVERVIEW OF CURRENT STATUS

The Great Lakes represent the largest concentration of fresh water in the world. In spite of their vast size, the Lakes have proved to be vulnerable to environmental change. The current status of Great Lakes water quality and habitat reflects these impacts and past and present efforts in pollution abatement and habitat restoration and rehabilitation.

The major issues concerning the Great Lakes aquatic environment today are eutrophication, toxic contaminants and habitat quality to support an ecologically balanced and healthy biological community. A general overview for all of the Great Lakes is presented here followed by a more detailed lake by lake summary.

TABLE B-2-3: COMPARISON OF THREE HUMAN USE COASTAL WETLAND STUDIES

	Michigan Coastal Wetlands Study (Jaworski and Raphael, 1978) value per wetland hectare 1977 for 42,839 hectares	Point Pelee Marsh Study (Kreutzwiser, 1981) 143,000 recreationists 1978% use and value per wetland hectare for 1113 hectares	Southern Ontario Marshes (Bardecki, 1984) 39 owner respondents reporting use by %
sport fishing	286.00/706.71	3.3%	by owner 12.8% by others 17.9%
waterfowl hunting	31.44/77.17	0.7%	by owner 17.9% by others 23.1%
trapping furbearers	30.44/75/72		by owners 2.5% by others 33.3%
nonconsumptive & nature study	138.24/341.59	83.9%	38.5%
sole recreation (hiking/ snowmobiling)			12.8%
canoeing		5.7%	
ice skating		6.3%	
water supply			
tree cutting			20.5%
commercial fishing	3.78/9.34		
privacy			2.6%
	$1,210.02 per hectare	$1,664,000 annual value for use of total area $1,495.06 per hectare	value per hectare per year $23.60 - $69.89 (partial valuation)

The status of eutrophication (nutrient enrichment) in the Great Lakes is presented in Figure B-2-12. Management strategies are to maintain the oligotrophic status of the open waters of Lakes Superior, Michigan, Huron and Ontario. The open waters of Lake Erie, Green Bay (Lake Michigan), and Saginaw Bay (Lake Huron) are being managed for mesotrophic conditions. Further reductions in nutrient loadings to achieve water quality objectives in Lake Erie, Green Bay and Saginaw Bay are called for in the Annex 3 supplement (phosphorus control) to the Great Lakes Water Quality Agreement (see International Joint Commission, 1988). Improvements are already underway in these areas (Table B-2-4) but further reductions in phosphorus concentrations are expected if non-point source control programs, especially on agricultural lands, are implemented.

The toxic contaminant issue is a pervasive one, affecting all portions of the Great Lakes. Conditions are most severe in 42 harbours, tributary mouths and embayments identified by the IJC as Areas of Concern (Figure B-2-13). Toxic heavy metals are especially high in sediments. Likewise, toxic organic chemicals are high in sediments where they bioaccumulate in organisms and biomagnify up the food chain. Concentrations of certain chemicals are sufficiently high in some species and sizes of fish that fish consumption advisories have been issued in 38 of these Areas to protect human health. Deformities, tumours and reproductive problems have been detected in fish in 19 of these Areas. Destruction of benthos, degradation of phytoplankton and zooplankton populations, and loss of fish and wildlife are also widespread. Research is underway to better understand the effects of these levels and kinds of contaminants on fish and other aquatic organisms. A summary of problems in these areas is presented in Table B-2-5.

Habitat quality is the newest issue of concern and perhaps is most ill-defined at this time. Habitat requirements for most species of fish are not well understood. We know habitats have been drastically altered in the connecting channels, embayments, and certain nearshore areas of the Great Lakes. Offshore habitats may also be degraded. For example, the inability of the lake trout to successfully reproduce in Lakes Michigan, Huron and Ontario may be related to habitat conditions on spawning shoals.

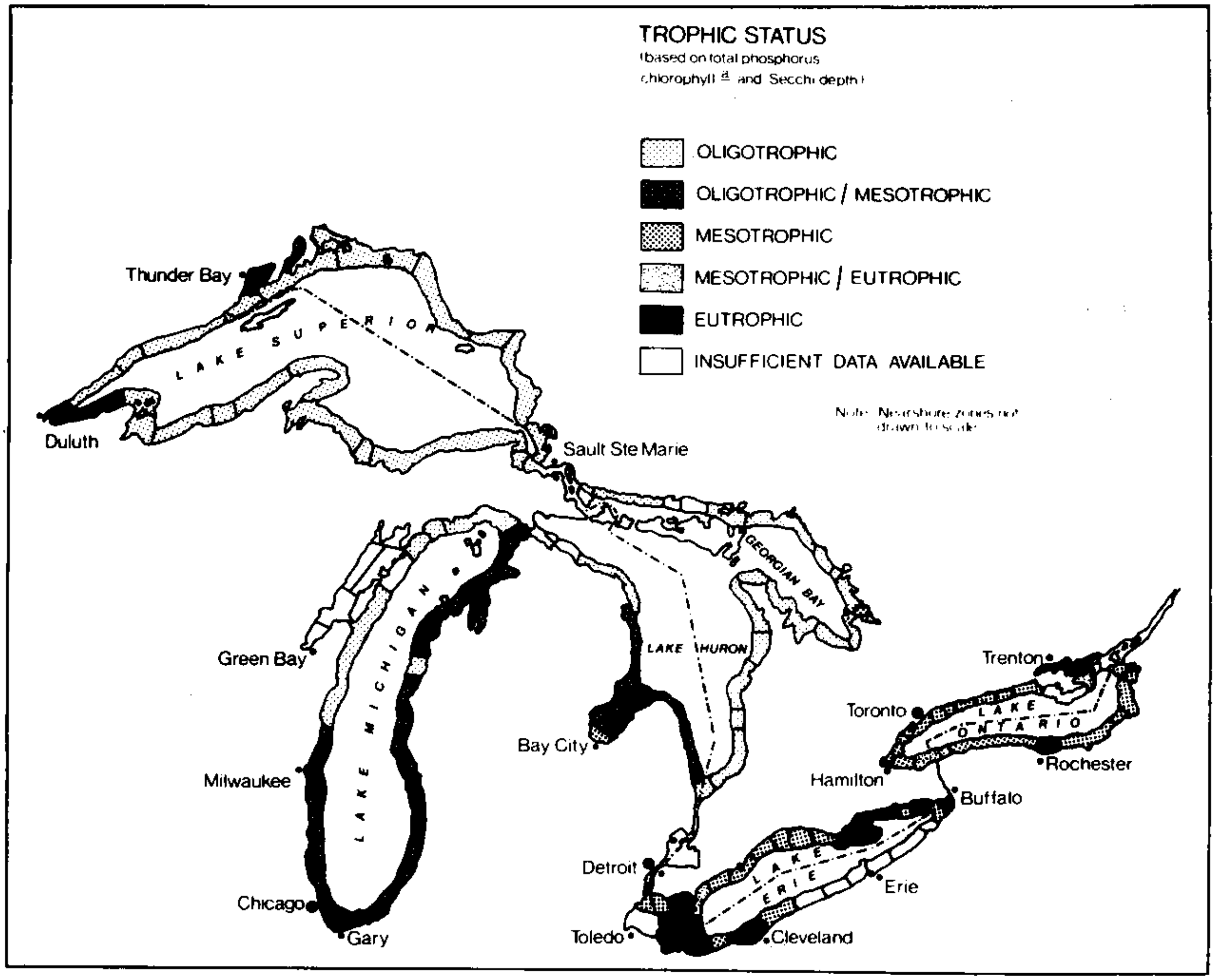
Biological community structure needs to be addressed along with habitat considerations. Stocking of fish predators may alter the predator-prey balance in pelagic communities that can be manifested in water quality indicators. The necessity for addressing the compatibility of water quality (nutrient abatement) objectives and fishery management (predator stocking) strategies is emerging.

LAKE BY LAKE DESCRIPTIONS

Lake Superior

Lake Superior is the largest of the Great Lakes, with a volume of 12,230 km^3, a surface area of 82,100 km^2, and an average depth of 149 m (Figure B-2-13) at low water datum. Because the Lake is so large and deep relative to its outflow at the St. Marys River, the hydraulic retention time is the longest

FIGURE B-2-12: TROPHIC STATUS OF THE GREAT LAKES



Source: Hartig and Gannon, 1986

TABLE B-2-4: A SUMMARY OF TRENDS IN TOTAL PHOSPHORUS AS AN INDICATOR OF TROPHIC CONDITIONS IN THE OPEN WATERS OF THE GREAT LAKES

Lake	Trophic Condition
Superior	No major change in concentration between 1967 and 1986 (1960s and 70s mean: 6 micrograms per litre; 1980s mean: 4 micrograms per litre, reflecting oligotrophic conditions).
Michigan	An apparent decrease in mean concentration from approximately 8 micrograms per litre in the mid-1970s to 5 micrograms per litre in 1987. Concentrations are slightly higher in the southern basin in comparison with the northern basin, but reflect oligotrophic conditions throughout the open waters.
Huron	No apparent change in concentration (5-8 micrograms per litre range) over an 18-year period (1968-1985).
Erie:	
Western	High year-to-year variability with an apparent decreasing trend from approximately 40 micrograms per litre in the early 1970s to approximately 20 micrograms per litre in the late 1980s. In spite of reductions, conditions remain eutrophic.
Central	Decreasing trend between 1968 and 1985 from approximately 20 to 12 micrograms per litre, tending towards mesotrophic conditions.
Eastern	A decreasing trend from approximately 18 micrograms per litre in 1968 to approximately 12 micrograms per litre in 1980, also towards mesotrophic conditions.
Ontario	A decreasing trend from 1973 to 1986 from approximately 25 to 10 micrograms per litre with most recent data indicating mesotrophic conditions.

Source: Hartig and Gannon, 1968 and Rathke and McRae, 1989

(191 years) of all the Great Lakes. Theoretically it takes that long for all the water to replace itself. Initially the large water volume can be viewed as beneficially diluting pollutants, but in the long-term it would take generations to cleanse the waters once polluted. Lake Superior is divided into two basins; the western basin is characterized as comparatively smooth bottomed, and the eastern basin contains a north-south trending valley and ridge system. Bottom sediments are primarily lacustrine muds; however, areas of rock outcrops and islands are found in both basins. The deepest sounding in the Great Lakes occurs in the eastern basin (407 m). The shoreline of Lake Superior extends for 4795 km.

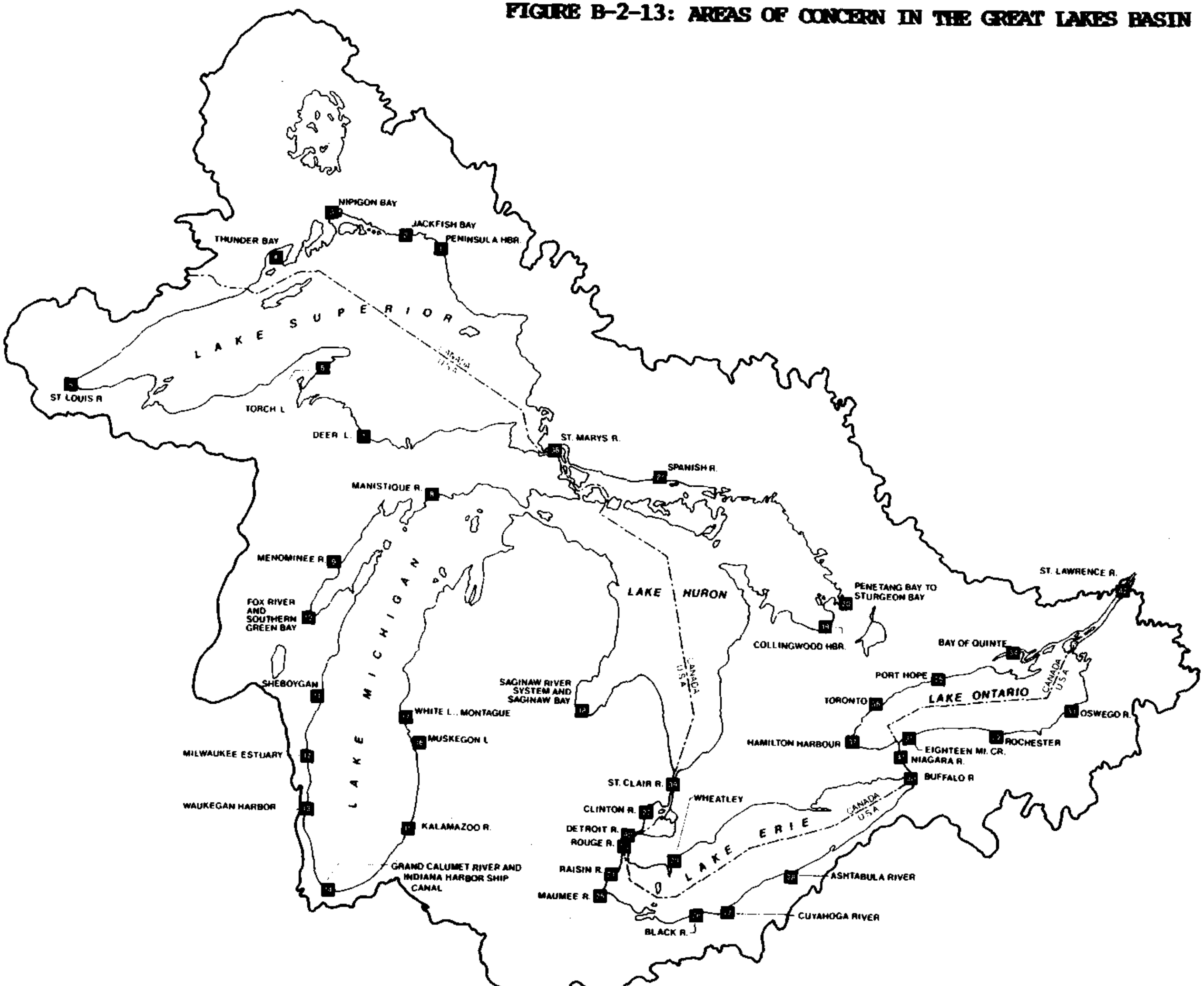
Lake Superior possesses the highest water quality of all the Great Lakes and is improving in certain harbors and river mouths where degradation once occurred (e.g., St.Louis River where habitat quality has improved and fish are increasing in abundance). The lakewide annual mean total phosphorus concentration of 3.5 micrograms per litre is the lowest in the Great Lakes and indicates the oligotrophic status of Lake Superior waters. Heavy metal concentrations in surface waters of Lake Superior are lower than metal concentrations in the other four Great Lakes. Contaminated sediments in Lake Superior are primarily found in seven Areas of Concern, as identified by the Great Lakes Water Quality Board (Figure B-2-13 and Table B-2-5).

The plant community in Lake Superior is dominated by phytoplankton, with only occasional macrophyte or macroalgal growth. The composition of the phytoplankton community reflects the oligotrophic status of the waters and is comprised primarily of nannoflagellates and diatoms. Approximately 140 species of zooplankton and benthos species have been identified from sediments of Lake Superior. Macrozoobenthos in Lake Superior is dominated by <u>Pontoporeia affinis</u> and clean water indicator taxa of oligochaetes, chironomids, and sphaeriids. The fish community reflects the oligotrophic status of the waters and is comprised primarily of cold stenotherm fish, such as lake trout (<u>Salvelinus namaycush</u>), whitefish (<u>Coregonus clupeaformis</u>), and an increasing number of lake herring (<u>Coregonus artedii</u>). Public health advisories against fish consumption are relatively few in the open lake, and they apply only to lake trout and walleye (<u>Stizostedion vitreum vitreum</u>) taken in Wisconsin waters. However, restrictions on fish and wildlife consumption exist for all seven Areas of Concern found in nearshore waters of the Lake.

There has been no indication that the habitat quality on Lake Superior has changed significantly for the past 100 years. No evident trend in nutrient increases has been observed during this period, and given the relatively slow rate of human population growth and land use changes in the watershed and the long residence time of water in Lake Superior, it is unlikely that nutrient levels will increase substantially. The lake continues to support organisms typical of cold, oligotrophic lakes. Lake Superior may be especially susceptible to toxic contaminant loadings from atmospheric deposition because once contaminants are deposited in the basin, their presence will persist, given the long residence time for Lake Superior waters.

Fish populations between the 1900s and 1950s were dominated by lake herring and lake trout. By the 1960s, these species declined markedly, probably as a result of competition for food with bloaters (<u>Coregonus hoyi</u>) and rainbow

FIGURE B-2-13: AREAS OF CONCERN IN THE GREAT LAKES BASIN



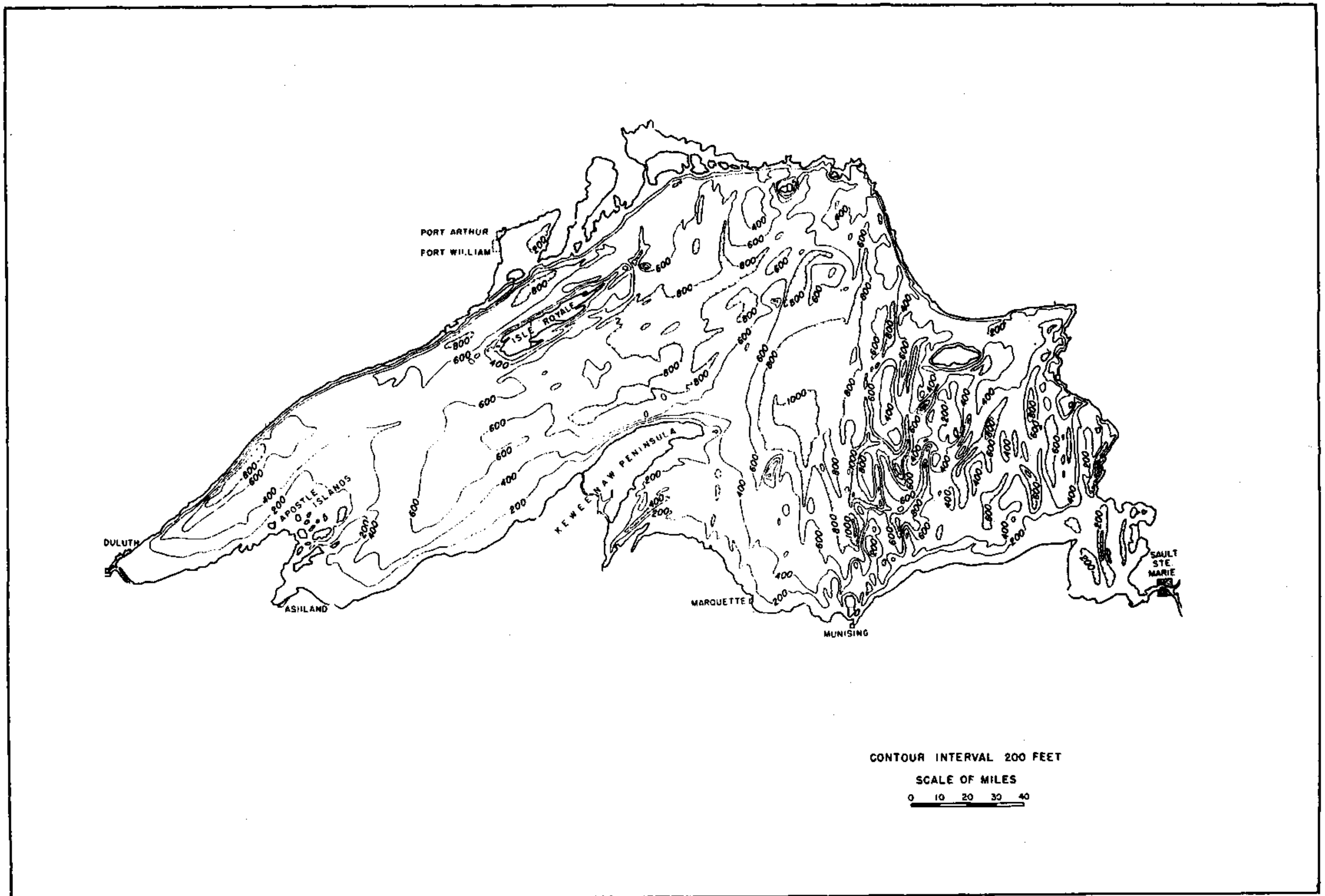
Source: Great Lakes Water Quality Board, 1985

TABLE B-2-5: A SUMMARY OF BENEFICIAL USE IMPAIRMENTS IN THE GREAT LAKES AREAS OF CONCERN

Use Impairment	Number of Areas Affected	Major Cause(s)
Degradation of benthos	40	Eutrophication Toxic substances
Restriction on fish and wildlife consumption	39	Toxic substances
Restriction of dredging activities	31	Toxic substances
Degradation of phytoplankton and zooplankton	28	Eutrophication Toxic substances
Undesirable algae	21	Eutrophication
Degradation of aesthetics	19	Eutrophication Toxic substances Habitat alteration
Degradation of fish and wildlife	18	Eutrophication Toxic substances Habitat alteration
Fish tumors and other deformities	17	Toxic substances
Loss of fish and wildlife habitat	17	Habitat alteration
Bird or animal deformities or reproduction problems	4	Toxic substances
Beach closings	4	Microbial contamination
Tainting of fish and wildlife flavor	3	Eutrophication
Restrictions on drinking water consumption or taste and odor problems	1	Eutrophication

Source: modified from Hartig, 1988

FIGURE B-2-14: PHYSICAL CHARACTERISTICS OF LAKE SUPERIOR



Source: Hough, 1958

smelt (Osmerus mordax), predation from sea lamprey (Petromyzon marinus), and overexploitation by man. Today, the lake herring population is steadily rebuilding and efforts to control the sea lamprey, combined with restoration efforts, may allow increased lake trout populations. Increased numbers of lake herring and lake trout will contribute to the community of prey fishes that is important to maintaining stable predator-prey populations.

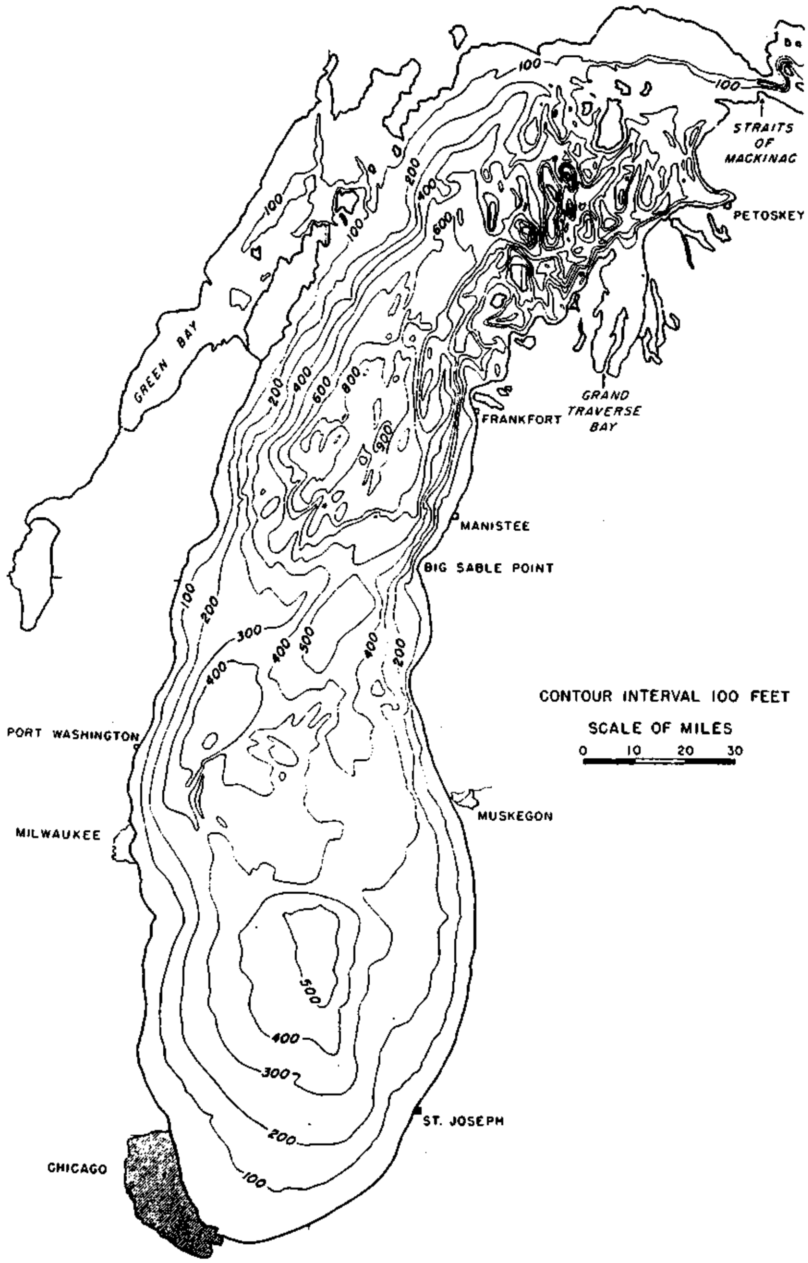
Lake Michigan

Lake Michigan is the third largest of the Great Lakes in area and second largest in volume. The area is 57,750 km^2, and the volume is 4,920 km^3 (Figure B-2-15). The Lake has an average depth of 85 m and the water retention time for this Lake is the second longest of the lakes, approximately 99 years. The Lake Michigan basin is topographically divided into three areas. The southern basin is gently sloping and contains mostly soft sediments, except for limestone deposits along the southwest shoreline. The central basin has an irregular bottom covered with limestone. The northern basin contains the deepest sounding in the lake (282 m) and is characterized by valleys, ridges, and rock outcroppings. Green Bay is a shallow arm on the northwestern side of Lake Michigan. The Lake Michigan shoreline extends for 2,670 km.

The trophic status of the open waters of Lake Michigan waters is oligotrophic, with phosphorus concentrations <7 micrograms per litre. Nearshore waters are mesotrophic. Eutrophic conditions are encountered in Green Bay and along the southern shoreline where phosphorus levels exceed 20 micrograms per litre (Figure B-2-12). Degradation of water quality from land-use activities and waste discharge has affected fish spawning success in certain areas. Lake Michigan, particularly Green Bay and Waukegan Harbor, has been the lake most affected by PCBs. Surface waters in Lake Michigan have higher burdens of heavy metals than any of the other Great Lakes. Concentrations of PCBs are about 1.2 micrograms per litre in the offshore waters, 3.2 micrograms per litre in nearshore waters and 3.5 micrograms per litre in the nearshore areas of Green Bay. PCBs in Lake Michigan offshore waters are highest in depositional zones in the southern basin and Green Bay. Concentrations of PCBs in these depositional zones are as high as 81 micrograms per kg of sediment. Contaminated sediments have been identified in ten Areas of Concern along harbors and tributaries of Lake Michigan (Figure B-2-13 and Table B-2-5).

The plant community in Lake Michigan is primarily phytoplankton, although substantial Cladophora growth occurs along shorelines in the central and southern basins. Composition of the phytoplankton assemblages is primarily diatoms; however, blooms of blue-green algae are frequent during the summer months, especially in Green Bay, and may be an indication of enriched water quality. A total of 200 zooplankton and benthic taxa have been identified in Lake Michigan. Rotifers numerically dominate the zooplankton community, with copepods being the next most common zooplankton. In general, oligochaete populations dominate the southern basins, and Pontoporeia affinis dominates the northern waters. Lake Michigan contains a diverse fish community as a result of the variety of habitats present in the Lake. The open waters are dominated by salmonids and whitefish, which subsist on a forage base of

FIGURE B-2-15: PHYSICAL CHARACTERISTICS OF LAKE MICHIGAN



Source: Hough, 1958

alewives (Alosa pseudoharengus) and rainbow smelt. Yellow perch (Perca flavescens) and ciscoes (Coregonus spp. especially hoyi) are also abundant in certain portions of the lake. Public health advisories exist lakewide against the consumption of large trout and salmon and several warmwater fish species in Green Bay.

Concentrations of nutrients and other chemicals have increased much more in Lake Michigan than in Lakes Superior and Huron. As a result, blooms of blue-green algae have become more common and the growth of Cladophora more widespread.

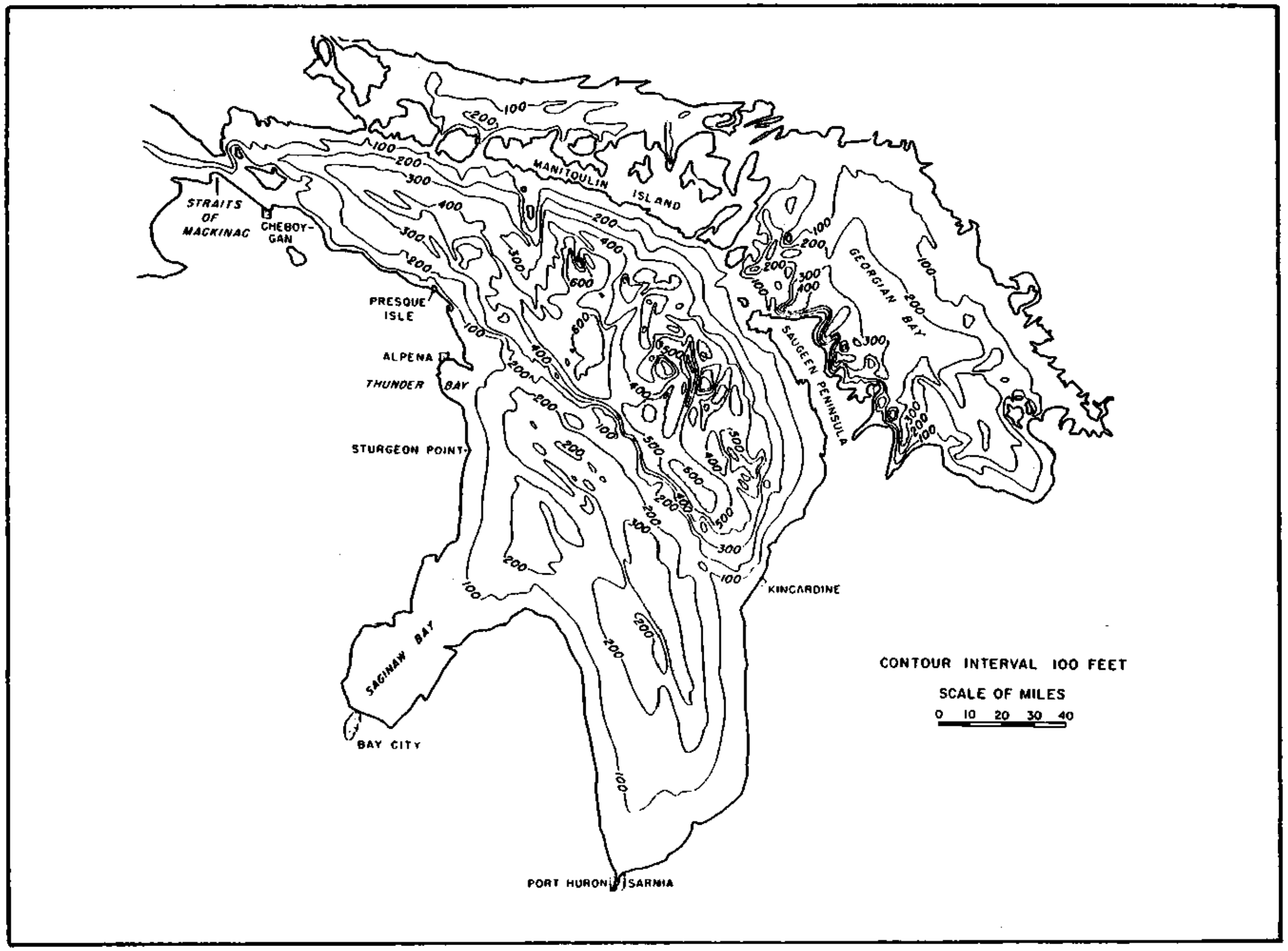
The fish community has changed considerably with the accidental introduction of the rainbow smelt in the 1920s, the sea lamprey in the 1930s and alewife in the late 1940s. These introductions had a dramatic impact on the living resources of the Lake, especially the native fish stocks and the zooplankton community. The impact of the sea lamprey was probably most dramatic because it preferred to prey on the large native fish species, such as lake trout, burbot (Lota lota), and lake whitefish (Coregonus spp.). The lamprey, in combination with overexploitation, pollution, and habitat destruction, eliminated sizable stocks of these valuable fishes. The increase in rainbow smelt and alewife reduced the availability of zooplankton and effectively reduced the feeding opportunities for larger whitefish species. The bloater actually shifted its feeding habits, becoming more benthic orientated and "changed" in morphology by reducing the number of gill rakers to adjust to benthic feeding. With artificial control of the lamprey and the introduction of Pacific salmon to prey on alewife, the Lake has returned to a more stable predator-prey ecosystem. At present it is difficult to predict what will happen to the fish communities of the lake, especially with the introduction of the water flea (Bythotrephes cederstroemi), a predator on other zooplankton that may affect the zooplankton community of the lake in the same way that the alewife did.

Lake Huron

Lake Huron has the second largest surface area of the Great Lakes and is the third in volume. Its surface area is 59,500 km^2 and its volume is 3,537 km^3 (Figure B-2-16). Average depth is 59 m. The retention time for water in the Lake is about 22.5 years. The lake bottom is composed of three basins:the shallow eastern basin of Georgian Bay, the northern main-lake basin and the southern basin. Saginaw Bay is a shallow arm of the southern basin. Bottom substrates in the nearshore areas contain sand deposits, and offshore areas are predominantly clay. The deepest sounding in Lake Huron is 229 m. The Lake Huron shoreline extends for 5,120 km.

The trophic status of the open waters of Lake Huron (Figure B-2-12) is olígotrophic, with phosphorus concentrations generally <10 micrograms per litre. However, the trophic status is considered to be intermediate between that of Lakes Superior and Michigan. Waste discharges and rising water temperatures from power plant discharges have reduced fish habitat in portions of Saginaw Bay. In addition, phosphorus concentrations in Saginaw Bay exceed 20 micrograms per litre and are some of the highest values reported in the

FIGURE B-2-16: PHYSICAL CHARACTERISTICS OF LAKE HURON



Source: Hough, 1958

Great Lakes. In comparison to Lakes Michigan, Erie, and Ontario, contaminant concentrations in Lake Huron are relatively low. Only Lake Superior waters are lower in heavy metal concentrations. None of the eleven heavy metals measured exceed implied Agreement Objectives. Contaminated sediments, as identified by Areas of Concern, exist at one site in Saginaw Bay and three sites in Georgian Bay (Figure B-2-13 and Table B-2-5).

The plant community in Lake Huron is dominated by diatoms indicative of the mesotrophic status of the water. Blooms of blue-green algae are common in Saginaw Bay. Moderate growths of Cladophora are present along most of the Lake Huron shoreline. Together, rotifers and copepods dominate the zooplankton community, with cladoceran zooplankton less common in Lake Huron than in Lake Michigan. Approximately 200 benthic taxa have been documented to occur in sediments of Lake Huron. The open lake benthos are dominated by Pontoporeia affinis, whereas Saginaw Bay is dominated by pollution-tolerant oligochaetes, such as Limnodrilus hoffmeisteri. The fish community in the deep, coldwater portions of the lake is dominated by lake trout, whitefish, and bloater, whose recovering population may, in part, be attributed to an increase in habitat quality. Saginaw Bay also contains several warmwater species such as walleye, carp, and yellow perch. Public health advisories exist regarding the consumption of trout from the open lake and from all four Areas of Concern identified in Lake Huron (Table B-2-5).

Habitat quality in Lake Huron has changed only slightly since the 1800s, except for significant increases in nutrient levels in Saginaw Bay and to a lesser extent in harbors of Georgian Bay and the North Channel. Descriptions of the Lake Huron plant and invertebrate communities have changed little since the earliest records.

The fish community has undergone several changes, such as the decline of lake herring and other ciscoes. However, most of these changes have been caused by human, rather than natural, processes. Historically, lake herring, ciscoes, whitefish, and lake trout dominated the commercial harvest of fish. In the 1940s a dramatic reduction in numbers of these species occurred as a result of the sea lamprey and overexploitation. In Saginaw Bay, relatively large harvests of walleye and yellow perch were taken in the pre-1940 period. These populations are returning to their former abundance. It is hoped that the introduction of Bythotrephes cederstroemi will not affect the zooplankton community, which would effect the balance of the predator-prey system.

Lake Erie

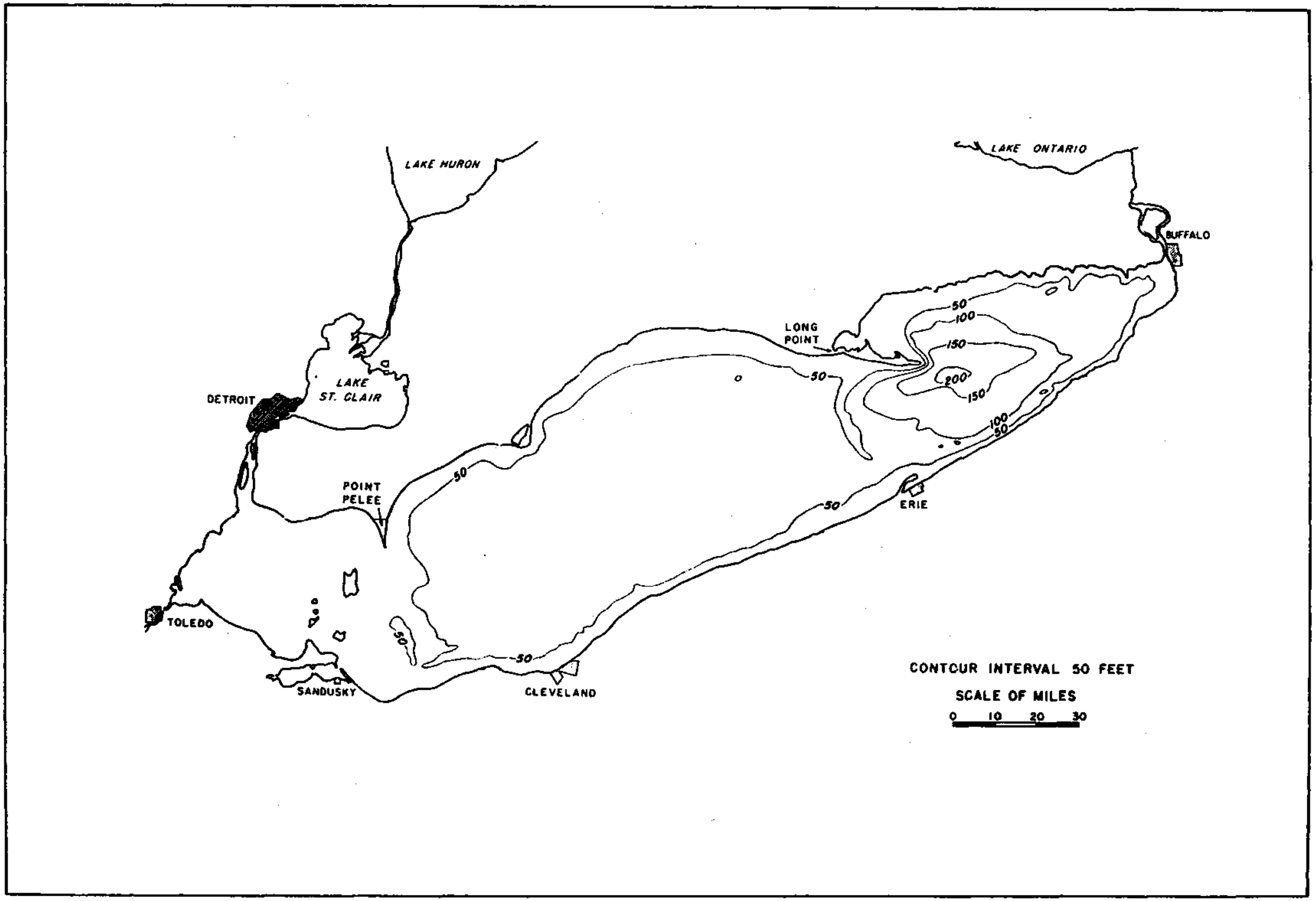
Lake Erie is the shallowest of the Great Lakes and has the least volume. The surface of the Lake is 25,657 km^2 and the volume is 483 km^3 (Figure B-2-17). Lake Erie has an average depth of 19 m and the shortest retention time for water of any of the Great Lakes (2.6 years). This short turnover time for water in the Lake is one reason why Lake Erie studies often detect changes in water quality due to human activities before they are detected in the other Great Lakes. Lake Erie is divided into three basins. The western basin is the most shallow, and the bottom substrates are composed primarily of silt and mud with some rocky reefs. The central basin is the largest of the three, and the bottom contains mostly clay. The eastern basin has the deepest sounding (64 m), and muds and silty clays are on the bottom.

Lake Erie is the most eutrophic of the Great Lakes (Figure B-2-12), with average open-water phosphorus concentrations of 11-13 micrograms per litre. Soil erosion has changed the bottom sediments of the Lake and may have affected spawning success in certain areas, thus degrading habitat. The western basin generally contains higher nutrient concentrations than the other basins, but has the most diversity in habitats with rocky shoals and submerged bedrock outcrops. Depletion of oxygen in the bottom waters occurs during the summer in the central basin. The eastern basin has the highest water quality in the lake. In general, chemical contamination is not a significant problem in most of Lake Erie. Organochloride contaminants in Lake Erie's surface waters are relatively low. Organochloride contaminants, such as PCB's, occur primarily near the mouths of tributary rivers. Lake Erie sediments have relatively high concentrations of heavy metals, similar to those found in Lake Michigan. A total of nine Areas of Concern have been identified as having contaminated sediments along the shores and harbors of Lake Erie (Figure B-2-13 and Table B-2-5).

Phytoplankton assemblages from the central and eastern basins of Lake Erie are indicative of the mesotrophic nature of these basins. While diatoms dominate the phytoplankton assemblage, green algae are also common. The growth of Cladophora in Lake Erie is greater than in any of the other Great Lakes. Macrophyte growth is also common along the Lake Erie shoreline, especially adjacent to wetlands and the islands in the western basin. Approximately 500 zooplankton and macrozoobenthic species have been identified in Lake Erie. Rotifers numerically dominate the zooplankton, with copepods and cladocerans nearly equally abundant. The western basin is dominated by the pollution-tolerant oligochaete Limnodrilus spp. and the central and eastern basins by the pollution-intolerant species Pelscolex ferox and Stylodrilus heringianus. Walleye, yellow perch, and smelt are principal components of the Lake Erie fish community, especially in the western and central basins. White bass (Morone chrysops) and, more recently, white perch (Morone americana) have also become well established in the Lake. Restrictions on the consumption of carp (Cyprinus carpio) and catfish (Ictalurus punctatus) exist lakewide.

Lake Erie has the shortest retention time of any Great Lake, and is therefore the Lake where changes occur most rapidly. The most dramatic example of change in Lake Erie has been the degradation of the trophic status of the Lake in response to cultural eutrophication and the partial recovery to date of the water quality in the Lake with the abatement of nutrient inputs. The increase in nutrients associated with cultural enrichment dramatically altered the benthic community in the western basin, caused anoxic conditions to form in the central basin, and made blooms of blue-green algae common throughout the Lake. As a consequence, in Lake Erie, much of the suitable habitat for native fish such as whitefish, lake herring, and lake trout has been removed, and those fish were replaced by species such as white bass and white perch. However the success of recent lake trout restoration efforts in Lake Erie indicate that the habitat in Lake Erie is improving and recovering from the adverse changes.

FIGURE B-2-17: PHYSICAL CHARACTERISTICS OF LAKES ST. CLAIR AND ERIE



Source: Hough, 1958

Lake Erie has probably received the most man-induced stresses of all the Great Lakes and the fish community has been permanently changed. Fish communities are dramatically different than they have been historically. Several major stresses on fishes in Lake Erie have been identified: the commercial fishery; cultural eutrophication; introduction of new species; tributary and shoreline restructuring; shoreline and agricultural land erosion and resulting siltation; and toxic discharges from industrial activities. Desirable species such as the lake herring, whitefish, blue pike (Stizostedion vitreum glaucum), and sauger (Stizostedion canadense) are no longer an important part of the commercial fishery. The commercial fishery is only a small part of the total fishery today; the sport fishery accounts for a majority of the fish harvested from the lake. Sport take from the Lake is composed primarily of yellow perch, rainbow smelt, walleye, and white bass. The effect on the food chain of the recently invading Bythotrephes cederstroemi, via fish-prey interactions and the zebra mussel Dreissena polymorpha, via the removal of plankton and detritus from the water column, is, at present, unknown.

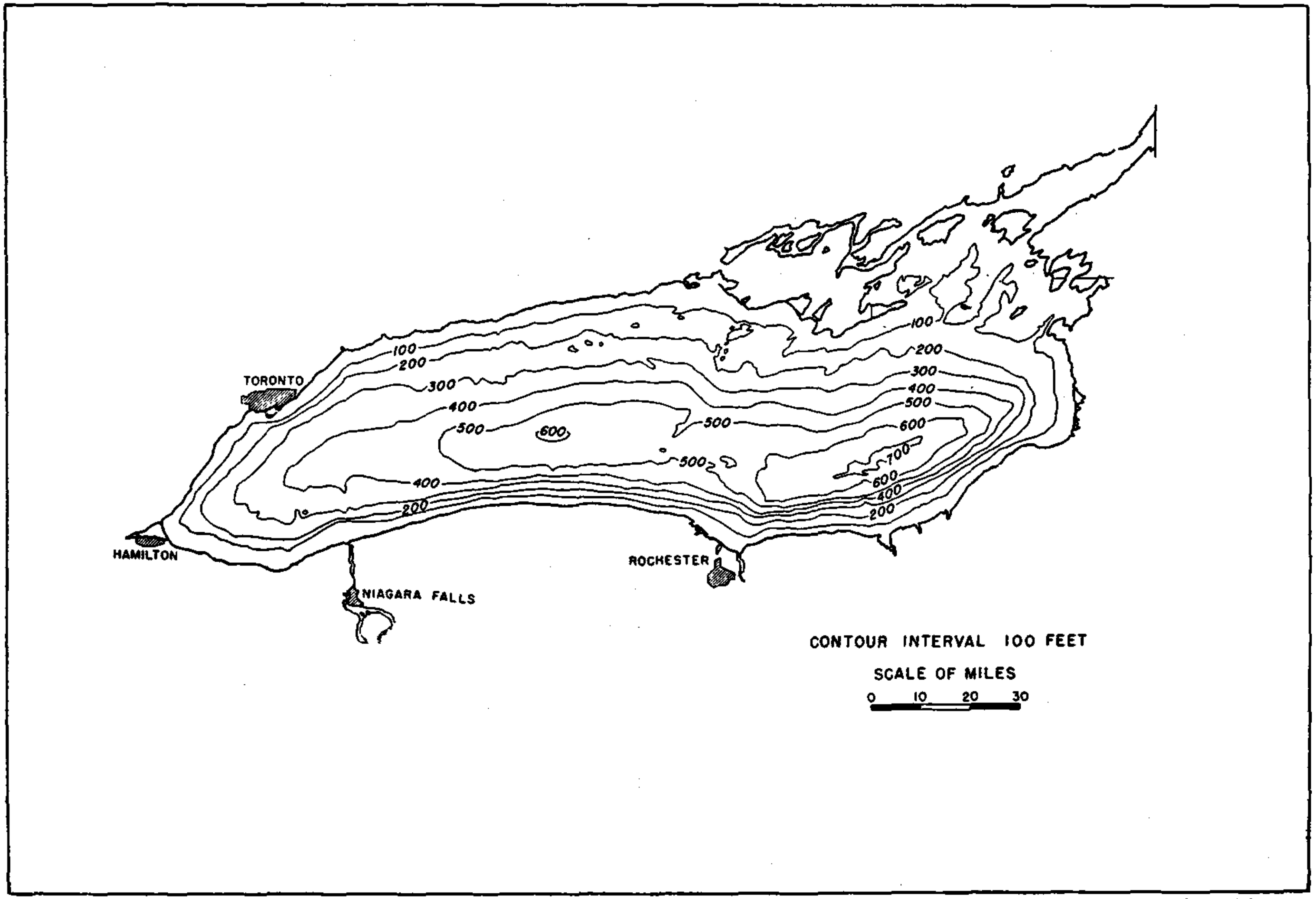
Lake Ontario

Lake Ontario is the fourth largest of the Great Lakes by volume and the fifth largest by area, with an area of 19,000 km^2 and a volume of 1,637 km^3 (Figure B-2-18). The average depth is 86 m. Retention time for Lake Ontario water is only 6 years. There are two basins in Lake Ontario. The western basin is gently sloping, with bottom deposits primarily of mud and clay. The eastern basin has the deepest sounding (245 m), and the bottom is also mud and clay, although rock outcrops and islands are common at the head of the St. Lawrence River. The Lake Ontario shoreline extends for 1168 km.

Total phosphorus concentrations in Lake Ontario average 10 micrograms per litre, which indicates mesotrophic water quality (Figure B-2-12). Poor habitat quality exists in several nearshore areas used for fish spawning. Contaminants such as mirex, PCBs, and mercury are a serious water quality problem. Organochloride concentrations found in surface waters are relatively low. However, relatively high concentrations of PCB (>1 microgram per litre) occur in the area coincident with inputs from the Niagara River. Heavy metal concentrations in waters of Lake Ontario are about one-half those found in Lakes Michigan and Erie, about double those in Lake Huron, and four times those in Lake Superior. In general, harbor and river mouth sediments have higher contaminant concentrations (e.g. cadmium, copper, iron, and lead) than do nearshore and open lake sediments. Seven sites containing heavily contaminated sediments have been identified and designated as Areas of Concern in Lake Ontario (Figure B-2-13 and Table B-2-5).

Phytoplankton, periphyton, and macrophytes are all major components of the plant community on Lake Ontario. The main phytoplankton are diatoms. Cladophora is the main periphytic alga, and the growth in Lake Ontario is second only to the growth in Lake Erie. Macrophytes are observed mostly in the western end near the outflow of the Niagara River and eastern regions of the Lake in the sheltered embayments. Only about 100 benthic taxa have been identified in Lake Ontario. The tubificid worms, Potamothrix and Aulodrilus,

FIGURE B-2-18: PHYSICAL CHARACTERISTICS OF LAKE ONTARIO



Source: Hough, 1958

occur throughout much of Lake Ontario. The worms are typical of moderately eutrophic habitats. Lake trout and salmon occupy the open waters of Lake Ontario, with alewives and smelt the principal forage fish. The commercial catch of Lake Ontario is composed primarily of catfish and bullheads (Ictalurus spp.), walleye, white perch, and whitefish. Public health advisories restrict the consumption of trout and salmon from Lake Ontario.

Habitat quality in Lake Ontario has not changed dramatically since 1910 despite increases in nutrient levels. Although the data base is small, it appears that the biota in Lake Ontario have changed little with the exception of the fish community. Human intervention and the introduction of exotic species have altered the composition of the fish community.

The open waters of deep, cold, Lake Ontario historically sustained valuable populations of fishes such as Atlantic salmon (Salmo salar), lake herring, whitefish, deepwater ciscoes, and lake trout. These species declined dramatically in the 1950s as a result of overexploitation, sea lamprey predation, and predation on eggs by the introduced rainbow smelt. Recent stocking of salmonids and lake trout have once again established those fish as the top predatory fish in Lake Ontario.

Connecting Channels

The connecting channels (St. Marys River, St. Clair River, Detroit River, Niagara River, St. Lawrence River) and Lake St. Clair are the major links between the Great Lakes and the Atlantic Ocean. The total area and depth of the connecting channels is small relative to the area and depth of the lakes. Sediments in the connecting channels are mostly clay in the areas exposed to water flow and are silt with soft sediments in areas of low flow. The connecting channels contain 4,820 km of shoreline.

Nearshore zones such as those found in the connecting channels are often the areas most heavily utilized by man. These nearshore areas are highly visible and often represent the image people have of the Great Lakes. Although the nutrients and trophic status in the connecting channels usually mirror the nutrients and trophic status upstream, local habitat conditions may vary widely from conditions found in the mainstream. A total of eight Areas of Concern have been identified as having contaminated sediments (Figure B-2-13 and Table B-2-5). The channels have a large number of contaminated sites because many municipalities and industries use and return water to the channels, where wastes accumulate.

Plankton communities of the connecting channels, including the phytoplankton and zooplankton, are primarily a result of plankton populations that flow into the channels from the upstream lakes. The flora of the connecting channels is primarily composed of submersed aquatic macrophytes. A total of four macroscopic algae and fifteen vascular macrophytes have been identified in the channels. Chara spp., Cladophora sp., Vallisneria sp., Elodea sp., and Potamogeton spp. (i.e., pondweeds) are the most abundant macrophytes. The principal sport fish are salmonids in the St. Marys River, walleye in the St. Clair River and Lake St. Clair, and white bass and walleye in the Detroit

River. Fish in the Niagara and St. Lawrence Rivers reflect the fish communities in eastern Lake Erie and Lake Ontario, respectively. Public health advisories exist against consumption of many sport fish species in the connecting channels, especially in the St. Clair - Detroit River system.

The lotic nature of the connecting channels determines that changes in the water itself are a reflection of the water entering the channel. However, because these channels are heavily industrialized, there have been marked changes in water quality and shoreline use in local areas. Water and substrate quality have been degraded in large portions of the St.Marys, St.Clair, Detroit, Niagara, and St.Lawrence rivers. In addition, extensive wetland-aquatic habitat areas have been lost in Lake St.Clair due to dredging, filling, and bulkheading of the shoreline for residential use. In total, there are five Areas of Concern located in primary channels and one Area of Concern(i.e., the Clinton River) on Lake St.Clair which have affected the local distributions of benthos, plankton, fish, and macrophytes in the connecting channels of the Great Lakes.

2.5 SUMMARY

The Great Lakes and connecting channels, including the St. Lawrence River, and their shores are an extensive, physically and biologically diverse environmental system. Three interrelated and interdependent environmental components of this system can be distinguished: terrestrial (shore), wetland and aquatic environments. These environments constitute a significant resource.

- The shores of the Great Lakes and connecting channels exceed 20,000 km and the following shore types can be distinguished, primarily on the basis of physical characteristics: bluffs; bluffs overlying bedrock; sand beaches; wetlands; rocky shores; barrier beaches; low coastal plains; and urban shores.

- About 170,000 ha of wetland along the Great Lakes and connecting channels remain. These can be categorized as: open shoreline; unrestricted bay; shallow sloping beach; river delta; restricted riverine; lake-connected inland; and natural and artificially protected wetlands.

- Coastal wetlands are the most productive and diverse components of the Great Lakes - St. Lawrence River ecosystem, providing habitat for numerous fish and wildlife, and providing water quality, recreational and commercial benefits to society.

- The Great Lakes have a surface area of about 244,000 km^2 and much variation in trophic state, from lake to lake and within some lakes, is evident.

- Toxic contamination affects some portions of the Great Lakes - St. Lawrence harbours, tributaries mouths and embayments.

- The quality and quantity of aquatic habitat is an emerging concern and the habitat requirements of many fish species must be better understood.

SECTION 3

PROCESSES INFLUENCING THE ENVIRONMENT OF THE GREAT LAKES - ST. LAWRENCE RIVER SYSTEM

3.1 INTRODUCTION

Section 2 offered a description of the environment of the Great Lakes-St. Lawrence River system, the land and water, the plants and the animals which contribute to its rich diversity of life and landform. These elements or components are important in their own right and as part of a larger entity - a functioning ecosystem.

The interaction between and interdependency among these ecosystem components are controlled by numerous physical and biological processes. Rather than being external forces, these processes, even those which are human-caused, need to be viewed as an essential part of the ecosystem. The environment of the Lakes was created, and continues to be shaped, by these processes. The biota and physical features of the Great Lakes, for example dune grasses and barrier beaches, have evolved over time in response to water-level fluctuations, climatic forces, and nutrient cycles, among other influential processes. At the same time, life and landform are dependent on these processes for continued survival and future evolution and development.

In order to understand how different types of human actions would bring about change in the system, we must comprehend these ongoing processes and their effects under existing conditions. By so doing, we enhance our ability to predict the environmental impacts of human activity as well as the consequences that would result from a more natural evolution of the Great Lakes - St. Lawrence River system.

The following subsections focus on the relationship between water-level fluctuations and physical and biological processes occurring on the shore, in coastal wetlands, and in the waters of the Lakes and connecting channels. As well, the impacts of human activities on the terrestrial, wetland and aquatic environment, and recent conservation initiatives are briefly reviewed. The final subsection questions how important physical and biological processes will operate in the future, given uncertainties such as potential climate change which may soon face us.

3.2 SHORE PROCESSES, WATER LEVELS, SHORE RECESSION AND FLOODING

INTRODUCTION

Shore processes are complex interrelationships of physiographic and climatologic factors. The development of a thorough understanding and description of processes is a continuing concern to those utilizing and studying the Great Lakes shore.

The processes described are those that lead to erosion and/or accretion of the Great Lakes shore and that transport sediments to, from and along the shore. There are many different processes involved; each depends on different phenomena and occurs in a different time frame.

In a geological time frame, the lower Lakes are evolving into large, oblong, shallow basins, as material is eroded from the shore and deposited in the lakes. In this time frame, the Lakes are also tilting slightly as the land mass rebounds from the retreat of glaciers following the last ice age. This in turn, is slightly affecting water levels and rates of erosion along some portions of the shore.

Over the centuries, headlands, bays and other features are developing as the shore, of the lower Great Lakes slowly retreat. This recession is caused principally by wave action. The rate of erosion is dependent upon the exposure to the wave climate, the degree of natural protection from waves and the resistance of the shore sediment to wave action.

The influence of a number of factors, including water-level fluctuations, on shore recession and flooding varies from one physical shore type to another. The shore types discussed in this report are rocky shore, coastal bluffs, coastal bluffs overlying bedrock, sandy beach/mainland, barrier beach/dune complexes, urban/protected, wetland, and low coastal plain. In some locations, a mix of environments occurs, for example a series of rock outcrops interspersed with a low plain or coastal bluffs.

As mentioned above, there are a number of principal parameters that can influence Great Lakes shoreline erosion and flooding. Aside from water-level fluctuations, these include wind/waves, nearshore currents, the orientation of the shore and adjacent bathymetry, groundwater levels, surface water runoff, ice, and weathering. These parameters are discussed below.

SHORELINE PROCESSES

The following sections briefly describe the main shore processes at work in the coastal zone. Much of this material has been taken from Great Lakes, Shore Processes and Shore Protection (Ontario Ministry of Natural Resources, 1981) and from the Shore Protection Manual (U.S. Army Corps of Engineers, 1984).

Wind-Generated Waves

Waves are formed by a complex process of energy transfer from blowing wind to water, through wind turbulence to ripples and from ripples to larger waves. This energy is carried by waves to the nearshore zone and serves as the primary energy source for shore changes. Wind-generated surface waves are a major factor in shore erosion, damage to shore structures, formation of depositional beach features and littoral transport.

Waves generated by commercial and recreational boats may cause erosion in the connecting channels, tributary streams and small harbours and may also be responsible for a significant part of the total wave action in these areas.

Waves are defined by their height, length and period. Wave height is the vertical distance between the top of the crest and the bottom of the succeeding trough. Wave length is the horizontal distance between successive wave crests. Wave period is the time between successive crests (or troughs) passing a fixed point. The various terms used to define a wave are illustrated in Figure B-3-1.

The height, length and period of waves are determined by the distance that the wind blows over water to develop waves (termed the fetch), the speed of the wind, the depth of water, the length of time the wind blows and the distance the wave travels after leaving the area in which it was generated. Since wind speed and direction are not constant, waves of many heights, lengths and periods can be generated, resulting in what is commonly called irregular waves. Although waves propagating in several directions are generated, it is generally assumed that the direction of wave travel in deep water is the same as the wind direction, and that a series of waves having a constant height and period are assumed to represent the actual irregular waves.

Waves can be limited by either fetch, water depth or wind duration. That is, for a given wind speed, the maximum wave height possible is governed by one of these variables. For example, where depth controls, the maximum wave height possible for a given wind speed is not affected by the fetch characteristics or how long the wind blows. This usually is a feature of shallow lakes and fetch areas. In deeper waters the maximum wave height possible is not restricted by water depth but either by the length of time the wind blows or the length of fetch over which it blows.

As waves approach the shore they undergo changes. These include refraction and shoaling, diffraction and breaking.

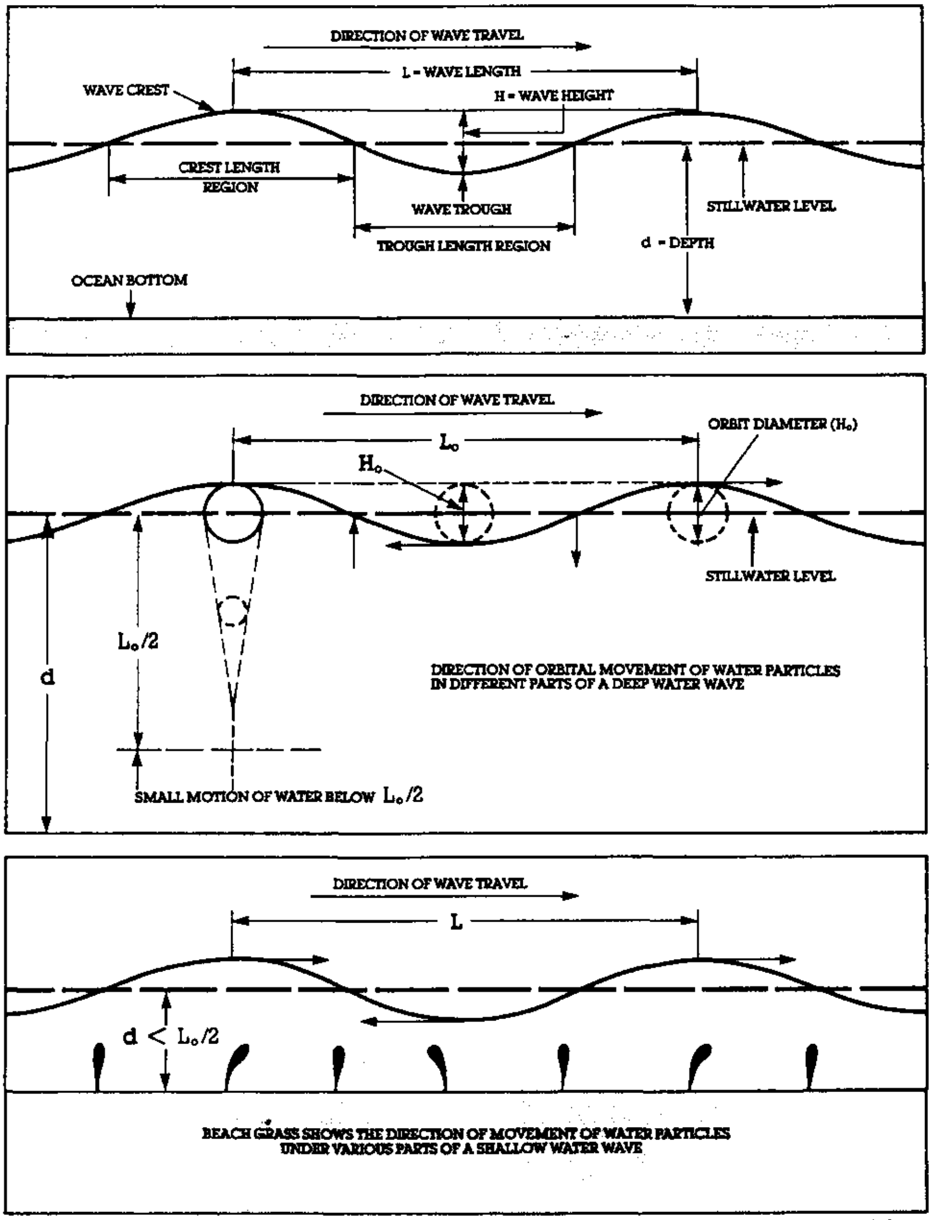
- **Refraction and Shoaling**

  As waves move from deep water into a shallower shore region, their direction changes so that the wave crests tend to align themselves parallel to the underwater depth contours. This is known as wave refraction. The degree of wave refraction depends on the wavelength, water depth and nearshore bathymetry.

  Refraction may increase or decrease the wave height at shore locations as well as change the wave direction. Consequently, refraction is a very important consideration in assessing the effects of wave action on the shore. This is a focusing effect and is illustrated in Figure B-3-2.

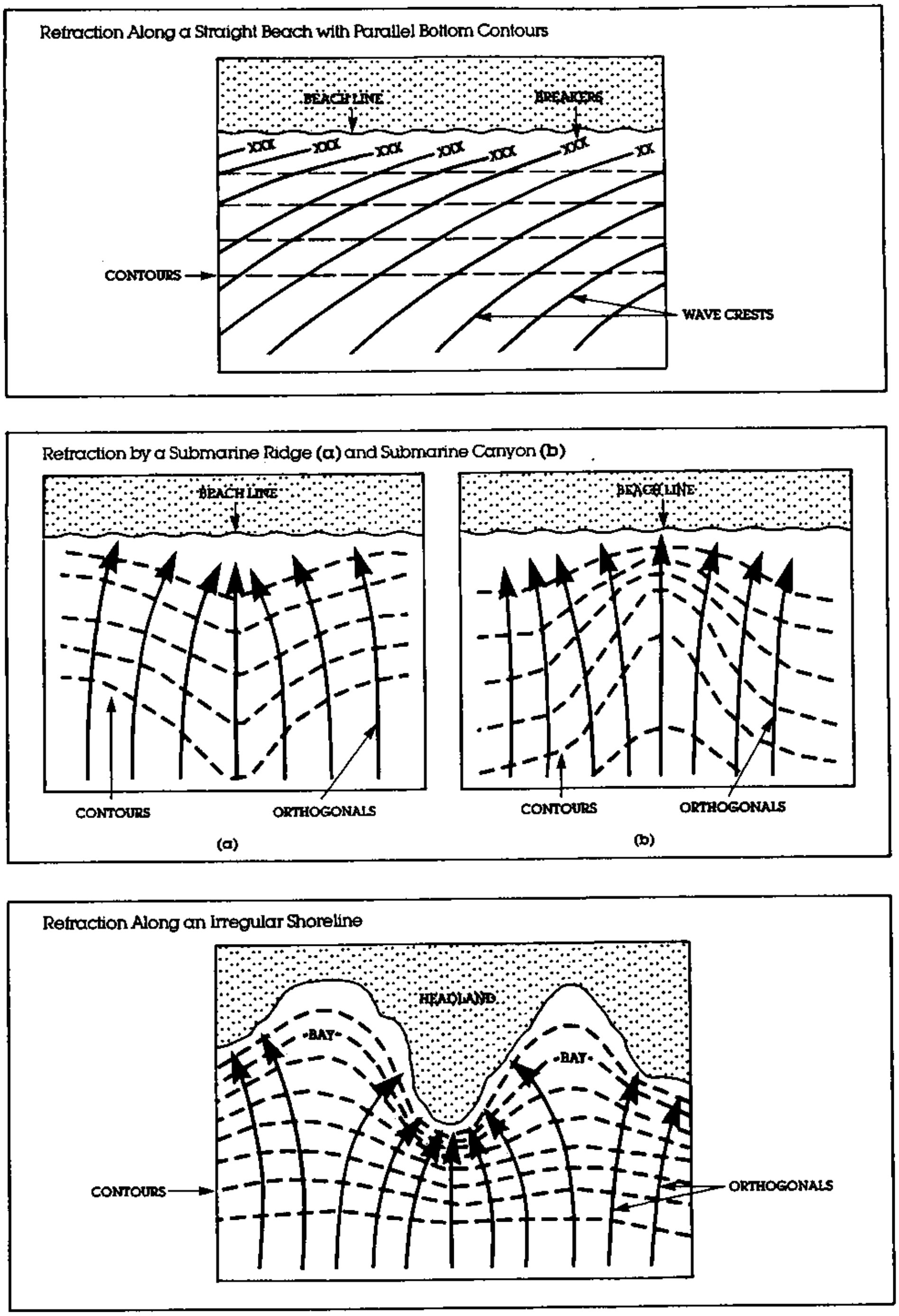
  In addition to wave refraction effects, the process of shoaling results in significant changes in the shape of a wave as it moves into shallow water. Generally, the length of a wave decreases and the height increases. Some reduction in wave height may also result from energy loss

FIGURE B-3-1: WAVE CHARACTERISTICS



Source: OMNR, 1981

FIGURE B-3-2: REFRACTION



Source: OMNR, 1981

caused by the roughness of the lake bottom in shallow water and this becomes more significant on gently sloping shorelines where the distance over which the wave shoals is long.

The determination of wave refraction and shoaling along a shore helps to define the wave height in shallow water and its direction of propagation for given, incident, deep water wave conditions. It affects the divergence or convergence of wave energy along the shore. Refraction and shoaling influence the littoral transport, the erosion and deposition patterns of materials along the shore, and therefore the development of shore forms.

- **Wave Diffraction**

  Headlands provide shelter from wave action to shoreline areas. However, waves do bend, to a limited extent, into the sheltered areas. This involves a lateral movement of the wave in a direction parallel to the wave crest, and is known as diffraction. Diffraction can be an important controlling factor on the deposition of material transported by nearshore currents.

- **Breaking Waves**

  Waves break in deep water (white-capping) when the wave height becomes too large relative to the wave length. In shallow water, waves break because of the limiting water depth. The depth at which the wave breaks, and the form of the breaking wave, are determined by the wave height and period, the water depth and the slope of the bottom. The depth of water shallow enough to initiate breaking of a wave is termed the breaking depth, dB. The breaking wave height is known as Hb. Waves will break when the ratio of Hb to dB is about 0.78 (Galvin, 1972).

  Depending on the wave height and nearshore slope, waves may break: 1) some distance offshore, forming a surf zone over which wave energy is dissipated and wave heights greatly reduced before they reach the shoreline; 2) on the beach, with energy being dissipated in the swash and backwash; and, 3) where there is relatively deep water close to the shoreline, such as on some rocky or bluff coasts, directly against the toe. Turbulence produced by wave breaking can lead to suspension of sediment on fine-grained beaches and to the erosion of the beach and nearshore profile on cohesive shores.

  The impacts of waves on erosion and accretion is discussed further in the Land/Lake Interaction section.

Nearshore Currents

Currents in the Great Lakes occur as a result of the earth's rotation, the inflow and outflow of the Lakes, the wind blowing over the surface of the Lakes and, at the shore, the process of wave breaking. Lake currents vary from

Lake to Lake and location to location and can be influenced by such factors as the direction of flow through the Lakes and the direction of the predominant winds.

Wave orbital motion and wave-generated currents are the primary processes resulting in sediment erosion, transport and deposition in the beach and nearshore zone. As waves shoal and break, the intensity of wave orbital motion on the bed increases, setting sediment in motion across the bed, and ultimately leading to suspension of sediment. The presence of any currents superimposed on this oscillatory motion then results in net transport of the sediment in the direction of the current flow, both on-offshore and alongshore. These currents may be wind-generated, but the most important currents in the nearshore zone are those generated by the momentum of the waves themselves. The momentum and excess water mass carried into the surf zone by breaking waves results in the set-up of water close to the shore. This in turn drives an offshore return flow which may occur either as a uniform "undertow" at mid depth, or as a more complex three-dimensional rip cell. Where waves approach at some angle to the shoreline, a portion of the momentum of the breaking waves is directed alongshore and results in the generation of longshore currents in the direction of wave approach. These longshore currents, together with beach drifting on the swash slope, are primarily responsible for the transport of sediment alongshore.

Wind and Wave Climate

The wave climate at any location along the shoreline can be defined as the average annual hourly frequency of waves of different classes (defined by height, period, and direction) reaching that location. This in turn depends on the location and orientation of the section of shoreline relative to the prevailing wind direction and on the fetch lengths for each direction. Sections of shoreline that are exposed to long fetches in the direction of the predominant winds are likely to experience high wave energy on a frequent basis. Conversely, areas that are sheltered from waves from the predominant wind directions are likely to experience much lower energy conditions. The offshore wave climate can be defined for a point in deep water just off the shoreline section. The inshore wave climate can be determined from this after the effects of wave refraction, diffraction and shoaling are taken into account. The total wave energy reaching a section of shoreline can be expected to exert some control on the potential rates of erosion of rocky and bluff shorelines, while the magnitude and direction of the net longshore component of wave energy controls the rate of potential longshore transport of sediment and is an important determinant of the sediment budget of sandy beaches (discussed further in the Land/Lake Interaction section).

Water Levels

Changes in water levels occur as a result of long-term and short-term factors. Long-term factors are precipitation, inflow to the Lakes (which is dependent on precipitation), outflow from the Lakes, and evaporation. Short-term factors are oscillations caused either by the wind blowing over the Lake for several hours or by atmospheric pressure changes. Levels are also slightly influenced by long-term movements of the earth's crust.

Seasonal and long-term changes in Great Lakes levels result from variations in the amount of precipitation, evaporation, runoff, storage capacity of the Lakes and the discharge characteristics of the channels connecting the Lakes. Long-term changes in levels can be considered random, while seasonal changes follow an annual cycle with peaks in the late spring or early summer and lows in the late fall or winter. Due to the size of the Great Lakes and the relatively small discharge capacities of their outflow rivers, extreme high or low lake levels exist for some time after the climatological factors which caused them. Historical records of long-term variations date back to the late 1800's. Monthly mean levels have varied over a range of 1.2 metres on Lake Superior and about two metres on the other Lakes.

Short-term fluctuations are produced by changes in atmospheric pressure and by the wind. Atmospheric pressure differences between the opposite sides or ends of lakes can produce fluctuations in water levels amounting to 0.2 m.

The main cause of short-term lake-level fluctuations is strong winds. When the wind continues to blow over the lake surface in one direction for a number of hours, a surface tilt is produced, referred to as "wind setup". With the same wind speed and duration, the range of setup varies spatially depending on the length of fetch, water depth and nearshore slope. The greatest impact is experienced at the western and eastern ends of Lake Erie, where short-term changes in water levels can reach 2 metres. Because it is relatively shallow and is oriented in an east-west direction parallel to the prevailing westerly winds, Lake Erie is subject to these short-term fluctuations more frequently than the other Great Lakes. Wind setups which may reasonably be expected at typical mid-lake shore locations are in the order of about 0.5 metre.

Both atmospheric pressure and wind-induced water level changes can be associated with a seiching effect. The return flow of water from the end with an elevated level to the depressed end can result in oscillations of levels similar to the sloshing action that occurs in an enclosed tank of water. Any given shoreline location may experience alternate periods of elevated and depressed levels over a period of several hours.

Following retreat of the ice that existed over the Great Lakes during the last ice age, the land mass has slowly risen through a process known as isostatic rebound (Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, 1977). The rise is producing minor tilting of the Great Lakes basin, resulting in emerging and submerging shores. In the modern Great Lakes, the present long-term geological rate of emergence or submergence is relatively small. For example, the north shore of Lake Erie is stable and the west end of Lake Ontario is subsiding at a rate of approximately 6 mm per year. These rates are not significant in terms of their effect on shore processes in the short-to medium-term, but they have significant implications over the very long term.

The water-level elevation determines the portion of the nearshore zone over which breaking waves expend their energy. During periods of elevated levels, a portion of the wave energy may reach the toe of bluffs or sand dunes, and some washover of low-lying beach areas may occur. It is during these events that rapid erosion of the bluffs and dunes occurs. Some of the wave energy during these events is dissipated on the nearshore lake bottom, causing underwater erosion as well (Davidson-Arnott, 1986). During periods of lower levels, a greater portion of the wave energy is dissipated on the lake bottom in the nearshore area, and greater erosion of the lake bottom occurs, while erosion of the bluffs and dunes is temporarily reduced.

It is unlikely that many areas of the Great Lakes shoreline will ever experience truly stable water levels because of the magnitude of the fluctuations associated with seasonal variations in runoff and evaporation and the short-term fluctuations created by winds and barometric pressure changes.

OTHER PROCESSES

Aside from shore processes, there are a number of other important physical processes acting in the coastal zone that are not shore processes per se, but can influence erosion and recession of the shoreline. These are briefly described here.

Groundwater

In bluff areas the presence and movement of groundwater can be a major factor in the erosion processes. Many bluffs consist of layers of different types of material of varying thicknesses. For example, the Scarborough Bluffs along the north shore of Lake Ontario contain layers of sand, silt and clay (Eyles, et al., 1985). The ability of surface water to flow vertically downward through the bluff depends on the types of material. Water passes quickly and easily through a layer of sand, but if the sand is underlain by a layer of impervious clay, then the groundwater moves horizontally along the sand-clay boundary to the bluff face. The water exits through the face of the bluff at this boundary and runs down the bluff face. This causes erosion of both the sand layer and the bluff face, leading to recession of the bluff.

The presence of groundwater in a bluff reduces its ability to resist collapse. This is due to the lubricating effect that a high water content has on the soil. A collapse of this type is most likely to occur when the soil is saturated with water, such as in the spring snowmelt period or after an extended period of heavy rain. A local supply of water, such as a leaking swimming pool, can also contribute to bluff collapse.

Surface Water

The flow of surface water down the face of a bluff can lead to erosion of the bluff. Frequently, surface flow leads to the formation of gullies along the bluff. As a gully grows, it may become the route for surface drainage from an increasing area, thereby increasing both the volume of water flow and the rate of growth of the gully. The creation of a water drainage network such as field tiles or drainage ditches can concentrate the flow and accelerate the formation and growth of gullies.

Ice

Ice cover varies significantly from Lake to Lake and from year to year; however, when formed, it provides significant shore protection on the Great Lakes during the winter months. Ice first forms along the shore, providing continuous protection from wave action. As winter proceeds, ice may form over the lake and restrict wave generation entirely.

Changes in water levels can cause shorefast ice to remove the frozen soil to which it is bound. Wind blowing over the ice can produce ridging and a large build-up of ice at the shore, in some instances exceeding 5 m (see Gilbert and Glow, 1986, for example). This shore ice can scour sections of the beach and nearshore as well as destroy structures close to shore. It can also remove boulders from the shallow areas, thereby reducing the shore protection provided by the boulders.

Shore ice can also pose a problem in connecting channels. Ice jams are a common occurrence on the St. Clair and Detroit Rivers and operation of the control works on the St. Lawrence River also allow for ice formation to take place, so that ice jams do not occur.

Weathering

During the winter months, repeated freezing and thawing (an example of physical weathering) of soil in the bluff face reduces the strength of the soil and makes it more prone to erosion from surface and groundwater flows. This process is most prevalent on bluffs with a southerly exposure, where the sun's rays are concentrated and thawing can occur when the air temperature is several degrees below freezing. Similarly, reduction in the strength of cohesive and overconsolidated bluff sediments can be caused by expansion and contraction due to wetting and drying of the bluff face. Chemical weathering of rock and bluff materials can also occur.

IMPACTS OF WATER-LEVEL CHANGES BY SHORE TYPE

The impacts of the various processes discussed above will differ with the physical shore type. The following sections discuss these variations.

Rocky Shoreline

Large sections of the northern shores of Lake Superior and Lake Huron, and significant portions of the other Lakes' shorelines, consist of bedrock. Generally, these bedrock areas are resistant to erosion by wave action. Limited recession of the shoreline may occur in these areas due to freeze/thaw effects, but this is usually negligible. There are some portion of the shoreline that consist of shale, which does erode slowly. Areas with bedrock consisting of weak materials such as shale or poorly cemented sandstone may be subject to erosion rates intermediate between those of resistant bedrock and bluff shorelines. Some of these areas are adversely affected by alternate wet/dry cycles. Low water levels, which expose the rock to air, can accelerate weathering processes and erosion rates in these areas (Coleman, 1936). Portions of the shoreline consist of a mixture of rock headlands interspersed with low plains or erodible bluffs. These headlands form a partial protection from wave action for the areas between them, but waves do pass the headlands and reach shore.

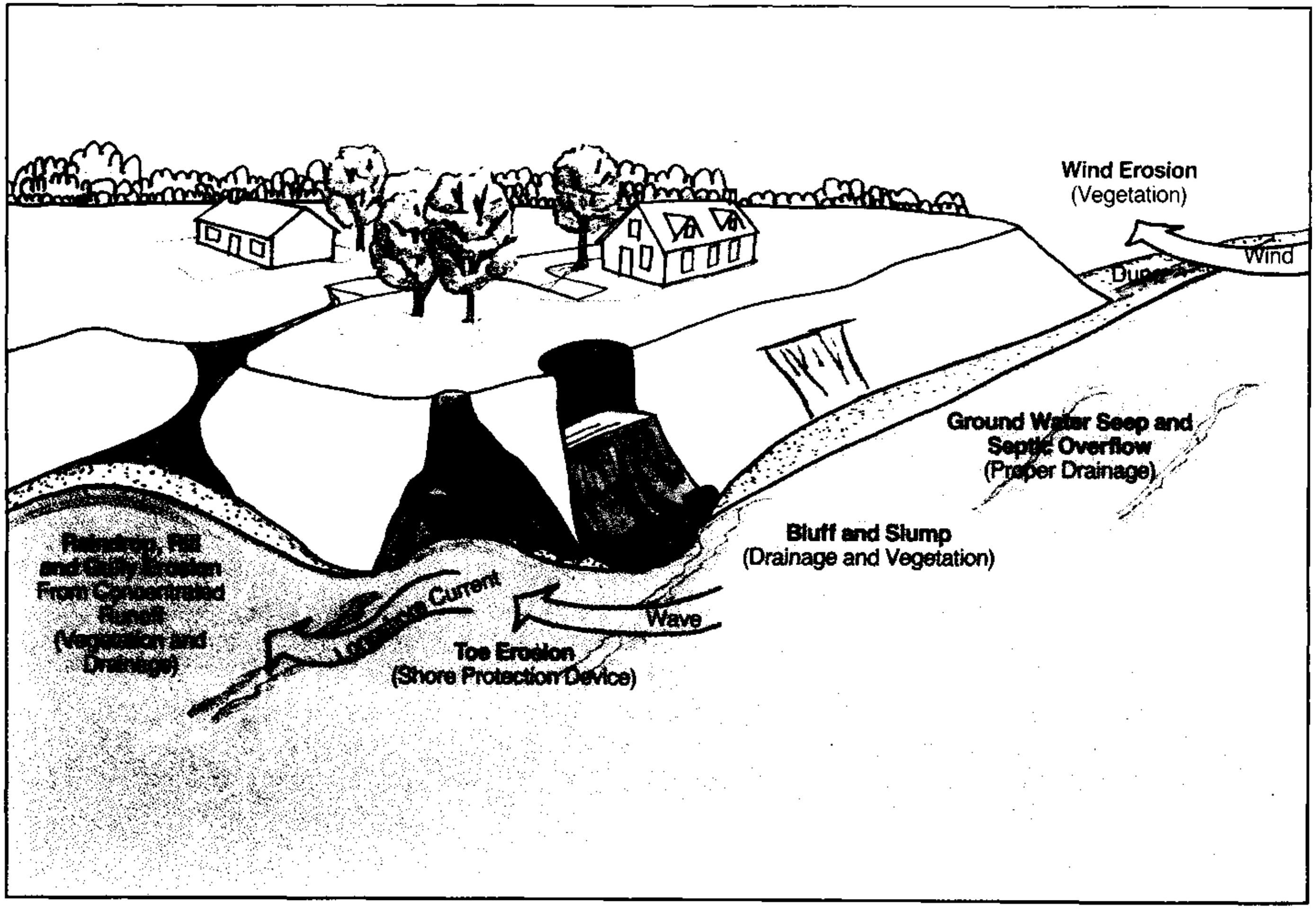
Coastal Bluffs

Some 35-40% of the shoreline of the lower Great Lakes is composed of cohesive and/or overconsolidated glacial sediments which form bluffs ranging in height from a few metres to over 40 m in places. These areas experience the most severe ongoing erosion along the shoreline. Some bluff areas have a wide sandy beach in front of them, but most bluff areas have little or no beach. Water level fluctuations determine the portion of the coastal profile impacted by waves. During high levels, waves may strike directly on the bluff face, while during low levels the waves expend most of their energy on the nearshore area. The processes controlling toe erosion and bluff recession are complex and are illustrated schematically in Figure B-3-3.

Erosion of the nearshore profile is an important factor in the recession of these bluffs. Regardless of the water level, the nearshore profile is exposed to wave action. The total wave energy acting on the profile is dependent on the wave climate, but is independent of water level. This wave action causes downward erosion of the profile. A decline in lake levels initially results in a lakeward movement of the area of active erosion. As the erosion of the profile continues over time, the water depth over any given point on the profile increases, allowing progressively larger waves to approach the shore and causing a recession of the profile in a landward direction. This process brings the area of active erosion back to the toe of the bluff, thereby resuming the process of active erosion (International Joint Commission Functional Group 2, 1989a).

Recession of the bluff is initiated by wave erosion at the toe and by the continued removal of slumped material by wave and current action. Recession of the bluff above the limit of wave action results from the operation of a number of sub-aerial processes, including: slumping and landsliding at a variety of scales; piping and groundwater flow; and erosion by sheetflow and gully development. The relative importance of each of these is dependent on the bluff height, stratigraphy, slope, and local groundwater conditions. In areas of low bluffs and simple stratigraphy, retreat of the bluff crest conforms closely to the rate of toe erosion. However, as the height of the bluff and complexity of the stratigraphy increases, the recession of the top of the bluff becomes less and less correlated, in the short term, with the

FIGURE B-3-3: CAUSES OF SHORE EROSION/PROCESSES CONTROLLING TOE EROSION AND BLUFF RECESSION



Source: OMNR, 1986

rate of toe erosion. In areas where groundwater flow is significant, large rotational failures may occur during periods of low lake levels (Quigley et al., 1977). In areas where large-scale rotational failures or rapid gully development are prevalent, the long-term recession rates are highly variable.

A change in the water level will have an initial impact on bluff recession rates, with an increase in rates associated with a rise in water levels and vice versa. Both theory and results reported from South Indian Lake, Manitoba (International Joint Commission Functional Group 2, 1989a) indicate that this initial change is only temporary while the beach and nearshore profile adjusts to the new level and the equilibrium profile is re-established. Actual measurements of erosion rates underwater on Lake Ontario (Davidson-Arnott, 1986) and analysis of erosional profiles on Lake Erie (Philpott, 1984) provide further support for these observations.

The establishment of a stable water level regime would probably reduce some of the year-to-year variability in erosion rates. At present there are higher erosion rates during periods of elevated water levels and lower rates during periods when water levels are falling and lower than the long-term average. A reduction in the range of water levels would tend to smooth out variations in erosion rates since there would not be as much variation in the location of the breaker zone and in the amount of wave energy reaching the toe of the bluff.

A reduction in the mean lake level would lead to a temporary reduction of toe erosion in most areas. However, erosion of the underwater profile would quickly lead to the establishment of a new equilibrium profile and a return to the long-term average recession rates (International Joint Commission Functional Group 2, 1989a). Exceptions to this could occur in areas where erosion of the nearshore profile would be restricted by the presence of bedrock or a well-developed boulder lag. However, in these areas recession rates are generally already low, so that the overall impact of water-level changes is likely to be small. It is also possible that some bluff locations that are receding at the top, primarily due to groundwater flows, may experience large rotational failures during periods of low lake levels or following an overall lowering of lake level. Reduced water levels would temporarily reduce toe erosion in these areas, but continued groundwater action would lead to recession of the bluff crest. This in turn would result in an overall flattening of the bluff slope which could permit a rotational failure of many metres in depth to occur (Quigley et al., 1977).

Factors other than wave energy contribute to the erosion of bluffs in many areas. Some of these areas are particularly susceptible to erosion caused by groundwater and/or surface water flows (e.g. Scarborough Bluffs, Lake Ontario). In such areas, a high rate of surface water or groundwater flow can lead to an accelerated rate of erosion. Both lake level and the volume of surface water and groundwater flows are dependent on the amount of precipitation (Quigley et al., 1977). Hence, it is likely that during periods of rising lake levels, there will be high rates of gully and bluff erosion in these areas due to above-average water flows.

Coastal Bluffs Overlying Bedrock

In several locations along the Great Lakes shoreline, the bedrock is very close to the water surface. In these locations, vertical erosion of the nearshore profile is slow and a gently-sloping rock platform develops which greatly reduces wave energy reaching the toe of the bluff. In other areas, where the sediments in the bluff have a high boulder content, the boulders may be concentrated in the nearshore to form a lag deposit which also reduces vertical erosion of the nearshore profile. The degree of protection afforded by the boulders depends on the thickness and continuity of the boulder lag. In most locations it is likely that boulders reduce the erosion rate but do not eliminate recession completely.

In both of these types of coastal areas, bluff recession occurs primarily during periods of elevated water levels, and a reduction in either the range of lake-level fluctuations, or in the long-term mean lake level, could lead to a reduction in the bluff recession rate. However, it should be recognized that in most of these areas the recession rate is already relatively low, and that a reduction of lake levels of the order of 1-2 m will have little or no impact on most problem erosion areas.

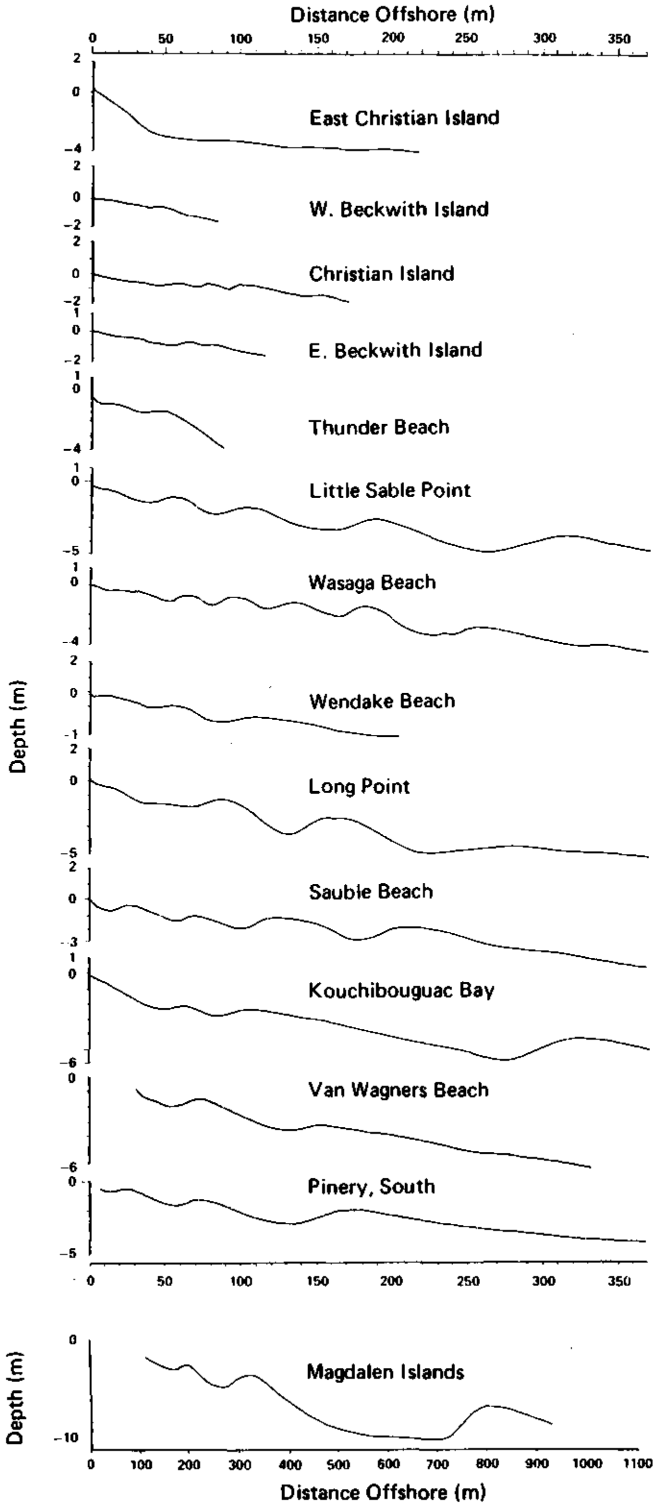
Sandy Beach/Mainland

Because even small waves are capable of eroding and transporting sand, sand beaches and their nearshore zones tend to undergo relatively rapid changes in form in response to changing wave conditions and water levels. The form of the beach is controlled by "static" factors such as sediment size and abundance, substrate slope and wave climate, and by "dynamic" factors such as wind, wave and water level conditions. Because of the limited fetch lengths on the Great Lakes, most profiles are characterized by the presence of one or more nearshore sand bars. The range of profile types and characteristics is illustrated in Figure B-3-4 and Table B-3-1.

The sandy beach profile exists in a state of equilibrium with the form reflecting a balance between processes tending to move sediment onshore and those tending to move it offshore. Changes in wave characteristics, wind-driven currents and water levels alter the rates and patterns of on-offshore sediment transport, leading to a re-adjustment of the profile towards a new equilibrium form. Generally these changes conform to the general model of storm and fairweather profiles (Komar, 1976; Figure B-3-5). During major storms, the increased wave energy and raised water levels lead to erosion of the beach and berm, flattening the profile and transporting sediment offshore. During periods of low wave activity, this sediment is moved back onshore and the beach builds up. The return of sediment to the beach may occur through the onshore migration and "welding" on inner nearshore bars (Davis and Fox, 1972; Davis et al., 1972; Stewart and Davidson-Arnott, 1988), or it may result from gradual rebuilding of the berm. Because storms are more frequent and intense in the spring and fall months, beach profiles tend to be much flatter during these periods as compared to the summer months. Widening of the beach is also enhanced by the seasonal fall in water levels

FIGURE B-3-4: SELECTED PROFILES FROM STUDY SITES

Note the differing scale for the Magdalen Is. profile.



Source: Davidson-Arnott, 1988

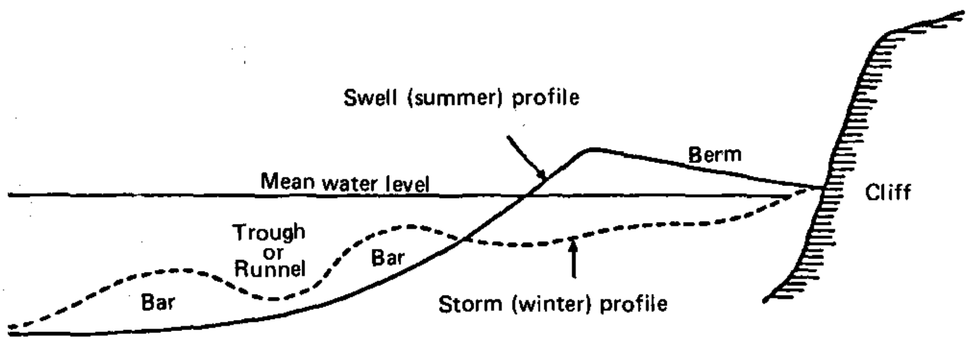
TABLE B-3-1: PROFILE SITES AND CHARACTERISTICS

SITE	FETCH (km)	SLOPE	BARS (N)	OUTER-BAR HEIGHT (m)	DEPTH TO CREST (m)	DIS-TANCE TO CREST (m)
East Christian Island, Georgian Bay	3	0.040	0	0.0	0.0	0.0
West Beckwith Island, Georgian Bay	3	0.032	1	0.10	0.25	40.0
Christian Island, Georgian Bay	15	0.007	6	0.40	1.1	130.0
East Beckwith Island, Georgian Bay	25	0.012	2	0.18	0.4	85.0
Thunder Beach, Georgian Bay	40	0.030	2	0.30	1.55	55.0
Little Sable Point, Lake Michigan	160	0.010	4	1.60	3.5	320.0
Wasaga Beach, Georgian Bay	170	0.008	5	0.50	1.0	120.0
Wendake Beach, Georgian Bay	170	0.013	2	0.6	1.1	70.0
Long Point, Lake Erie	230	0.009	4	2.2	3.5	280.0
Sauble Beach, Lake Huron	270	0.007	4	1.2	1.5	200.0
Magdalen Islands, Gulf of St. Lawrence	300	0.008	3	4.0	5.6	800.0
Kouchibouguac Bay, Gulf of St. Lawrence	300	0.012	3	2.0	2.5	275.0
Van Wagners Beach, Lake Ontario	320	0.018	2	0.6	2.9	140.0
Pinery South, Lake Huron	340	0.011	3	1.2	2.0	175.0

Sources: Data for Little Sable Point from Hands 1976, for Magdalen Islands from Owens 1977, and for Pinery South from Gillie 1980; data for Van Wagners Beach supplied by John Coakley, Canada Centre for Inland Waters; data for other sites from author's research.

From: Davidson-Arnott, 1988

FIGURE B-3-5: STORM VERSUS FAIR WEATHER PROFILE FORMS



Source: Komar, 1976

during the summer and early fall, while conversely, the seasonal highs can lead to erosion of the backshore and dune cliffing during spring storms.

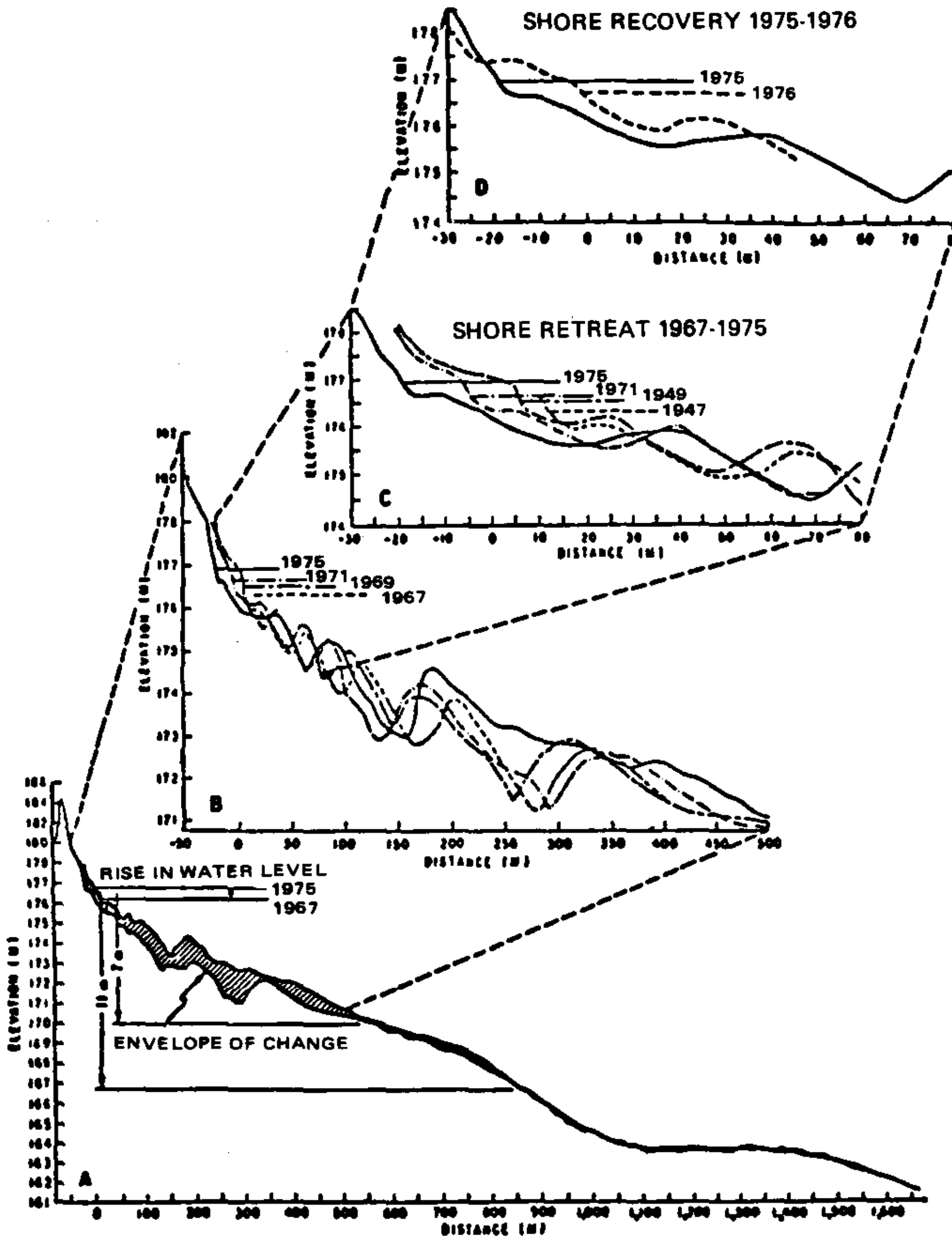
Long-term water-level fluctuations also affect the beach and nearshore profile by shifting the location of wave shoaling and breaking. This in turn alters the sediment transport patterns until a new equilibrium profile is established. Essentially the profile shape remains the same but its location shifts. Work by Hands (1976; 1983) has demonstrated the dynamic response of the nearshore to changing water levels (Figure B-3-6). When water levels rise, the nearshore bars migrate landwards and upwards, and when water levels fall, the bars migrate offshore to lower elevations. The effect is to maintain a characteristic profile with the number of bars and the depth of water over the bar crests remaining roughly constant. However, because of the large volumes of sediment involved, profile changes usually lag behind water-level changes. Thus the narrowest beaches and greatest potential for erosion occur during a period of rising water levels before landward migration of sediment catches up with the migrating shoreline. Once water levels stabilize, the nearshore bars will migrate to their equilibrium depth and offshore location, leading to greater energy dissipation in the nearshore. Conversely, during periods of falling lake levels, beaches tend to be wider than average and once water levels stabilize, sediment will be transported offshore until the equilibrium profile is re-established.

Sandy beaches also exhibit longshore variations in beach form and width on a range of longshore length scales associated with features such as beach cusps, giant cusps and rhythmic topography, and longshore sandwaves (Komar, 1976; Greenwood and Davidson-Arnott, 1979; Stewart and Davidson-Arnott, 1988). Beach cusps are transitory features with relatively small dimensions; however the other two types of variation are more significant because of their greater longevity (weeks to years) and size. Giant cusps and rhythmic topography are often associated with the development of rip current cells and three-dimensional nearshore bars, and have longshore wave lengths of 100m and shore-normal dimensions of 10m. Longshore sandwaves have alongshore lengths of 1000m and shore-normal lengths of 100m. The presence of these features on the beach increases the dynamic range of changes in beach slope and form.

Barrier Beach / Dune Complex.

Barrier sand beaches differ from mainland beaches in that the beach/dune area is backed by a body of water such as a bay, lagoon, river or marsh. Barriers on the Great Lakes include barrier spits such as Long Point and Presque Isle on Lake Erie, baymouth barriers such as the Burlington Bar and Sandbanks on Lake Ontario and numerous smaller barriers across the mouths of small rivers, and complex cuspate features such as Point Pelee. While the beach and nearshore profile and dynamic behaviour are similar to mainland beaches, barrier beaches have the added complexity that beach and dune erosion during severe storms can result in breaching of the foredune and creation of overwashes or inlets as water flows across the barrier into the body of water behind. The washovers and inlets play an important role in the dynamics of the barrier system, particularly in areas with a negative sediment budget where landward sediment transfer is essential to maintaining the integrity of the barrier.

FIGURE B-3-6: MEASURED PROFILE ADJUSTMENTS OVER A 9-YEAR PERIOD OF RISING THEN STABLE WATER LEVELS ON LAKE MICHIGAN



Source: Hands, 1983

Overwash and inlet formation occur during major storm events and their temporal frequency is very closely controlled by lake-level fluctuations. Work by Fisher (1989) has documented the relationship between overwash occurrence, sediment budget and water-level fluctuations for the Long Point barrier. Generally, a reduction in the range, or mean lake level, would probably lead to a temporary reduction in the frequency of occurrence of overwash events on the Great Lakes barriers, and remove the cyclic dependency. Overwash occurrence is ultimately dependent on the storm wave climate and on the local sediment budget.

Low Coastal Plain

Along the connecting channels and in protected bays, the lack of wave action restricts sediment transport and the development of either beaches or erosional coastal forms. The beach consists of a narrow expanse of poorly-sorted sediment and there is very little sediment transport either on-offshore or alongshore. In low-lying areas, particularly where marshes are present, dynamic processes are related to the water-level fluctuations and not to wave-generated processes, and most problems relate to inundation during periods of high lake levels.

Wetlands

Wetlands comprise an important part of the Great Lakes shoreline. They are critical habitats for numerous species of waterfowl, fish and other wildlife. They also play an important role in water quality. Water-level fluctuations can have impacts on all of these factors and in fact are likely necessary to maintain the habitat diversity found in wetlands. Because of their importance, wetlands are treated as a separate environment in this Annex. Detailed discussion of the impacts of fluctuating water levels on wetlands can be found in Section 3.3.

Urban / Protected

While urban and protected shorelines are not "natural" shorelines per se, they make up a sizeable percentage of the Great Lakes - St. Lawrence River shoreline, and thus, deserve mention. Urban, as referred to here, indicates that there are few natural remnants of the shoreline visible and that the shoreline is almost totally artificial. An example would be the city of Chicago, Illinois, where the shoreline consists of artificial parkland and high density residential development.

A number of physical impacts on protected shorelines exist and have been discussed in FG2's Coastal Processes Workshop (International Joint Commission Functional Group 2, 1989a). Protected shorelines, in general, tend to modify the natural processes, i.e. wave reflection, wave refraction, etc. The form of modification will be determined by the type of shore protection present, be it shore-perpendicular, shore-parallel or offshore.

Water levels were identified as an important factor affecting protected shorelines. In the short-term, low water levels would expose structures, causing previously unexposed sections to be subject to degradation by the elements. However, with extreme low water levels, structures might not be needed since storm wave activity may not reach them. Storm waves during high water level periods can overtop structures causing inland flooding and erosion. Structures such as groynes would deflect longshore sediment offshore. Shore-parallel structures would reflect more wave energy, which would scour the sediment at the structures' lakeward base.

Long-term high water levels may make present structures redundant and necessitate the construction of new ones. The accelerated erosion of the lakeward side of some structures would, in the long-term, decline with a reestablishment of an offshore equilibrium profile. However, in many cases, the accelerated erosion on the structure's lakeward toe would undermine the structure causing it to fail. When a structure does fail, the area landward of the structure can experience rapid erosion, since the profile is not in equilibrium with the coastal process.

Long-term low water levels may negate the necessity of the structure in the short-term. However a lowering of the offshore profile through erosion may quickly reestablish erosion at the location of the structure. The impact of a drop in mean water level on a protected shoreline would depend upon what type of substrate becomes the focal point for wave attack. If the material is resistant to erosion (e.g. bedrock), the need for structures may be negated. However, if the material is more susceptible to erosion, the recession rates may accelerate in the short-term and eventually undermine the structure, causing it to fail. Some structures may be rendered ineffective if designed for present mean water levels. Lowering of mean water levels could also have significant impacts on navigational structures such as harbour walls or jetties. Increased dredging, or increasing the length of jetties, may be necessary.

The presence of ice along the shoreline in winter also adversely affects low-lying, protected shorelines. Ice rafting during winter can seriously damage the protection structures, as well as scour sediment away from the structures' supports.

In addition to coastal processes, there are a number of non-coastal processes that should be considered, as they can have a significant impact on protected shores. Various geotechnical and hydrologic processes such as groundwater seepage, surface runoff and gullying can all affect protected shorelines in some manner.

LAKE / LAND INTERACTION

The interaction of air, water and land in the coastal zone comprises a unique geomorphological system which leads to the transformation of the coastal landforms through the action of processes generated by winds and waves. The processes themselves and the nature of their interaction with the materials that make up the "land" are extremely complex and are described in detail in a number of textbooks (e.g. Komar, 1976; U.S. Army Corps of Engineers, 1984; Carter, 1988). The following section briefly describes how these processes control shoreline changes in the Great Lakes, particularly as they relate to problems associated with coastal erosion and flooding. These are reviewed in somewhat greater detail in the Coastal Processes Workshop (International Joint Commission Functional Group 2, 1989a).

The area of lake/land interaction can be termed the coastal zone, and this in turn can be divided into: 1) the littoral zone, extending from the limit of storm wave action on the beach or bluff offshore to the maximum depth at which wave action can effectively transport sediment on the bed (roughly 8-10m in the Great Lakes); and, 2) the coast, the area of land behind and generally above the limit of wave action which is influenced by proximity to the water body. This may include coastal bluffs, sand dune fields, wetlands, and areas subject to occasional inundation. The shoreline can be defined as the intersection of the still water line with the land. Short-term changes in its position occur as a result of water-level fluctuations due to wind and wave action and to seasonal changes of net basin supply. Small changes also occur in response to local patterns of beach erosion and accretion. These changes can be thought of as oscillations about a mean position, as can the changes related to the longer-term lake-level cycles. Over a longer period of time, shoreline displacement leading to submergence or emergence occurs in response to "permanent" changes in water level resulting from post-glacial isostatic adjustments and changes in the elevation or depth of the lake outlets. Finally, horizontal displacement of the shoreline occurs as a result of net erosion or accretion of the coast. The latter occurs primarily in response to processes operating in the littoral zone, and it is important to distinguish these effects from those associated with the seasonal and long-term lake-level fluctuations.

Littoral Zone and Beaches

As waves travel from deep water towards shore, they reach a depth where water motion begins to exert enough force to move bottom material (i.e., bed load transport). When the depth is further decreased, the force becomes stronger and material becomes agitated and suspended (i.e., suspended load transport). Finer material is moved lakeward, while coarser particles may migrate shoreward. When a depth is reached where the wave can no longer support itself, it breaks and travels as a flood of water, carrying with it suspended bottom material.

As the waves break, they dissipate energy in the surf zone. Their remaining energy is dissipated as they finally rush up the foreshore, where it is either dissipated or reflected from the toe of the bluff at times when the foreshore is submerged. The travel beyond the static level of water on exposed foreshores is known as wave uprush. A wide beach is the most effective method of dissipating wave energy.

Outside the surf zone, in the area where waves "feel" bottom, underwater topography may influence the diffraction and distribution of wave energy reaching the shore. If the offshore slope is uniform and even, the wave attack along the shore will be fairly uniform. If the offshore bottom is irregular, the wave attack may vary considerably within a short length of shore. Underwater valleys tend to disperse the waves over a wider length of shore, while humps and ridges tend to focus the waves on a shorter stretch of shore.

Wind waves can build or destroy beaches. Short, steep storm waves are destructive and tend to strip the beach of sand. Long swells, originating from distant or abating storms and mild winds, are constructive and tend to rebuild the beaches. Beaches may undergo alternate erosion and accretion and be subject to frequent variations. The Great Lakes wave climate is primarily destructive.

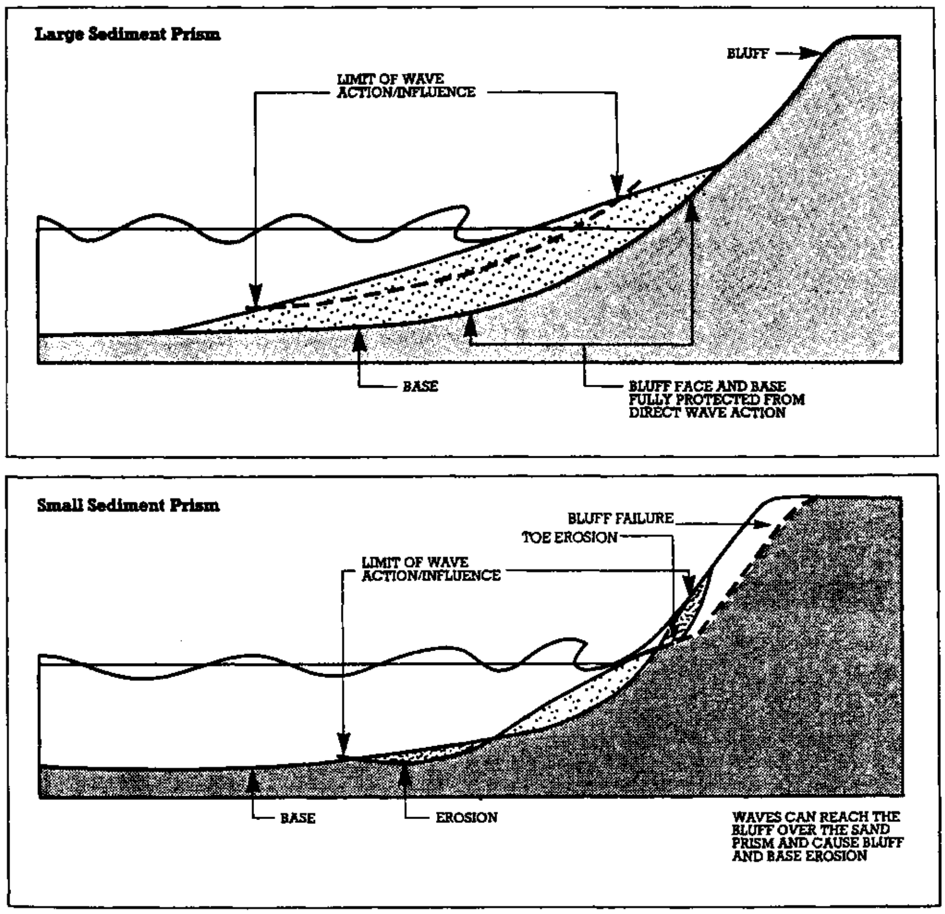
During storm conditions, several factors combine to erode the shore. In a train of storm waves, the waves may have varying characteristics. They break at different depths, widening the surf zone and resulting in a larger bed and suspended load transport area. They are also steeper and have a cutting action on the shore. The downrush of each wave carries away more material than is brought shorewards by the run-up of the following wave. The result is shore erosion. If the waves are accompanied by currents and high water levels associated with wind setup, parts of the normally dry shore can be inundated and eroded.

The term "unconsolidated littoral sediment prism" is used to define the total exposed and submerged unconsolidated sediment deposits (primarily sand) within the littoral zone that significantly influence shore processes from wave action and currents. It extends from the effective limit of storm waves to a point in the littoral zone where sediment is less actively transported by waves and currents. It is a temporary deposit or resting place for sediments in active transit along the shore, or on and off the shore, and is subject to periodic shape changes due to wave action.

The effectiveness of active sediment prisms for shore defense rests in their ability to dissipate wave energy and protect the nearshore zone bottom and shore bluff from direct wave action. Their effectiveness depends on their size at any particular time, the duration of their temporal existence and their stability, as illustrated schematically in Figure B-3-7. However, they are "dynamic" or "active" in nature in contrast to the "static" character of lag deposits. They are formed in part by unconsolidated granular material derived from shore erosion and brought by waves as littoral drift. To retain their effectiveness as a shore defense, any material removed from the prism must be replenished by littoral drift from an outside source, a river supply, erosion of adjacent shoreline or from the offshore. If the natural beach or nearshore sediment prism material supply is temporarily upset or permanently cut off, the size of the beach and nearshore sediment prism may diminish and its effectiveness as a shore defense may be temporarily reduced or completely lost.

In order for a stable beach and nearshore sediment prism to form, not only must there be an abundant supply of sand, but a certain grading of the supply

FIGURE B-3-7: EFFECTIVENESS OF ACTIVE SEDIMENT PRISM AS SHORE DEFENCE



Source: OMNR, 1981

of beach and nearshore prism material from littoral transport must be satisfied. A unique relationship between the total volume of littoral material supply, particle size distribution, wave parameters, wave energy, base slope and permeability of base, and the beach and nearshore deposits must be satisfied; otherwise, a stable beach prism will not form. Even with a large volume of littoral transport, if there is a deficiency of coarser beach material, only a marginal unconsolidated sediment prism would form with a narrow or non-existent beach.

Absence or virtual absence of beaches is quite common on sections of the Great Lakes bluff shore, in spite of large volumes of littoral transport consisting mainly of fine to very fine sand. The active sediment prism on the Great Lakes does not extend beyond a depth of 10 metres and often is found only to a depth of less than 3 metres.

The lakeward limit of the shore zone is the physiographic shore zone or the littoral zone, taken as the limit of littoral movement which significantly influences shore processes. This zone contains the active sediment prism and is where virtually all wave energy is expended. The maximum depth to which significant sand movement occurs is the depth below which shore-parallel contours give way to irregular contours. This marks the local transition between the nearshore zone, where sands are moved by the waves in significant quantities, and the offshore zone, where sand is moved in lesser quantities. In most areas this depth is about 10 metres.

Littoral Processes

Littoral processes are the result of interactions among winds, waves, currents, water levels, sediment supply and other phenomena in the littoral zone. The dominant processes leading to erosion, sediment transport and deposition within the littoral zone are associated with waves, wave-generated currents and, to a lesser extent, wind-generated currents. These in turn control the resultant movement of sediment alongshore and on-offshore. These littoral processes may be modified by water-level changes and by the presence of ice during winter.

Wherever consolidated material such as bedrock or bluff sediments is exposed to wave action, erosion takes place as a result of fluid stresses generated by the wave orbital motion, turbulence due to wave breaking and the direct impact pressures generated by waves breaking at the toe of a bluff. Where some sediments are present on the bed, much of the erosion takes place as a result of abrasion by the impact of particles being rolled across or hurled against the substrate. On relatively weak material such as glacial till, wave action can result in erosion rates of tens of centimetres per year, while in areas of resistant rock such as limestone or granite, erosion rates may be measured in millimetres per thousand years.

The material eroded directly by wave action or brought to the littoral zone by rivers and by slumping of bluffs is winnowed by wave action, with the fines (generally less than 0.06mm) being dispersed offshore and deposited in the deep lake basins, and the coarser sediments being retained in the littoral zone to form the sediment prism of the beach and nearshore zone. The thickness and extent of the beach and nearshore sediments that make up the littoral sediment prism depend both on the magnitude of sediment supplied from wave erosion and land sources and on whether the sediment is retained in place or removed alongshore to some other location by longshore sediment transport.

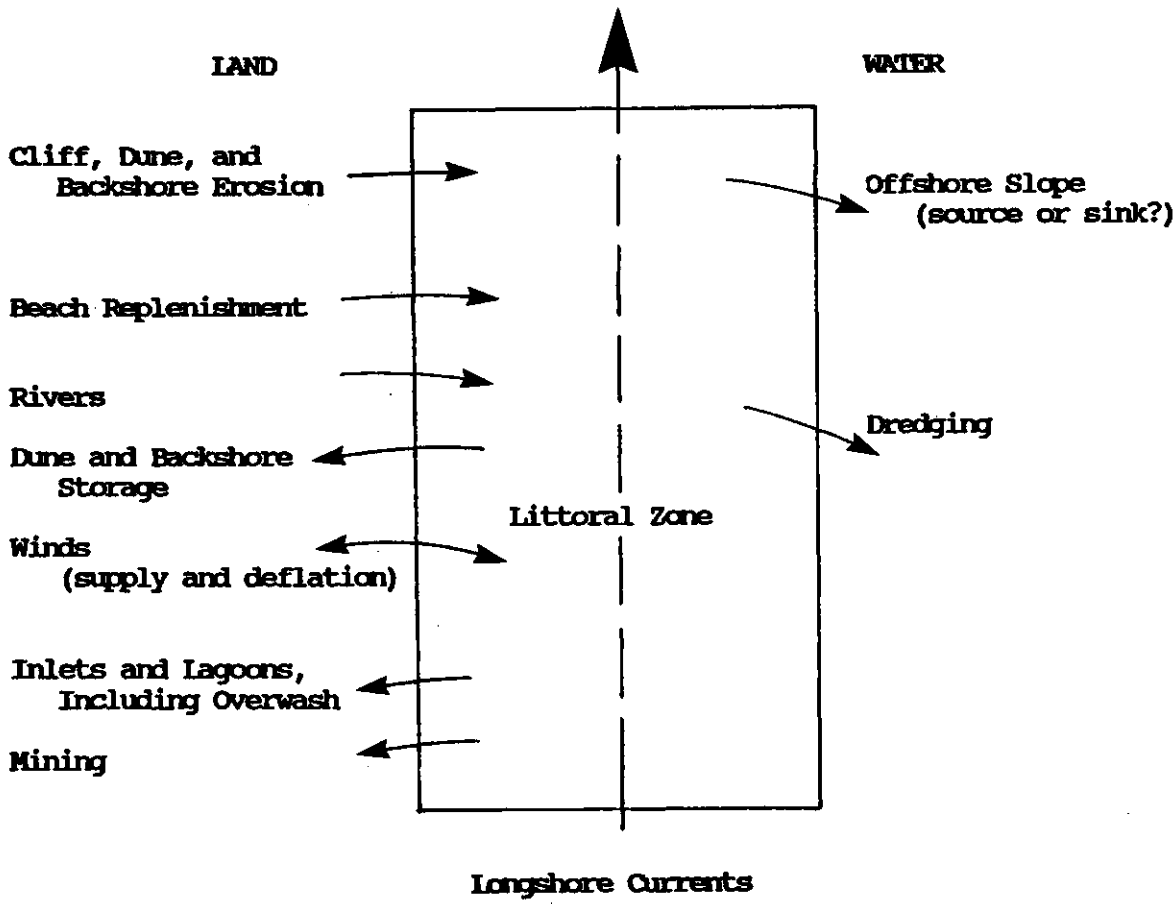
The sediment of the beach and nearshore zone acts to dissipate wave energy and to protect underlying consolidated material and the bluff toe from erosion. Where sediment is abundant and the littoral sediment prism extends from the beach to the limit of wave action, coastal erosion ceases entirely. However, on many parts of the shoreline of the Great Lakes the littoral sediment prism is nearly absent, or only partially developed, so that it offers only limited protection from wave action, and erosion of the coast continues. In many bluff areas, the sediment prism is poorly developed despite the continuous addition of large volumes of sediment to the littoral zone through bluff recession. The controls on the volume of sediments that occurs in the beach and nearshore zone in any area can be examined through formulation of a littoral sediment budget, and within the framework of a littoral cell.

The sediment budget is simply a means of accounting for all inputs, transfers and outputs of sediment in the littoral zone for a defined shoreline length. The inputs and outputs most relevant to the Great Lakes are shown in Figure B-3-8. In the Great Lakes, river sources are relatively unimportant and most sand is derived from bluff erosion and reworking of glacial and post-glacial sediments. In some areas, such as the bedrock coasts of eastern Georgian Bay and Lake Superior, the volume of sediments in the littoral prism may be small because of the small volume of sediment supply. In many other areas, particularly along the bluff shorelines of the lower Great Lakes, sediment inputs are high and the extent of development of the littoral prism depends primarily on the balance between sediment input from updrift and output downdrift by longshore sediment transport.

Longshore sediment transport results from wave approach at an angle to the shoreline and the rate is a function of wave height and the angle of wave approach. Most of the movement takes place in the zone extending from the beach to just outside the breaker line. The gross longshore sediment transport can be defined as the total sediment transport summed for all wave conditions over a period of one year. Of greater importance for the sediment budget is the net longshore sediment transport, which is the difference between sediment movement to the right and to the left over the one year. This defines the direction and rate of net sediment transport along the coast and is controlled by the annual wave climate (frequency of waves by height, period and direction classes), refraction of waves in the nearshore, and by the shoreline orientation.

Along most of the Great Lakes coast it is possible to divide the shoreline into littoral drift cells, characterized by net sediment transport in one direction and defined by updrift and downdrift boundaries across which there is little sediment exchange. Ideally, a littoral cell consists of an updrift source where sediment is supplied to the system, a central area dominated by transport, and a downdrift sink where there is net deposition. In the lower

FIGURE B-3-8: COMPONENTS OF THE BEACH SEDIMENT BUDGET



Source: International Joint Commission Functional Group 2, 1989a

Great Lakes, most of the cells are associated with eroding coastal bluffs as the updrift source, with spits and baymouth barriers forming the downdrift sink (Figure B-3-9). Because of the elliptical shape of each of the Great Lakes, there is usually a major change in the direction of sediment transport midway along the shoreline because of the relationship between fetch length and the size of waves generated. Thus, on Lake Ontario, net sediment transport at the western end of the Lake is to the west because of the much larger waves generated by winds blowing from the east over the full length of the Lake. However, moving towards the east, the fetch length from the east decreases while that from the west increases until a point is reached at which the waves from the west become dominant and net sediment transport switches towards the east.

In the idealized littoral drift cell depicted in Figure B-3-9, the potential net sediment transport (which is a function of available wave energy) exceeds the sediment actually available from bluff erosion and from updrift over much of the cell. In this area, the littoral sediment budget will be negative because longshore sediment transport out of any stretch of the shoreline will exceed inputs from updrift. As a result, the littoral prism will be thin, affording only limited protection to the toe of the bluff and the nearshore, and leading to continuing erosion. It is only at the extreme downdrift end, where there is a reduction in potential transport, that the sediment budget becomes positive, leading to the building of a wide beach and complete sediment cover across the nearshore which offers total protection against further erosion.

Shore Changes

Examination of shore forms and features can provide a clue to the nature and character of shore processes, and identification of the erosional and depositional sections of the shore.

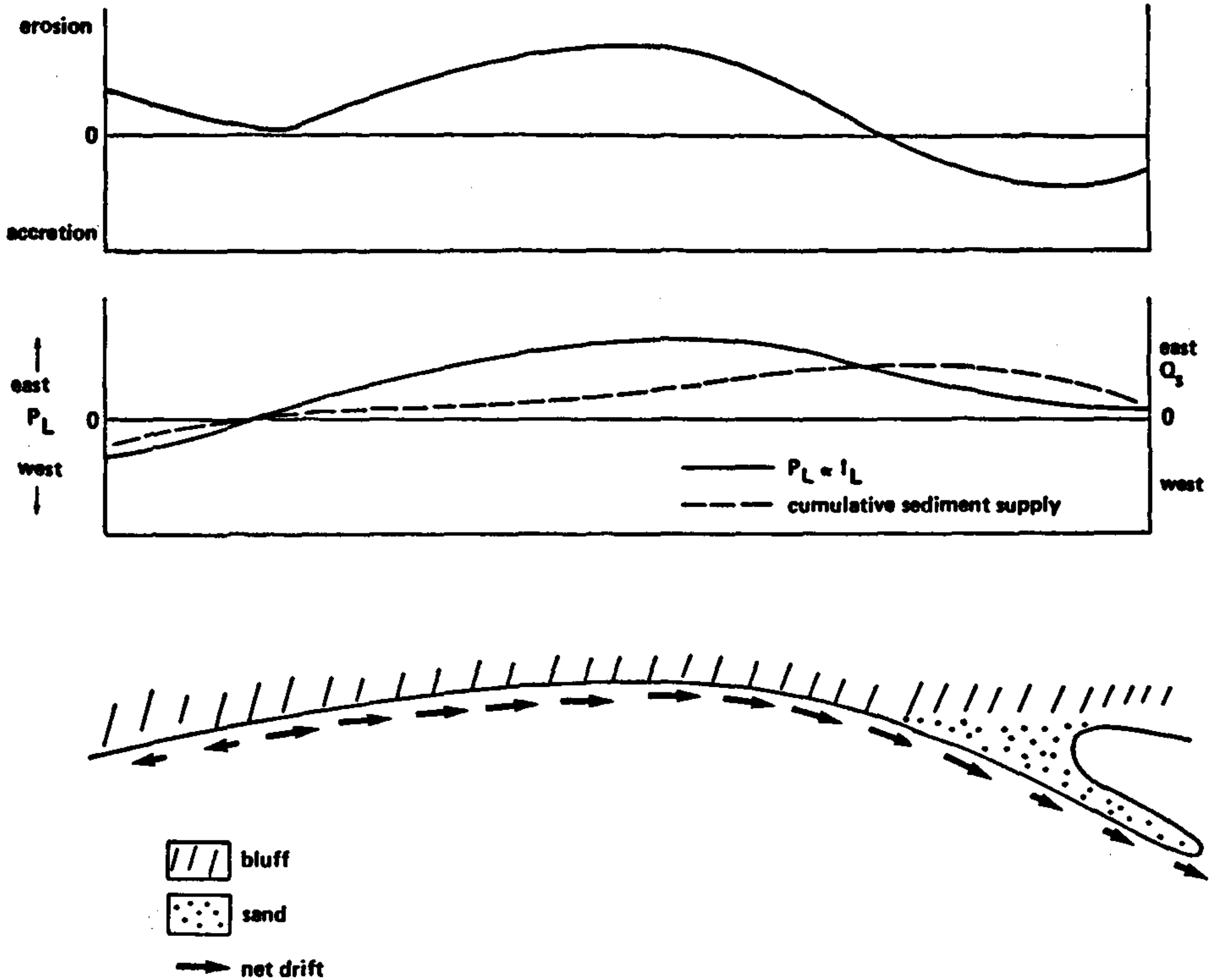
Shore form changes are generally described in terms of recession, erosion, deposition or accretion. The processes are illustrated in Figure B-3-10. Recession is the landward retreat of the shore by removal of shore materials in a direction perpendicular and/or parallel to the shore. This can occur with erosion above and below the water level.

Erosion is a volumetric reduction of shoreline material by natural processes. It is removal of soil, surficial deposits or rock from any part of the shore face with a net loss of the eroded material through longshore or offshore-onshore movement.

Accretion is a volumetric addition of shoreline material by natural deposition. It is an accumulation of excess sediment material on the beach foreshore by littoral drift deposition. Beach accretion may be seasonal and alternates with recession. When accretion predominates over recession, the shore is aggrading.

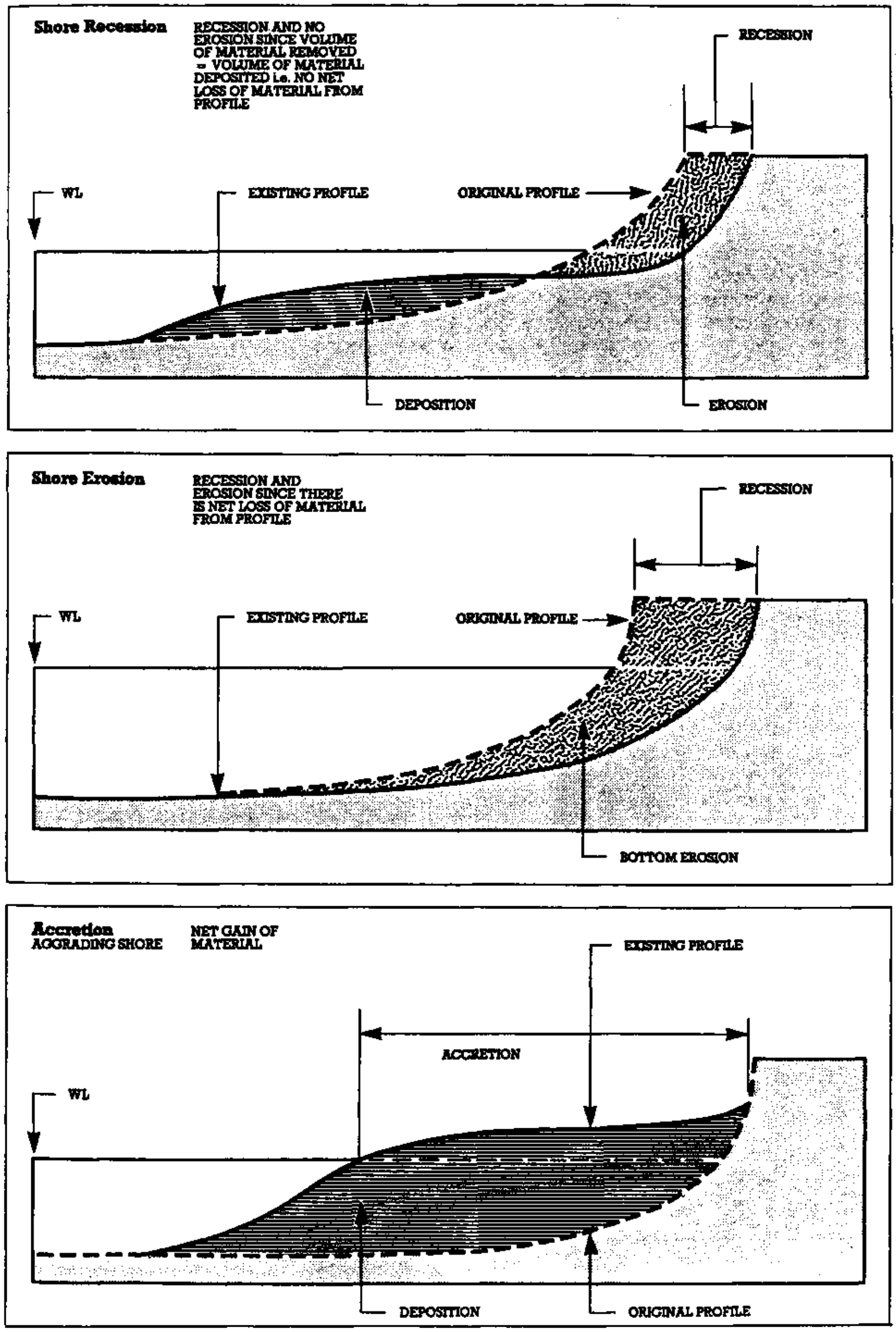
Shore reaches can be classified as aggrading, erosional or recessional, depending on whether accretion, erosion or recession is taking place. On

FIGURE B-3-9: LITTORAL DRIFT CELL, COHESIVE COAST



Source: International Joint Commission Functional Group 2, 1989a

FIGURE B-3-10: SHORE RECESSION, SHORE EROSION AND SHORE ACCRETION



Source: OMNR, 1981

any shore, the erosional and depositional features may alternate not only in space but in time.

On the basis of its horizontal position, a section of the shoreline may be experiencing stability, transgression (shoreline moving landward), or regression (shoreline moving offshore). Transgressions or regressions may result from relative displacement of the land and water body, as noted earlier, and small regressions and transgressions result from the seasonal and long-term water-level fluctuations. Relative shoreline displacement is also still taking place due to differences in the rate of isostatic rebound between the lake outlets and shorelines. Generally, shorelines that lie north of a lake outlet are experiencing regressions, while those that lie to the south are experiencing transgressions. The vertical displacements are very small in the lower Lakes and the effects are negligible when compared to shoreline changes due to erosion or accretion. In northern Lake Huron and Lake Superior, however, continued isostatic uplift is an important element along with the prevalence of bedrock in maintaining shoreline stability.

If the effects of relative movement of land and water are neglected, shorelines can be divided into stable, accreting and eroding types. Stable shorelines can be further subdivided into static and dynamic types. Static stable shorelines occur where erosion is negligible due to very low wave energy (e.g. in protected bays and connecting channels) or on bedrock coasts where the rock is extremely resistant to erosion. On coasts where a full sediment prism is developed, a dynamic stability occurs with wave energy being dissipated over the beach and nearshore profile. During periods of low wave energy, sediment is stored in the beach and foredune, and during storms this is eroded and transported offshore, forming a wide beach and surf zone. Where the sediment budget is negative, there is insufficient sediment to absorb all the wave energy and an erosional shoreline develops with the rate of erosion being controlled by the wave energy, strength of the underlying material and by the extent of sediment deficit. Where the sediment budget is positive, such as the downdrift end of littoral cells, the excess sediment inputs from updrift lead to progradation of the shoreline.

Equilibrium Shore Forms

A shore is said to be in equilibrium when it maintains its typical profile or geometrical form. It may be eroding, accreting or stationary. If a shore is eroding or accreting but maintains its geometrical form, it is said to be in a state of dynamic equilibrium. If a shore, after developing a geometrical form, has become stationary, it has reached a condition of static equilibrium.

The concept of equilibrium profile is useful when considering equilibrium shore forms. When a uniform, erodible nearshore slope on an erodible base is subjected to a uniform wave attack at a constant water level, the profile will gradually be remolded by the waves until a point is reached where no further change in shape occurs under continuing wave attack. This equilibrium profile shape is unique for the specific level of wave attack, water level and base and beach materials.

When the water level, intensity of wave attack, or both are changed, a new equilibrium profile shape will be formed. The rate of change from one equilibrium profile to another with changing wave and water-level conditions will be rapid at first, and then diminish as the adjusting beach profile approaches a new equilibrium. This trend in rate of adjustment from one equilibrium condition to another has been observed both in the laboratory and in the field. However, very little information is available on the actual rates and their relationship to wave parameters, magnitude and rate of water-level change and nearshore material characteristics.

The variability of water levels and wave climate in nature probably never allows full adjustment from one steady state to another. However, water-level and wave attack changes on a given shore are within a certain range and, therefore, one can speak of an effective mean equilibrium profile characteristic of the specific section of shore. The concept of mean equilibrium profile is useful when considering the effect of water-level or wave climate change on the beach and nearshore zone profile.

Shore erosion occurs only under equilibrium profiles which maintain a maximum steepness corresponding to wave current and sediment conditions at the site. Shore aggradation may occur with or without equilibrium profiles.

In its natural development, a shore will tend to "face" the waves so as to minimize longshore transport and/or satisfy the continuity of the relationship between wave attack and littoral transport. Because of the relationship between littoral transport, direction of wave attack and equilibrium forms, the identification of equilibrium forms is helpful when interpreting littoral transport patterns and direction of predominant wave attack from examination of shore forms on charts and aerial photographs of beach forms. The geometry of shore forms can be derived from the relationship between littoral drift capacity and direction of wave attack.

One of the most frequently encountered shore forms in nature is a crenulated bay with a geometrical form which can be described by a logarithmic spiral. It is a "no drift" form and has been suggested and used to stabilize shores, with the use of artificial hard points as headlands and crenulated bay formation by natural wave action.

Sources and Sinks

Deposition of eroded material is a continuous process along the shore. In studying shore processes it is necessary to identify zones of deposition or net accumulation in the nearshore area such as beaches, offshore bars, and shoals, where they can affect the nearshore process or be a source of material for beach nourishment, and to identify areas which contribute sediment to the littoral zone. These are usually identified as "sources" and "sinks".

A "source" is a supply of littoral drift material to the shore. It may be either a line source (erosion of the shore or bluffs), or a point source (material supplied to the shore by rivers and streams). Artificial nourishment, deposition of material by humans from inland sources or from dredging outside the littoral drift zone, is also considered a source.

A "sink" is a loss of littoral drift material from the littoral transport zone. It may be a line sink (offshore loss to deep water), a point sink (loss into an offshore canyon), or deposition on a shoal. Losses of material to accretion and deposition areas (shoals, aggrading beaches, spits, etc.) are considered sinks. Any removal through dredging is considered a sink. The addition of material by man, such as beach replenishment, is considered a source.

Consideration of the shore in terms of sinks and sources is important for critical analysis of longshore transport, evaluation of long-term trends in natural geomorphological development of shore forms, and estimation of sediment budgets.

FLOOD AND EROSION SUSCEPTIBILITY

Much of the Great Lakes - St. Lawrence Shoreline is prone to flooding or erosion, or both. Figures B-3-11 through B-3-16 depict these areas in a general way. Work currently being conducted in the Reference Study is intended to refine our knowledge of these areas and the lake forces which affect them.

In many areas, the hazard risk is either from erosion or flooding, but in other areas the risk is primarily storm related and occurs in the form of waves undermining structures as well as crashing into them. Waves are also important to coastal flooding and as such, all the factors which affect their height, period and speed are important to flooding as well as to erosion. However, it should be pointed out that flooding can still occur independently of wave activity. The nearshore morphology also plays an important role as it affects the ability of waves to penetrate into normally dry areas behind the beach.

Flooding is a phenomenon which is more sensitive to water-level fluctuations than is erosion. Because the Great Lakes shores have many areas of low plains, the pre-storm water level is important to the extent of flooding when storm setup and wave run-up "push" water towards a shoreline. If the area of inundation is a wetland or an undeveloped area, the "damage" is minimal. Indeed, periodic flooding is found to be beneficial for the maintenance of wetland vegetation, because flooding helps to eliminate the invasion of upland vegetation that occurs during low water periods. In terms of human use of Great Lakes floodplains, low water levels ironically present the most serious problem. During lower water levels, the flood hazard to homes, cottages and other development often goes unrecognized. Consequently, when flooding does occur, damages are more significant.

Erosion along the Great Lakes shoreline is a major concern and occurs at significant rates along a higher percentage of Great Lakes shoreline than along the ocean coasts. For example, approximately 34 percent of the U.S. Great Lakes shoreline has been classified (U.S. Army Corps of Engineers, 1971)

FIGURE B-3-11: FLOOD AND EROSION PRONE AREAS ALONG THE LAKE SUPERIOR SHORELINE

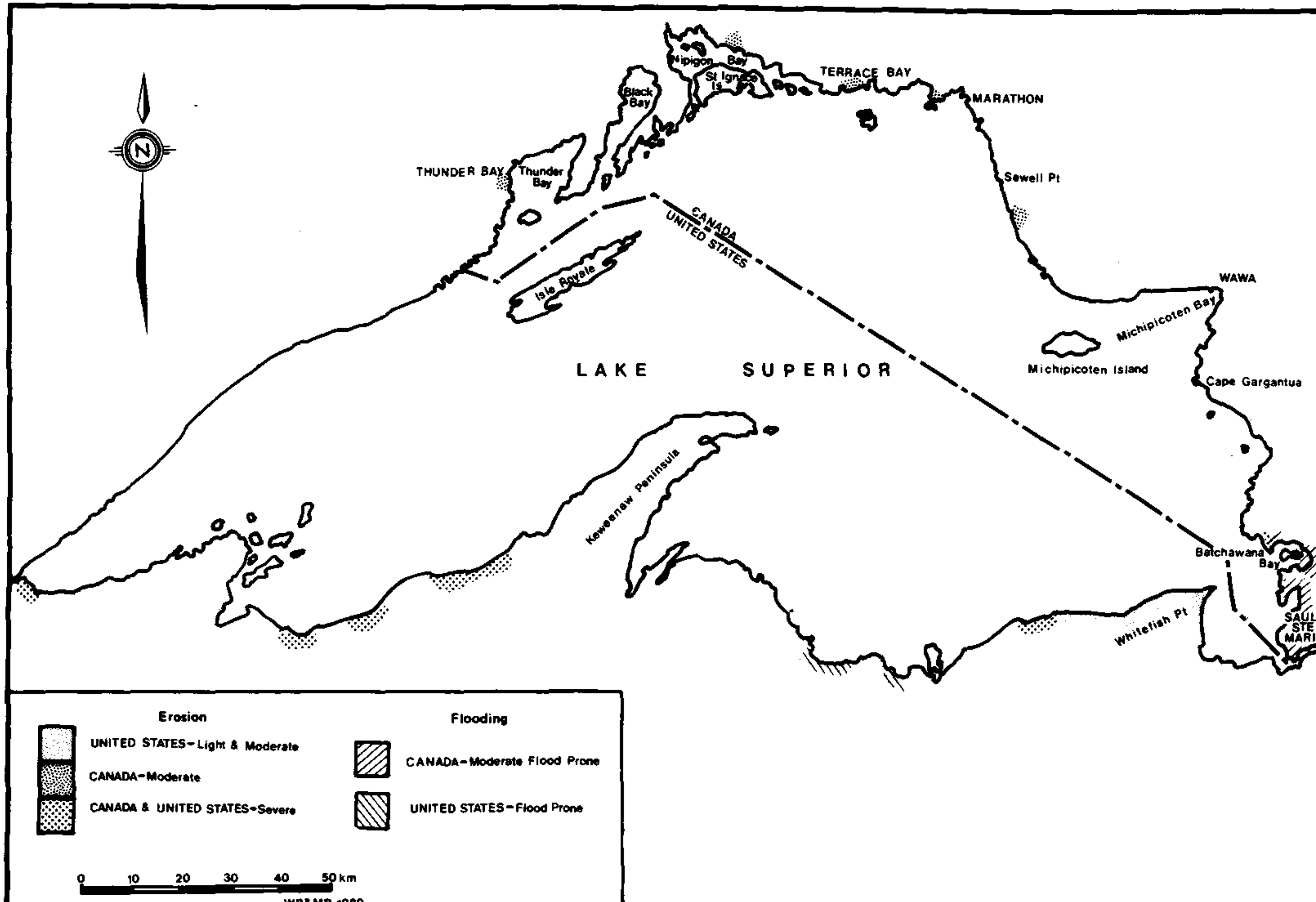


FIGURE B-3-12: FLOOD AND EROSION PRONE AREAS ALONG THE LAKE MICHIGAN SHORELINE

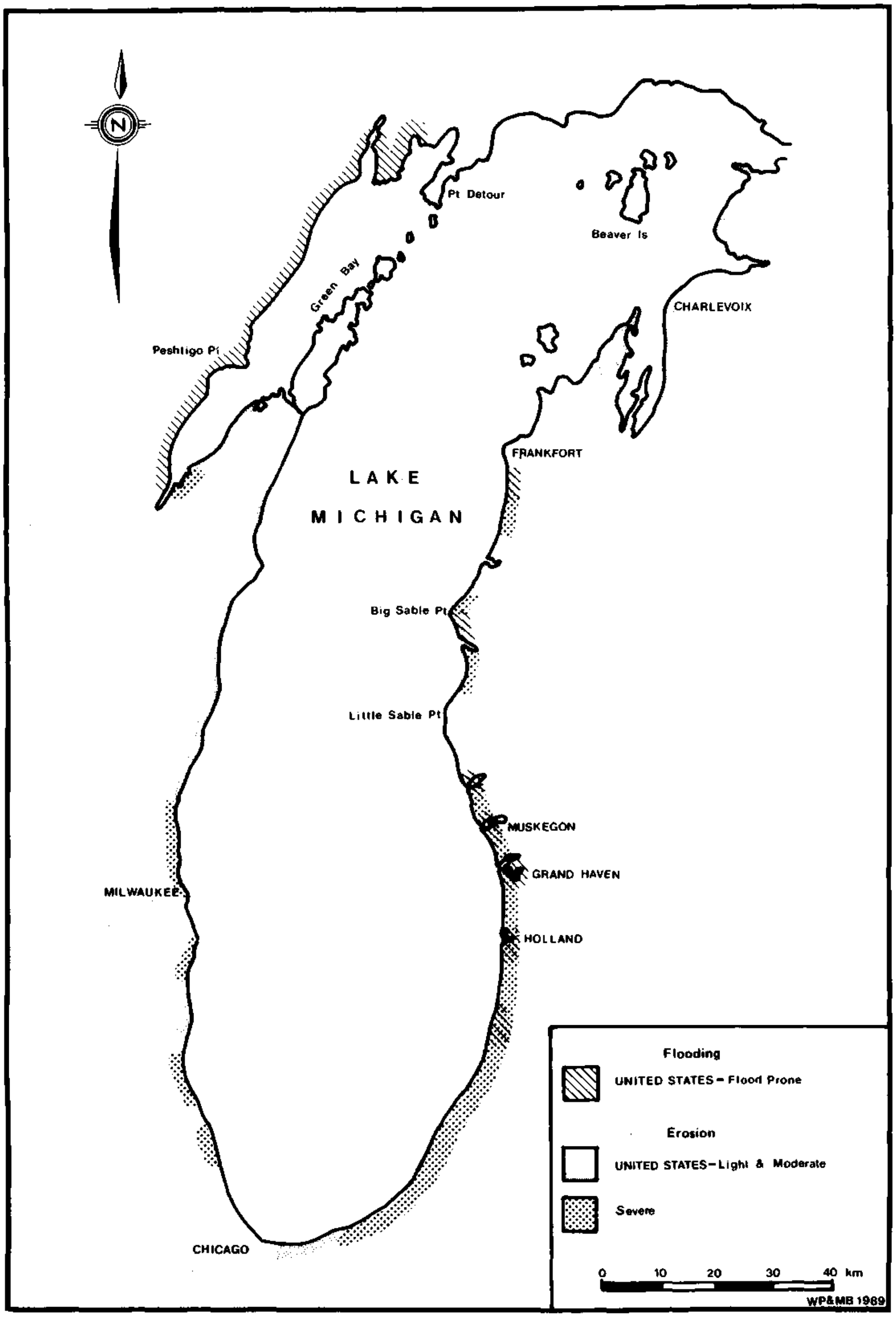


FIGURE B-3-13: FLOOD AND EROSION PRONE AREAS ALONG THE LAKE HURON SHORELINE

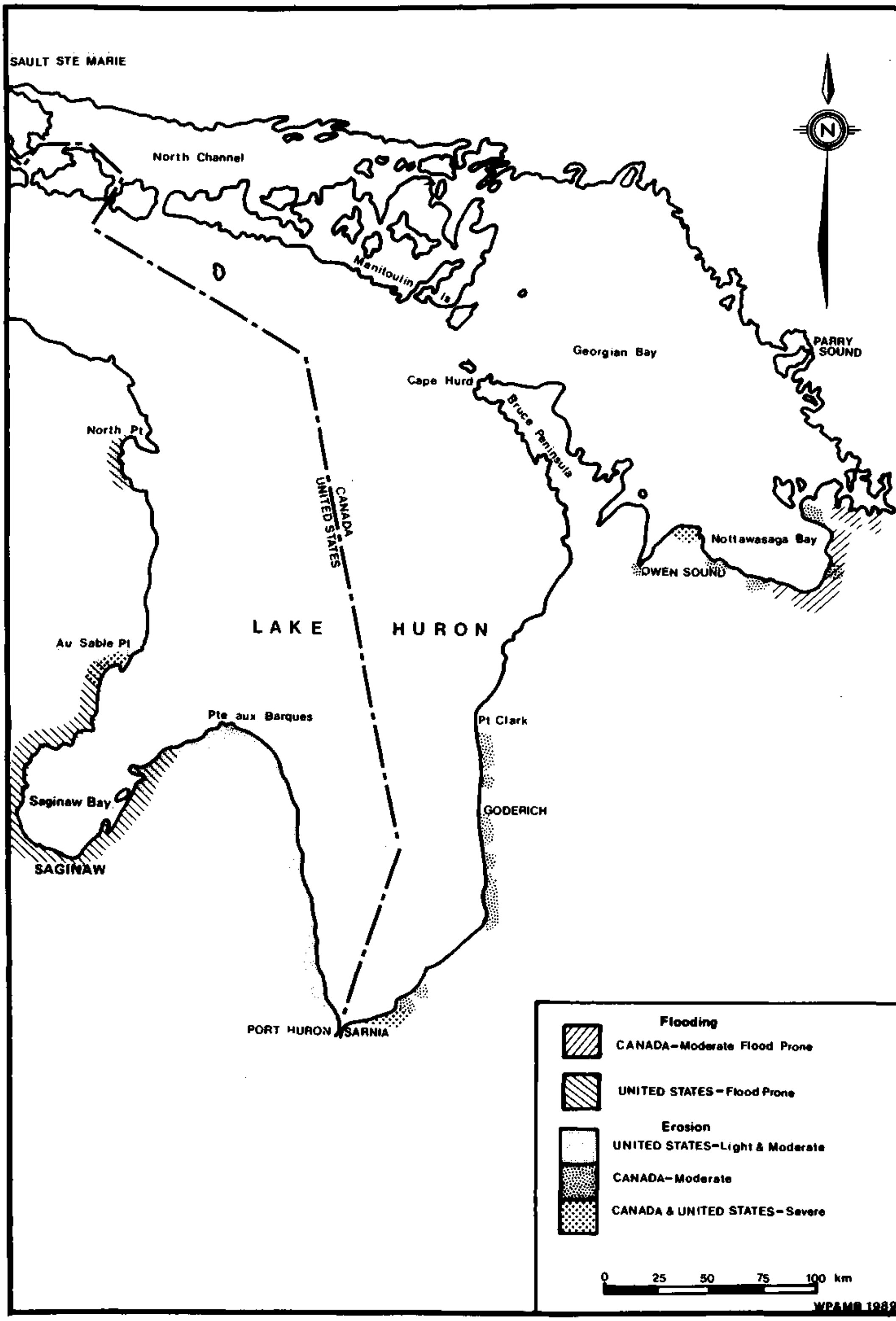


FIGURE B-3-14 : FLOOD AND EROSION PRONE AREAS ALONG THE LAKE ERIE SHORELINE

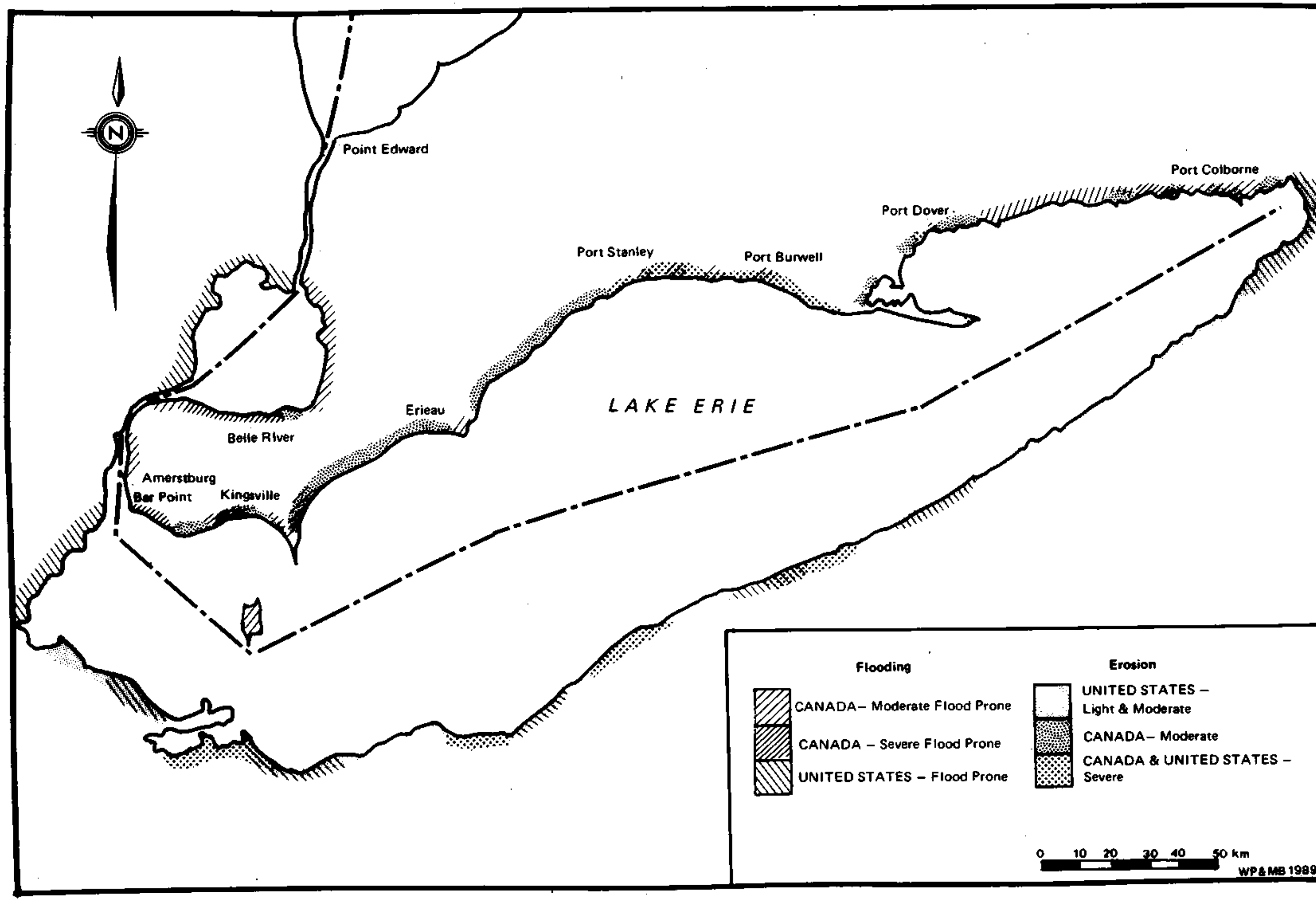


FIGURE B-3-15: FLOOD AND EROSION PRONE AREAS ALONG THE LAKE ONTARIO SHORELINE

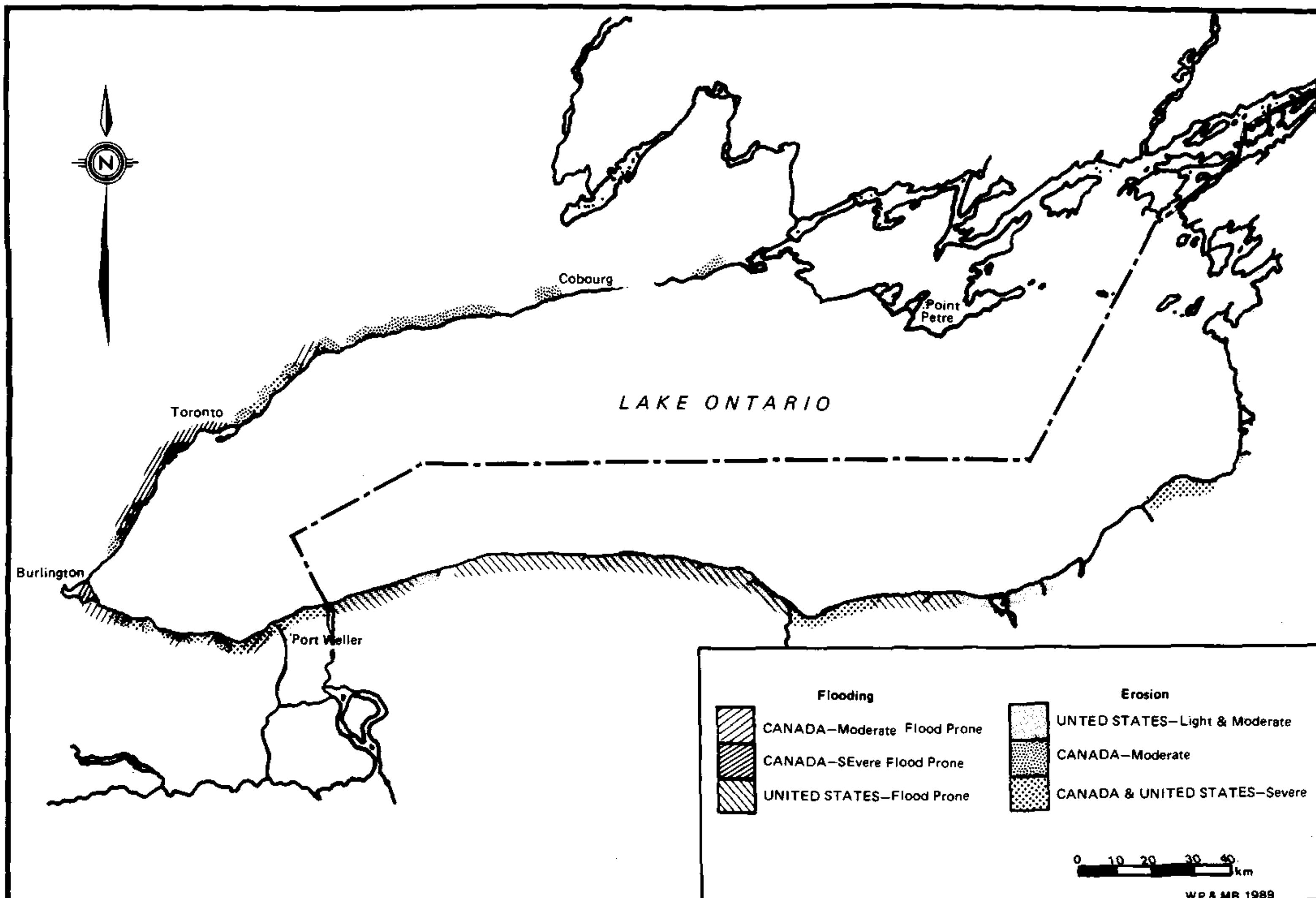
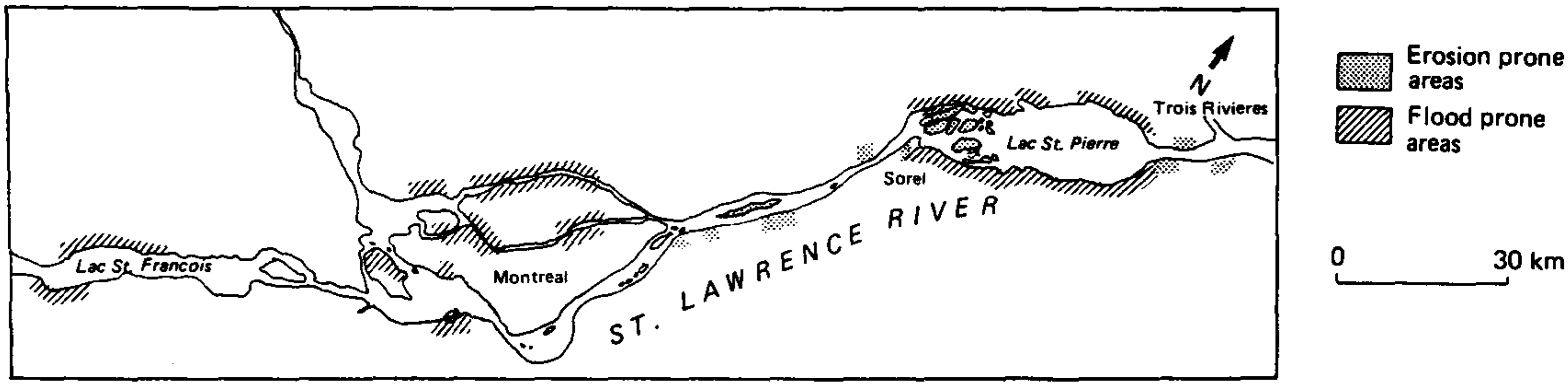


FIGURE B-3-16: FLOOD AND EROSION PRONE AREAS ALONG THE ST. LAWRENCE RIVER SHORELINE



as undergoing significant erosion whereas only 24 percent of the U.S. mainland ocean coast has that classification.

The assessment of flood risk is made on the basis of past and potential damages and the magnitude of water-level fluctuations necessary to cause damages. Given the importance of waves in flooding mentioned above, studies to determine the risk of inundation should also include analysis of the potential still water elevation, wave height, storm setup, and wave-run up. The assessment of erosion risk is based on long-term average recession rates.

Beach areas are more complex, in that some of these areas undergo alternating periods of erosion and accretion. Furthermore, erosion on beach areas is more difficult to measure due to fluctuating water levels alternately covering and exposing the beach area. There are very few beach areas that undergo continuous erosion.

3.3 WATER LEVELS AND WETLANDS

The extent and quality of wetlands found along the shores of the Great Lakes during any time period, are, in a sense, the product of seasonal and long-term environmental conditions. The wetland area can be estimated from knowledge of the range of water-level fluctuations and the distance between the contours above and below the water line (Bukata et al., 1988). In order to address wetland quality, on the other hand, much more detailed data are needed, including the timing, duration, and frequency of flooding and drying, and information on substrate. The length of time that water-level conditions can influence wetlands is not only the current year (annuals) but also the past few years (perennials) and even through decades. The contributions from seed banks are dormant until conditions become suitable.

GENERAL WATER LEVEL AND WETLAND RELATIONSHIPS

The following excerpts relating to water-level fluctuations and the wetland vegetation of the Great Lakes are taken from Keddy and Reznicek (1985).

The factors influencing lakeshore wetland zonation have been reviewed by Hutchinson (1975) and Spence (1982). Although introductory ecology texts still sometimes infer that this zonation represents succession, in most cases the two phenomena are unrelated on lakeshores. Zonation is better viewed as simply the response of different wetlands species to fluctuating water levels. Lakeshore wetlands are also often exposed to erosion from water. In such cases, the upper shorelines are eroded and deposition occurs in the deeper water. Bernatowicz and Zachwieja (1966) have distinguished ten types of littoral zones, considering primarily the effects of erosion on different substrate types. As well as being influenced by water depth, lakeshore wetlands may also have strong gradients parallel to the waterline as waves sort material from highly exposed shore to sheltered shores (Hutchinson, 1975; Davidson-Arnott and Pollard, 1980; Spence, 1982; Keddy, 1982, 1984).

Since seasonal (or within-year) water-level fluctuations are superimposed upon long-term (or among-year) fluctuations, we will first consider the effects of long-term fluctuations. The present distribution and abundance of shoreline plant species will be determined by past as well as present water levels. How far into the past, or with what weighting, is not known. The extreme highs and lows will produce the most rapid vegetation change; low periods are considered first.

Low Water Periods

During low water periods, several changes can be expected. Soil chemistry may change dramatically as soils become less anoxic (Ponnamperuma, 1972). Some plant species will change their growth form to accommodate drier conditions (Sculthorpe, 1967; Hutchinson, 1975), but the vegetation will usually change dramatically as species intolerant of drying die and are replaced by species emerging from reserves of buried seeds. Much emphasis has been placed on documenting this regeneration from buried seeds (e.g., Kadlec, 1962; Harris and Marshall, 1963; Salisbury, 1970; van der Valk and Davis, 1976, 1978, 1979; van der Valk, 1981; Keddy and Reznicek, 1982; Smith and Kadlec, 1983).

High Water Levels

Rising water levels will change soils from oxic to anoxic (Ponnamperuma, 1972). Organic matter and fine particles (e.g., silt and clay) may be removed by water circulation (Jaworski et al., 1979). Simultaneously, mud flat species disappear (e.g., Salisbury, 1970; van der Valk, 1981). Emergent species will propagate vegetatively under shallow water, but will gradually die out under deeper water (Harris and Marshall, 1963; van der Valk and Davis, 1978). Farney and Bookhout (1982) describe how high water levels in Lake Erie converted emergent vegetation to open water. Even cattails (Typha spp.), which covered more than 20 percent of their study area, were eliminated. Other common cover types such as Hibiscus palustris and Leersia oryzoides also disappeared. Jaworski et al. (1979) provide many similar examples from Lakes Michigan, Huron, St. Clair and Erie. High water periods therefore eliminate one group of marsh species and allow them to be temporarily replaced by floating-leaved and submerged species more tolerant of flooding. The causes of death of emergents are unclear.

High water levels may have a very adverse effect on the emergent and submergent vegetation communities if there is no room for a landward shift. Such habitat is required by migratory birds which use coastal and connecting channel wetlands. Some of these sites are shore swamps which are inundated through the spring but dry through the summer. These may be characterized by herbs (e.g. Phalaris arundinacea) and agriculturally-cultivated cover; others are shrub swamps with willow (Salix spp.) and Cornus spp. and hardwood swamps with maple (Acer. spp.). Herb swamps are among the most intensively used by migratory birds. Other critical areas for many waterfowl species, including Snow Geese, are the intertidal wetlands along the St. Lawrence River dominated by Scirpus spp. (Glooschenko and Grondin, 1988).

High water levels have a second important effect on lakeshore marshes, the elimination of trees and shrubs. Recently, evidence of this process was found in Matchedash Lake (Keddy and Reznicek, 1982). The upper limit of many herbaceous species on lakeshores coincides with the lower limits of woody species, and where waves or ice remove shrubs, herbaceous species grow further landward (Keddy, 1983). If woody plants set the upper limit of herbaceous species, then high water levels, by eliminating woody plants, may increase the area occupied by herbaceous wetlands species. An observation consistent with this proposal is that in small lakes with stable water levels, the shrub zone frequently occurs right to the water line, leaving only a narrow zone of emergents.

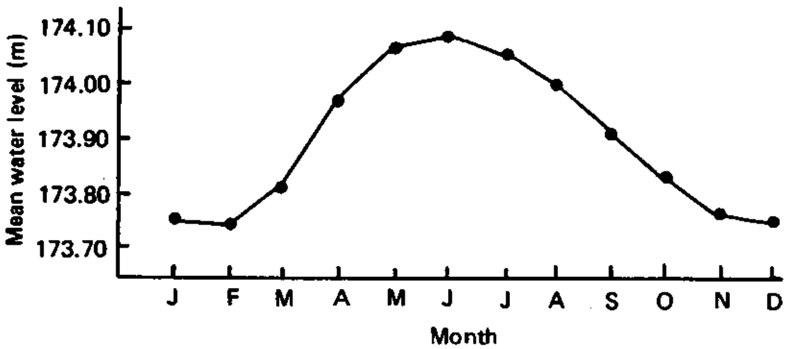
Along the St. Lawrence River, annual flooding of shore swamp wetlands can vary widely. These wetlands are characterized by Acer saccharinum-Laportea canadensis and Onoclea sensibilis. If periods of flooding exceed critical thresholds, these swamps experience stress which may lead to their alteration or decline. For example, Couillard et al. (1985) have shown that flooding for more than 63 days after the beginning of the growing season in swamps (June 27 in the Montreal area) leads to deterioration or destruction of these swamp ecosystems. This has occurred in Lac Saint-Louis on the upper St. Lawrence River, with specific examples documented by Couillard et al. (1985) during years of abnormally high flood levels in the 1972-1976 period.

Seasonal Fluctuations and Strand Vegetation

Water levels fluctuate on many time scales. Seasonal fluctuations (Figure B-3-17) are likely to have very different effects than fluctuations with a period of a decade or longer. In the latter case, population responses can occur, with some species surviving only as buried seeds, and others temporarily exploiting the existing conditions. With seasonal fluctuations, population responses are possible only for annuals, which complete their life cycle rapidly. As the water level falls, different annuals will germinate and temporarily exploit favourable sites. In contrast, perennial species must be able to survive the entire range of conditions encountered during seasonal fluctuations in order to occupy a site during the growing season. Thus, they may produce different shoot morphologies as the season progresses (Sculthorpe, 1967; Hutchinson, 1975) and have different metabolic pathways for surviving anoxic periods (McMannon and Crawford, 1971; Barclay and Crawford, 1982). The annuals can escape seasonal fluctuations; the perennials must tolerate them. Seasonal fluctuations may increase species diversity. Stuckey (1975) observed at Put-in-Bay, Lake Erie, that " The greatest diversity of vegetation zones and greatest diversity of species within zones occur in that part of the marsh where the water level fluctuated the most throughout the season." He recognized 12 "dominant vegetation zones," seven of which were associated with fluctuating water levels.

At the very least, seasonal fluctuations increase the annual component of the vegetation. For perennial species that can only germinate on exposed mud flats, the seasonal low may supplement or accentuate regeneration phases provided by long-term fluctuations. Lastly, since many wetlands species are apparently intolerant of continual submergence (e.g., Harris and Marshall, 1963; van der Valk and Davis, 1978), seasonal lows may allow shoreline species to occur deeper into the lake.

FIGURE B-3-17 SEASONAL (WITHIN-YEAR) FLUCTUATIONS IN WATER LEVEL AT PORT STANLEY ON LAKE ERIE, AVERAGING DATA FROM 1927-1980 (EXCEPT 1978).



Water-Level Fluctuations: A Natural Disturbance

Water-level fluctuations are a natural form of disturbance. The role of natural disturbance in promoting vegetation diversity has been discussed by Grubb (1977), Connell (1978), Huston (1979), White (1979) and Grime (1979).

A disturbance has several quantifiable components including intensity and frequency. It is not yet known what intensity (amplitude) or frequency of disturbance from fluctuating water levels will maximize species diversity. Some combinations of high intensity and frequency have a negative impact on shoreline vegetation, as illustrated by the sparse vegetation of the margins of some hydroelectric reservoirs. Stabilizing water levels (reducing the intensity and frequency of disturbance) would also be expected to cause major changes in wetlands, particularly: 1) the loss of species which germinate during low water periods; and, 2) increased dominance by a few species such as woody plants and *Typha* spp.

A Model of Water Levels and Shoreline Vegetation in the Great Lakes

A model outlining the relationships of Great Lakes wetland vegetation types to water-level fluctuations is depicted in Figure B-3-18. This model is simplistic in that it considers only the role of water-level fluctuations in determining wetland vegetation types. Topography, substrate type, wave actions, latitude, water quality, fire, water currents, exposure, and length of time since the last high or low water phase are not considered. While the model thus is not refined enough to predict the occurrence of communities or species associations, it is a useful conceptual framework for interpreting the large-scale cyclic processes in Great Lakes wetlands.

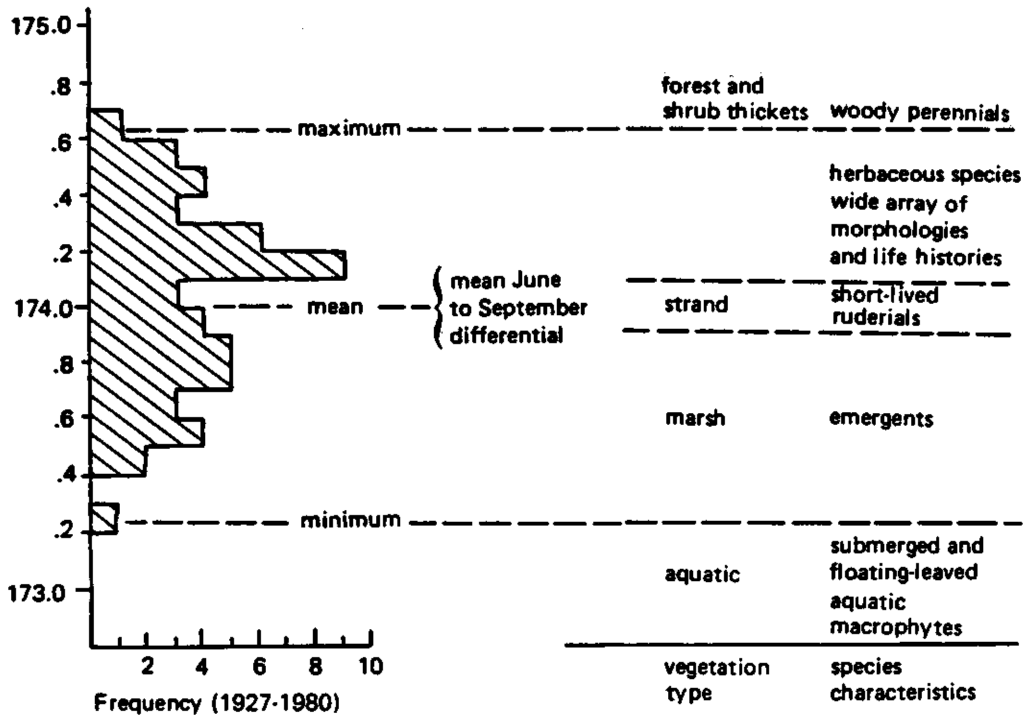


FIGURE B-3-18 PROPOSED RELATIONSHIP BETWEEN WATER LEVELS AND VEGETATION TYPES ON THE GREAT LAKES SHORELINE.

The following discussion summarizes the hypothesized dynamics of the wetland types described earlier. Only strand vegetation is omitted, since it results primarily from various kinds of disturbance near the water line.

The upper part of the shore is dominated by woody species intolerant of flooding. They form forest and shrub thickets.

Wet meadow vegetation develops between the maximum high and present water level. The dynamics of this vegetation are probably similar to the dynamics of vegetation on shores of smaller lakes with fluctuating water levels (Keddy and Reznicek, 1982). During high water phases, these communities are narrowed in width or even totally flooded. Woody plants that have invaded since the last high water level are killed, as are many herbaceous species. When water levels recede, wet meadow species re-establish from buried seeds and from individuals which survived on the upper fringes of the wet meadow zone. August water level data was used in Figure B-3-18, but it is likely that higher water levels in June set the lower limits of woody plants; thus the upper limit of meadow species is probably higher than indicated.

Between the present water line and the extreme minimum water level is the zone in which shallow marsh vegetation is best developed. The emergent aquatics can survive permanent flooding but many require occasional low water levels to expose the lake bottom in order for seedlings to establish. Thus, periodic seed recruitment of species can only occur above the extreme low water line, although some emergent aquatics can spread vegetatively into water deeper than the minimum low water line. A major difference between wet meadows and marshes is thus the relative frequency of flooding; meadows are occasionally flooded, whereas marshes are usually flooded.

Below the minimum low water level is the zone where aquatic vegetation survives continuously. In the shallower levels of the zone, emergent aquatics may invade during low water, although they will be eliminated again when water levels rise.

The water-level data represent Lake Erie 1927-1980, minimum 1934, maximum 1973. The boundaries between the vegetation types will shift as water levels change; the strand, composed of short-lived ruderals, tracks the waterline with a width resulting from the fall in water levels from June to September. Other environmental factors such as slope, substrate type, wave action, water chemistry and fire will influence the species composition within each vegetation type.

Specific Sensitivity of Wetlands

- **Seasonal patterns:** High levels maintained longer into the growing season will shorten the season for maturation. Wetlands benefit when the high water period occurs during the spring and early summer (April, May and June) and levels decrease afterward.

  Mid-and late-summer high water has adverse effects on wetlands. Lake Superior, with its August high, has a noticeably slimmer flora. When highs occur in July, productivity is decreased and ruderals may decrease, as might gap colonizers. The shortened growing season affects recruitment. This temporal limitation is damaging, for example, to wild rice.

- **Sensitive wetlands:** Water-level impacts depend on specifics of the wetland. Work at Delta Waterfowl Research Station has shown that a 20 cm increase in water levels resulted in a replacement of some vegetation types with others. It wiped out dominants, which were replaced by other species. A few centimetres difference in water levels can prevent sensitive species from completing their life cycle. Some very sensitive species include Iris lacustris, Scirpus smithii, and annuals like Eleocharus. Wet meadow species are generally the first to be lost with high levels and long-term low levels (invaded by trees).

  Taxa that are good bioindicators on the water side include the very sensitive rosette-forming plants. These plants cannot be overshadowed by other plants. Some of the least sensitive species are Carex, Scirpus, and other monoculture forms.

  Exotics and problem species will benefit from reduced water-level fluctuations. Disturbance of the historic water-level fluctuations generally provides a window of opportunity for invasion. These plants are generally persistent, flexible and adaptable. Plants that are included are European Frogspit, Purple loosestrife, narrow-leaf cattail, Epilobium parvoflosum, Najas minor and Potomageton crispus. Generally, opportunities for control of these species are not well understood.

WILDLIFE RESPONSE TO FLUCTUATING WATER LEVELS

Wetlands of the Great Lakes are exposed to variations in water levels caused by long-term climatic cycles, short-term climatic occurrences, the annual distribution of water, seiches, and, wave actions. The present beneficial state of these wetlands has been attained in association with these productive historic water-level fluctuations. Wetland communities will react to those water-level variations according to the pattern and magnitude of water-level changes, and the tolerance of the biotic community to them.

Periodic disturbances of flooding and drying interrupt plant succession to prevent the formation of dense beds of emergent vegetation and promote interspersion of vegetation and water. These interruptions periodically release nutrients to the wetland, thereby promoting renewed plant vigor and increased invertebrate populations essential to wetland wildlife. Such disturbances promote diversity of the plant and animal community structure.

Weller and Spatcher (1965), Weller and Fredrickson (1973), and Murkin (1979), describe optimum wetland wildlife habitat as a hemi-marsh, i.e., 50 percent open water and 50 percent wetland vegetation. The hemi-marsh condition produces the greatest habitat diversity for wetland-dependent wildlife species. Weller and Spatcher (1965) correlated the changes in marsh cover - water ratios, and vegetation density to bird population dynamics. They concluded that the hemi-marsh was the most productive successional stage of wetlands for marsh birds (see Table B-3-2).

Water-level fluctuations comparable to recent historical conditions (i.e., they last 20 years) are required to maintain the long-term productivity and diversity of the wetlands. High water conditions (i.e., levels above the historical long-term mean) produce habitat conditions approaching the hemi-marsh which benefits wildlife such as waterfowl, muskrats, black terns and herons. These conditions increase wildlife species diversity, and "... provide improved habitat conditions for invertebrates, amphibians, and reptiles...". High water may facilitate the interchange between the lake and wetland, and thus permit fish spawning (e.g., northern pike) as well as wetland rearing of forage fish (Jaworski et al., 1979).

Low water conditions (i.e., water levels below the historical long-term mean) encourage the predominance of the sedge-meadow and dense emergent zones. During extended low water years, wildlife species diversity decreases with habitat conditions favouring red-winged blackbirds, short-billed marsh wrens, rails, white-tailed deer, cottontail rabbits and small rodents.

In Lakes St. Clair and Erie during the 1973-75 high water period, the shoreline marshes experienced diebacks of vegetation and reverted to more open water. With receding water levels, many vegetative communities reestablished themselves (Raphael et al., 1978). There has been effective recolonization by

TABLE B-3-2: WILDLIFE USE AND OTHER FUNCTIONS OF COASTAL WETLANDS AT LOW AND HIGH WATER LEVELS

Use/Function of Wetlands	Low Water	High Water
A. Use by Wildlife		
Blue-winged teal (breeding)	- - - ---------	
Red winged blackbird	----------- - - -	
Mallard (breeding)	- - ----------	-------- - - -
Short billed wren	---------- - -	
Muskrat	- - - ----------	------ - - -
Black Tern		- - ----------
Yellowhead blackbird		- - ----------
Great blue heron	- - - -	------------------
Belted kingfisher	- - - -	------------------
Crayfish	- - - -	------------------
Frogs and turtles	- -	------------------
Dabbling ducks (feeding)	-- - - ----------	---------- - - - -
B. Other Functions		
Hemi-marsh		- - - ------------
Dominance of land drainage	--------- - -	

Source: modified from Jaworski et al., 1979 some plants such as sedges but not by others such as cattail. It should be noted that neither flooded nor dry marshes are by themselves most suitable for wildlife. Combining these changes over a period of time, however, seems to maintain the most desirable conditions. Kadlec (1962) states that "... although these (water-level) fluctuations are sometimes the subject of considerable concern, they are probably important in maintaining the productivity of the marshes...".

WATER-LEVEL REQUIREMENTS OF PARTICULAR WETLAND TYPES

System-wide diversity of various wetland types will decrease with a decrease in the frequency of water-level fluctuation. There will be gains in some types if the annual and long-term cycle is changed. For example, cattail, sago pondweed and willows will increase.

Scrub-shrub cannot accommodate prolonged high water levels; however, this is dependent on the requirements of the individual species. Generally, flooding range is from 6 weeks to 2 years. The seasonal fluctuation cycles should be maintained.

Annual plant communities (strands, mud flats) need the seasonal fluctuation. They require a rather rapid drawdown by mid-summer so that they can complete their growing and maturation for next year's seed supply. Winter conditions may be important in that ice will scour out exposed areas. The annuals are most dependent on water-level fluctuations.

Emergents like bare, wet soil. Adult plants prefer 0 to 0.5 meters of water with ideal conditions of no water cover during the growing season. During a 10-year period, very high water levels are needed for about 2 years to push back emergents and to encourage species diversity. Water levels should be 1 meter above normal for one summer growing season and into the next, with lower levels afterward.

Wet meadows (fens, wet prairie, inter-dunal meadows) need to be emerged in July, August and September of most years. However, summer flooding is needed for a 3 to 5 year period in a cycle (approximately 15 years). The flushing that occurs during the flooding period is in a sense the equivalent stress of "fire" in other ecosystems. Fens require water input through seepage. Wet prairies (grass-dominated) are key sites in need of protection. Peatlands will be invaded by shrubs if a dry period lasts too long. If the flood period lasts too long, ice scouring will expose bare substrate and this could continue landward toward the wet meadows. However, these systems are usually sheltered from direct lake effects. Riverine systems have more opportunities for scouring. Flooding depth should be >0.25 meter.

The effects of future water-level conditions on wetlands will be related to the degree and direction of changes to the historic water levels. If most of the range is maintained, i.e. 80 to 90 percent of the recorded fluctuations, as well as the frequency and duration of high and low periods, the changes to wetlands would be very difficult to quantify. Significant compression of the range of fluctuation would have systemwide impacts on plant species diversity, and wetland area. It would also have an indirect effect in that society would move closer to the shoreline and increase the physical changes to the shoreline. In addition, the runoff path of contaminants from developed uplands to the lake would be shortened.

WATER-LEVEL PROFILES AND WETLAND REQUIREMENTS

Work is underway on an evaluation of the historic water-level profiles for each Great Lake and how to use these data to address the requirements of wetlands (International Joint Commission Functional Group 2, 1989c). The seasonal water-level profiles are usually represented by the monthly levels for a particular year or by the mean monthly levels for the period of record. However, the actual water levels for each of the Great Lakes show significant variations between years on both short-and long-term time scales. Therefore, mean monthly data often masks important information on the range and timing of deviations from the average. Such deviations provide for a larger area of wetlands, extended over a larger range of elevation contours, than could be calculated from mean water-level data.

Figures B-3-19 through B-3-23 provide, for each Great Lake and for Lake St. Clair, the single monthly maximum and minimum levels, levels which were exceeded 10 and 90 percent of the time, and the median monthly level. The minimum and maximum levels indicate the absolute range during the period of record. The individual profiles from "exceeded 10 and 90 percent of the time" and the vertical distance between those profiles are very uniform around the median for all Lakes except Ontario. The Ontario data shows a tendency for lower levels from April through December.

The data presented in Figures B-3-19 through B-3-23 can be viewed as a set of water-level related factors which are important to wetlands. For the unregulated Lakes (Michigan, Huron, St. Clair, and Erie), the range between the "exceeded 10 and 90 percent of the time" levels should be recognized as a minimum amount of water-level fluctuation which is essential to maintaining the current conditions which control the occurrence and extent of wetlands. Further data refinement may indicate that the needed range of fluctuation is better represented by boundaries nearer to the historical maximum and minimum.

The profile for each lake, represented by the median level, suggests the seasonal timing which has supported the recorded wetland communities. The data in Figures B-3-19 through B-3-23 further indicate that wetland plants which need to go through sexual reproduction will do better in Lake Ontario than in the other Lakes. Only Lake Ontario levels decline early enough in the summer to allow these plants to complete their growth and maturation. This condition preceded the regulation of Lake Ontario water levels and has been largely unaffected by regulation (although the amplitude of the fluctuations has been dampened).

During the January Wetlands Workshop (International Joint Commission Functional Group 2, 1989c), participants concurred that a generic set of water-level profile characteristics, including the following, could be

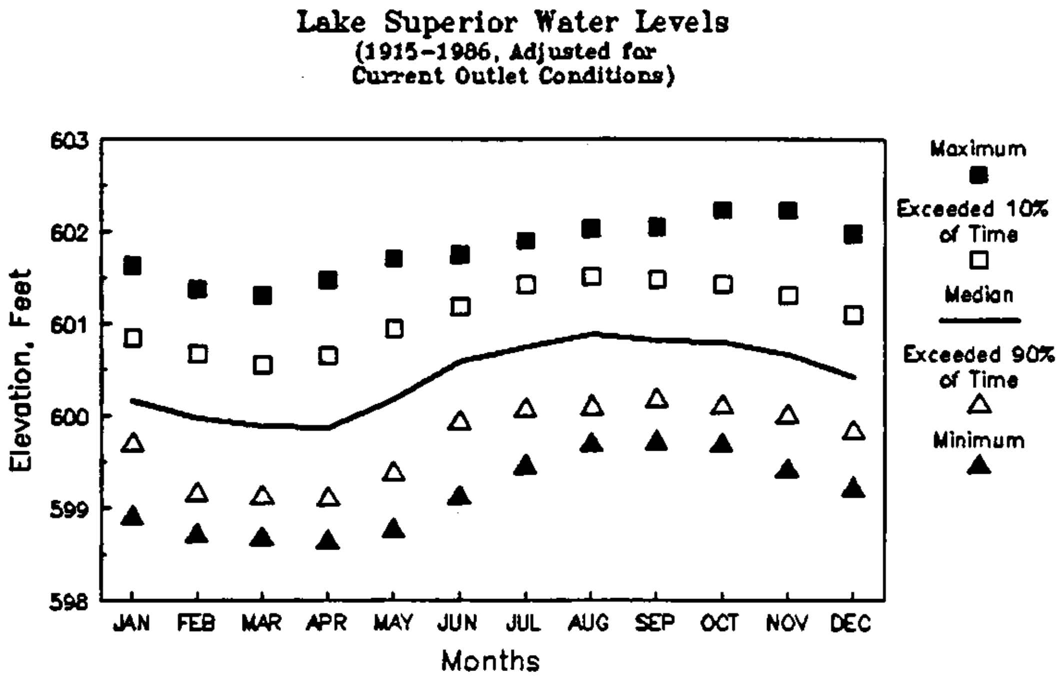


FIGURE B-3-19: LAKE SUPERIOR WATER LEVELS, PRESENTED AS THE MONTHLY 1915-86 MEDIAN LEVELS, THE MAXIMUM AND MINIMUM AND THOSE EXCEEDED 10 OR 90% OF THE TIME

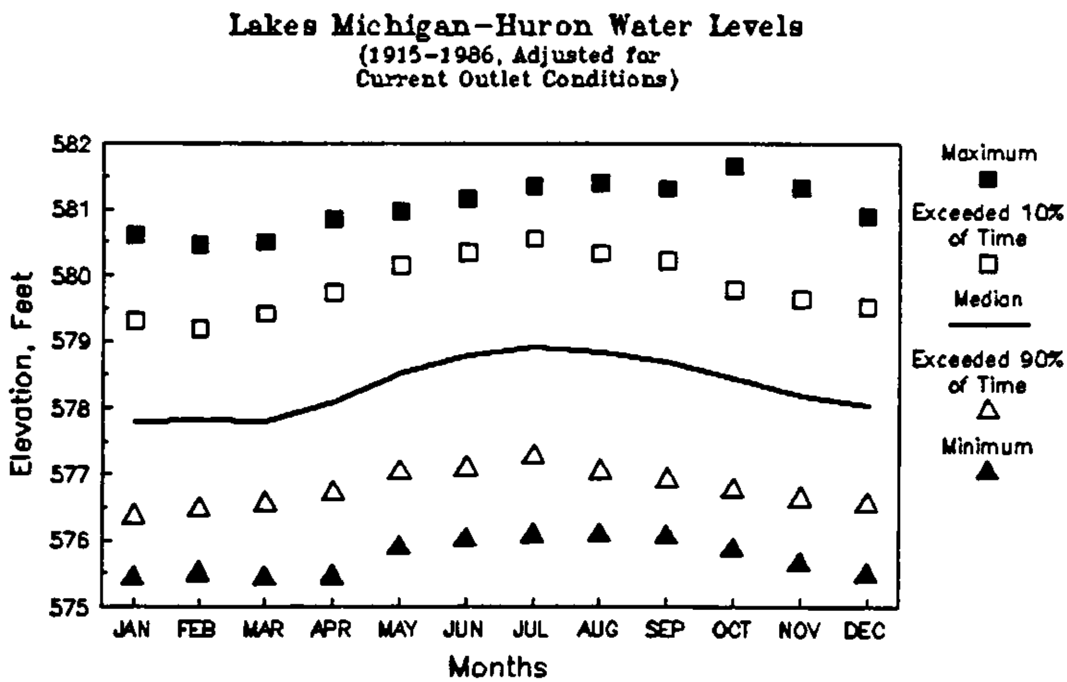


FIGURE B-3-20: LAKES MICHIGAN-HURON WATER LEVELS, PRESENTED AS THE MONTHLY 1915-86 MEDIAN LEVELS, THE MAXIMUM AND MINIMUM AND THOSE EXCEEDED 10 OR 90% OF THE TIME

International Joint Commission Functional Group 2, 1989c

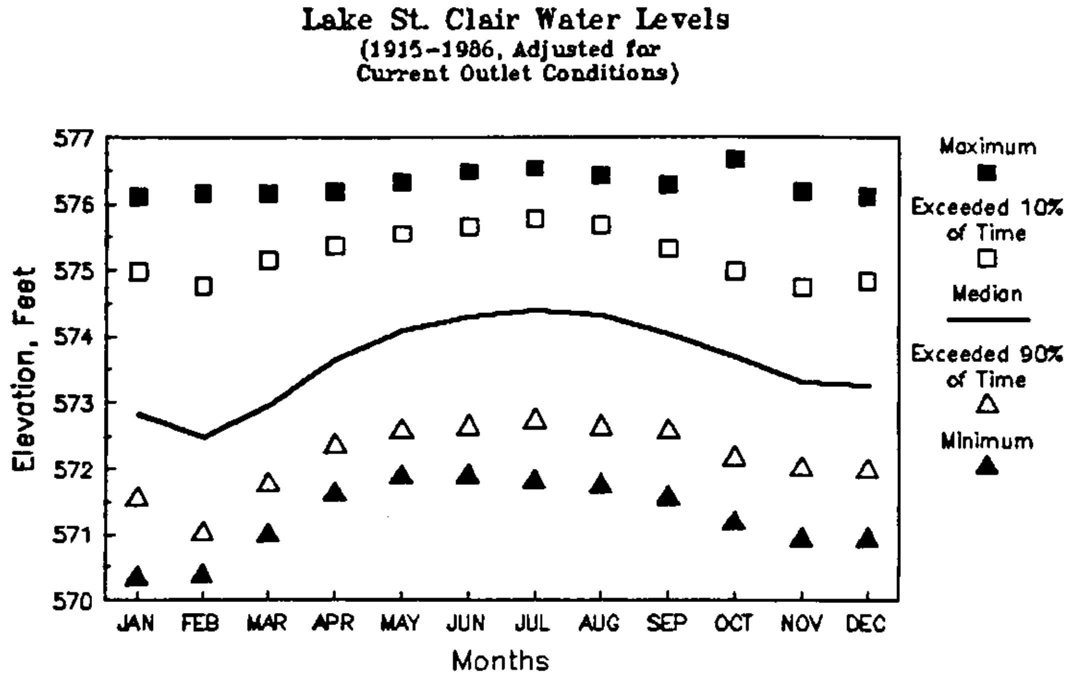


FIGURE B-3-21: LAKE ST. CLAIR WATER LEVELS, PRESENTED AS THE MONTHLY 1915-86 MEDIAN LEVELS, THE MAXIMUM AND MINIMUM AND THOSE EXCEEDED 10 OR 90% OF THE TIME

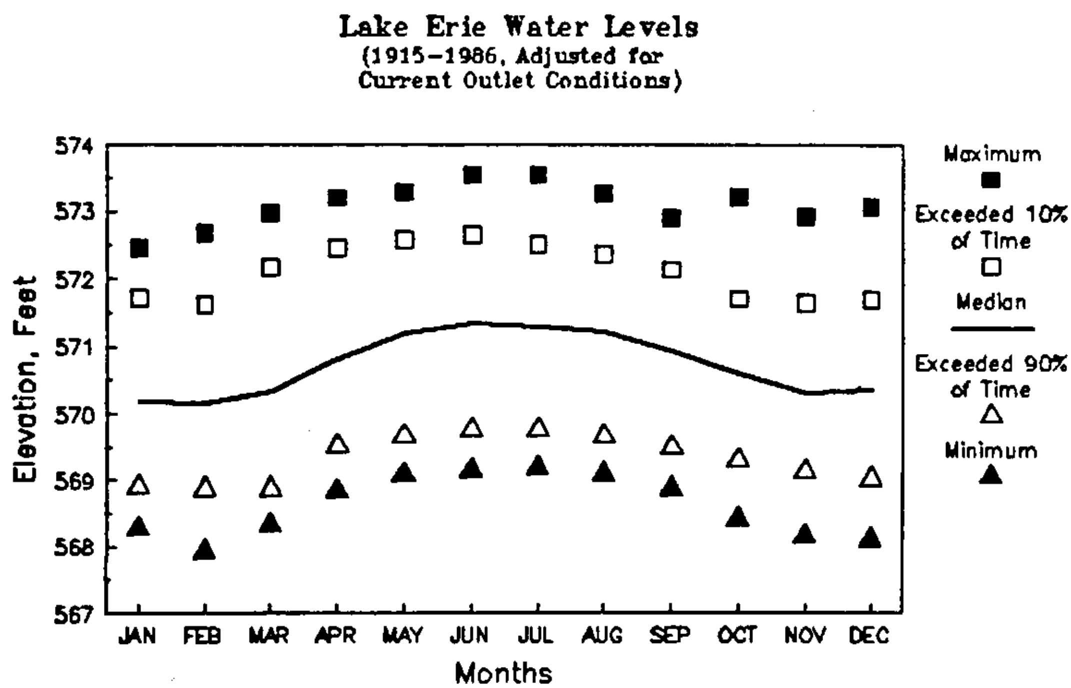


FIGURE B-3-22: LAKE ERIE WATER LEVELS, PRESENTED AS THE MONTHLY 1915-86 MEDIAN LEVELS, THE MAXIMUM AND MINIMUM AND THOSE EXCEEDED 10 OR 90% OF THE TIME

Source: International Joint Commission Functional Group 2, 1989c

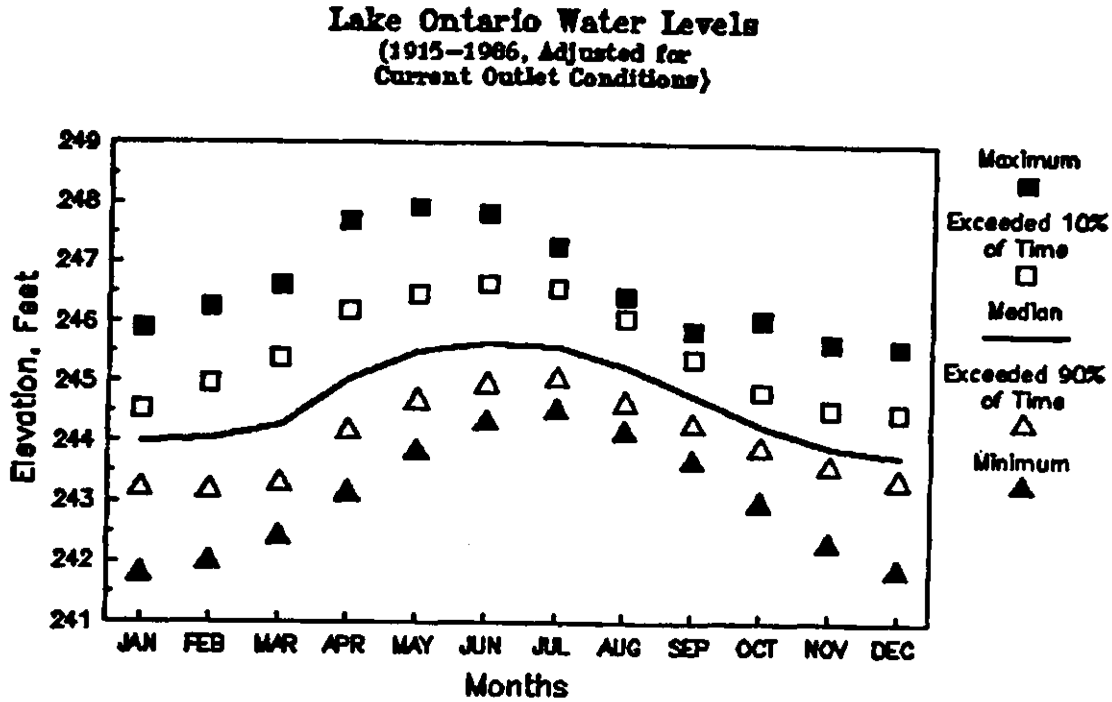


FIGURE B-3-23: LAKE ONTARIO WATER LEVELS, PRESENTED AS THE MONTHLY 1915-86 MEDIAN LEVELS, THE MAXIMUM AND MINIMUM AND THOSE EXCEEDED 10 OR 90% OF THE TIME

Source: International Joint Commission Functional Group 2, 1989c identified for all of the Lakes:

- o **Seasonality** - This is described by the within-year shape of the recorded water-level curve. Spring or early-summer highs and mid-summer lowering have a positive influence on wetlands; mid - to late-summer highs have a negative influence.

- o **Amplitude** - A decrease in the range of fluctuations would have system-wide impacts on plant species diversity. In general, scrub-shrub, Typha, rooted aquatics, and exotics would increase, and the number of plant species, the vegetation types, and the smaller and rarer species would decrease.

- o **Frequency of variability** - This includes the rate of change, timing, and duration, and is of great importance. The conditions of benefit to wetlands have not been defined in detail by numerical parameters. The length of the significant time period for variability is 10 to 30 years.

3.4 WATER LEVELS, FLOWS AND AQUATIC HABITATS

The effects of water quantity on water quality and fishery resources has not been rigorously investigated in the Great Lakes, but has been discussed in general terms as part of previous references and special studies through the International Joint Commission. Especially pertinent summaries were completed on water quality (Morgan and Sonzogni, 1980) and fishery resources impacts (International Lake Erie Regulation Study Board, 1981). As part of this study, literature reviews were conducted to update information on water quantity effects on Great Lakes water quality (Manny, 1989), Great Lakes fish reproduction (Hatch and Potter, 1989), and water quality and fisheries ecology in the Great Lakes connecting channels (Edsall and Cleland, 1989). In comparison to the previous reviews, more information is now available on the toxic contamination issue in the Great Lakes and on environmental conditions in the connecting channels. Overall conclusions remain the same, however, as water quantity changes and fluctuations have a relatively minor effect on water quality and fishery resources, relative to other factors.

The aquatic ecosystem is generally less susceptible to adverse effects of water-level fluctuations than are wetland habitats. Within the aquatic medium, mobile organisms are able to shift their horizontal and vertical distribution in response to water-level changes. In fact, the flora and fauna in the Great Lakes developed under a regime of fluctuating water levels following the retreat of Pleistocene glaciation. These fluctuations vary greatly in both period and amplitude. Short-term fluctuations (seiches) are measured in hours and days and amplitudes of as much as 2 m in Lake Erie and 3 m in Lake Michigan have been observed. Annual variations from winter low to summer high water level are 0.3 m in Lakes Superior, Michigan and Huron; 0.5 m in Lake Erie; and 0.6-0.8 m in Lake Ontario. Longer-term fluctuations with amplitudes of about 0.5 to 2.0 m have occurred every 10-15 years over the past 100 years.

The mean range of historical low and high water levels is plus or minus 1 m in comparison with the 1955 mean datum. As noted above, storm-induced short-term fluctuations can be considerably greater than long-term fluctuations due to weather cycles. The effects of violent storms, which can occur every year in the Great Lakes, particularly in the fall, may have more impact on water quality and habitat than longer-term fluctuations. The effects of storms, however, have received little attention because of the difficulty in studying the Great Lakes during and immediately following a storm event.

Any proposed measures to control water-level fluctuations must view the Great Lakes as a basinwide system. The connecting channels, for example, are an integral part of the Great Lakes. Substantially increased control in one lake will necessitate major fluctuations in levels and flows in the connecting channel outlet of that lake.

Within the range of historical low and high water levels in the Great Lakes (i.e., the 100-year minimum and maximum), it can be stated that the aquatic ecosystem is more adversely affected by extreme low in comparison with extreme high water levels. In fact, some beneficial aspects of high water levels on the aquatic ecosystem have been noted. Moreover, fluctuations are generally viewed as beneficial by promoting biological and habitat diversity and enhancing productivity. Available information indicates that the aquatic ecosystem in the Great Lakes has exhibited considerable resiliency and adaptability to water-level changes and fluctuations.

Effects of water levels on water quality and fisheries resources are treated in subsections below. In reality, it is not possible to treat them independently because of natural interrelationships. Some overlap has been purposefully retained where such interrelationships required emphasis.

WATER QUALITY

In general, changes in Great Lakes water quality have been attributed mostly to watershed perturbations (e.g., eutrophication, toxic and microbial contamination, changes in land use), not fluctuations in water levels. Measures designed to compress the range of water-level fluctuations would likely have little impact on water quality. Fluctuating water levels of plus or minus 1 m will have little effect on water quality, but sustained highs or lows within this range would influence water quality changes. Sustained high water levels will benefit water quality, increasing the oxygen in bottom waters of central Lake Erie, diluting waste discharges, and reducing the need for dredging to maintain navigation in nearshore and connecting-channel areas. On the other hand, sustained high levels will degrade water quality by increasing non-point runoff of contaminants and sediment, flooding vegetated shorelines, interfering with septic system performance, and stimulating methylation of toxic heavy metals in nearshore areas. Sustained low water levels will not benefit water quality. Low levels will degrade water quality by increasing anoxia in bottom waters of central Lake Erie, concentrating waste discharges, increasing the need for dredging to maintain navigation, resuspending fine sediments laden with toxic substances, and increasing sewage treatment costs. A more detailed summary of these impacts on water quality is found below.

High water levels will benefit water quality by reducing the temperature, increasing the dissolved oxygen content, and increasing the volume of hypolimnetic waters in central Lake Erie and shallow embayments. Benefits include creation of summer refuges for coldwater fishes, and cessation of phosphorus and toxic substance release from the sediments in these bottom waters. High water levels may also benefit water quality by diluting waste discharges at point sources, but these benefits may be offset by increased loadings of contaminants from non-point sources. High water levels would be detrimental to water quality by increasing land-use runoff of nutrients, toxic contaminants, and sediment and by increasing shoreline erosion in some areas.

Low water levels will reduce water quality throughout the Great Lakes, particularly in harbors, connecting channels, and shallow embayments, by reducing the volume of water available to dilute waste discharges, increasing water temperature and turbidity, and decreasing available dissolved oxygen. These impacts are alleviated by fluctuating or high water levels. Low water levels will require increased dredging for maintenance of access and shipping channels in harbors and river mouths, many of which are IJC-designated Areas of Concern that are polluted with contaminated sediments unsafe for open-lake disposal. Lower water levels will also require increased dredging in the Great Lakes connecting channels (GLCC), which will in turn lower water levels in wetlands adjacent to the channels, with attendant adverse impacts on biota. Dredging at the head of a channel will also contribute to the permanent lowering of water levels in upstream areas, including the Great Lakes proper, if the dredged channel is not equipped with flow-control devices. Dredging of GLCC will increase the availability of contaminants in sediments (in-place pollutants) to biota in downstream areas.

Primary and secondary production cycles in the Upper Great Lakes Connecting Channels (UGLCC) are linked to cyclic, seasonal changes in water levels during which aquatic plants alternately trap and release minerals,nutrients, and organic matter in littoral areas and wetlands. Disruption of water-level fluctuations would reduce nutrient and energy transport to offshore waters, thus reducing secondary production and probably also subsequently limiting fish production in offshore habitats.

Lower water levels in Great Lakes connecting channels (GLCC) promotes diking, draining, and filling of wetlands and submerged bottom lands and conversion to agriculture or other purposes inconsistent with fish and wildlife production; return to higher water levels renders these converted lands unusable, does not restore fish and wildlife production, and may result in degraded water quality due to inundation of sewage treatment systems and soils contaminated with toxic substances, and erosion of filled shorelines. Leaching of contaminated groundwater into GLCC will be accelerated at low water levels, thus increasing the exposure of aquatic habitat and biota to contaminants. Lower water levels will dewater and reduce the amount of "river shoulder" habitat that supports most of the submersed plant stands in the St. Clair and Detroit rivers; this habitat is important to juvenile fish.

Increases in water levels that temporarily submerge and destroy emergent wetland vegetation will reduce sediment and nutrient trapping and create anoxic soils that will release phosphorus and other nutrients into the water column and cause accelerated eutrophication of downstream areas in GLCC. Higher velocities and flows will reduce nutrient spiralling in UGLCC by transporting detritus and nutrients out of the system more quickly.

FISHERY RESOURCES AND HABITAT

Native fish species and those introduced intentionally or unintentionally have also evolved under conditions of fluctuating water levels during the reproductive stanzas of their life history. The season in which high or low water may be expected to occur, as well as the deviation from normal levels, determines the degree to which a species' reproductive capacity may be affected by water-level fluctuations. In general, spring spawners are triggered by rising water temperatures and levels and utilize shallow water reefs, nearshore littoral areas, and wetlands for spawning and nursery areas. Fall spawners, on the other hand, use either tributary streams, deeper reefs, or spawn pelagicly, although lake trout and whitefish may also spawn in quite shallow water. Shallow areas such as Black Bay and Chequamegon Bay, Lake Superior; Green Bay and the islands area of Lake Michigan; Saginaw Bay, Lake Huron; Sandusky Bay, Long Point Bay, and the western basin of Lake Erie; and the Bay of Quinte and the islands area of Lake Ontario are especially important as nursery areas for the larvae of spring spawners; these are also the areas most likely to be affected by fluctuating water levels. Fall spawners are little affected by fluctuating water levels so long as access to tributary streams is not impeded nor eggs exposed to freezing or ice scouring.

In general, high water levels will increase habitat for fish utilizing nearshore/littoral areas for spawning and/or nursery grounds, and thereby increase fish production, whereas low water levels will diminish littoral habitat and decrease fish productivity. Elevated water levels could reduce the volume of the summertime anoxic hypolimnion in the Central Basin of Lake Erie, in proportion to the volume of the oxygen-rich epilimnion, or perhaps even absolutely, providing more habitat for fish production.

Yellow perch, rainbow smelt, alewives, trout perch, walleye, and several other species each have sub-populations that utilize both the open-lake and estuarine environments for part or all of their life cycles. These differences in reproductive strategy may have a genetic basis that is linked to fluctuating water levels, and continued fluctuations are probably necessary to maintain the genetic diversity of those species.

Short-term impacts of low water levels on fish habitat of Great Lakes wetlands or other littoral zones are those associated with fish that require certain vegetation types for food, cover, or completion of life history stages. Spawning and nursery areas could be rapidly reduced and even dewatered, causing heavy mortalities of eggs or fry. Persistent low flows and elevated water temperatures in streams tributary to the Great Lakes would probably reduce spawning and nursery habitats for anadromous species, such as Pacific and Atlantic salmon, and steelhead and brown trout. Dropping water levels in embayments and shallow basins (e.g. western Lake Erie) will increase water temperatures, reduce oxygen levels, and increase contaminant uptake, all negative impacts on many valuable species of fish. At lower water levels, more dredging would be required to deepen shipping channels, releasing more chemicals, possibly deleterious to fish, from the sediments. Losses of fish at water intakes are proportional to the volume of water withdrawn from the waterbody. A reduction in water volume in the Great Lakes connecting channels in the face of fixed withdrawal rates at water intakes will increase the portion of the fish population that is lost to entrainment; conversely, higher flows and velocities will reduce the portion of the population that is entrained.

Fish larvae that migrate passively through GLCC will proceed more slowly at lower flow velocities and the period of time that they will be vulnerable to entrainment will increase proportionally; exposure to degraded habitats and stressors or mortality agents will also be increased by extended residence times. Higher water levels will produce higher water velocities and flows in GLCC, which in turn will more rapidly dilute and flush out wastes added to the channels, thus helping to maintain and improve the quality of the fish habitat in the channels.

3.5 HUMAN IMPACTS AND CONSERVATION INITIATIVES

TERRESTRIAL ENVIRONMENT

Human Impacts on the Terrestrial Environment

Throughout the development of the basin there has been an ever-increasing demand on the natural resources of the Great Lakes - St. Lawrence River system. Increasing development pressures and the rapid growth of the recreation and tourism industry over the past ten years have often been in conflict with the environment, resulting in a number of impacts on the shore zone of the Great Lakes.

Perhaps the most obvious kinds of human-induced impacts are those that occur because of construction in the coastal zone. Due to human "need" or desire to be near the water, many sensitive coastal areas have been turned into beachfront cottages and urban areas. Dunes have been bulldozed to provide an unobstructed view of the water. Vegetation that is critical to the establishment of these dunes and to the stabilization of bluff areas has been removed or destroyed for similar reasons. In both cases this can lead to accelerated erosion. Those dunes that do exist are often subject to trampling by foot traffic or recreational vehicles, leading to an acceleration in erosion of the dunes by wind action.

Construction itself takes away the natural flexibility of the nearshore profile. This is especially important with regard to fluctuating water levels because it limits the degree to which the profile can adjust to high or low lake levels. For example, during the high water period of 1985-1986, beaches were "lost" because homes and shore protection structures did not allow room for the beach to re-adjust. As a result, these structures suffered damage during storm activity. If the beach had room to adjust, then these homes would not have been damaged. Studies of other impacts of shore protection structures on beaches have been conducted, a number of which are summarized in Davidson-Arnott et al., (1989) and International Joint Commission Functional Group 2 (1989a).

Another obvious human impact is the effect of shore protection structures on the shore environment (Davidson-Arnott et al., 1989). Seawall construction in many places actually increases the erosion rate, as increased scour due to wave reflection takes place in front of the wall. Groynes and other shore-perpendicular structures interfere with the natural transport of sand along the shore and can cause increased erosion downdrift of their location. There are also many aesthetic problems with shore protection. Many private and some publicly constructed structures are unsightly and in many cases restrict public and private access to and from the water.

Public access is a critical issue. Because of the large amount of private ownership along the shoreline and increasing development pressures, the amount of land left available for public access is limited. With the growing demand of the recreation and tourism industry throughout the Basin, pressures on those areas already reserved for public access, such as National or State or Provincial Parks, is increasing, which in turn may contribute to the degradation of these natural areas.

There are also a number of indirect human impacts on the terrestrial zone. Increasing development in coastal areas will put a greater demand on the resources of the lakes (e.g. consumptive use, diversion of water to inland areas) and can increase the potential for pollution of these areas. This may detract aesthetically from natural areas if garbage is dumped, carried by the wind or carried by the water. Septic tanks may leak, or they may be damaged or overloaded by storm activity, creating the potential for local water quality problems. Waves from ship and recreational boating traffic may cause accelerated erosion in confined areas, including the connecting channels. Human-influenced water-level changes (through diversions, lake-level regulation, increased consumptive use, etc.) may also impact some shore environments.

Conservation Initiatives

A number of steps have been, or are being, taken to limit human impacts on the shores of the Great Lakes and connecting channels. Both the Province of Ontario and a number of states, notably Michigan, have recently undertaken a number of shoreline management initiatives to help protect the coastal zone. For example, the Province of Ontario, through its Shoreline Management Review Committee (1986) and the Ontario Shoreline Management Advisory Council (1988), has made a number of recommendations regarding shoreline management, including naming Ontario Conservation Authorities as the lead implementing agency for shore management. Other recommendations suggest improvement in shore protection and shoreline development regulations, as well as programs that will assist owners of current structures located in hazard areas. Similar recommendations and guidelines exist in the United States, for example, under the Coastal Zone Management Act (United States Congress, 1972).

In other cases, significant habitats (both terrestrial and wetland) are being acquired by public agencies and either left in, or reverted back to, their natural state. Others are being declared as significant natural areas, with worldwide importance. For example, Long Point on Lake Erie has recently been declared as a United Nations Biosphere Reserve.

While not without problems, programs and initiatives like these need to be considered for implementation throughout the entire Great Lakes - St. Lawrence River basin. They are crucial for the maintenance and preservation of the terrestrial environment and to the creation of a suitable balance between public, private and municipal land use. This balance will ensure that the coastal zone is used in such a manner that all can benefit from its presence, and so that it will be preserved for generations to come.

WETLAND ENVIRONMENT

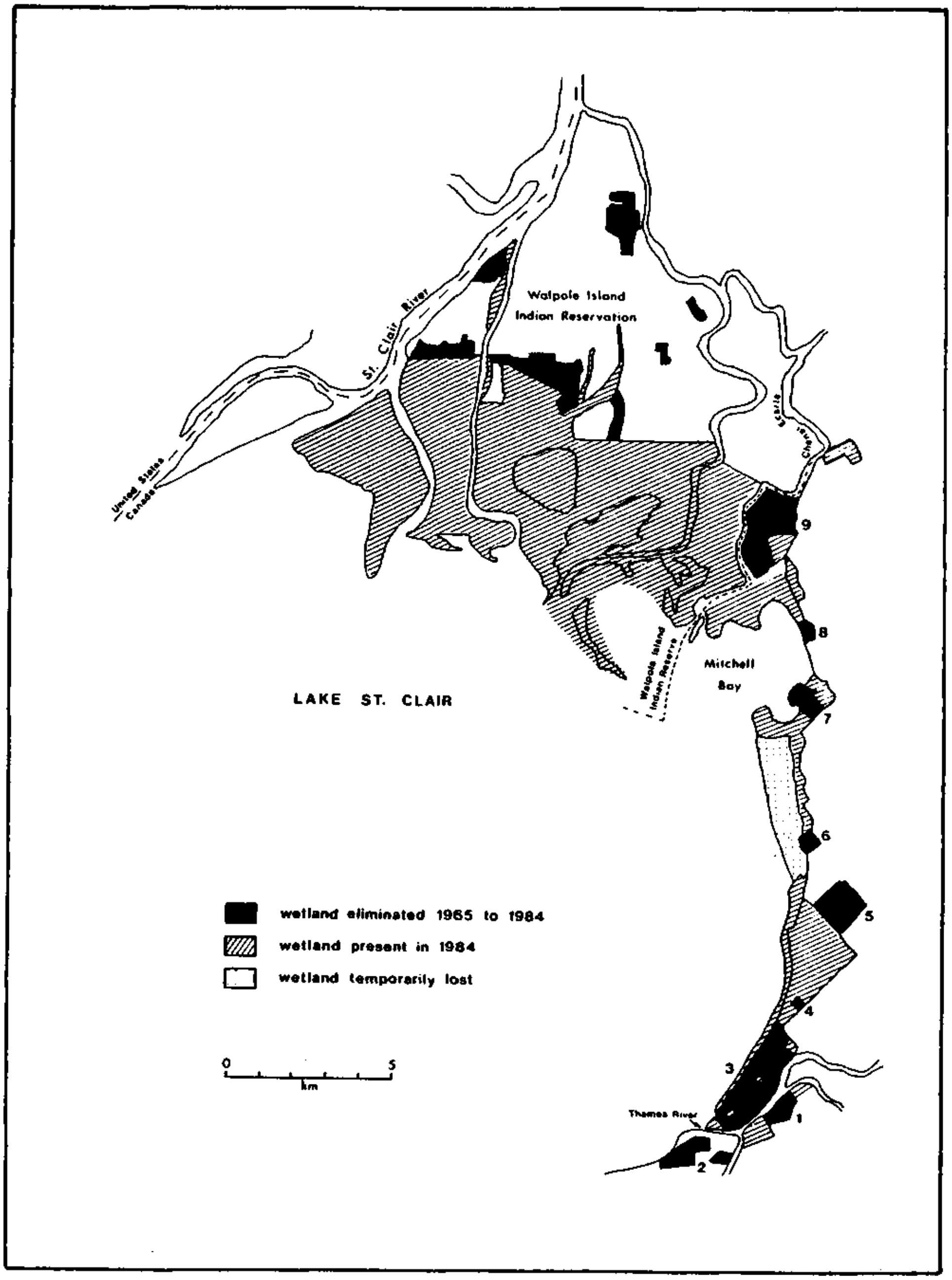
Human Impacts on Wetlands: Alterations and Losses

In recent years, there has been an increasing awareness of the resource value of our coastal wetlands and the urgent need to protect and conserve these ecosystems. The wetlands of the Great Lakes have been greatly altered by natural processes and cultural practices. The impacts to coastal wetlands in the Great Lakes region have become a subject of particular concern for the emerging coastal management programs in the eight states and the two provinces bordering the Great Lakes - St. Lawrence system.

Generic stresses on Great Lakes wetlands that impact their functions can be compared to the various functions discussed for Great Lakes wetlands. In essence, the most frequently encountered stresses on Great Lakes coastal wetlands are: filling/morphometric alteration and dredging, which affect both physical and biological functions of wetlands; water-level changes (either human-caused or natural), which certainly affect hydrologic functions and to some degree biological functions; discharges of pollutants and contaminants, which are an immediate stress on water quality and secondly on biological functions; harvesting activity, which may affect biological functions; and non-consumptive use disturbance, which may affect sensitive species as well as other human uses.

Recent historic losses of wetlands in the Great Lakes basin have been estimated to be 8,100 ha/year (Great Lakes Basin Commission, 1981) with approximately 50% of the original wetlands having been lost (United States Fish and Wildlife Service, 1988). A number of studies have documented the loss or alteration of coastal wetlands in the Great Lakes. McCullough (1981) and Whillans (1982) commented on the Canadian Lake Ontario shoreline, where urbanization has played a large part in the loss/degradation of wetlands. McCullough (1985) documented the destruction of 30% of the eastern shore Lake St. Clair wetlands from 1965 to 1984, due primarily to drainage for agriculture (Figure B-3-24). Use of the remaining wetlands by true marsh-dwelling ducks declined dramatically during that same time period. Herdendorf et al., (1986) discussed human impacts on the U.S. wetlands in Lake St. Clair through agricultural, recreational and urban development.

FIGURE B-3-24: WETLAND LOSSES AT LAKE ST. CLAIR, 1965 TO 1984



Source: McCullough, 1985

Selected data from the Ecological Profile series are also presented in Figures B-3-25 and B-3-26. Long-term declines in both the St. Clair River/Lake St. Clair/Detroit River system and the Western Lake Erie wetlands are apparent.

Herdendorf et al., (1986) list the adverse cultural effects of most concern to Great Lakes coastal wetlands: wetland loss; fragmentation, diking, and loss of hydrologic connectivity; and changes in the environmental gradient and plant communities. Further, Herdendorf et al.,(1986) note that the loss of coastal wetlands along the Michigan side of Lake St. Clair has resulted in a loss of wetland functions and values. For example, public drains installed to improve runoff now occupy former creek channels, which no longer benefit from the flood water storage, sediment trapping, and nutrient uptake afforded by the natural wetlands. Nor do the remaining wetlands along the river mouth and shorelines, which have been reduced in size, partially developed (especially on the lakeward side) and otherwise impacted, have the fish and wildlife value they once had.

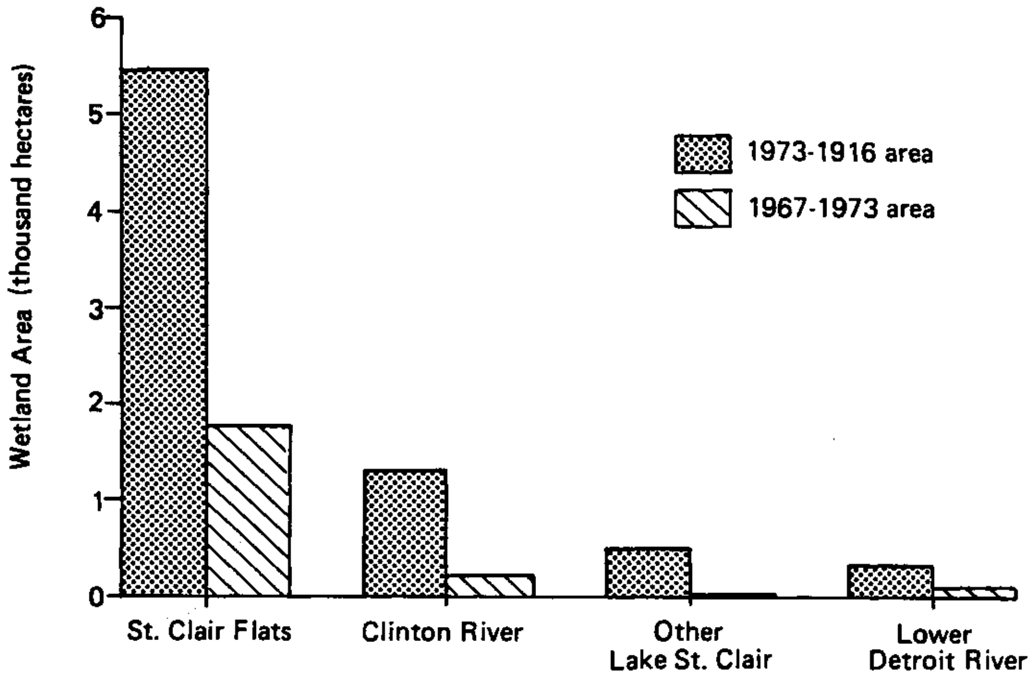
Current coastal development not only results in fragmentation and loss of hydrologic connectivity, but also frequently is associated with the loss of upper plant communities (Jaworski and Raphael, 1976). Therefore, most of these extant wetlands consist of just cattail and submersed aquatic communities, rather than a complete wetland community continuum. Changes in water levels in the Great Lakes would, then, result in the loss of the current functions in most wetlands as opposed to the shift of this function laterally in accord with the vegetation movements. In contrast, as exemplified by Dickinson Island, wetlands that are connected directly to Lake St. Clair and exhibit a full environmental gradient, tend to experience lateral shifts in function and values. Furthermore, they are maintained at little or no cost to the public.

Small, isolated wetlands near developments, such as suburban housing and marinas, exhibit proximity and off-site impacts. Proximity impacts include ambient noise levels as well as human and pet intrusions. Off-site effects center on nutrient and sediment loading resulting from wind and water transport mechanisms. If the extant parcel of wetland is zoned for residential or some other intensive use, there are pressures for filling and development. Fire, as a disturbance, seems to be limited to cattail and sedge marshes, such as those on Dickinson Island (Jaworski et al., 1979).

Coastal wetlands in the Great Lakes are multi-functional because these environments are part of both the uplands and the open-water ecosystems. It is the interface with the Great Lakes that multiplies the wetland functions and contributes to the "open system" dynamics. Streams and coastal waterways enhance the ecosystem connectively, while obstacles such as earthen berms and dikes result in coastal wetland fragmentation and loss of function. Functional loss then, can result from both bank-derived and lake-derived forces.

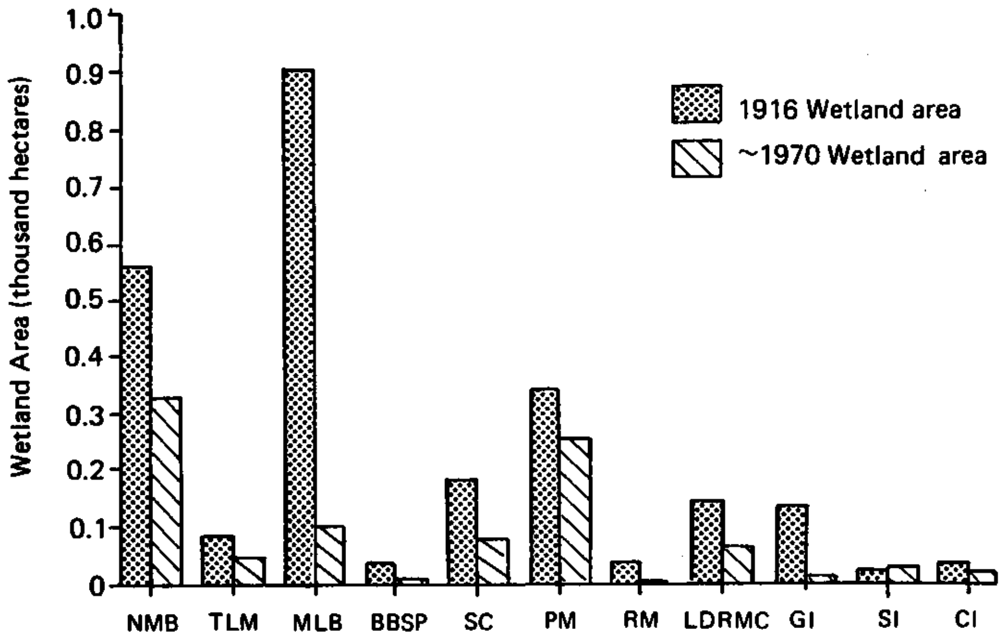
At present, there is no indication that without intervention the trends in coastal wetland destruction and degradation will change.

FIGURE B-3-25: HISTORICAL WETLAND LOSSES IN MICHIGAN, 1873-1973 FOR LAKE ST. CLAIR AND 1916 TO 1967-1973 FOR LOWER DETROIT RIVER FOR SELECTED WETLANDS



Data Source: Jaworski and Raphael 1976, 1978

FIGURE B-3-26: COMPARISON OF WETLAND AREA IN WESTERN LAKE ERIE (MICHIGAN ONLY) BETWEEN 1916 AND 1967-1973



NMB - North Maumee Bay, TLM - Toledo Beach Marsh, MLB - Monroe/La Plaisance Bay, BBSP - Brest Bay/Stony Point, SC - Swan Creek, PM - Point Mouillee, RM- Rockwood Marsh, LDRMC - Lower Detroit River and Marsh Creek, GI - Grosse Isle, SI - Stony Island, CI - Celeron Island

Data Source: Jaworski and Raphael, 1978

Conservation Initiatives

Under the Migratory Birds Convention Act and Regulations, the Canadian Wildlife Service (CWS) of Environment Canada is responsible for the management of most migratory birds, and the Canada Wildlife Act of 1973 gave the federal government authority to acquire and manage habitats for migratory birds and other wildlife. Several National Wildlife Areas have been established on the Great Lakes that protect and manage some 4000 ha of nationally important Great Lakes shoreline wetlands, although construction of dikes has isolated many of these wetlands and reduced their functional value. Internationally, Canada has emphasized its support for wetlands protection through the designation of several Great Lakes wetlands under the RAMSAR Convention (The Convention of the Conservation of Wetlands of International Importance).

A wetland evaluation system was developed by Environment Canada and the Wildlife Branch of the Ontario Ministry of Natural Resources (Environment Canada and Ontario Ministry of Natural Resources, 1984). This method has been used to assess 1,982 wetlands totalling 390,000 hectares. Virtually all of southern Ontario's most significant wetlands have now been evaluated, including 160 coastal wetlands and wetland complexes on the Great Lakes and connecting channels (Glooschenko, et al., 1989).

To help stem the continuing loss of Ontario's wetlands, the provincial government has developed and implemented a wetlands program that has to date focused on: 1) wetland evaluation; 2) a wetlands policy for land use planning; and, 3) a tax rebate to encourage wetland protection by private landowners.

The 1983 Planning Act of Ontario states that the "protection of the natural environment" and "features of significant natural...interest" are "matters of provincial interest". This is the authority under which the 1988 wetlands policy statement has been released for public comment. Municipalities as well as provincial government ministries, agencies, boards and commissions are "to have regard to policy statements".

The draft policy states that all municipalities, planning boards and resource management agencies should identify and protect provincially significant Class I and II wetlands within their jurisdictions in the context of local, regional and provincial land use planning objectives.

The recently announced Ontario Conservation Land Tax Reduction Program will provide up to one hundred percent tax rebate to landowners of Classes 1-3 wetlands as well as certain other heritage lands. To be eligible, landowners must agree to long-term maintenance of the land and not to carry out activities that would have a negative impact on its values. These measures, along with enlightened public support, may begin to reverse the pressures on the remaining Ontario coastal wetlands.

Within the United States, wetlands are managed through a mixture of federal, state, and local initiatives, with public input from citizens and interest groups. The federal government's primary tool for protecting wetlands is Section 404 of the Clean Water Act Amendments of 1977. In accordance with Section 404, the U.S. Army Corps of Engineers (Corps) regulates the discharge of dredged or fill materials in "all waters of the United States". Under Section 404, the Corps considers the advice of the U.S. Environmental Protection Agency (EPA), the U.S. Fish and Wildlife Service, other agencies and the public when deciding whether to issue or deny a permit.

One state in the Great Lakes basin (Michigan) has assumed administration of the Section 404 program. Most, but not all, wetland permit actions are handled by the Department of Natural Resources in Michigan. The other states in the basin also have wetland management laws that afford varying levels of protection to wetlands. Each state operates independently according to its own laws.

Federal agencies are obliged to comply with the Federal Wetlands Executive Order 11990 and Federal Floodplains Executive Order 11988, which direct that wetland and floodplain impacts should be avoided or minimized to the extent possible. The Order requires specific procedures for agency activities related to: 1) acquiring, managing and disposing of federal lands and facilities; 2) providing federally undertaken, financed or assisted construction and improvements; and, 3) conducting federal activities related to land use.

The conservation provisions of the 1985 Food Security Act (Farm Bill) are encouraging the preservation of a vast acreage of agricultural wetlands and highly erodible croplands. The Swampbuster provision eliminates price supports for individuals who convert wetlands to produce agricultural commodities. In addition, the eight states in the Great Lakes basin have enrolled a total of over 1.3 million hectares in the first seven Conservation Reserve Program (CRP) sign-up periods, over 11.6% of the national total. Most of this area is not near the Great Lakes shoreline. Areas continue to be enrolled, as this program enjoys strong support.

The North American Waterfowl Management Plan (Plan) is a joint Canadian - U.S. - Mexican effort and offers many opportunities for wetland protection and enhancement in the Great Lakes Basin. The Lower Great Lakes-St. Lawrence Joint Venture (habitat area of major concern under the Plan) has among its goals to acquire an additional 4,000 hectares of black duck migration and wintering habitat and 24,000 hectares of breeding and migration habitat for black ducks and mallards. Ongoing losses and alteration of shore habitat were the reasons for setting these goals. Should water-level decisions be made that would reduce existing wetland resources, (i.e. stabilization of levels) the binational agreement would likely fall short of these goals.

Some solutions to the various environmental stresses that cause losses and alterations of wetlands have to be implemented at the lowest level of government. Advice, advocacy, data, education, funding and lobbying offered by any group to local clientele may facilitate a solution. Successful local management ordinances are often those with: 1) an underpinning of sound technical data, a comprehensive plan, and evenhanded administration; and 2) the evolution of a partnership between the Federal/State/Province, the local community, and its citizens in developing and implementing the ordinance.

Despite the number of significant wetland protection initiatives over the past

20 years, substantial losses (on the order of 5% per year) are still occurring. Among the reasons for this are varying levels of commitment to wetlands protection by the United States and the Province of Ontario, inconsistent administration of the Section 404 program by the U.S. Army Corps of Engineers, and slow development of protection policy (the Ontario policy for example, is still in draft form). Despite heightened public awareness, there are still many who view a wetland as a future agricultural field, shopping mall, or housing development. There are hopeful signs however, among them the positive reception given by the Bush administration in the U.S. to the "no net loss" recommendations of the National Wetlands Policy Forum, and the draft "no net loss" policy of the Canadian Department of Fisheries and Oceans.

AQUATIC ENVIRONMENT

Human Impacts on The Aquatic Environment

Land use alterations in the Great Lakes - St. Lawrence River basin, use of the Lakes as waste receptacles, and invasion of exotic species through navigation structures have had a greater overall impact on water quality and fishery resources than have changes in water levels and flows, on which human influence has been minimal.

Perhaps the lowest point in the environmental health of the Great Lakes occurred in the 1950s and 1960s. Eutrophication, toxic contaminants such as DDT and mercury, intensive overfishing, and introduction, or invasion, of exotic fish species had disrupted the ecological balance of the Lakes. The consequences of eutrophication, caused primarily by phosphorus loadings from municipal sources, were excessive algae and weed growths, beaches fouled with putrefying organic matter, and summertime oxygen depletion in rivers, embayments and the central basin of Lake Erie. While substantial government investment in sewage treatment and limitations on phosphorous content in detergents in the 1970s have largely controlled eutrophication, another contaminant issue has emerged.

The chemical industry underwent massive expansion in the 1940s, 1950s and 1960s. In the rush to develop and manufacture products for industrial, agricultural, and household use, thousands of synthetic chemicals were created and many of them have been detected in Great Lakes water, sediment and biota. Except for a few well known contaminants, most of these chemicals were rarely, if ever, measured and their fate and effects on fish and other organisms were largely ignored. The 1978 Great Lakes Water Quality Agreement and its revised protocols of 1987 (International Joint Commission, 1988) specifically address toxic contaminants, but these substances are perhaps more pervasive and difficult to address than any previous form of contamination.

There are 362 contaminants with known or suspected toxic properties that have been detected in the Great Lakes. These substances enter the Lakes through direct discharges, spills, urban and agricultural runoff, and atmospheric deposition. Many of them are persistent and bioaccumulate readily in the food chain, reaching sufficiently high levels in fish and fish-eating birds and mammals to cause health concerns. Some tumours in fish and reproductive dysfunction and developmental abnormalities in aquatic birds and mink have been attributed to toxic substances. Even if sources of toxic contaminants are controlled, historical releases remain as in-place pollutants in sediments for extensive periods of time, and can be available for cycling through the food chain.

Meanwhile, massive changes in the Great Lakes fishery were continuing. In the 1950s, the parasitic sea lamprey had spread throughout the Great Lakes, devastating commercially-valuable fish stocks such as the lake trout and lake whitefish. The Great Lakes Fishery Convention of 1955 was signed by the United States and Canada in an effort to control sea lamprey populations and rehabilitate native fish stocks. Following some measure of sea lamprey control, Pacific salmon were stocked to control populations of forage fishes, especially the alewife that had invaded the Great Lakes in the same manner as the lamprey.

Today there are signs that Great Lakes water quality and fisheries are recovering from two centuries of abuse and exploitation. A significant sport fishery has developed and eutrophication has been reduced, enhancing the recreational, aesthetic and other resource values of the Great Lakes. However, rehabilitation of aquatic habitat in the connecting channels, tributary mouths, harbours and nearshore areas remains a concern, and toxic contamination represents a challenge of considerable proportions. The future of the aquatic environment of the Great Lakes - St. Lawrence River system depends largely upon land use improvements and waste management and reduction in the basin to reduce contamination and sediment impacts, and on restoration and rehabilitation of habitat.

Conservation Initiatives

Progress has been made in recent decades in pollution control but there is still a long way to go in order to achieve the objective of restoring biological integrity and environmental quality in the Great Lakes. As noted in the recently completed upper connecting channels study, the largest loadings of contaminants are still coming from point sources in the vicinity of municipal and industrial areas even though most of these discharges are regulated. A significant effort must be exerted to review and improve the multi-jurisdictional regulatory network in the Great Lakes. Similarly, there is considerable rhetoric about non-point sources of contamination and many plans have been developed, but there is currently little implementation of these plans to improve non-point pollution control. Agricultural and urban runoff, atmospheric deposition, groundwater infiltration, and elimination of combined sewer overflows need to be addressed. Fortunately, all of these requirements have been recognized by the U.S. and Canadian governments and are incorporated into the 1987 protocols of the Great Lakes Water Quality Agreement (International Joint Commission, 1988). The challenge is to translate agreements and plans into effective corrective action.

Specific attention is required for cleanup of the most polluted regions of the Great Lakes, the 42 so-called Areas of Concern. The 1987 protocols call for the development of Remedial Action Plans (RAPS) to clean up pollution and restore beneficial uses in these areas. This planning process has generated considerable excitement and hope in the Great Lakes basin through unprecedented multi-agency involvement and public participation. The challenge, again, will be to translate planning into action.

Through the RAP process and other initiatives within the Great Lakes basin, an ecosystem perspective towards Great Lakes management is emerging. Terrestrial, wetland, water quality and fisheries programs traditionally have been fragmented in the Great Lakes. Now it is being recognized that interdisciplinary cooperation is essential if we are to break the cycle of tackling one crisis after another in the Great Lakes. Ecological restoration and rehabilitation are common objectives of the International Joint Commission (IJC) and the Great Lakes Fishery Commission (GLFC). The importance of cooperation to better understand the relationships between water quality and biological community structure is being recognized. Lakewide toxic management plans and nutrient reduction plans are being developed under the auspices of IJC, while discussion on establishing fish community goals by the lake committees of the GLFC is underway.

Habitat is being recognized as the integrator where water quality and fishery resources concerns merge. Unfortunately, our understanding of aquatic habitat attributes and requirements is considerably behind that of terrestrial and wetland habitat. One of the first steps is to be able to better define aquatic habitat. A workshop on Classification and Inventory of Great Lakes Aquatic Habitats was held last year and guidelines and recommendations are currently being finalized. Meanwhile, the GLFC's Habitat Advisory Board is developing an international policy on Great Lakes habitat and is working on habitat criteria for certain fish species as well as habitat goals for each of the Great Lakes.

In spite of past problems and current concerns, perhaps the most encouraging aspect in the Great Lakes basin is an emerging sense of environmental ethics and caring for the Lakes. Our recent accomplishments in water quality and fishery management have resulted in more aesthetically-pleasing Lakes and a Great Lakes-focused recreational boom is underway. Environmental quality improvements are being translated into economic benefits estimated at 4.2 billion dollars for the recreational fishery alone. A Great Lakes constituency is growing and coalescing into a strong and unified voice, speaking out for Great Lakes protection. Strong public support is critically important for nurturing the political will for continued improvements in environmental quality.

3.6 FUTURE UNCERTAINTY

There is a good deal of uncertainty surrounding the future condition of the terrestrial, wetland and aquatic environments of the Great Lakes-St. Lawrence River system. These environments have evolved naturally over thousands of years in response to important physical and biological processes, including changes in water-level and temperature regimes, and will continue to do so. Over the past century and a half however, the nature, diversity and potential consequences of human interference with environmental processes have changed dramatically. Forest clearance, overfishing, wetland drainage, channel dredging and filling, thermal power generation and the processing and use of synthetic chemicals are a few among many human activities stressing the environment. Some human stresses threaten to alter, profoundly, and in a relatively short period of time, the distribution, extent, productivity and stability of specific environments.

This section explores possible consequences of several human stresses on terrestrial, wetland and aquatic environments of the basin. Emphasized are implications of climate change which could occur as a consequence of a doubling of atmospheric carbon dioxide. Also discussed are implications of toxic contamination and shoreline modification.

CLIMATE CHANGE

Global models of CO_2-induced climate change, notably those produced by the Goddard Institute for Space Studies (GISS) and the Geophysical Fluid Dynamics Lab (GFDL), have been used to predict change in temperature, precipitation and wind conditions in the Great Lakes basin over the next half-century. Changes in these climate parameters, in turn, can be used to project change in net water supplies in the basin, lake levels, connecting channel flows and ice cover conditions. Cohen (1986), for example, generated several scenarios of Net Basin Supply (NBS) from the GISS and GFDL models. All scenarios projected a decrease in NBS, ranging from 11.7 to 28.9%, suggesting lower levels and flows. Cohen (1986) stressed that significant uncertainty surrounds such projections, in part due to difficulty in predicting change in precipitation.

A climate scenario for the Great Lakes basin based on the GISS model (Cohen, 1986; Sanderson, 1987) is offered here as a basis for discussion. Average annual temperature in the basin is projected to increase 4.5 degrees C, 3-4 degrees in summer and 5-6 degrees in winter. These increases would be fairly uniform throughout the basin. Precipitation is projected to increase 6.5% on average across the basin, up 8% in the western and central portions and down 3-6% in the eastern portion. A 2.3% mean annual decrease in cloud cover is projected. Both evaporation and evapotranspiration would increase. Basin runoff would decrease 10.9%. A reduction in wind speed is possible, due to a reduced equator-pole temperature gradient (and reduced pressure gradients). Average ice cover on all lakes, except Erie, would be reduced to 0 percent. Ice cover on Lake Erie would be reduced from 90% to 50%.

The impact of climate change on levels and flows in the Great Lakes-St. Lawrence River system is salient to the Reference Study. Assuming an average reduction in NBS of 15%, the mean levels of Lakes Michigan-Huron and Erie could decline 59 and 44 cm, respectively. It would be expected that existing lake regulation structures on Superior and Ontario would be used to minimize reductions in mean levels on those Lakes, with implications for further reductions in downstream flows. The range between maximum and minimum monthly levels would increase marginally on Lakes Michigan-Huron and Erie. Mean flows in the St. Clair, Detroit, Niagara and St. Lawrence Rivers would decrease 15 percent, with corresponding decreases in water levels along these watercourses.

Another influence on lake levels expected to change over time is consumptive use of water for a variety of domestic, industrial and agricultural purposes. The IJC has estimated that consumptive use of Great Lakes water, presently about 170 cms, could increase to 720 cms by the year 2035 (IJC, 1985; Cohen, 1986). This estimate does not recognize any increase in consumption, primarily for irrigation, which might occur as a consequence of climate change. The combined effect of the above climate change scenario and a 550 cms increase in consumption would be a decrease in the mean levels of Lakes Michigan-Huron and Erie of 83 and 68 cm respectively (Sanderson, 1987). Flows in all connecting channels would also decrease.

IMPACTS OF CLIMATE CHANGE

Possible consequences of the above-described climate change scenario are discussed with respect to Great Lakes terrestrial, wetland and aquatic environments.

Terrestrial Environments

On bedrock shores, lower lake levels would have little impact, except in low-lying areas where reduced flooding would be expected. Storm-induced flooding would still be a problem, especially on Lake Superior, where maximum levels are not expected to decline substantially and where the absence of ice cover could render low-lying areas more vulnerable to severe winter storms. On bedrock shores composed of sedimentary rocks, lower levels would expose these formations to sub-aerial weathering processes, contributing to localized problems.

In areas of cohesive bluffs and sandy beaches, lower lake levels generally would have no impact. The rate of recession of cohesive bluffs is related to wave-induced erosion of the nearshore and only a rapid lowering of levels would effect a temporary reduction in recession. The reduction in levels projected in the above scenario is not out of scale with the range of the annual fluctuation in levels experienced historically and, importantly, would occur gradually over a number of decades. In most locations, the nearshore profile would adjust to this lowering as it occurs. Consequently, lower levels as a result of climate change would not be expected to impact on shore recession in most areas, except where bedrock or more resistant stratigraphy is encountered as the nearshore profile is lowered (Section 3.2).

Sandy beaches would also maintain a state of dynamic equilibrium with lake levels and would be expected to accommodate a gradual decline in levels. More crucial to change in beach shores is the sediment budget. If the budget is negative (more sand moving out of, than into, the local area), beaches recede; if positive, progradation or lakeward advance of the beach occurs. In locations where the sediment budget is positive, lower levels could result in wider beaches and the formation of a new foredune ridge. As discussed previously (Section 3.2), wave and sediment regimes, rather than long-term water levels, are the key factors in long-term evolution of bluff and beach shores.

While lower levels would have little impact on most shore areas, a reduction in ice cover could be of considerable consequence. Ice cover over the Lakes, as occurs over much of Lakes Erie and Michigan-Huron (and to a lesser extent the other Lakes), reduces or eliminates wave action and, consequently, wave erosion and sediment transport. Shore-fast ice, which may extend 20 m or more offshore, protects the beach and much of the nearshore area. On Lake Erie, shore-fast ice typically begins to form in early December and may not melt until April, affording three to five months of protection at a time when storms are frequent and intense.

A projected warming of 5-6 degrees C in winter would eliminate ice cover from all lakes except Erie, which would experience a significant reduction in ice cover. Undoubtedly, the protection afforded by shore-fast ice would be diminished substantially on all Lakes, with resultant increases in erosion and sediment transport. Recession of bluffs and some sandy beaches would be increased, while additional sediment supply would lead to increased progradation of some sand depositional features. Davidson-Arnott (personal communication, 1988) speculated that a 50 percent reduction in shore ice along bluff shores could increase recession rates 20-30 percent.

On the other hand, a reduction in wind speed conditions over the Lakes as a result of climate change would be expected to reduce wave energy, erosion and sediment transport. Much uncertainty surrounds the degree to which a reduction in wind speed would occur (Cohen, 1986), and from a shore processes perspective, a slight reduction in windspeed would be insignificant relative to a reduction in ice cover.

The climate change scenario described above is not expected to have a major impact on reducing shore recession in most areas and, in fact, loss of ice protection may exacerbate erosion. Inundation of some low-lying areas would be reduced. Importantly, lake levels would continue to fluctuate (a slight increase in range is projected), with implications for human encroachment lakeward.

The projected increase in temperature would likely have some longer-term implications for terrestrial biota throughout the basin. A global projection of the impact of climate change on terrestrial ecosystems (Emanuel et al., 1985) suggests a shift northward in plant communities and the faunal species dependent on these communities. The extent and significance of these potential shifts in the Great Lakes basin is presently not known.

Wetland Environments

Shore wetlands are physically, biologically and culturally significant environments. In Ontario, for example, two-thirds of the Province's endangered species depend on these wetlands (Kirkham, 1988). In both Canada and the United States, wetlands in the basin have suffered significant losses as a consequence of agricultural drainage and other human disturbances (Jaworski and Raphael, 1978; McCullough, 1981; Whillans, 1982; United States Fish and Wildlife Service, 1988). Shore wetlands will be affected by climate change directly as a consequence of increased air and water temperature and lowered water-level regime.

Patterson and Whillans (1985) summarized impacts of increased water temperature on wetlands. Warmer air and water temperature would be expected to increase the growing season and biological activity in shore wetlands. Higher rates of decay and decomposition would increase the availability of key nutrients. Winter habitat for some wildlife would be enhanced. Increased water temperature and nutrient availability, however, would result in increased biological oxygen demand (BOD) and algal growth and reduced quality of habitat for some fish species; carp and some other warm-water species would be favoured.

The impact of a lower water-level regime would differ substantially among specific types of wetland. The slight increase in range of levels projected would have a generally positive effect on areal extent of most wetland types. The projected lowering of mean levels would have minimal or no adverse impact on those wetlands open to the lake, such as open shoreline, unrestricted bay and river delta wetlands (Section 2.3), assuming suitable substrate and slope of the nearshore profile which would permit wetland plant communities to migrate lakeward in response to a lower regime (International Lake Erie Regulation Study Board, 1981). Thus, the areal extent of these types of wetlands generally would be maintained.

Lower mean levels, however, would have drastic effects on the areal extent of existing shore wetlands that are isolated physically from the lakes, for example, by barrier beaches. In these situations, lakeward migration would not be possible, and lower water in these wetlands (as a consequence of lower lake levels) would reduce substantially the extent of wetland vegetation. The fringes of such wetlands would dry out and terrestrial species would invade (International Lake Erie Regulation Study Board, 1981; Wall et al., 1986). Lower and higher forms of faunal life dependent on these wetlands would also be affected. There is potential for creation of additional wetlands, given suitable substrate and slope, but information on the extent of this process is not known.

On the lower lakes (St. Clair, Erie and Ontario) and connecting channels (St. Clair, Detroit, Niagara and St. Lawrence Rivers), some 78,700 acres (32,000 ha) of restricted riverine, lake-connected inland, and protected shore wetlands (52% of total wetland area) could be impacted by lower mean levels and flows (Section 2.3, Table B-2-1). Of this total, about 57% is naturally or artificially protected wetland, about two-thirds of which is along the United States shore. Much of this United States area is diked marsh where water levels in the wetland can be manipulated to maintain species and vegetative communities (Patterson and Whillans, 1985). Thus, the adverse impacts of lower mean levels could be mitigated to some extent.

A potential indirect effect of lower lake levels would be further agricultural, residential and other encroachment into wetland or adjacent areas. Pressure would also likely exist for further diking and human manipulation of wetlands. The cumulative effects of increased shore and wetland modification are presently largely unknown. One concern would be increasing isolation of wetland and aquatic environments, with consequent reduction in faunal access to wetlands and nutrient exchange between wetland and aquatic environments.

Aquatic Environments

The aquatic environments of the Lakes and their connecting channels would be impacted directly through increased water temperature and lower mean and minimum levels and flows.

Although temperature is an important physical factor affecting the distribution of fishes, a projected mean annual air temperature of 4.5 degrees C is not expected to extirpate fish species in the Great Lakes basin (Meisner et al., 1987). Impacts on geographical extent, numbers and productivity of specific fisheries, however, would be expected. Water temperature would increase in response to a rise in air and ground temperature, and higher increases would be expected in tributaries and small lakes in the basin than in the Great Lakes themselves.

Increased water temperature would increase the productivity of the Great Lakes fishery generally. Schlesinger and Reiger (1982) calculated that a 2 degree C increase in average air temperature would lead to a 26 percent increase in aggregate maximum sustained yield of commercially-valuable fish. This gain in productivity, however, would be due to increased production of warm-water species, while the production of lake trout, lake whitefish, northern pike and walleye in the basin would be expected to decline (Schesinger and Reiger, 1983; Meisner et al., 1987).

The distribution of fish would also be affected by increased water temperature. The geographical range of cold-water species such as lake trout and lake whitefish would be reduced, as the southern limit of these species would be shifted north. Conversely, numerous warm-water species in the basin would become more widely distributed (Meisner et al., 1987) and up to 27 new warm-water species not presently in the basin could invade (Kirkham, 1988).

Warmer temperatures of deeper Lakes throughout the year would likely reduce or eliminate fall turnover (Sanderson and Quinn, 1985). This mixing of top and bottom waters as surface waters cool, become denser and sink, is ecologically important as it transfers oxygen in surface waters to deeper waters, preventing the development of anoxic conditions. Reduced winds over the Lakes would also affect their thermal structure.

Lower water levels and flows in the Great Lakes, connecting channels and tributary streams would also impact on fish. Lower water levels would reduce the areal extent of the hypolimnion (cool bottom waters) and lower connecting channel and tributary flows could restrict access for migratory species and impair habitat. Access to some shore wetlands could also be restricted (Patterson and Whillans, 1985).

Lower levels and flows and higher water temperatures would indirectly impact fish populations by decreasing water quality (Section 3.4), particularly in shallow embayments. Disease and pests could become more stressful to some fish species under reduced water quality conditions. Any reduction in wetland area as a consequence of lower mean levels would also impact on fish and other aquatic fauna dependent on wetlands.

POLLUTION

Water quality of the Great Lakes has been a long-standing concern and the focus of almost two decades of concerted bi-national remedial effort, for example, through the Great Lakes Water Quality Agreements. Significant progress has been made in addressing cultural eutrophication, largely through improvements in municipal sewage treatment. With increased production and widespread use of synthetic organic chemicals and metals since the 1940s, toxic contaminants have emerged as a major threat to environmental quality and human health (Section 3.5). About a thousand chemicals have been identified in the water, fish and other Great Lakes resources that humans use (National Research Council and Royal Society of Canada, 1985). Many of these bioaccumulate readily, increasing in concentration in aquatic food chains, and can have a variety of serious impacts on fish, wildlife and humans. Toxic contaminants were a major focus of the 1978 Water Quality Agreement and 38 of 42 IJC Areas of Concern contain toxicants.

Toxic contamination will remain a difficult problem to solve, and one surrounded by much uncertainty. While major point sources of pollution in the basin will need to be addressed, atmospheric deposition is an important source of contamination, some of which originates far beyond the basin. The synergistic effects of chemicals in aquatic environments add a major dimension of uncertainty.

SHORELINE MODIFICATION

Physical modification of the shores and nearshores of the Great Lakes and connecting channels represents another source of uncertainty. Landfilling, wetland drainage, shoreline protection, dredging, and destruction of shoreline vegetation are some of the kinds of physical modification that continue to occur (Section 3.5). Some modifications have been the subject of study and debate (for example, Hartley, 1964; Greenwood and McGillivray, 1978; Parker and Quigley, 1980), but typically individual modifications have been deemed to have little or only minor localized impact.

Over time, however, extensive reaches of Great Lakes shoreline have been modified and little attention has been given to the cumulative effects of many, individual actions. Potential impacts include: modification of sediment budgets with concomitant alteration of patterns of shore recession and accretion; restricted access to land and water habitats for a variety of fauna; and loss of specific habitats, notably wetlands and dunes.

CLIMATE CHANGE IN PERSPECTIVE

While climate change, and an associated possible lowering of Great Lakes water levels, has captured much recent attention, it should be borne in mind that there are many human-induced changes occurring which create uncertainty as to the future state of the environment of the Great Lakes-St. Lawrence River system and the many benefits and advantages this environment provides for its inhabitants. As discussed, lower lake levels are unlikely to reduce shore recession or totally eliminate flooding. Aquatic and, particularly, wetland environments are more problematic. Some environments, and the species using them, however, are likely to be impacted more significantly by a change in temperature regime than a change in water-level regime. Moreover, the utility of some environments and environmental resources may be impacted more profoundly by pollution than by climate change. The cumulative effects of many individual modifications of shore and other environments remains an issue to be reckoned with. Clearly, in the context of the Great Lakes-St. Lawrence River basin, human use of the basin's environmental resources, and fluctuations in water levels and flows, it is simplistic to view change in levels and flows as the only, or even most significant, source of uncertainty.

3.7 SUMMARY

The life and landforms of the Great Lakes - St. Lawrence River system have evolved over thousands of years in response to numerous forces of natural and, more recently, human change. Key physical and biological processes which control the evolution and present functioning of terrestrial, wetland and aquatic environments must be more fully appreciated.

- o The shores of the Great Lakes erode, recede and accrete primarily in response to the energy exerted by wind-driven waves.
- o Shore recession varies based on exposure of the shore to wave attack, shore stratigraphy, and processes such as chemical and physical weathering, surface runoff, and ice push.
- o The long-term rate of recession for many shore types is essentially independent of water-level fluctuations, although erosion will temporarily increase or decrease as a result of higher and lower levels, respectively.
- o The concepts of littoral cell and sediment budget are useful in describing and understanding shore processes and variation in recession and accretion along many shores.
- o Flooding of low-lying shore areas is sensitive to lake-level fluctuations, most particularly to short-term, wind-induced water level increases.

- Water-level fluctuations comparable to recent historical conditions are necessary to maintain the long-term productivity, diversity and extent of coastal wetlands.

- Seasonal water-level fluctuations may increase species diversity of wetland vegetation; a decrease in the frequency of water-level fluctuations will decrease diversity.

- Some modifications could be made to the water-level regimes of presently regulated lakes that would be beneficial to wetlands.

- The aquatic environment is less affected by water-level fluctuations than are wetlands; storm impacts on aquatic habitat and water quality may be more substantial than those due to long-term fluctuations in levels.

- Within the historical range, aquatic habitat and water quality are more adversely affected by extreme low than by extreme high water levels.

- Fish species have evolved under, and are adapted to, conditions of fluctuating water levels; species which spawn in spring are more affected by seasonal water-level fluctuations than are fall spawners.

- Human use and modification of the Great Lakes - St. Lawrence River system have stressed terrestrial, wetland and aquatic environments: construction has reduced the natural flexibility of the nearshore profile to accommodate shore processes; up to one-half of coastal wetlands have been lost to agricultural and other developments; and water quality has been significantly degraded by human activity, although recent improvement is evident.

- While a number of significant conservation initiatives have been implemented in both countries, adverse environmental change due to human activity is still widespread throughout the system.

- Climate change, toxic contamination, and shoreline modification are among the human-caused stresses on the Great Lakes - St. Lawrence River system which create considerable uncertainty over future environmental conditions.

- Climate change will likely result in reduced supplies of water, lower lake levels and channel flows, and a potential, with reduced ice cover, for increased shore erosion during the winter.

SECTION 4

ENVIRONMENTAL ASSESSMENT OF MEASURES

4.1 INTRODUCTION

Environmental impact assessment (EIA) is an activity designed to identify, predict, evaluate and communicate information about the impact of a proposed human action on the environment. This activity is integral to the Reference Study because there is a requirement for a full description and evaluation of a broad range of measures which could be adopted to address the adverse consequences of fluctuating levels of the Great Lakes. EIA is also significant to the Study in that it helps to articulate an ecosystems approach to investigating the water-levels issue by stressing the interrelationships and interdependencies among people, activities and environments.

Over the past two decades, EIA has become an accepted basis for decision-making on major projects by federal, state and provincial governments throughout the Great Lakes-St. Lawrence River basin. The U.S. National Environmental Policy Act of 1969, Canadian Environmental Assessment and Review Process (1973), and Ontario Environmental Assessment Act of 1975 are examples of legislative and administrative procedures for environmental assessment. Many of the measures inventoried in the Reference Study would be subject to such procedures, as well as to other decision rules, prior to implementation.

Traditionally, environmental, socio-economic, and technical aspects of decisions concerning human actions have been considered in an inconsistent, incomplete, and often independent fashion. Comprehensive EIA has helped to overcome some of these deficiencies. A response to these concerns in the Reference Study has been the development of an evaluation instrument, a framework for making judgements about diverse measures in a more comprehensive and consistent manner.

FG2 is supportive of a broader, more integrative evaluation of potential responses to the water levels issue which would serve to maintain and enhance the environmental integrity of the Great Lakes - St.Lawrence River system and sustain the many and significant resources that flow from that system. Further, FG2 believes that elements of EIA are essential to any meaningful evaluation of measures. Among these elements are a description of the biophysical and human environment affected by a potential measure, an understanding of how that environment functions and responds to forces of change, and the development of evaluative criteria to judge the significance of change in that environment. While recognizing the importance of socio-economic and other considerations, FG2 has directed its effort toward enhancing understanding of the biophysical environment.

The following subsections outline in general terms the process of environmental impact assessment, describe the approach FG2 has used to organize current understanding of the environmental impacts of measures, summarize that understanding, and highlight from an environmental perspective critical issues which should be addressed in any substantive evaluation of measures.

4.2 THE PROCESS OF ENVIRONMENTAL IMPACT ASSESSMENT

The ability to anticipate the environmental consequences of any proposed human action depends on several things. First, the nature of the human action itself must be well understood. This means not only the component parts of the action, but the way, and the location and time frame, in which they will be put into effect. Second, the physical and biological environment, including landforms, organisms and the processes which influence these elements, must be known in sufficient detail. And third, the manner in which the proposed action will interact with the environment, resulting in impacts, must be known. In the absence of knowledge, assumptions must be made. An EIA can be no better than the least well understood of these things.

In an idealized form, environmental impact assessment can be characterized as a series of sequential steps: specification of the context for the EIA; description of the affected environment; identification of environmental impacts; evaluation of the significance of these impacts; and communication of the findings of the EIA (adapted from Lang and Armour, 1980). Several reviews of EIA practice (Beanlands and Duinker, 1983; Lee, 1983; Whitney and Maclaren, 1985) provide a basis for the following discussion of these steps.

SPECIFICATION OF THE CONTEXT FOR THE EIA

A rationale for undertaking the EIA must be established and the proposed human action or actions clearly and fully defined. This would include a description of the timing and duration of the action and the spatial scale of the action. As well, spatial and temporal boundaries for the impact study must be established.

DESCRIPTION OF THE AFFECTED ENVIRONMENT

The biophysical and human environment likely to be impacted by the proposed action must be adequately described. Key elements or features of that environment must be identified. However, a simple description of these elements is insufficient. It is necessary to recognize processes which influence how that environment functions and evolves. And while it may be tempting to try to know all about the affected environment, some elements and processes are clearly more salient than others. Careful conceptualization of the affected environment is crucial to this step in the EIA process, and the product should be a meaningful evaluation of current conditions.

IDENTIFICATION AND PREDICTION OF IMPACTS

Fundamental to EIA is a scoping of the kinds of impacts which must be measured and evaluated. Innumerable indicators of impact or change in environmental conditions can be identified, and one challenge is to identify those most salient. Matrices are a commonly used tool to display the interaction between specific human actions and particular environmental elements and processes, but map overlays, network diagrams and other methods have also been used. Careful conceptualization at this stage is essential. Models which aid our understanding of the structure and, particularly, the functioning of environments are helpful in scoping appropriate impact indicators or parameters. And while it is obvious that indirect as well as direct impacts are of consequence, another challenge is to determine at what point in time and space impacts become sufficiently far removed to be of little concern.

Once impact indicators have been identified, it is necessary to predict the direction and magnitude of environmental change (in each indicator) attributable to any proposed action. This necessitates comparing predicted conditions with and without the action in place. The accuracy of predictions will depend on our understanding of how environments functions, the capability of predictive models used and the quality of data available. However, there will be a degree of uncertainty associated with any prediction made, and this should be made explicit.

EVALUATION OF IMPACTS

Predictions of the direction and magnitude of environmental change must be interpreted as to their significance. Important characteristics of impacts which must be evaluated include the geographic location and extent, timing, and duration of impact. The cumulative and synergistic nature of some impacts must be considered, as well as the degree of irreversibility of impacts and opportunities for mitigation. The relative significance of different kinds of impacts can be particularly problematic in EIA, and much controversy surrounds the aggregation and weighting of impacts.

COMMUNICATION OF EIA FINDINGS

It is important to be able to effectively communicate findings and conclusions about environmental impacts to decision-makers and the public . Maps, matrices, network diagrams and computer simulations are among the techniques available to communicate impacts.

4.3 AN APPROACH TO UNDERSTANDING IMPACTS OF MEASURES

Most of the development that has taken place within the Great Lakes-St. Lawrence basin, and indeed within the world, has been driven by economic considerations, with relatively little thought to environmental impacts. The consequences of this are widely evident in the basin, and impacts such as toxic contamination and loss of wetland habitat have been discussed in Section 3.5 of this Annex.

The purpose of this section is to describe the approach FG2 has used to organize and summarize some of what is currently known about the environmental impacts of measures (human actions) which could be taken in response to fluctuating Great Lakes' levels. It must be stressed that this approach is in the very early stages of evolution. FG2 has not undertaken an environmental assessment of measures. However, the approach described below has been of value in providing some preliminary, qualitative descriptions of impacts and in raising some important issues that should be addressed in any meaningful impact assessment. These will be discussed in the following section.

An impacts matrix provided the conceptual framework for an initial, qualitative assessment of how terrestrial, wetland and aquatic environments might respond to different types of measures (Table B-4-1). For this assessment, measures were organized into three broad classes: lake regulation (measures that modify in some way lake levels and connecting channel flows); shore protection (measures that structurally protect shoreline from flooding and erosion); and, non-structural (measures that do not involve construction). Separate tables were prepared for each class of measure.

DESCRIBING THE AFFECTED ENVIRONMENT

Environmental impacts should be expressed first in terms of the influence of fluctuating water levels and other processes on the natural environment and, second, in terms of the effects of measures. By understanding the interrelationships between naturally-occurring physical and biological processes, we are better able to identify and evaluate the environmental impacts of various measures. It is important to distinguish major components of the Great Lakes - St.Lawrence River ecosystem (Column 1, Table B-4-1), that is, terrestrial, wetland and aquatic environments of the Lakes and connecting channels. These components can be further subdivided to reflect variations within components that may be important to understanding how these environments respond to fluctuating levels and other processes, and to measures (Column 2, Table B-4-1). Environmental components and subcomponents have been described in some detail in Section 2 of this Annex.

Another characteristic of the Great Lakes - St. Lawrence River system important to EIA is the water-level regime. Some measures, such as lake regulation structures, will alter lake levels and connecting channel flows, resulting in environmental consequences. The environmental implications and effectiveness of other measures may be influenced by a change in the water-level regime. The water-level regime, along with other environmental features, provides a context for assessing the impacts of measures. Five potential alterations to Great Lakes levels are shown on Table B-4-1, Column 3.

While the components of the affected environment, themselves, are important, a significant contribution of an ecosystem perspective or approach is its stress on spatial and temporal links among components, and on understanding processes rather than simply describing features. Wetlands, for example, capture and process nutrients from terrestrial environments and feed nearshore and offshore aquatic environments. Higher lake levels and storms may facilitate this nutrient transfer, spatially, between wetlands and open water. Time is also an important ecosystem dimension. The timing and duration of water-level fluctuations, for example, are critical to the reproduction of many wetland plants.

TABLE B-4-1: ENVIRONMENTAL ASSESSMENT OF MEASURES

1. ENVIRONMENTAL COMPONENT	2. ENVIRONMENTAL SUB-COMPONENT	3. LAKE LEVEL SCENARIO	4. ENVIRONMENTAL CRITERIA AND IMPACT INDICATORS	5. PREDICTION AND EVALUATION OF IMPACTS	6. LEVEL OF UNDERSTANDING	7. FUTURE DATA NEEDS RESEARCH PROBLEMS
Lake Environment						
Terrestrial	- rocky shoreline, coastal bluffs, coastal bluffs overlying bedrock, sandy beach/mainland, barrier beach/ dune complex, low coastal plain, urban protected	- water level reduction - water level increase - compression of range - expansion of range - changes in timing of highs and lows	- productivity e.g.net primary productivity in mg/m²/day - diversity e.g. number of species - resilience e.g. technical judgement of of stability - purity e.g. biological oxygen demand - quantity e.g. hectares of wetlands	- description of impacts (magnitude, duration, timing, degree of resiliency, etc.) - significance of impacts	- concerns/issues - comments - qualitative assessment of understanding	- topics - limitations - research in progress
Wetland	- open shoreline, unrestricted bay, shallow-sloping beach, river delta, restricted riverine, lake-connected inland, protected-man-made (diked), protected-barrier beach					
Aquatic	- open water, nearshore, lake bottom					
Connecting Channels Environment						
Terrestrial	- rocky shoreline, coastal bluffs, coastal bluffs overlying bedrock, sandy beach/mainland, barrier beach/dune complex, low coastal plain, urban protected					
Wetland	- open shoreline, unrestricted bay, river delta, restricted riverine, lake-connected inland, protected-man-made (diked)					
Aquatic	- open water, nearshore, channel bottom					

IDENTIFYING ENVIRONMENTAL IMPACTS

The Reference Study has adopted environmental integrity as one of several criteria for the evaluation of measures (Annex F). Westman (1985) defines environmental integrity as the desirability and necessity of preserving the ability of living things to interact and maintain their structure and function in some self-regulating, homeostatic fashion. This criterion recognizes the importance of short-term variability in environmental processes to the long-term maintenance of environmental systems; that is, environmental quality is not achieved by eliminating change. Environmental integrity also acknowledges the desirability of maintaining the quantity and quality of a wide range of habitats.

The criterion of environmental integrity can be further defined by a set of operational criteria. These operational criteria are helpful in identifying environmental impact indicators to be predicted and evaluated. Impact indicators may be a process or function, environmental condition, species of plant or animal, physical feature, or a combination of these. Productivity, diversity, resilience, purity, and habitat quantity are suggested operational criteria (Table B-4-1, Column 4). For some of these criteria, well established standard units of measurement and assessment techniques exist. Examples include gross and net primary productivity. Means of expressing other criteria, notably diversity and resilience, are subject to ongoing discussion and debate.

Support for the following criteria can be found in the ecological and environmental impact literature and in recent major documents such as the World Conservation Strategy, Brundtland Commission report, Great Lakes Charter, and draft Habitat Policy from the Habitat Advisory Board of the Great Lakes Fishery Commission.

Environmental Productivity

Terrestrial, wetland and aquatic environments produce a variety of outputs. In a biotic context, plants convert solar energy into chemical energy necessary to the maintenance of all life. Primary productivity puts an upper limit on the size of the animal populations. Species, and collectively environments, vary in their productivity. Wetlands and estuaries, for example, are generally very productive. Environments can also be productive in an abiotic sense. For example, erosion of shores can produce sediment for redistribution. Changes in productivity (both biotic and abiotic) can result from increases or decreases in the productivity of a unit area of environment or from changes in the quantity of particular environments (habitats).

Environmental Diversity

The richness of species and environments is significant in several respects. Species diversity helps maintain important environmental processes or functions such as energy flow and nutrient cycling. Thus, simplification of environments can impair these processes and reduce the stability-resilience of environments. The diversity of vegetative communities (their spatial arrangement) may also contribute to stability, for example by impeding the spread of pests or diseases. And the desirability of maintaining genetic diversity (through minimizing species extinction) is increasingly acknowledged. In this regard, rare or endangered species are significant. While much attention is focussed on biological diversity, it is also important to maintain physical diversity, for example a range of different geomorphological shore types, features and processes, as the diversity of habitat for living things depends, in part, on this.

Environmental Resilience

Environmental resilience (or stability-resilience) is the ability of an environment to maintain itself or recover from some disturbance (human or natural). Many factors appear to influence resilience, including species diversity and linkages among vegetative communities (for example the proximity of recolonization sources). Abiotic influences may also be important, for example the nature of nutrient cycles, fire, water-level fluctuations or the significance of sediment supply to the stability of depositional shore environments.

Environmental Purity

Environmental purity refers to the desirability of minimizing chemical contamination, exotic organisms, thermal pollution and other human inputs harmful to environmental structure (species or components) and function (energy flow, nutrient cycling and other processes).

Habitat Quantity

The above criteria articulate the quality of environment or habitat. It is also important to recognize the impact of fluctuations in levels and flows and measures responding to these fluctuations on the quantity of various habitats. As noted above, quantity can be reflected in a consideration of environmental productivity. The size of habitat units can also influence species diversity and environmental resilience. However, the amount of particular types of environments is significant to both environmental functioning and human use of environment, for example recreational use of sand beaches, and resources which are dependent on those environments, such as fish and waterfowl.

PREDICTING AND EVALUATING IMPACTS

There are many characteristics of environmental impacts. The geographic location, magnitude, timing, duration, degree of irreversibility, and cumulative nature are among those noted earlier (see, also, Table B-4-1, Column 5). To predict impacts of measures, in terms of these and other characteristics, it is useful to construct process-response models of the impacts of fluctuating levels and flows and other natural processes, and to recognize that impacts vary across and within different types of terrestrial, wetland and aquatic environments. These models are qualitative and quantitative descriptions of how particular environments respond to changes in levels, flows and other key processes. For example, the impact of levels is likely to be quite different among bedrock, fully developed beach, and bluff shore types. Similarly, open and naturally-protected wetlands may respond differently to changes in lake-level regime. These process-response models can be used to predict specific impacts of measures on particular environmental features and processes, for example, the response of downdrift beaches to reduced sediment supply as a consequence of the construction, updrift, of shore protection. A basis for the development of process-response models has been established in Section 3 of this Annex.

To utilize fully the analytical and predictive capabilities of process-response models, it is necessary to construct a framework which recognizes spatial variation across and within terrestrial, wetland and aquatic environments, and organizes and applies appropriate data. To this end, FG2 has developed a spatial evaluation framework. This framework is a classification and delineation of environments in spatial units meaningful in terms of process-response models. For example, distinctive shore types or reaches have been defined and will be mapped along the shores of each Great Lake and connecting channel. FG2 has also established an integrated data base to organize information on shore recession rates, wetland diversity, structures at risk, and many other biophysical and human features and processes relevant to impact assessment.

The spatial evaluation framework and integrated data base can be brought together in a Geographic Information System (GIS). The GIS and its components are described in some detail in Section 5. The GIS can be used to characterize terrestrial, wetland, and aquatic environments and, in conjunction with process-response models, can assess the consequences of fluctuations in water levels and flows, and other processes such as erosion and sedimentation, and the impact of measures that could be taken in response to adverse consequences of fluctuations.

As noted earlier, environmental criteria such as diversity and productivity, which help define environmental integrity, are useful guides to specifying impact indicators. These criteria are also relevant to evaluating the significance of impacts that are predicted. The vegetative species composition of a wetland may change as a consequence of the implementation of a measure. If this change results in a long-term decline in species diversity of that wetland, the impact takes on greater significance.

LIMITATIONS TO ASSESSING IMPACTS

Any prediction of environmental change is subject to some degree of uncertainty. Current understanding of the functioning of environmental components and subcomponents, particularly in a site-specific context, is variable. Columns 6 and 7 of Table B-4-1 call for an assessment of the current understanding of impacts and identification of information needs and research issues. FG2 found that an explicit questioning of our current understanding of environmental impacts was valuable in identifying priorities for further work. Some of these research needs are discussed in Section 4.4 and Section 6.

4.4 FINDINGS OF FG2 AND IMPLICATIONS FOR ENVIRONMENTAL IMPACT ASSESSMENT

ENVIRONMENTAL IMPACTS OF MEASURES

The selection of measures to minimize the effects of fluctuating water levels has historically tended to concentrate on altering the natural environments rather than adapting to environmental conditions and processes. Consequently, environmental impact assessments have tended to focus on measures that structurally alter or control lake and shoreline processes.

A combination of methods and information sources were employed by FG2 to gain an understanding of the nature and significance of environmental consequences of a range of measures. Scoping, networks, simple process-response models, matrices, and overlays were used to identify impacts and assess their significance. Information was derived from the professional judgement of members of FG2, literature reviews, results of research conducted as part of Phase 1 of the Reference Study, and the consensus of opinion obtained through workshops attended by experts outside of FG2.

The following discussion provides a brief overview of some of the environmental impacts that are attributed to three general categories of measures: lake regulation structures; shore protection; and non-structural.

Lake Regulation Structures

Lake regulation structures are any human-engineered structures that can be used to alter Great Lakes water supplies, levels, or flows. They are usually massive structures that are designed to modify water-level fluctuations on the Great Lakes. For example, control structures currently exist on Lakes Ontario and Superior, and other studies (e.g. International Lake Erie Regulation Study Board, 1981) have looked into the possibility of placing control structures on Lake Erie. These human-engineered structures could also include diversions of water into or out of the Great Lakes - St. Lawrence River system. A number of these diversions currently exist, while many others have been theorized.

The main function of control structures is to modify the water levels in the Great Lakes or the flows in the connecting channels. Thus, the impacts on the environment will be related to these water-level or flow changes. Previous studies (International Great Lakes Levels Board, 1973; International Lake Erie Regulation Study Board, 1981) have looked at impacts of water-level modification on the environment. In this Annex, Section 3 has provided a description of the impacts of water-level fluctuations on the terrestrial, wetland and aquatic environments of the Great Lakes - St. Lawrence River system. While Section 3 did not specifically address the impacts of water-level regulation, a number of impacts discussed therein apply here.

In this section, however, the impacts of water-level regulation are looked at directly, through a number of water-level "conditions" that could occur if further lake regulation structures were put in place. As an exhaustive EIA has not been conducted for water level regulation, the impacts discussed below are by no means all that could potentially occur.

Reductions in water level would have mixed effects on water quality, with positive effects through reduced infiltration of septic systems and negative effects through increased release of phosphorous and toxics from bottom sediments. Reduced water levels would also decrease the nearshore habitat for fish spawning and nursery grounds, thereby reducing fish production. Reductions in level would result in a temporary decrease in erosion rates, but would not result in a long-term erosion decrease in many shore areas. Beach widths would initially increase, and bluff erosion, which is critical for the maintenance of beaches, would be temporarily decreased. With lower water levels the incidence of, or potential for, flooding could be reduced.

Increases in water levels, or in flows of connecting channels, could improve the flushing of shallow embayments and increase the dilution capacity. Increases in levels may be beneficial to fish by improving the nearshore habitat for spawning. Increases in levels would lead to temporary increases in erosion rates and temporary reductions in beach width, and could also lead to increased sediment transport to beach areas due to this increase in erosion.

Stabilization of water levels would likely be detrimental to fish production, particularly for species dependent on wetlands because water-level fluctuations are very important for maintaining the diversity and extent of wetland habitat. Impacts on erosion, beaches and flooding would be similar to those described above.

Changes in the timing of high and low levels (on a seasonal basis) would likely have negative impacts on fish production and wetland plant reproduction, due to their dependence on the present annual water-level cycle. Impacts on the terrestrial zone are unknown, but it is thought that they would be of a relatively small magnitude. The impacts on flood potential are also unknown, but any change in the timing that shifted the seasonal highs to the spring or fall storm seasons could significantly increase the potential for storm damage in developed areas.

Shore Protection Measures

Shore protection can be defined as the construction of a structure that strives to control shore processes for human benefit. There are five general classes of shore protection structures: 1) offshore parallel structures, which include detached breakwaters, barrier island construction and any other structure that is constructed offshore and parallel to the shoreline; 2) onshore parallel structures, which include many common structures such as seawalls, revetments and bulkheads; 3) shore-perpendicular structures, which include groynes, jetties and attached harbour breakwaters; 4) complex protection structures, an example of which is artificial headlands; and, 5) beach nourishment, a "non-structural" protection measure, where sand is imported and placed upon a beach.

There is a large amount of literature on the design and implementation of various types of shore protection structures and beach nourishment techniques. The majority of these studies have dealt with ocean coastlines, but a few have dealt with the Great Lakes. While most of the literature provides detailed descriptions of design criteria and methods of construction, very few sources directly address the environmental impacts that these shore protection structures can cause. Fortunately, there is a growing amount of literature on this topic and examples include Herbich and Ko (1968), FitzGerald et al. (1981), Freese and Kulhawy (1983), Krauss (1987), Douglass (1987), Griggs and Tait (1989) and Nakashima (1989). Recently, computer modeling has been used to analyze shoreline change caused by shore protection construction (Hanson, 1989). Another document that is useful in this regard is the Great Lakes Shore Management Guide (Strelchuk, 1981).

Despite being grouped into similar categories, shore protection structures can vary considerably in style, size, quality, and durability. The construction of shore protection structures, and use of beach nourishment techniques, commonly take place in a number of different shoreline environments. The impact of an individual structure varies widely with the characteristics of the environment in which it is placed, the material used in its construction, and its design and emplacement. Thus, the impacts of one kind of protection measure could be different for each different environment. While this is likely the case, it is also possible at this point to make some generalizations about the kinds of impacts that can be caused by shore protection measures.

There are four general types of impacts that can be caused by shore protection structures: 1) physical; 2) biological; 3) aquatic; and, 4) aesthetic. Physical impacts are direct impacts of the construction and the operation of the structure. These include the alteration of erosion and accretion patterns, interference with longshore sediment transport and material supply, impedance of water flow and changes in exposure to currents and waves, and the alteration of shoreline topography. Shore-perpendicular structures, for example, typically modify local patterns of erosion and accretion.

Biological impacts for the most part are indirect, unless construction of a structure physically destroys an existing biological habitat. These indirect impacts may include a decrease in suitability of the area for certain plant or fish communities, or the creation of new habitat for other species. Aquatic impacts are similar to biological, although structures may directly impede longshore fish movement and migration or provide a barrier to the movement of land organisms and amphibians to and from the water.

Aesthetic impacts include the obstruction of public access to and from the water, an increase in noise and human activity during construction of the structure, and a change in the overall appearance of the shoreline during and after construction.

Non-Structural Measures

Non-structural measures include: fee simple purchase of property rights; mandatory structural setback zoning; subsidized structure relocation; regulation of consumptive use; interest rate subsidy; real estate disclosure; tax abatement to cover increased operating costs; public information and education; and storm forecasting.

Impact assessments of non-structural measures have typically focussed on their social and economic effects. Issues or variables that contribute to the success or failure of non-structural measures include implementation, enforcement, funding, expertise, and social acceptability. The environmental impacts of non-structural measures are difficult to assess because they are often subtle and it is difficult to predict the consequences of not applying these measures.

Categorically, non-structural measures are flexible, can be applied in a variety of environments, and can be tailored to address particular issues, be they environmental, social, or economic. While flexibility can be advantageous, it makes it more difficult to generalize about non-structural measures or to evaluate specific measures. A more detailed environmental assessment of non-structural measures will require an inventory of non-structural measures applied to date in the Great Lakes - St. Lawrence River system.

Overall, it would appear that non-structural measures are generally effective in protecting wetland, aquatic and terrestrial environments. This is accomplished by directing development away from hazardous and sensitive environments. Non-structural measures can be used to control environmentally-depreciative activities such as dredging, shoreline filling, wetland conversion, and sewage disposal. Thus, non-structural measures permit a naturally-functioning ecosystem, which has persisted in the Great Lakes - St. Lawrence basin for centuries, to continue. As such, shore features are able to adjust naturally to erosion and depositional processes and wetland and aquatic ecosystems are able to freely respond and adapt to fluctuating water levels.

The effectiveness of non-structural measures increases proportionally to the number of measures applied and to the level of commitment toward implementation and enforcement of the measures. One concern about uneven application is that development pressure will shift to other sensitive areas not yet protected.

IMPLICATIONS FOR ENVIRONMENTAL ASSESSMENT

The environmental components of the Great Lakes - St.Lawrence River system, and impacts on these components, are diverse, complex, and interdependent. Management of this system through the implementation of measures will require coordination and cooperation amongst and between agencies and the public. There is a need for a shared approach and conceptualization of the Great

Lakes-St.Lawrence River system and the impacts of water-level fluctuations and measures. The diversity of environments, types of measures, impacts, and agencies involved are evidence that the assessment of environmental impacts and the selection and successful implementation of measures will require an ecosystem approach.

Current evaluations of environmental impacts are general in nature, limited by our understanding of: ecosystem level management; the reversibility of biological and physical impacts; ecosystem functions and values; the detailed aspects of shore processes; the success rates of various restoration techniques; and the complexities associated with the extensive diversity of environments. Evaluations tend to give high priority in the ranking and evaluation of the significance of impacts to those impacts that are well understood, and impact evaluations tend to concentrate on impacts that are measurable. This situation is typical of environmental impact assessment, and it is often a function of limited information or research.

The impact of fluctuating water levels on naturally-occurring wetland, aquatic, and terrestrial environments is as varied as the diversity, productivity, resilience, purity, and quantity of these environments. There is growing evidence however, that despite the diversity of environmental impacts resulting from fluctuating water levels, these impacts tend to have beneficial rather than adverse consequences for shoreline ecosystems. Our current understanding of natural processes confirms that water-level fluctuations are integral to the maintenance of terrestrial, aquatic, and wetland environments. Although the impact matrix provides a generalized view of impacts, it oversimplifies the range of impacts. By generalizing the impacts, the complexity, diversity, and linkages among sensitive biological and physical environments have been obscured. More detailed modeling of environmental impacts through the application of the Geographic Information System will provide a more sensitive interpretation of the response of various ecosystems to water-level fluctuations and measures applied to ameliorate the adverse impacts of fluctuating water levels.

It must be stressed, again, that existing aquatic, wetland, and terrestrial environments of the Great Lakes reflect decades and centuries of water-level fluctuation. Dynamic water levels represent perhaps the most significant source of change in the Great Lakes - St.Lawrence environment. This change is not without detrimental environmental consequences; however, without change, continued improvement or regeneration of life and landform will cease. The long-term maintenance of aquatic, wetland, and terrestrial environments will not be enhanced by reducing the forces of short-term change that have structured these environments.

The efforts of Functional Group 2 have concentrated on developing a clearer understanding of the existing environment and the role and significance of fluctuating water levels and flows to that environment. The impact matrix (Table B-4-1) provided a conceptual framework to identify potential impacts and the links between environmental components. The matrix also helped to characterize our current understanding of measures and identify areas where further documentation or research is needed before an environmental impact assessment can proceed. There is a large range of potential environmental impacts of measures. The type, magnitude and duration of impacts are influenced by the environmental component or subcomponent in which they occur. These observations confirm the need for more detailed, site-specific evaluations that address specific measures. The significance of a spatial perspective is addressed further in Section 5 of this Annex.

4.5 SUMMARY

Environmental impact assessment (EIA) has become an accepted basis for decision-making on many major projects and must be an important part of the Reference Study.

- An approach to organizing current understanding of the environmental impacts of measures has been developed. This approach involves the identification of environmental components, the specification of environmental criteria and impact indicators, and an assessment of the current level of understanding of impacts.

- This approach was applied to summarizing some of what is presently known about the environmental impacts of lake regulation structures, shore protection structures, and non-structural measures.

- Environmental integrity has been offered as a major criterion for the evaluation of measures; environmental productivity, diversity, resilience, purity, and habitat quantity are suggested guides to the specification of impact indicators.

- Many gaps exist in our present understanding of impacts; greater attention must be given to, among other things, the spatial characteristics of measures and their impacts.

SECTION 5

A SPATIAL PERSPECTIVE ON DESCRIPTION, PROCESS AND IMPACT

5.1 INTRODUCTION

A major attribute of the Reference Study is the adoption of a spatial perspective. This perspective recognizes variation from Lake to Lake, and along sections of Lakes and connecting channels, in the distribution of important environmental and human features. It acknowledges spatial variation in the response of specific terrestrial and other environments to key processes, including fluctuations in levels or flows. Consequently, understanding of the sensitivity to these processes of human activities, which depend on these environments, is enhanced. A spatial perspective also highlights the distribution of various anticipated impacts of measures or actions proposed to address adverse consequences of lake-level fluctuations.

The adoption of a spatial perspective by FG2 has resulted in the development of a spatial evaluation framework and an integrated coastal zone data base which is stored and analyzed in a computerized Geographic Information System (GIS). The spatial evaluation framework is simply the classification and delineation of terrestrial, wetland and aquatic environments in spatial units meaningful to an assessment of fluctuating levels and of measures. The coastal zone data base represents a compilation of data necessary to this assessment. The GIS is the computer technology used to manipulate and display geographically-referenced data. In conjunction with process models of how environmental and human use systems function, the GIS represents a powerful descriptive and analytical tool (Figure B-5-1).

The following subsections describe the GIS systems being developed by FG2, detail the American and Canadian data bases and spatial evaluation frameworks, and illustrate several applications of a GIS.

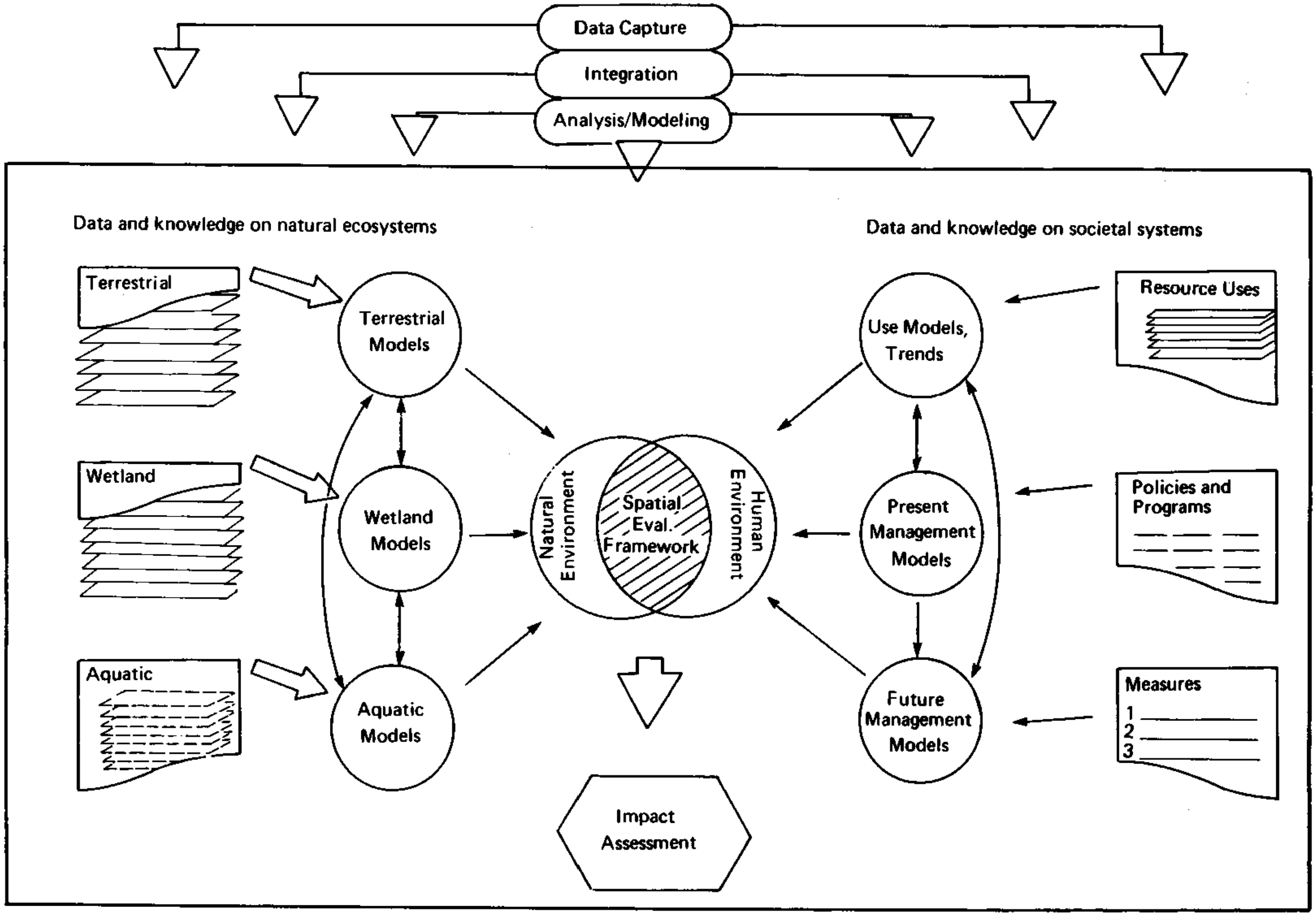
The GIS systems are not yet fully operational because data limitations exist for some parameters and locations in the basin. More work also remains to be done in developing process-response models to utilize more fully the potential of a GIS.

5.2 DESCRIPTION OF THE GEOGRAPHIC INFORMATION SYSTEMS

WHAT IS A GEOGRAPHIC INFORMATION SYSTEM?

A Geographic Information System is simply a computer-based "tool" which captures, displays and manipulates geographically-referenced data. A GIS allows users to think spatially and to work with spatial data to solve problems. A GIS will permit integration of data from many sources in a wide range of formats, and the construction of versatile and flexible geographical models quickly, simply and cost-effectively.

FIGURE B-5-1: APPLICATION OF A GIS TO ENVIRONMENTAL MODELING AND IMPACT ASSESSMENT



FUNCTIONAL GROUP 2 GIS SYSTEMS

Due to the bilateral nature of the IJC and the Reference Study, and current investments in existing systems and data, both an American and a Canadian Geographic Information System are being employed by FG2 to store and analyze the integrated Great Lakes coastal zone data base. These systems generally contain similar data, although different methodologies and compilation techniques are being used by both countries. While it is technically feasible to integrate both data bases into one format/system, it is not necessary since there is a consistency between data variables and classification systems which will facilitate integration if and when it is required or desired. It is recommended that only the interpreted results be integrated at an appropriate scale to provide a comprehensive overview.

The data base for the Great Lakes shoreline of the United States is being developed in the State of Michigan GIS through a cooperative agreement between the U.S. Army Corps of Engineers (COE) and the Michigan Department of Natural Resources (MDNR) and through services of a contractor. Following the standards and specifications recently used by Michigan to establish a data base for the Michigan shoreline, the data base will be expanded to include the entire U.S. shoreline. The U.S. GIS operates in an Intergraph/Vax environment and has sophisticated mapping and good analytical capabilities.

The Spatial Analysis System (SPANS), a powerful microcomputer-based GIS developed by TYDAC Technologies, Inc., is being used to store and analyze the Canadian coastal zone data base. Highlights of the SPANS system include the use of a variable size raster (quadtree) to accommodate the level of detail required, a host of integration functions (overlays), a variety of interpolation techniques to convert point data to continuous data, and the use of browse picture files for quick visual display of results.

Most of the data proposed for the coastal zone data bases already exists and was simply converted into a machine readable format (e.g. D-Base, Lotus). The desired Canadian information has been assembled by an FG2 group within the Water Planning and Management Branch of Environment Canada with inputs from the Canadian Wildlife Service (CWS), Department of Fisheries and Oceans (DFO), Hydrographic Service, National Waters Research Institute (NWRI), Ontario Ministry of Natural Resources (OMNR) and the Department of Geography, University of Guelph.

THE U. S. GREAT LAKES COASTAL ZONE DATA BASE

This section identifies and describes the various attributes of the key Great Lakes ecosystem components stored in the American coastal zone data base. The U.S. shoreline data base will consist of data on the land cover/current use of a strip of shoreline from the water's edge to approximately two miles inland. The land cover/current use data are subdivided into 52 categories (Table B-5-1) within major classes such as residential development, industrial, and wetlands. The entire data base is being developed from source material at a

TABLE B-5-1: CURRENT LAND COVER/USE LEGEND FOR UNITED STATES' GIS

1 URBAN
- 11 RESIDENTIAL
  - 111 MULTI-FAMILY,HIGH RISE
  - 112 MULTI-FAMILY,LOW RISE
  - 113 SINGLE FAMILY,DUPLEX
  - 115 MOBILE HOME PARK
- 12 COMMERCIAL, SERVICES, INSTITUTIONAL
  - 121 PRIMARY/CENTRAL BUSINESS DISTRICT
  - 122 SHOPPING CENTER/MALL
  - 124 SECONDARY BUSINESS/STRIP COMMERCIAL
  - 126 INSTITUTIONAL
- 13 INDUSTRIAL
  - 138 INDUSTRIAL PARK
- 14 TRANSPORTATION, COMMUNICATIONS, UTILITIES
  - 141 AIR TRANSPORTATION
  - 142 RAIL TRANSPORTATION
  - 143 WATER TRANSPORTATION
  - 144 ROAD TRANSPORTATION
  - 145 COMMUNICATIONS
  - 146 UTILITIES
- 17 EXTRACTIVE
  - 171 OPEN PIT
  - 172 UNDERGROUND
  - 173 WELLS
- 19 OPEN LAND, OTHER
  - 193 OUTDOOR RECREATION
  - 194 CEMETERIES

2 AGRICULTURE
- 21 CROPLAND
- 22 ORCHARDS,BUSH FRUIT,VINEYARDS,ORNAMENTAL HORDICULTURE
- 23 CONFINED FEEDING
- 24 PERMANENT PASTURE
- 29 OTHER

3 NONFORESTED
- 31 HERBACEOUS
- 32 SHRUB

4 FORESTED
- 41 DECIDUOUS
  - 411 NORTHERN HARDWOOD
  - 412 CENTRAL HARDWOOD
  - 413 ASPEN/WHITE BIRCH ASSOCIATION
  - 414 LOWLAND HARDWOOD
- 42 CONIFEROUS
  - 421 PINE
  - 422 OTHER UPLAND CONIFER
  - 423 LOWLAND CONIFER
  - 429 CHRISTMAS TREE PLANTATION

5 WATER
- 51 STREAM
- 52 LAKE
- 53 RESERVOIR
- 54 GREAT LAKES

6 WETLANDS
- 61 FORESTED
  - 611 WOODED
  - 612 SHRUB, SCRUB
- 62 NONFORESTED
  - 621 AQUATIC BED
  - 622 EMERGENT
  - 623 FLATS

7 BARREN
- 72 BEACH, RIVERBANK
- 73 SAND DUNE
- 74 EXPOSED ROCK

scale of 1:24000. The land cover/current use data for all states other than Michigan is being interpreted from 1:24000 scale aerial photography taken in September, 1988. The Michigan portion will utilize existing data in the Michigan Resources Information System (MIRIS).

Along with the land cover/current use data, areas subject to flood hazard and erosion hazard are being incorporated. Lands in public ownership, primarily state and federal, are being identified.

This data base will represent a framework into which other types of shoreline data can be incorporated in the future. It will facilitate consolidation of a very diffuse body of knowledge and will focus future shoreline research and management efforts toward a better-defined common goal.

Figure B-5-2 portrays the land cover/current use data of a section of shoreline in Bangor Township, Bay County along Saginaw Bay, Lake Huron. Figure B-5-3 portrays a composite of flood hazard area with lake bathymetry. Such data will be used to quantify the probable extent to which land use is impacted by various lake-level scenarios. Further uses of these data will be for analysis of the impacts of water-level and shoreline management scenarios on critical natural habitats such as coastal wetlands and fish spawning sites.

THE CANADIAN COASTAL ZONE DATA BASE

This section identifies and describes the various attributes of the key components of the Great Lakes ecosystem stored in the Canadian coastal zone data base. The outline of the Canadian Great Lakes shoreline has been taken from 1:25000 and 1:50000 National Topographic Series (NTS) maps. A total of 255 map sheets will be digitized, which represents the entire Canadian Great Lakes shoreline from the western border of Lake Superior to Trois Rivieres on the St. Lawrence River.

For each lake, a number of littoral drift cells are identified based on the OMNR Littoral Cell Definition report (Ontario Ministry of Natural Resources, 1988a). For each littoral cell, a sediment source, transport and sink zone can be identified. The shoreline has been further divided into "reaches" as initially defined by the Great Lakes Erosion Monitoring Program (Boyd, 1981). The GIS facilitates the analysis of measures and fluctuating water levels at a number of scales: the lake; littoral cell; and the reach. For the Canadian portion of the shoreline, there are approximately 1700 reaches. Shore type, physiography and orientation to waves are used to delineate the reach boundaries alongshore. The rationale for delineating reaches according to shore types is that the effects of fluctuating water levels vary with different shore types. The landward reach boundary is defined by the 1:100 year flood or erosion line (whichever is farthest landward), obtained and upgraded from the Great Lakes Flood and Erosion Prone Area Maps (Environment Canada and Ontario Ministry of Natural Resources, 1978). This boundary serves to identify the coastal zone terrestrial resources which are potentially at risk from erosion or flooding. An additional 200 metre landward buffer is added for future "what if" scenarios. The offshore reach boundary is defined by the 5 metre depth contour (calculated from hydrographic charts), which was

FIGURE B-5-2: LAND COVER/CURRENT USE DATA FOR A SECTION OF SHORELINE IN BANGOR TOWNSHIP

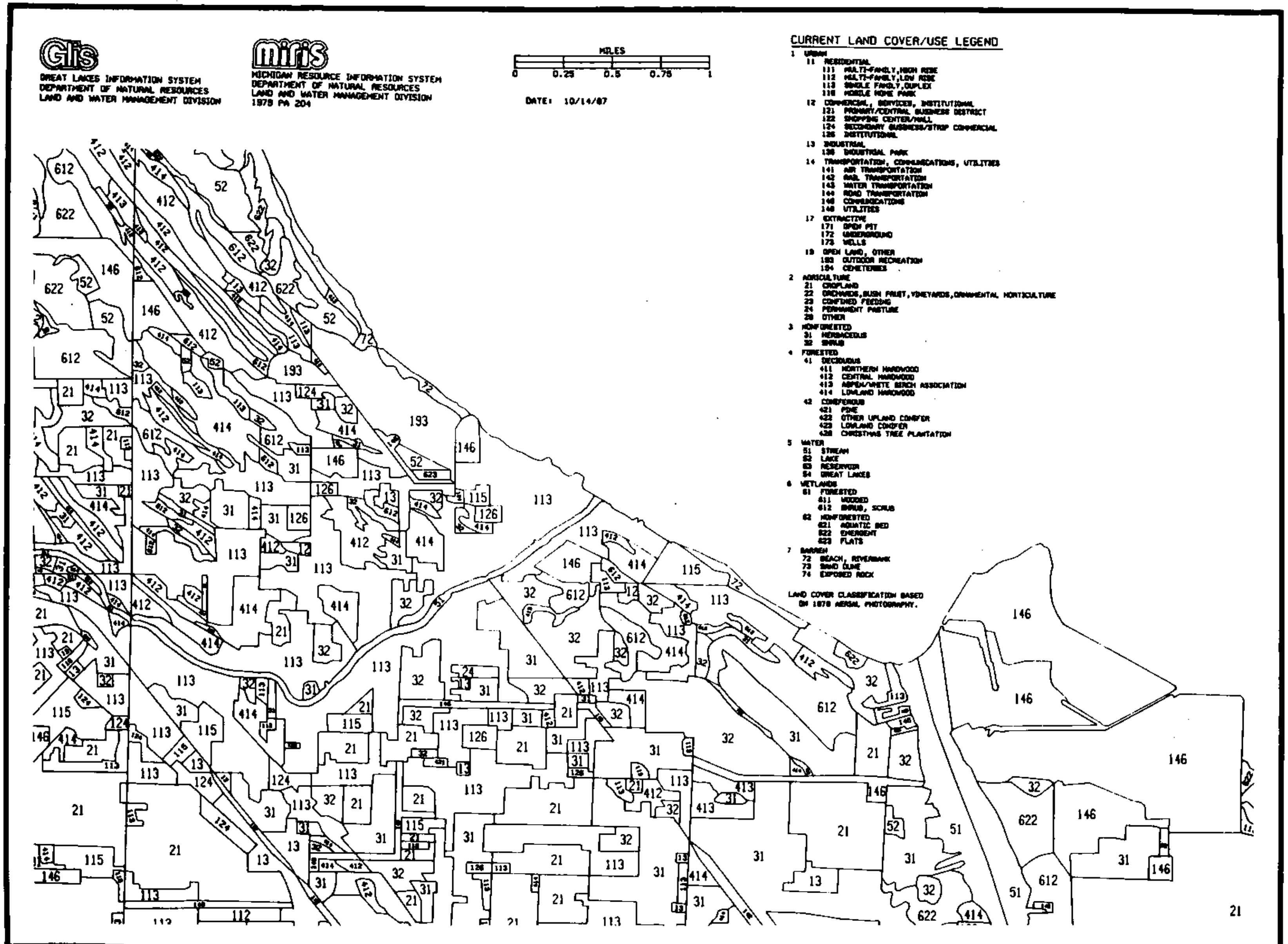
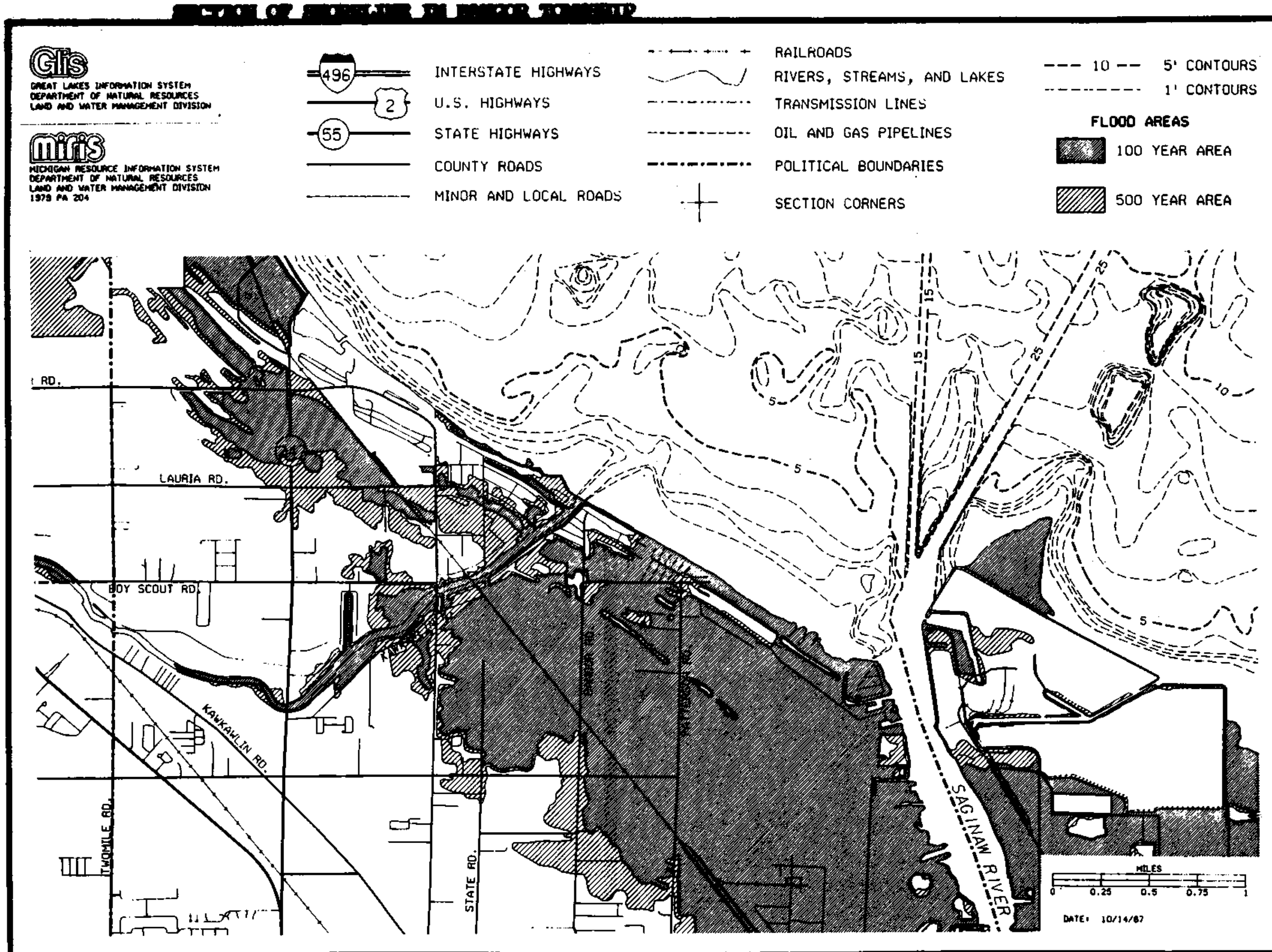


FIGURE B-5-3: COMPOSITE OF FLOOD HAZARD AREA AND LAKE BATHYMETRY FOR A SECTION OF SHORELINE IN BANGOR TOWNSHIP



accepted as the general lakeward extent of longshore sediment transport and limiting depth of light penetration and therefore fish rearing habitat. Figure B-5-4 provides a diagrammatic representation of some reach delineations. The GIS will show these areas in a simplistic image as demonstrated in Figure B-5-5.

REACH INFORMATION

A number of attributes associated with the physical location of the reach which are also important for process modeling are being compiled and entered into the GIS in a Lotus format.

Reach Location and Size

The ends of the reach are identified by latitude and longitude taken from the NTS maps. A reach number, lake/channel name association, and alongshore length are noted.

Reach Classification

Each reach has a backshore/foreshore classification. For example a reach would be classified as sand dunes behind a beach or a wetland behind a barrier spit. This information is obtainable from available air photos flown in 1985 and 1988, cross-referenced with the Coastal Zone Atlas (Haras and Tsiv, 1976).

Physiographic Information

For bluff reaches composed of consolidated materials, the average bluff height, recession rate, sand and gravel composition, and erosion volume are obtainable from a variety of sources including Boyd (1981), Coastal Zone Atlas (Haras and Tsiv, 1976), and various OMNR/Environment Canada studies. In addition, cross profiles for 162 erosion monitoring stations in the lower Great Lakes have also been obtained from the Great Lakes Erosion Monitoring Program (Boyd, 1981). Some of these profiles have been updated by OMNR and the Conservation Authorities. For beach/dune reaches, an average topographical elevation has been calculated.

Reach Fetch and Wave Energy

For each reach the aspect of the major fetch and the fetch for 8 major compass directions has been determined from NTS maps. Using hindcasting information obtained from the OMNR Wave Climate Database (Ontario Ministry of Natural Resources, 1988b), attempts are being made to calculate the wave energy of the major fetch and of the 8 major compass directions.

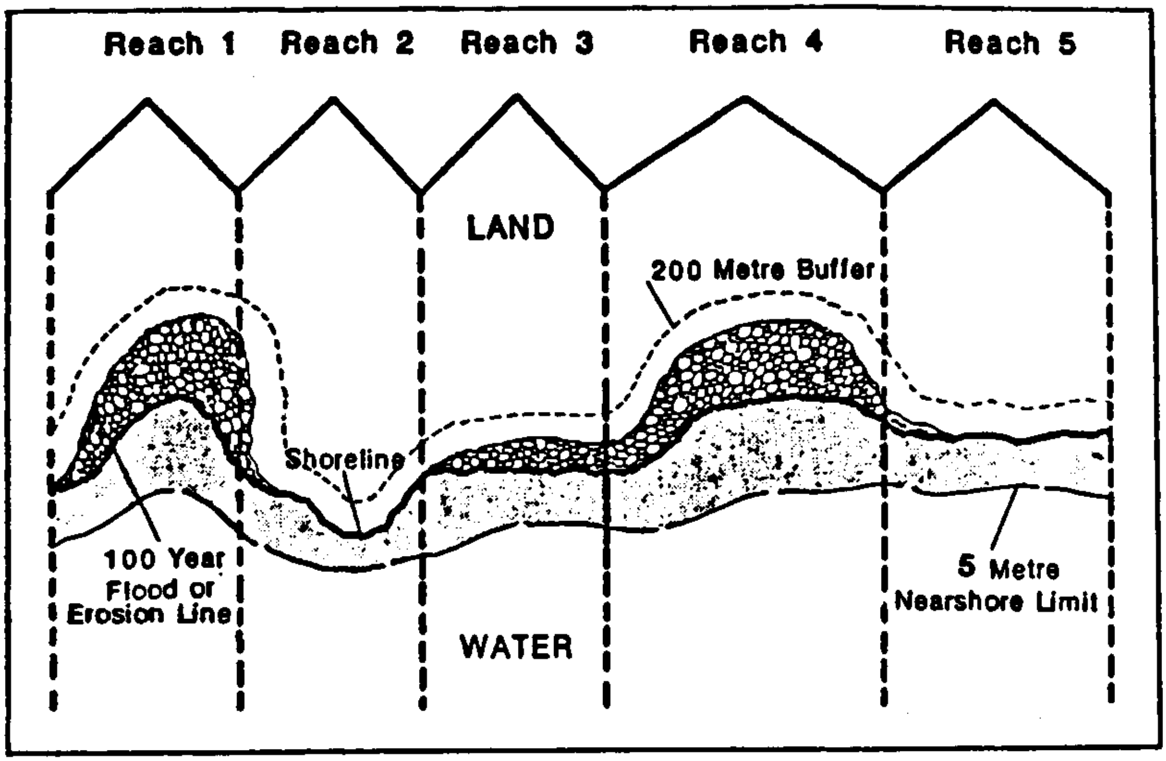
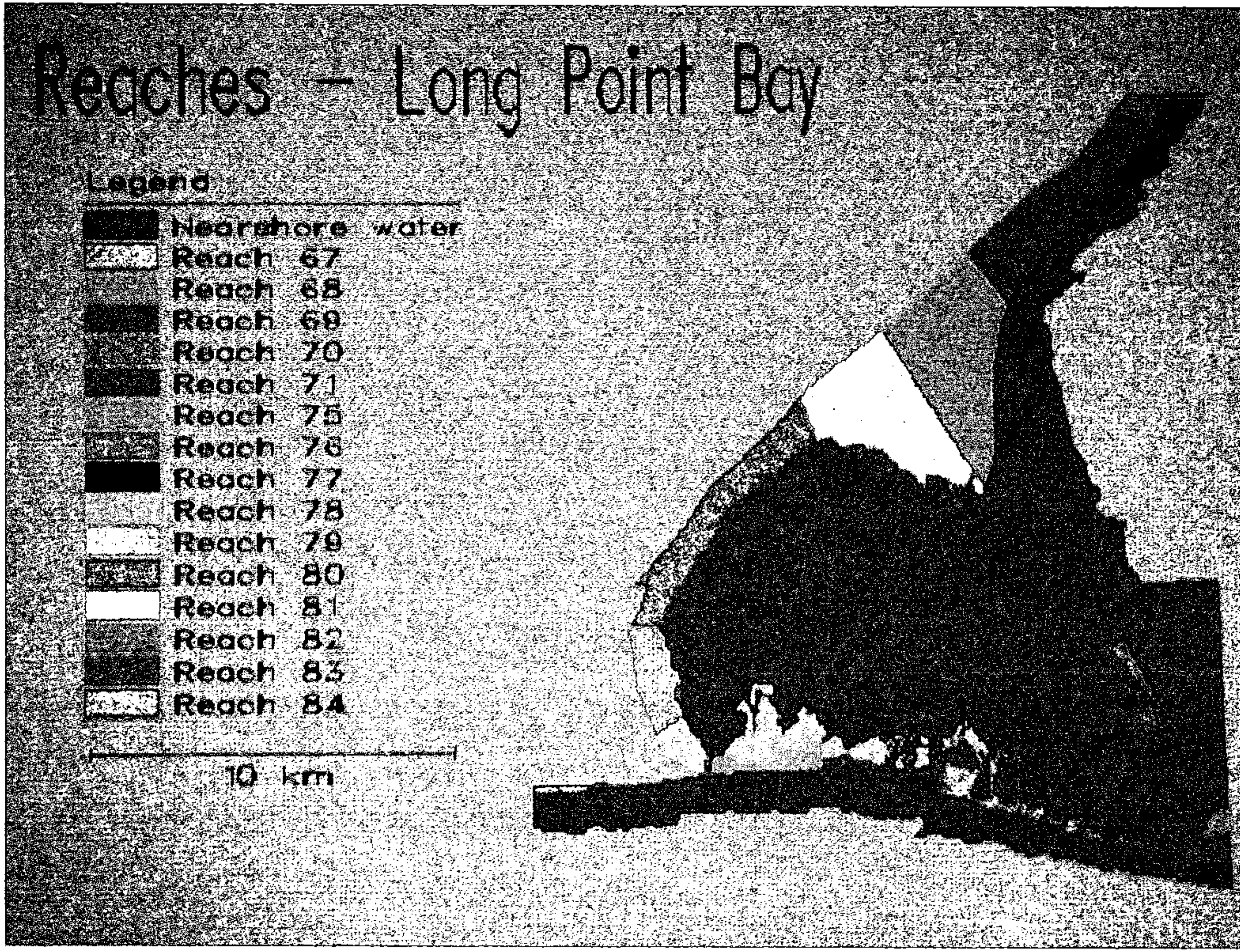


FIGURE B-5-4 SPATIAL EVALUATION FRAMEWORK (CANADA) - REACH DELINEATIONS

FIGURE B-5-5: GIS REPRESENTATION OF REACHES FOR LONG POINT BAY, LAKE ERIE



Offshore

Each reach is assigned a profile class. From NWRI nearshore and cruise information, 800 point measurements are being used to calculate and contour the percent composition of gravel, sand, silt and clay in the surface substrate, using a GIS. From hydrographic charts, the 2 and 5 metre offshore contour are also being mapped.

Sediment Volume

Using existing information and predictive equations, the sediment volume into and out of the reach is being calculated, as well as the proportion of sediment moving on/offshore. From previous studies and some limited modeling, an attempt is being made to obtain longshore sediment transport rates for littoral cells based on reach characteristics.

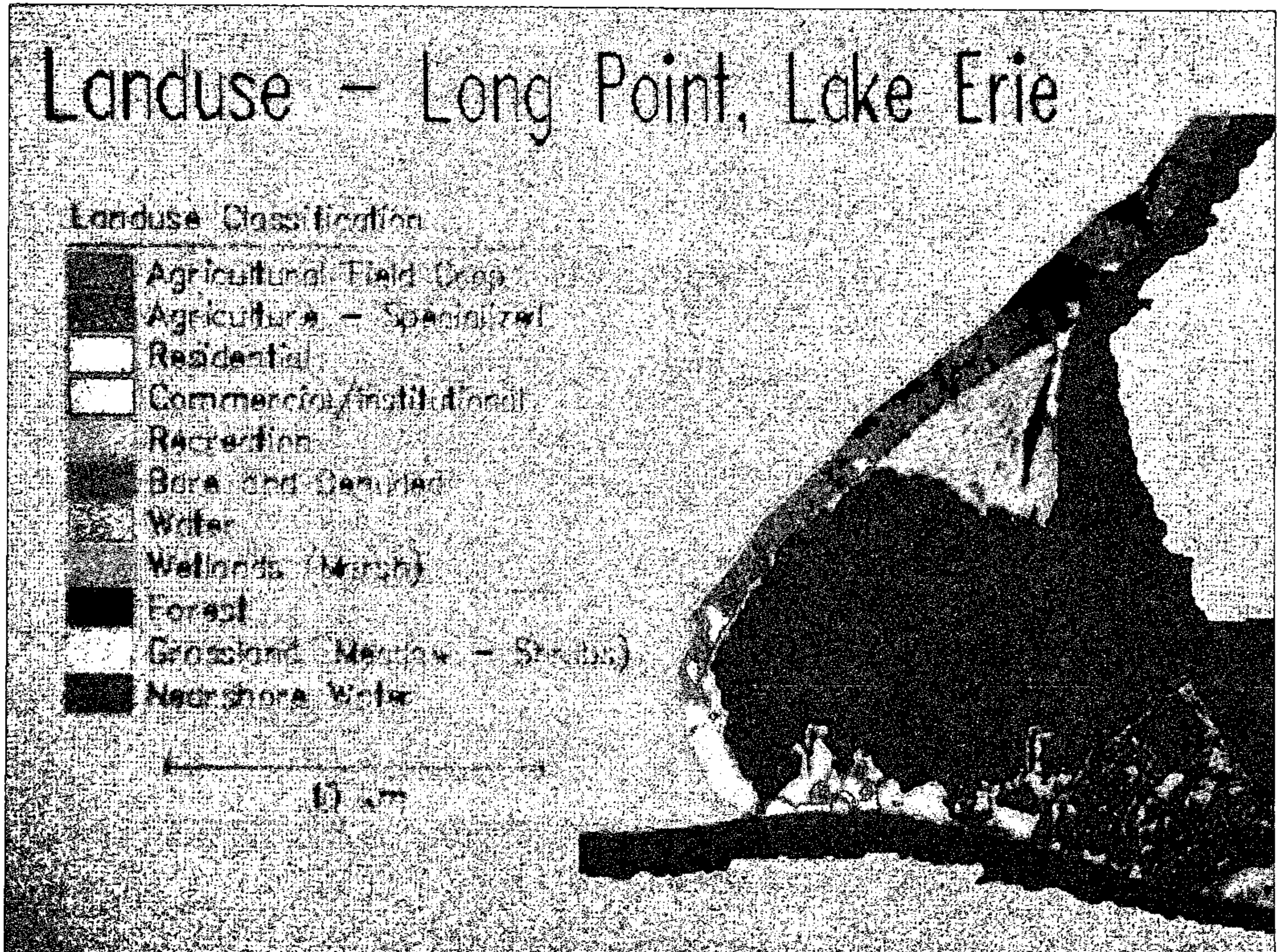
Reach Land Use

Land use coverage from 1:8000 scale air photographs flown in 1985 and 1988 is being mapped up to 1.6 kilometres inland onto the NTS topographic maps. Table B-5-2 lists the 13 land use classes used in this study. Figure B-5-6 is an example of land use coverage for a composite of five 1:25000 map sheets for the Long Point area, Lake Erie.

TABLE B-5-2: CLASSES OF LAND USE COVERAGE

CLASS	FOR EXAMPLE:
Agricultural Field Crops..........	corn, wheat, beans, grain
Agricultural Specialty Crops.......	tobacco, orchards, vineyards
Residential........................	all household dwellings
Commercial and Institutional......	businesses, schools, jails
Industrial.........................	automotive, hydro, petro-chemical
Transportation and Communications..	roads, canals, radio towers
Recreation.........................	marinas, parks, golf courses,
Extraction.........................	pits and quarries
Water..............................	ponds, streams, rivers
Wetlands...........................	see Table 5.3
Forest.............................	woodlot,
Grassland..........................	shrubs and immature forest
Barren/Denuded.....................	beaches, bare rock

FIGURE B-5-6: LAND USE - LONG POINT, LAKE ERIE



Wetland information obtained from CWS for Lake Erie and Lake Ontario has been mapped at a scale of 1:25000. Several vegetative zones and categories of wetland types (Table B-5-3) have been identified and associated with wetland locations.

TABLE B-5-3 WETLAND VEGETATION ZONES AND TYPES

Wetland Vegetation Zones	Wetland Type
-open water/floating leaved/submergent -emergent -sedge/meadow -shrub/tree	-open shoreline -unrestricted bay -shallow sloping beach -river delta -restricted riverine -lake-connected channel -protected

Reach Problem Class Code

Each reach is assigned a code indicating if the reach is susceptible to flooding and/or erosion. The code is determined by the 1:100 year flood and erosion lines. The percent of shoreline protected by shore protection works for each reach is also being compiled and summarized.

Aquatic Information

All known data presently available on the location of fish (spawning, juvenile and adult) habitat and migration routes for 50 fish species is being compiled and is being entered into the GIS data base.

5.3 APPLICATION OF THE GIS AND COASTAL ZONE DATA BASE

DESCRIPTION OF THE COASTAL ZONE

The GIS provides a means of generating comprehensive cross-sectoral pictures and tabular summaries of the coastal zone. Through the process of overlaying maps, the biophysical, human activity, wetlands, and aquatic components of the Great Lakes environment can be viewed in an integrative manner to identify and analyze those areas susceptible to fluctuating lake levels, flooding and erosion. The biophysical, wetlands and aquatic resources at risk within these hazard areas can be displayed, summarized and tabulated.

PROBLEM IDENTIFICATION AND ASSESSMENT OF THE IMPACT OF ACTIONS

The GIS has important application to assessing the impacts of measures or actions on the environment. The key component in this capability is the linked process sub-models describing wetlands, aquatic, terrestrial and process inter-relationships. From the linkages, induced or secondary impacts will be derived and feedback mechanisms which magnify or dampen impacts can be identified. Impacts can be identified at various scales, for example, a specific reach, littoral cell or even an entire lake.

The GIS can be used to address a number of questions, including the following:

- Which actions are viewed as potentially beneficial?
- Which areas have problems that can be controlled by this kind of action?
- Where are they located?
- What are the environmental impacts of implementing the action?
- Are there other actions that have lesser consequences or give better protection?
- What is the relative impact of actions on environmental factors?

These questions cannot be answered directly by the GIS but rather will be dealt with by professionals in various disciplines. The data base acts as a resource base and the GIS provides calculated results. This information will point to directions needing more detailed impact assessment or will identify areas where further information is required.

PUBLIC INFORMATION

The interactive GIS component can be useful for public consultation and education. Queries could be accommodated relatively quickly in both tabular and graphic formats.

The possibility also exists for interpreted results of various lake-level and action scenarios to be disseminated (in graphic form) to stakeholders or anyone with access to an IBM PC/AT compatible micro-computer. The possible applications of the GIS in public relations and education appear to be substantial.

5.4 PRELIMINARY APPLICATIONS OF THE GIS AND DATA BASE

Recently, attempts have been made to use the data base and the GIS to describe various components of the Great Lakes ecosystem, to address the potential for assessing the impacts of fluctuating water levels, and to assess possible remedial actions. This section outlines the preliminary findings of three applications. Although applications are not complete, preliminary results illustrate the potential utility of the GIS and the data base.

RESIDENTIAL BUILDINGS AND LAND USE IN THE FLOOD HAZARD ZONE

Through several overlays, it is possible to identify and visually illustrate the land use and residential structures located within the 1:100 flood and erosion hazard zones. Figure B-5-7 is a composite of five overlays for Turkey Point, Lake Erie. The overlays include the shoreline, 2 and 5 metre offshore contours, land use, location of residential buildings, and the 1:100 year floodline. From the figures it is apparent that 288, or 51%, of the residential buildings in the community of Turkey Point are located within the flood hazard zone and therefore potentially susceptible to flood damage. The GIS is also capable of providing tabular summaries of all attributes located within the flood hazard zone.

The modeling capabilities of the GIS enables the user to change the location of the floodline. The floodline can be altered by creating a new line or by simply defining a buffer of a known width from the existing floodline. The number of buildings and percent land use within the buffer, or for the entire flood-prone area, can then be tabulated and shown visually. The impacts of fluctuating water levels on existing resources can also be addressed in a similar manner. Future addition of property ownership and attributes into the database will greatly enhance the ability of the GIS to describe the impacts of future actions on the coastal zone.

The above information is obviously very useful to those interested in the coastal zone, such as shoreline managers and local planners. The images and tables produced could also be used to heighten public awareness of the hazard, not only among those already living in the area, but also those who may be considering living there in the future. This could potentially aid in reducing the element of surprise often expressed by riparian owners when lake levels rise to flood levels.

LONGSHORE SEDIMENT TRANSPORT IN A LITTORAL CELL

Using the modeling capabilities of the GIS and information contained within the coastal zone data base, it is possible to describe various coastal processes. In this example, the GIS is used to describe the longshore sediment transport process for a littoral cell. This type of information is necessary to assess the impacts of fluctuating lake levels and structural actions.

For this application, the Long Point littoral cell on the north shore of Lake Erie is used. The Long Point littoral cell is composed of 31 reaches (Figure B-5-8) that begin east of Port Glasgow and extend eastward to the tip of the Long Point sand spit.

An estimate of the amount of longshore sediment transport for each reach is determined by combining the amount of potential longshore transport with the amount of sediment supplied from the updrift reach and the amount of local sediment input (from erosion). From these estimates, the amount of sediment supplied to the Long Point spit is estimated to be approximately 570,000 cubic

FIGURE B-5-7: STRUCTURES IN FLOOD PLAIN, TURKEY POINT, LAKE ERIE

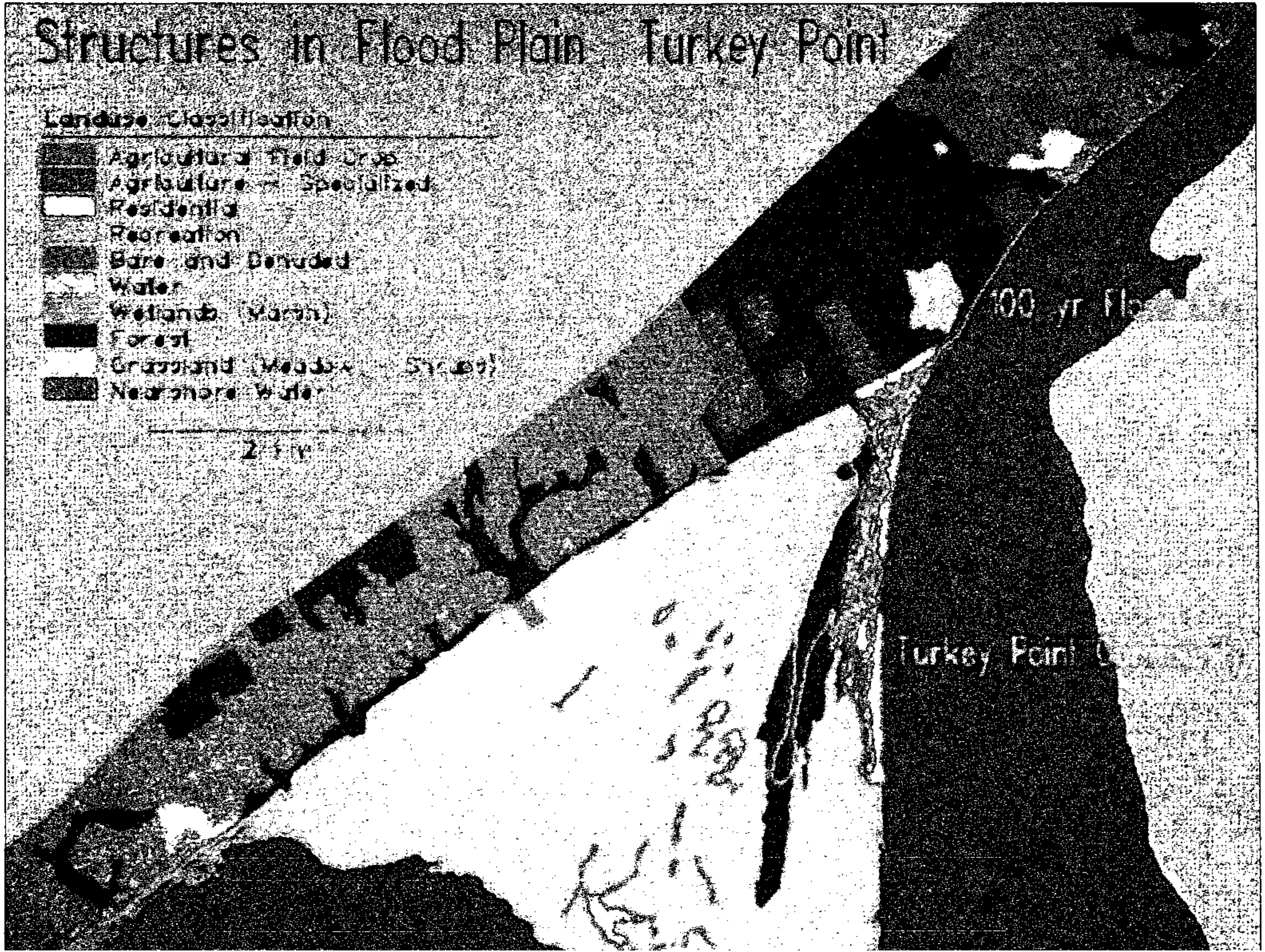
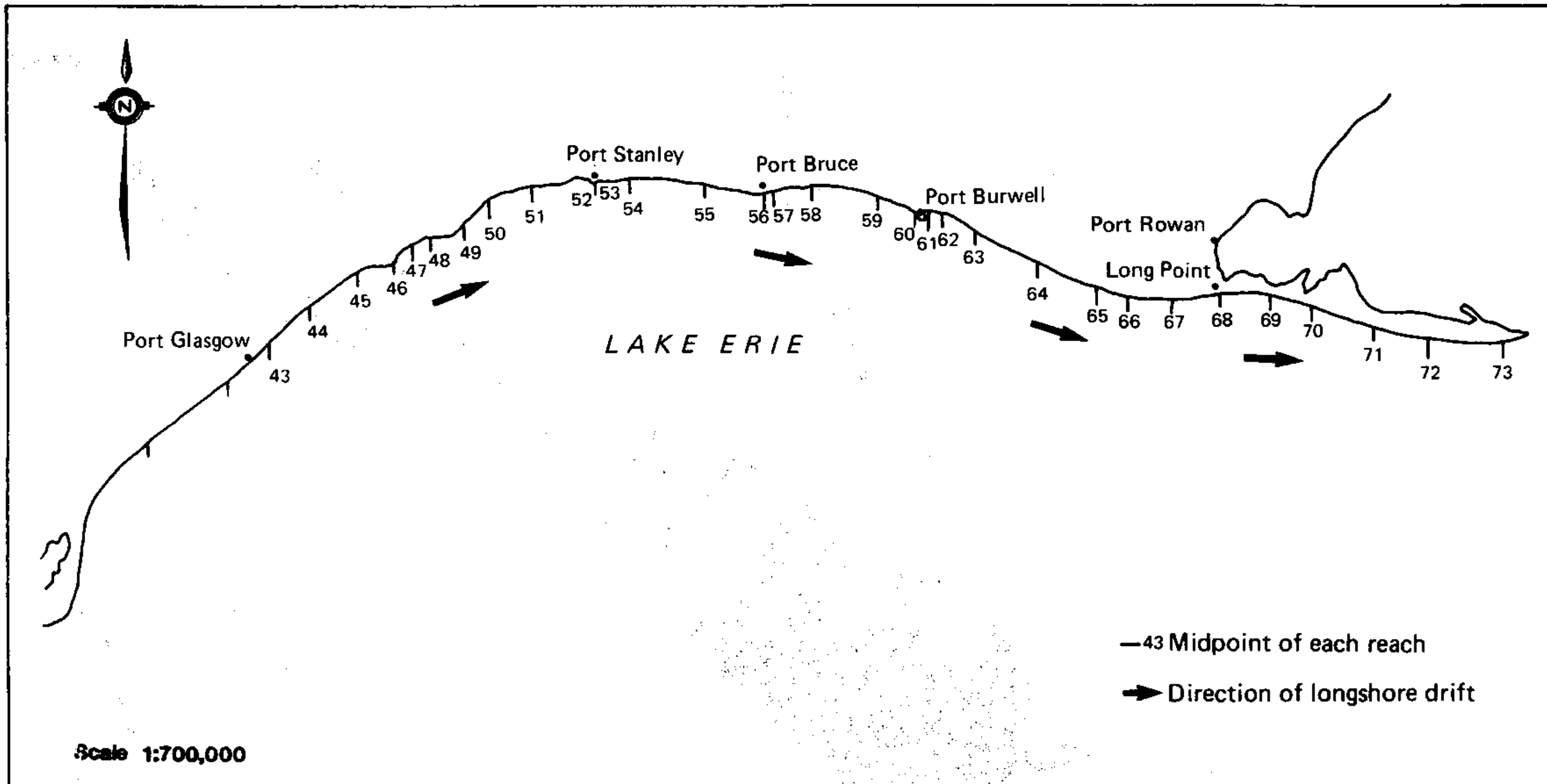


FIGURE B-5-8: LONG POINT (LAKE ERIE) LITTORAL CELL



metres per year. This figure is close to that found by Rukavina and Zeman (1987).

The potential amount of longshore transport was determined for each reach, using equations in the Shore Protection Manual (U.S. Army Corps of Engineers, 1984). The values obtained from these equations are not precise. However they do illustrate how the amount of potential longshore sediment transport will change with changes in shoreline orientation, shore type, and wave energy. The amount of sediment supplied to the littoral zone is estimated, taking into account the average height, average annual recession rate, length, and percent sand and gravel composition of the reach.

Initial calculations show that most of the sediment transported eastward from Port Glasgow is deposited in the fillet beaches of Port Stanley, Port Bruce and Port Burwell. Consequently, in this example, the amount of sediment transported to the Long Point sand spit is supplied from reaches 62 to 66, inclusive. The calculations for these reaches indicate that in reach 64, the amount of sediment available for transport (being a combination of updrift and local input) exceeded the possible potential sediment transport and therefore deposition occurred. This finding was verified by aerial photographs that showed persistent beaches in this reach. Calculations for reaches 62, 63, 65 and 66, however, indicated that the potential sediment transport exceeded updrift and local inputs, suggesting that these reaches are recessional and will not normally have adjacent beaches. This again was verified by aerial photographs. Consequently, the Long Point spit is supplied by very few reaches. Actions which adversely affect the sediment supply could potentially have large-scale impacts on the spit itself. Reaches 67 to 73 are located on the Long Point spit. The calculations suggest that reaches 67-70 are recessional while reaches 71-73 experience deposition.

IMPACT OF A DETACHED OFFSHORE BREAKWALL ON LONGSHORE SEDIMENT TRANSPORT

The purpose of this example is to illustrate how the GIS and the data base can be used to assess the impacts of structural actions on coastal processes. The figures obtained in the previous application are used to identify the impact of constructing a detached offshore breakwall on the sediment supply to the Long Point spit.

The hypothetical breakwall is located in front of the residential buildings on Long Point (Figure B-5-9). The purpose of the structure is to prevent storm and erosion damage caused by high waves. The basic assumptions in this example are quite simplistic. First the structure is shore-parallel, approximately 6500 metres in length, located in approximately 3 metres of water and 700 metres from shore. The volume of the nearshore zone landward of the breakwall was determined using the nearshore contours.

Since the breakwall prevents the onshore waves from reaching the land, the longshore current landward of the breakwall will diminish, causing deposition of updrift sediment in the lee of the breakwall. If all the sediment supplied to the reach containing the breakwall is deposited in the lee of the breakwall, it would take approximately 19 years to fill in (assuming no

FIGURE B-5-9: HYPOTHETICAL BARRIER ISLAND ON LONG POINT COMMUNITY

dredging or loss of sediment landward). In reality, the updrift portion would fill in first, then sediment would be deflected in front of and along the breakwall. Still, deposition of longshore sediment in the lee of the breakwall for even just one year would be of sufficient magnitude to increase the erosion rate drastically on the downdrift reaches.

The Long Point spit downdrift of the hypothetical breakwall location is composed of sand beaches and low dunes. Consequently, large increases in the downdrift reach erosion rates would soon lead to overwash and breaching of the spit. This would cause sediment to be redirected into Long Point Bay, reducing the amount of longshore sediment supplied to the adjacent downdrift reach(es). As a result, there would be an increase in the erosion rate of the adjacent downdrift reach(es).

5.5 SUMMARY

A major attribute of the Reference Study is the adoption of a strong spatial perspective. This perspective is important to describing effectively the environment of the Great Lakes - St. Lawrence River system, understanding more fully how terrestrial, wetland and aquatic environments function, and assessing adequately the impacts of fluctuating water levels and flows and of measures that might be taken in response to these fluctuations.

- Canadian and United States Geographic Information Systems (GISs) have been developed to capture, display, and allow analysis of spatially-defined data to identify and solve problems.

- Information captured in the GISs includes land use and physical and biological attributes of terrestrial, wetland and aquatic environments; information on both features and processes is included.

- The GIS effectively and efficiently integrates information on the natural and human components of the Great Lakes - St. Lawrence River system; its analytical capability facilitates a holistic evaluation of the consequences of natural processes and human actions; and its interactive and visual display capabilities makes it useful as a means of communicating with, and involving, the public.

SECTION 6

INFORMATION NEEDS AND INTERIM RESEARCH

6.1 INTRODUCTION

A number of information gaps must be addressed to identify and understand all of the impacts of fluctuating water levels and proposed measures on terrestrial, wetland and aquatic environments of the Great Lakes - St. Lawrence River system. Some of the information gaps relate specifically to simply being able to describe and spatially define the "current situation" of this system and its various environmental components. Other information needs relate to understanding the salient processes, including fluctuating water levels and flows, on the various terrestrial, wetland and aquatic environmental components. Some of these information gaps, in turn, limit our ability to assess the environmental impacts of proposed structural and nonstructural measures. Some of the information needs are presently being addressed by various terrestrial, wetland and aquatic studies already in progress; however, the results of these studies are not available for inclusion in this Annex.

Many of the information gaps identified through the course of Phase 1 were not addressed as Phase 1 activities. Consequently, Functional Group 2 is recommending a number of "interim" and Phase 2 projects that will address some of these gaps. The following proposals are preliminary and further proposals are expected.

6.2 GEOGRAPHIC INFORMATION SYSTEMS (GIS) AND SHORELINE DATA BASES

The GISs are being used as tools to integrate the environmental attributes used to describe the entire Great Lakes terrestrial, wetland and aquatic environments. The shoreline data bases will not be complete for the entire Great Lakes and connecting channels by the end of Phase 1. In addition, information on a number of environmental attributes does not exist, nor has it been compiled from existing reports. A large amount of the information needed to complete the data bases is described in the following proposals. The purpose of the following section, however, is to outline projects that will obtain information needed to assess the impacts of fluctuating water levels and proposed measures.

Presently, the Canadian shoreline in the data base is taken from 1:25000 and 1:50000 NTS map sheets that were compiled over a number of years. Consequently, the shoreline depicts a number of water levels. To assess the impacts of fluctuating water levels on the coastal zone, one or more shorelines obtained from the same "date" information must be used. A proposed Canadian project is to use aerial photographs taken in the same year for the entire Canadian Great Lakes shoreline. This will provide a "base" shoreline from which water-level fluctuations can be assessed. The American Great Lakes "base" shoreline is being taken from one set of aerial photographs flown in 1988.

NEARSHORE AND ONSHORE CONTOURS

To identify and assess the impacts of changes to coastal processes (and therefore the coastal zone) caused by fluctuations in water levels requires detailed contour information for both onshore and nearshore areas to be entered into the data bases. A proposed Canadian project is to obtain detailed contours from the ongoing Canada-Ontario Flood Damage Reduction mapping and nearshore contours from maps compiled by the Canadian Hydrographic Service. American sources of onshore contour information include the ongoing mapping by the Federal Emergency Management Agency (FEMA) and nearshore information from the proposed Great Lakes Shoreline Mapping Plan under the supervision of the National Oceanic and Atmospheric Administration (NOAA) and the United States Geological Survey (USGS) under Public Law 100-220.

WAVE REFRACTION

To assess the impacts of waves on the terrestrial, wetland, and aquatic environments in the coastal zone, a number of wave refraction projects must be undertaken for areas potentially susceptible to serious flooding and erosion.

SHORELINE STRATIGRAPHY

To understand the impacts of fluctuating water levels on shoreline environments, a detailed description of the Great Lakes shoreline stratigraphy is required. In addition, to determine long-term erosion rates (to assess both the sensitivity of shoreline areas to fluctuating water levels and the impacts of proposed actions), a knowledge of the inland stratigraphy is necessary. A proposed Canadian project is to obtain well and gas records for the Canadian shoreline which include detailed bore stratigraphy. This information can be spatially located using digital topographic maps (already obtained). A preliminary report on information sources and areas where bedrock is near the current water level has recently been completed (Karrow, 1989).

Recession rates for Great Lakes environments have to be verified and some re-examined to determine the impacts of proposed measures and water-level scenarios. This should be addressed using available aerial photographs and information already compiled; however, some ground truthing will be required. FG2 recommends a contract to compile the information and enter it into the GIS data base.

6.3 WETLANDS

At the end of Phase 1, the spatial location and extent of wetlands has been compiled for Lake St. Clair, the St. Clair and Detroit Rivers, the Niagara River and the St. Lawrence River (to Quebec), Lake Ontario, and Lake Erie. There is a need to complete the upper Lakes Coastal Wetlands Inventory, amalgamate the St. Lawrence River Wetland Information, and enter it into the GIS data base.

There is a need to identify significant wetlands where impacts should be evaluated. This could be done by amalgamating the present GIS inventory with existing Ontario Ministry of Natural Resources wetland evaluations.

Additional investigations to address the impacts and relationships between historical water-level fluctuations and wetland vegetation in specific locations are recommended by Functional Group 2.

To further our understanding of the impacts of water-level fluctuations on wetland vegetation communities, there is a need for detailed bottom contouring of site-specific areas. This will permit a better understanding of both past and present wetland locations and vegetation communities and allow prediction of future scenarios.

There is a need to explore further the interrelationships between wetlands, fish and wildlife, and water-level fluctuations. This basic information is needed before the assessment of any measures can take place.

6.4 SHORELINE MANAGEMENT

Many Functional Group 2 activities have found support for the adoption of non-structural measures, specifically shoreline management. The FG2 Shoreline Management Workshop held in Chicago (International Joint Commission Functional Group 2, 1989b) however, showed that there are many different interpretations of what "shoreline management" means and involves. Consequently, a number of proposals are recommended to clarify and assess the impact of shoreline management as a government action in addressing the water-level issue.

ASSESSMENT OF NON-STRUCTURAL SHORELINE MANAGEMENT MEASURES

To define the impacts of shoreline management, FG2 recommends an assessment of current non-structural shoreline management measures currently applied in the United States and, to a limited degree, in Canada.

The assessment should focus on three key areas. First, a common terminology for what shoreline management is and what it entails must be developed and adopted by the participating government agencies. Second, there is a need to identify and assess the various non-structural measures currently applied (e.g. their applicability to various shore types, the benefits to be realized, etc.). Third, all institutional barriers to implementation of non-structural shoreline management measures must be identified and their impacts determined.

FG2 recommends that the three key areas of analysis should be addressed through a series of small, issue-specific workshops held in various representative locations throughout the Great Lakes - St. Lawrence basin. The workshops should involve experts from the respective federal, provincial, state and local governments as well as academic and private organizations.

SHORELINE MANAGEMENT PROJECTS

For some areas in the Great Lakes, there is a need to develop and, in turn, assess conceptual shoreline management scenarios and plans. FG2, through its ongoing activities, has identified some of the most crucial areas and therefore recommends that the following be targeted in the interim and in Phase II.

1) Point Pelee, Lake Erie, Ontario
A sand spit environment threatened by a mosaic of human activities.

2) Stoney Creek, Lake Ontario, Ontario
A large section of the littoral cell armoured by shore protection works.

3) Southern Section of Saginaw Bay, Lake Michigan, Michigan
An extensive wetland area threatened by human occupation and encroachment.

4) Lake St. Clair, Ontario and Michigan
Extensive wetland areas backed by shore protection. A unique site due to the short fetches and ice conditions.

5) Wetland areas in Lake Ontario and Lake Superior
Assessment of lake regulation on wetland communities.

POTENTIAL DAMAGE SURVEY

An assessment of the potential for flood and erosion damages to structures and property is an important component in the evaluation of impacts of measures. FG2 has identified a number of critical locations for damage assessments.

6.5 AQUATIC HABITAT

A number of project proposals are recommended to identify spawning, juvenile and adult habitat, and to assess the impacts of fluctuating water levels and proposed actions on fish habitat.

Precise definition of the effects of water-level changes on fish habitat cannot be made without computation of the area of each habitat type lost or gained under various water-level regimes. The geographic information system should be applied to specific locations in the Great Lakes where sufficient data exist to make this kind of determination. Emphasis should be given to historically important spawning shoals. Substrate, depth information and the GIS can also be used to spatially define all potential fish habitat areas. These assessments would be checked by field crews.

A GIS is essential to data base consolidation, successful cause and effect modeling, and developing a fuller understanding of the processes operating at the population and community levels in the Great Lakes and their connecting channels, as influenced by water-level fluctuations.

The effects of sustained high or low water levels on dissolved oxygen content and volume of the bottom (hypolimnetic) waters of the central basin of Lake Erie requires investigation pertinent to suitability of this habitat as an over-summer sanctuary for coldwater fishes.

The effects of wave action on offshore spawning reefs, as influenced by water levels, requires examination. The importance of cleansing action in enhancing habitat quality of these reefs has been suggested, but quantitative evidence of such an effect is lacking.

Fish species most affected by water-level fluctuations are those that require shallow, protected areas for spawning and/or nursery habitat. These areas include coastal wetlands, tributary streams and edge habitat along the connecting channels and nearshore areas of the Great Lakes proper. Characteristics determining habitat quality of these areas require investigation.

Detritus appears to be a critical link in the food web of the connecting channels ecosystem. More emphasis needs to be given to research on energy flow and food web interactions in the connecting channels, with emphasis on detritus as influenced by water-level fluctuations.

Continued development of the ecosystem objective or indicator species concept (e.g., Hexagenia as an indicator of clean water and sediment) is needed to assess water quality and habitat status in the Great Lakes and their connecting channels.

Remedial action plans for the Areas of Concern include objectives for habitat restoration and rehabilitation. Habitat evaluations relative to the influence of water-level fluctuations in these areas are required. In particular, degraded areas that are slated for restoration should receive attention. Moreover, modification of existing engineering structures (e.g., breakwaters, piers, jetties, water intakes, and walls of confined disposal facilities) or construction of new ones should be evaluated for their ability to provide incidental habitat for fish and fish food organisms.

Fish migration routes should be mapped from existing information.

All digitized fisheries data compiled for the GIS during Phase I should be critically reviewed, and fisheries maps should be distributed to fisheries agencies for review.

Conditions suitable for fish habitat vary spatially and temporally in response to natural and human stresses. The GIS should be developed further to facilitate the identification of critical habitat and specifically where the adverse impact of measures can or cannot be mitigated.

SECTION 7

FINDINGS AND CONCLUSIONS

7.1 INTRODUCTION

The Great Lakes ecosystem is a complex, interrelated and interdependent set of environments that have been evolving since the departure of the Ice Age glaciers some 10,000 years ago. This ecosystem includes animals and plants, the land and water, and the various physical and biological processes that tie them together. It is essential to recognize that humans are also an integral part of this system. The effects they create, and the manner in which "nature" affects them, cannot be separated from the remainder of the system.

FG2, in its activities during the last 18 months of the Water Levels Reference Study, as well as through the training and experience of its diverse membership, has arrived at certain findings and conclusions regarding the Great Lakes ecosystem, the role of fluctuating water levels in it, and ways in which people can best fit into that system. In many cases, these conclusions are based on well-documented scientific research, some of it carried out within the context of the current study. In other cases, conclusions are based on a synthesis of professional judgment and experience in the natural and physical sciences, resource management, and environmental protection. Some conclusions call into question assumptions strongly adhered to by others, and many suggest areas where concentrated effort in Phase II of the study would greatly enhance our current understanding of Great Lakes water-level impacts and facilitate the assessment of potential government actions.

The specific findings and conclusions that follow are in no particular order. Their relative significance may vary over time, as well as between the different orientations and backgrounds of those who review, accept, or question them.

7.2 FINDINGS AND CONCLUSIONS OF FUNCTIONAL GROUP 2

1. Water-level fluctuations are an integral component of the Great Lakes ecosystem. The present environment, including human activity, has been shaped to varying degrees by the seasonal and longer-term water-level changes. Rather than viewing these fluctuations as simply an external force acting on the Great Lakes ecosystem, we need to recognize their stature as an important component of the system, as well as the linkages between water-level changes and the rest of the system.

2. Variations of levels over time and space have been a driving force in the creation, adaptation, and evolution of both life and landforms. From the standpoint of the natural environment, the consequences of water-level fluctuations are primarily beneficial, especially over time. Some elements of the Great Lakes' shores are nationally and internationally recognized as manifestations of certain eco-types that have been maintained by the historic

fluctuations of the Lakes. Fluctuations are important to terrestrial and aquatic habitats, but wetlands are especially dependent on both seasonal and long-term water-level changes to maintain their productivity, diversity, and resilience. While extremely high or low levels can have some adverse short-term effects on wetlands, even these conditions are needed over the longer term to periodically renew the plant and animal communities within them.

3. Coastal wetlands are a critical element of the ecosystem and a significant resource. They serve as important habitat for fish, waterfowl, and other wildlife, providing a major source of food and energy to adjacent land and water areas. Wetlands buffer the effects of land-based activity on water quality and, in turn, can help protect the shore from erosion and recession. They also directly and indirectly support numerous consumptive and nonconsumptive human uses.

4. Adverse consequences of water-level fluctuations have often resulted from a lack of human adaptation to their range. When levels are low, development pressures along the shore have been observed to escalate. Further, while structures are usually designed to meet historically experienced conditions, evidence now exists of greater variation over the long term. In fact, the recent (1985-86) high water period and current predictions of the consequences of the "greenhouse effect" emphasize that the historical range could be exceeded on either the high or low end.

5. Any attempt to modify the historic water-level regime will cause environmental change. Although we can predict with some confidence that a significant compression of the range of levels will have substantial adverse environmental effects, in most other scenarios the impacts will be more difficult to predict, may take years to become evident, and may not be reversible once detected. A large share of the adverse effects of lake levels on human activity are the result of storms which, while becoming easier to predict, are clearly beyond human control.

6. Water-level fluctuations have little influence over the long-term rate of recession for many shore types. The shores of the Great Lakes are geologically very young and still undergoing substantial change. A dynamic equilibrium exists between the land and water. Water-level increases (especially those due to storms) will temporarily increase the rate of erosion, just as water-level decreases will temporarily reduce it. However, due to the dominant influence of waves, the shore and nearshore profiles will re-adjust over time and equilibrium will be restored. In fact, the most active erosion areas may adjust the fastest to water-level change, with recession rates quickly (in relative terms) returning to the long-term average.

7. Given the low likelihood of "full regulation" of the Lakes, non-structural measures are an especially appropriate means to address the adverse consequences of fluctuating water levels on human activity over the long term. Non-structural measures adapt human activity to the variability of the system. Such measures are usually less costly and more adaptable to changing circumstances than their structural counterparts. Structural approaches (lake regulation, shore protection) are attempts by people to control processes that, over time and space, are beyond our ability to shape substantially.

Structural measures also have effects, often adverse, on the physical and biological components, including important processes, that define the Great Lakes ecosystem. "Control" of fluctuations shifts change elsewhere within the system (e.g. increasing the variability of flow in the connecting channels). Reduced variation in lake levels will not substantially affect long-term recession rates in many shore areas, nor will it eliminate flooding due to storms or the need to periodically dredge navigation channels. Many structural measures require a substantial investment, which over time may find itself, as well as the development it was designed to protect, in harm's way. The "false sense of security" that has plagued many flood control projects may lead to greater encroachment into the hazard area and ultimately, in the absence of some action to increase the level of protection even further, to greater damages than those that occurred before the project was built.

8. <u>In spite of their recognized advantages (and being recommended numerous times in past government reports), non-structural measures remain difficult to put into practice and, with some notable exceptions, lack widespread public acceptance.</u> This may be the result of a number of social, economic, and political conditions. It seems to be "human nature" to resist limits on our activities. We prefer to act in ways that increase our vulnerability to natural phenomena, rather than change our behaviour to be consistent with the physical and biological processes around us. While recommending non-structural measures, governments have not abandoned the consideration of increased lake-level regulation as a viable approach. As long as this option remains (or at least until the limits of acceptable lake-level regulation are clearly identified), many who live on the shore or use the Lakes will perceive non-structural measures as burdensome on them and will resist their adoption or effective implementation. The constraints on greater acceptance and use of non-structural measures need to be better understood.

9. <u>The environmental (and socio-economic) implications of water-level fluctuations, and of measures proposed to address them, are best understood in a spatial context.</u> The ecosystem, as well as the composition and views of the "interests", vary from one part of the Great Lakes - St. Lawrence basin to another. The magnitude and complexity of the system cannot be appreciated without a comprehension of its geography. Many consequences of water-level fluctuations and impacts of measures have localized elements that differ from Lake to Lake or even from one shoreline reach to another. Within this spatial context, we need sufficient basic information to disclose the interconnectedness of the biophysical processes and other ecosystem components. Without an improved understanding, our assessments of impacts will remain largely anecdotal rather than systematic. In other words, we will continue to have to extrapolate a relatively few "knowns" over broad areas at no small risk of being substantially wrong. Detailed, site-specific data throughout the basin, on the other hand, is neither possible now nor likely to become available in the foreseeable future. However, we must improve our understanding of many environmentally sensitive and flood and erosion susceptible areas so, regardless of whether accurate quantification throughout the system ever becomes a possibility, we can at least predict the direction and potential significance of impacts.

10. <u>The maintenance of environmental integrity is an essential element of sustaining an adequate standard of living over the long term.</u> Maintaining, enhancing and restoring environmental integrity is not just an "environmental" criterion useful to the evaluation of measures responding to fluctuating water levels. The sustainability of critical biological and physical processes is key to our sense of well-being and, ultimately, to our very survival. An ecosystem that is highly productive, demonstrates substantial diversity, retains its resiliency to recover from adverse impacts of human activity and natural events, and is not subjected to excessive contamination or to the introduction of potentially harmful exotic species, can continue to serve us well into the future as a life-support system. We are indeed a part of the natural systems of this planet, and we cannot escape the individual and cumulative consequences of our actions that impinge on the ecosystem of the Great Lakes.

This view argues for evaluating any measure against a minimum threshold of acceptability for environmental integrity, and perhaps a similar approach for the other criteria as well. It is difficult to conceive of any measure being found acceptable if it scores poorly on any criterion. Above a certain threshold level, trade-offs between criteria may be acceptable.

7.3 PRELIMINARY RECOMMENDATIONS

1. In the use of "core criteria", such as economic sustainability and social desirability to evaluate proposed measures, there needs to be an established minimum of acceptability of all measures against the core criteria before measures are subject to further evaluation. This includes decisions on "weighting" of criteria or "trade-offs" between criteria. A measure that, for example, has a poor score on maintenance of environmental integrity should, in our judgment, receive no further consideration regardless of how well it might score on one or more of the other core criteria.

2. Governments must act to reduce or eliminate confusion over the relationship between fluctuating lake levels and various related physical and biological processes. In particular, there needs to be a clearer recognition outside of the scientific community of the relative independence of long-term shoreline recession in many areas of the Great Lakes from water-level changes. There also needs to be a recognition that the existing environment of the Lakes, which many people find especially appealing and upon which many people depend for a living or for their quality of life, has been shaped by and continues to respond to the variation in water levels.

3. To the extent that the relationship between lake levels and environmental processes is unknown or insufficiently understood, governments need to devote time and resources to improving the knowledge base upon which decisions regarding proposed measures might be made. Shore erosion, wetland rejuvenation, and the creation and alteration of nearshore depositional features are all processes that must be understood more fully by the public and by many decision-makers. Efforts in Phase II must focus on increasing awareness of these critical areas, particularly on a site-specific basis.

4. There must be a clearer understanding of the limitations, including potentially substantial adverse environmental effects, of structural measures, whether for increased regulation of lake levels or for increased armoring of the shoreline. In addition, a more effective approach to the use of non-structural measures needs to be taken. Governments have already been advised several times that shoreline management is an essential part of any effort to deal with the adverse consequences of water-level fluctuations on human activity. Without a clearer understanding of the constraints that continue to inhibit the use of these measures and a commitment to begin to overcome them, further recommendations to consider their use will sound hollow. Because large-scale (or "full") regulation of the Lakes is not deemed likely to occur, the time is appropriate to shift the focus from control to adaptation.

5. Analyses of the impacts of measures need to be done in a spatial context and with a data base that permits the analysis to proceed without questionable assumptions. The GISs being developed by FG2 are an appropriate tool for use in more detailed evaluation of measures in Phase II, and the development and refinement of these systems should continue.

6. This Reference Study should advocate taking a long-term view in determining the consequences of water-level fluctuations, the relationship between human activity and the processes at work in the Lakes and along their shores, and the ultimate dependence of large numbers of people on the continued functioning of that system over time. It is not prudent to take actions that accept long-term problems as a trade-off for apparent short-term gain. Instead, society should be encouraged to seek solutions to problems that do not create a serious risk of harmful environmental and social consequences in the future.

APPENDICES

APPENDIX B-1: GLOSSARY OF TERMS

Accretion: The natural or artificial volumetric addition of shoreland material. Natural accretion is the build-up of land, solely by the action of the forces of nature, on a beach by deposition of sediment by water. Artificial accretion is a similar build-up of land by human actions, such as the accretion formed by a groin, breakwater, or beach fill deposited by mechanical means.

Aeolian: Created or shaped by wind.

Anadromous: A fish species which, after living most of its life cycle in one of the Great Lakes, travels up a tributary stream to spawn.

Angiosperm: Flowering plant.

Anthropogenic: Of human origin.

Average Water Level: See Monthly Mean Level

Backshore: Upper shore zone beyond the reach of ordinary waves and tides; One or more nearly horizontal surfaces called berms formed landward from the beach crest.

Backslope: The landward border of a wetland or other shoreline feature; refers to a gradual (gentle) or steep slope of the land.

Barrier beach: Refers to a single elongate sand ridge rising slightly above the waterline and extending generally parallel with the coast, but separated from it by a small bay, or body of water. The beach absorbs the energy of waves breaking on the shore, thus protecting low-lying areas.

Basin (Great Lakes - St. Lawrence River): The surface area contributing runoff to all of the Great Lakes and the St. Lawrence River downstream to Trois Rivieres, Quebec.

Basin: The rounded depression of a lake bed.

Bathymetry: The measurement of depths of water in oceans, seas and lakes; also information derived from such measurements.

Beach: The zone of unconsolidated material that extends landward from the average annual low water level to either the place where there is marked change in material or physiographic form, the line of permanent vegetation, or the high water mark.

Beneficial Consequence: Positive implication of fluctuating water levels for social, economic, environmental or political investments.

Bioaccumulate or Biomagnify: An increasing concentration of a substance in organisms at progressively higher levels in a food chain.

Bioindicators/Indicator Species: Organisms that can be monitored to detect changes in environmental conditions, such as water quality.

Bluff: A steep bank or cliff of variable heights, composed of glacial tills and lacustrine deposits consisting of clay, silt, gravel and boulders.

Bog: A wetland with spongy ground, often a filled-in lake composed primarily of dead plant tissues (peat), principally mosses.

Breakwater: An offshore barrier to break the force of waves, which affords shelter to shore structures.

Climate: The sum total of meteorological phenomena over a period of time which combine to characterize the average and extreme condition of the atmosphere at any place on the earth's surface.

Closed-state wetlands: A wetland characterized by very dense growth of emergent vegetation with little or no open water present.

Coastal Zone Data Base: Information on the various attributes of the key components of the Great Lakes ecosystem, gathered and stored in a GIS.

Cohesive: Unconsolidated material which is held together primarily by electrical charges on the soil particles rather than by intergranular friction.

Commercial Fishing: Commercial fishing interests use the Great Lakes habitat and shore access services to earn income and sustain a lifestyle from sale of fish and fish products.

Connecting Channels: A natural or artificial waterway of perceptible extent, which either periodically or continuously contains moving water, or which forms a connecting link between two bodies of water. The Detroit River, Lake St. Clair and the St. Clair River comprise the connecting channel between Lake Huron and Lake Erie. Between Lake Superior and Lake Huron, the connecting channel is the St. Marys River. The Niagara River connects Lake Erie and Ontario.

Consumptive Use: The quantity of water withdrawn or withheld from the Great Lakes and assumed to be lost or otherwise not returned to them, due to evaporation during use, leakage, incorporation into manufactured products or otherwise consumed in various processes.

Contaminant: A substance foreign to a natural system or present in unnatural concentrations.

Control Works: Hydraulic structures (channel improvements, locks, powerhouses, or dams) built to control outflows and levels of a lake or lake system.

Crenulated: Having small folds, notches, or indentations; wrinkled.

Criteria: A principle or standard by which a judgement or decision is made. Criteria are conceptual but must have operational (measurable in principle) components. Any single criterion can be used to compare the merit of measures or policies along the dimensions encompassed by the criterion. Criteria are used to assess measures and criteria are used to assess the decision making process (for example, group access to the decision making bodies).

Criteria, Core: The broad principles upon which the overall value of any measure can be assessed relative to other measures. They include economic sustainability, environmental integrity, social desirability, uncertainty and risk, political acceptability and implementability, and equitability.

Criteria, Operational: These criteria are sub-sets of the core criteria. These sub-criteria are quantified on the basis of the application of specific group rules to data or estimates of impacts of the measure. Impact assessments used to score sub-criteria are ultimately used to compare the profiles of measures.

Crustal Movement: The change in elevation of the earth's surface at a location with respect to another location. Crustal movement is expressed as a differential rate of change in elevation over time.

Current: The flowing of water in the lakes caused by the earth's rotation, inflow and outflows, and wind.

Cusp: One of a series of naturally formed low mounds of beach material, separated by crescent-shaped troughs spaced at regular intervals along the beach.

Denitrification: The reduction of nitrogen compounds to a state of lower oxidation.

Depositional zones: Areas where water currents are low enough to allow accumulation of suspended materials.

Detritus: An accumulation of organic debris from decomposing plants and animals.

Digitizing: The manual tracing of spatial information on a map using an electronic cursor which converts map features to co-ordinate values.

Dike (Dyke): A wall or earth mound built around a low-lying area to prevent flooding.

Diurnal Tide: A tide with one high water and one low water in a tidal day.

Diversions: A transfer of water either into the Great Lakes watershed from an adjacent watershed, or vice versa, or from the watershed of one of the Great Lakes into that of another.

Dune: A low hill, ridge, or bank of sand created by wind action.

Drainage Basin: The area that contributes runoff to a stream, river, or lake.

Drawdown: A lowering of the water level to expose the bottom sediments.

Dynamic Equilibrium: The state whereby a shoreline is actively eroding or accreting but maintains its overall geometric form.

Ecology: The science which relates living forms to their environment.

Economic Sustainability: The objective of maintaining, at a minimum, the existing level of economic activity within the Great Lakes-St. Lawrence River Basin. Economic growth and development can be realized through greater productivity in the application of existing economic and natural resources so that these goals are not achieved at the expense of environmental, social, and cultural resources of significant value to society.

Ecosystem: A subdivision of the Biosphere with boundaries arbitrarily defined according to particular purposes. An ecosystem is a dynamic totality comprised of interacting living and non-living components. The Great Lakes-St. Lawrence River Basin Ecosystem is an example which encompasses the interacting components of sunlight, air, water, soil, plants, and animals (including humans), within the Basin.

Emergent: Erect, rooted, herbaceous angiosperms that may be temporarily to permanently flooded at the base but do not tolerate prolonged inundation of the entire plant, e.g. bullrushes.

Empirical: Relying or based solely on experiment and observation rather than theory.

Environment: Air, land or water; plant and animal life including man; and the social, economic, cultural, physical, biological and other conditions that may act on an organism or community to influence its development or existence.

Environmental Gradient: The variation in an environmental condition between two or more locations.

Environmental Integrity: The sustenance of important biophysical processes which support plant and animal life and which must be allowed to continue without significant change. The objective is to assure the continued health of essential life support systems of nature, including air, water, and soil, by protecting the resilience, diversity, and purity of natural communities (ecosystems) within the environment.

Epilimnion: The warm, upper layer of a lake that occurs during stratification.

Equitability: The assessment of the fairness of a measure in its distribution of favorable or unfavorable impacts across the economic, environmental, social, and political interests that are affected.

Erosion: The wearing away of the shoreline and lake or river bed by the action of waves and currents, and other natural processes.

Eutrophic: Waters high in nutrient content and productivity arising either naturally or from agricultural, municipal, or industrial sources; often accompanied by undesirable changes in aquatic species composition.

Eutrophication: The process of nutrient enrichment that results in high productivity.

Evaluation: The application of data, analytical procedures and assessment related to criteria to establish a judgment on the relative merit of a measure, policy or institution. Evaluation is a process which can be conducted both within formal studies and by separate interests, although different data, procedures and criteria may be employed in the evaluation by different interests.

Evapotranspiration: Evaporation from water bodies and soil and transpiration from plant surfaces.

Exotics/Exotic Species: Species that are not native to the Great Lakes and have been intentionally or inadvertently introduced into the system.

Fen: Sedge-dominated peatlands; often with shrub cover and sparse trees, (white cedar or tamarack) with water less acidic than bogs. Usually very slow internal drainage through seepage.

Fetch: The distance over which waves are generated by a wind having a generally constant speed and direction.

Flooding: The inundation of low-lying areas by water.

Fluctuation: A period of rise and succeeding period of decline of water level. Fluctuations occur seasonally with higher levels in late spring to mid-summer and lower levels in winter. Fluctuations occur over the years due to precipitation and climatic variability. As well, fluctuations can occur on a short-term basis due to the effects of periodic events such as storms, surges, ice jams, etc.

Food chain (web): The process by which organisms in higher trophic levels gain energy by consuming organisms at lower trophic levels; the dependence for food of organisms upon others in a series beginning with plants and ending with carnivores.

Foreshore: Lower shore zone, between the ordinary low and high water levels.

Geographical Information System (GIS): A computer-based "tool" which captures, displays and manipulates geographically referenced data.

Geomorphology: The field of earth science that studies the origin and distribution of landforms, with special emphasis on the nature of erosional processes.

Greenhouse Effect: The warming of the earth's atmosphere and associated meteorological effects due to increased carbon dioxide and other trace gases in the atmosphere. This is expected to have implications for long-term climate change.

Groundwater: Subsurface water occupying the zone of saturation. In a strict sense, the term is applied only to water below the water table.

Groundwater recharge: The addition of water to the zone of saturation by percolation or other means.

Gullies: Deep, V-shaped trenches carved by newly formed streams, or groundwater action, in rapid headward/forward growth during advanced stages of accelerated soil erosion.

Hazard Land: An area of land that is susceptible to flooding, erosion, or wave impact.

Herbaceous: Soft-stemmed; no persistent parts above the ground; distinct from woody species such as shrubs and trees.

Herpetofauna: Reptiles and amphibians.

Homeostatic: The attribute of automatically compensating for external environmental change in a manner that restores or maintains equilibrium.

Hydraulic retention time: The theoretical length of time water is held in a lake basin before being totally replaced.

Hydric soil: Soil that is wet long enough to produce anaerobic conditions, thereby influencing the growth of plants.

Hydrodynamics: A branch of science that deals with the motion of fluids and the forces acting on solid bodies immersed in fluids and in motion relative to them.

Hydrology: The applied science concerned with the water of the earth in all its states.

Hydrometeorology: A branch of science concerned with the study of the atmospheric and land phases of the hydrological cycle, with emphasis on the interrelationships involved.

Hydrophyte: Any plant growing in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content.

Hypolimnion: The cold, dense lower layer of water in a lake that occurs during stratification.

Ice Boom: A structure installed to aid in the formation and maintenance of an ice arch at the head of a river, thus reducing the adverse effects of ice on river levels and flows.

Ice Jam: An accumulation of river ice, in any form which obstructs the normal river flow.

Ice Retardation: The difference between the amount of water discharged at given lake and river stages under open water conditions and under ice conditions.

Infiltration: Movement of water through the soil surface and into the soil.

In-place Pollutants: Pollutants in the botton sediments of a river or lake.

Institution: An organization of governmental units which have the authority and ability to facilitate and/or make decisions affecting the water levels issue.

Interests: Any identifiable group, including specialized mission agencies of governments which (1) perceive that their constituents'/members' welfare is influenced by lake level fluctuation or policies and measures to address lake level fluctuation, and which (2) are willing and able to enter the decision making process to protect the welfare of their constituents/members.

International Joint Commission (IJC): A binational Commission created under authority of the 1909 Boundary Water Treaty. The IJC has three primary functions: 1) quasi-judicial, with responsibility for approving applications to affect natural flows or levels of boundary waters; 2) investigation of matters at the request of the two governments, with the limitation that resulting recommendations are not binding on the governments, and can be modified or ignored; 3) surveillance/coordination, through monitoring or coordinating the implementation of recommendations, at the request of the governments.

Interspersion (of vegetation): In the case of vegetation, the property of diverse species being scattered throughout an area along with patches of unvegetated areas.

Invertebrate: Animal which does not have a backbone or spinal column (e.g. amoeba, worms, snails, flies).

Isostatic Rebound: The gradual uplift of landmass following removal of the ice sheets. Results in a relative change between land elevation and water level.

Jurisdiction: The extent or territory over which authority may be legally exercised.

Lacustrine: Associated with a lake environment.

Lag Deposit: Residual accumulations of coarser particles from which the finer material has been blown away.

Lake Outflow: The amount of water flowing out of a lake.

Lake Year: A hydrologic year considered to begin in August.

Littoral: Pertaining to or along the shore, particularly to describe currents, deposits and drift.

Littoral Cell: An area under the continuous influence of specific longshore currents.

Littoral Drift (Longshore Sediment Transport): The movement of sediment along beaches and in the nearshore zone by the prevailing currents and oblique waves.

Littoral Zone: The area extending from the outermost breaker or where wave characteristics significantly alter due to decreased depth of water to: either the place where there is marked change in material or physiographic form; the line of permanent vegetation (usually the effective limit of storm waves); or the limit of wave uprush at average annual high water level.

Loading: Total mass of a pollutant discharged to a water body over a specified time; e.g. tons per year of phosphorus.

Lotic: Of, relating to, or living in flowing water, as in a river or stream.

Macrobenthos: Bottom dwelling invertebrates that are large enough to be seen with the un-aided eye.

Macrophyte: A plant large enough to be seen with the un-aided eye.

Marsh: An area of soft, wet or periodically inundated land, generally treeless and usually characterized by grasses and other low growth.

Measures: Any action, initiated by a level(s) of government to address the issue of lake level fluctuations, including the decision to do nothing. NOTE: Measures are defined by three elements. The first element is the specific investment or action intended to affect the land and water resource and/or the human use of the land and water resource. The second element is the manner in which the socio-economic cost burden for an action is distributed (i.e. who pays?). And the third element refers to the implementing authority (i.e. who is responsible for executing and enforcing the action). Actions have been classified into six types:

> Type 1 - Regulation and Diversions: Any engineering action which can alter Great Lakes water supplies, water levels and flows.
>
> Type 2 - Land and Water Adaptations: Actions which involve government investment to adapt to or modify local land and water use in an effort to adapt to water-level fluctuations and natural shore processes.

Type 3 - Restrictions on Land and Water Use: Actions whereby governments restrict how interests may use the land and water of the Great Lakes Basin.

Type 4 - Programs to Influence Use: Public programs and policies to provide information and alter financial incentives to influence the ways in which interests make decisions about the use of the land and water.

Type 5 - Emergency Response: Actions by governments to emergency situations. These are short-term measures to ease immediate problems.

Type 6 - Combinations: Two or more of the above types of actions combined to address the issue of fluctuating water levels.

Measures, Non-Structural: Any measure that does not require physical construction.

Measures, Structural: Any measures that require some form of construction. Commonly includes control works and shore protection devices.

Median: The middle value of a series; Half of the items are larger and half of the items are smaller.

Mesotrophic: Waters with intermediate levels of nutrients and productivity.

Metabolic: Related to the processes in living organisms by which assimilated material is built up into cell material or cell material is converted to energy.

Meteorological: Pertaining to the atmosphere or atmospheric phenomena; of weather or climate.

Methylation: The introduction of a methyl group into a compound.

Model: A model may be a mental conceptualization; a physical device; or a structured collection of mathematical, statistical, and/or empirical statements.

Model, Computer: A series of equations and mathematical terms based on physical laws and statistical theories that simulate natural processes.

Model, Hydraulic: A small-scale reproduction of the prototype used in studies of spillways, stilling basins, control structures, river beds, etc.

Monoculture: Single-species vegetation community, e.g. large expanses of cattail or sedges.

Monthly Mean Water Level: The arithmetic average of all past observations (of water levels or flows) for that month. The period of record used in this Study commences January 1900. This term is used interchangeably with average.

Morphology: The form and structure of an organism or landform.

Morphometric factor: Physical shape and setting, e.g. behind a barrier beach as opposed to a shoreline exposed directly to lake effects.

Nearshore: An indefinite zone extending lakeward from the average annual water level to beyond the breaker zone, defining the area of nearshore currents formed primarily by wave action.

Net Basin Supply: Represents the supply of water a lake receives from its own basin less the losses by evaporation from the lake surface and loss or gain due to seepage.

Nutrient cycling: The movement of nutrients from the nonliving (abiotic) through the living (biotic) parts of the ecosystem and back to the abiotic parts.

Oligotrophic: Waters low in nutrients and productivity.

Organochlorine contaminants: Chlorinated hydrocarbon pesticides.

Outcrop: The exposure of bedrock or strata projecting through the overlying cover of detritus and soil.

Oxic: To expose to oxygen.

PCB - polychlorinated biphenyls: A class of organic chemicals that bioaccumulate and are suspected carcinogens.

Permeability: The capacity of a porous material to transmit fluid.

Pelagic: Inhabiting the mass of water of a lake, in contrast to the lake bottom.

Physiography: A descriptive study of the earth and its natural phenomena, such as climate, surface, etc.

Pioneer vegetation: Vegetation characterized by herbaceous annual and seedling perennial plants that colonize bare areas as a first stage in succession.

Planimetric Capabilities: The capability of a system to measure areas.

Plankton: Microscopic or readily visible, free floating plant (phytoplankton) or animal (zooplankton) life of water bodies.

Policy: The position adopted by a government on an issue which is expected to structure and guide the decision making process.

Productivity: The creation of living matter from non-living matter and energy (primary productivity) or from other living matter (secondary productivity).

Purity: The state of being free of contamination by chemicals, energy, or exotic forms of animals or plant life.

Quadtree: A method of structuring data hierachically in the computer; can be visualized as a variable sized grid cell that can vary to capture the degree of resolution appropriate to the original map.

Raster: A means of storing geographic information in a computer; the raster format is computationally similar to a matrix original.

Reach: A length of shore with fairly uniform onshore and offshore physiographic features and subject to the same wave dynamics.

Rebound (Crustal Movement): The uplift or recovery of the earth's crust in areas where a past continental glaciation had depressed the earth's crust by the weight of the ice.

Recession: A landward retreat of the shoreline by removal of shore materials in a direction perpendicular or parallel to the shore.

Regression Equation: A mathematical expression which statistically relates two or more variables.

Regulation: Control of land and water use in accordance with rules designed to accomplish certain goals.

Regulation: Artificial changes to the lake levels or their outflows for specific purposes or to achieve certain objectives.

Riparians: Persons residing on the banks of a body of water.

Riverine wetlands: All wetlands within a channel except those dominated by trees, shrubs, persistent emergents, emergent mosses or lichens.

Ruderal: A weedy plant.

Runoff: The portion of precipitation on the land that ultimately reaches streams and lakes.

Seiche: An oscillation in water level from one end of a lake to another due to wind or atmospheric pressure. Most dramatic after an intense but local weather disturbance passes over one end of a lake.

Shore Reach: A length of shore with fairly uniform onshore and offshore physiographic features and subject to the same wave dynamics.

Shorefast Ice: Ice that is immediately adjacent to, and often attached to, the shoreline.

Shoreline: Intersection of a specified plane of water with the shore.

Sills: Underwater obstructions placed to reduce a channel's flow capacity.

Sink: An area within a lake which receives littoral drift material.

Snowpack Water: The depth of water which would result from the melting snow cover of a given area.

Socio-economic conditions: Pertaining to the demographics of a region.

Source: An area of the shoreline or nearshore zone which contributes material to the littoral drift.

Spatial Evaluation Framework: The classification and delineation of terrestrial, wetland and aquatic environments in spatial units meaningful to an assessment of fluctuating levels and measures.

Stakeholder: An individual, group, or institution with an interest or concern, either economic, societal or environmental, that is affected by fluctuating water levels or by measures proposed to respond to fluctuating water levels within the Great Lakes-St. Lawrence River Basin.

Stenotherm: An organism that can only tolerate a narrow range of temperature.

Strand: Land at the edge of a body of water, especially an area from which water has recently receded.

Strategy: A general conceptual framework for guiding action based upon a particular purpose and selected means for achieving agreed-upon ends.

Stratigraphy: The vertical variation in unconsolidated material or rock at a given location.

Submergent: In plants, a vascular or nonvascular hydrophyte, either rooted or nonrooted, which lies entirely beneath the water surface, except for flowering parts in some species, e.g. wild celery, stonewart.

Substrate: Solid material upon which an organism lives or to which it is attached.

Swamp: A flat, wet area usually or periodically covered by standing water and supporting a growth of trees, shrubs and grasses; organic soil is thin and readily permeated by roots and nutrients.

Synergistic: The act of two or more things working together to create a greater effect than the sum of their individual effects.

Terrestrial: Having to do with the land. In the context of this Annex, having to do with land near the shore.

Trophic status: A measure of the biological productivity in a body of water.

Turbulence: An irregular movement of a fluid, characterized by randomness.

Urbanization: The change of character of land, due to development, from rural or agricultural to urban.

Vulnerability: Vulnerability is a concept pertaining to a relative susceptibility of interests to the adverse consequences of water-level fluctuations. Depending on the choice of level of resolution, the concept of vulnerability could pertain to a spectrum of interests ranging from an individual to a group of interests (industry) or to some notion of "society as a whole." Vulnerability would thus be dependent on the concentration of interests in the Basin, the type of activity they are engaged in, the assets they employ, including such factors as location and setting, design range of the building or equipment, the ability of the interest to adapt, and the like.

Watershed: The area drained by a river or lake system.

Water Supply: Water reaching the Great Lakes as a direct result of precipitation, less evaporation from land and lake surfaces.

Water Table: The upper surface of a zone of saturation. No water table exists where that surface is formed by an impermeable body.

Wave: An oscillatory movement in a body of water which results in an alternate rise and fall of the surface.

Wave Climate: A term describing the nature (height, period, length) and type of waves occurring at a particular location along the shoreline.

Wave Crest: The highest part of a wave

Wave Direction: The direction from which a wave approaches.

Wave Period: The time for two successive wave crests to pass a fixed point.

Weather: The meteorological condition of the atmosphere defined by the measurement of the six meteorological elements: air temperature; barometric pressure; wind velocity; humidity; clouds; and precipitation.

Weathering: Total of all processes (physical and chemical) acting at or near the earth's surface to cause the physical disruption and chemical decomposition of rock.

Wetland: Lands where the water table is at, near, or above the land surface long enough each year to support the formation of hydric soils and to support the growth of hydrophytes, as long as other environmental variables are favourable.

Wetland Function: A physical or biological process which occurs within a wetland.

Wetland Value: The extent of benefit to humans derived from one or/more wetland functions.

Wind Set-up: (Storm Surge) The vertical rise above normal water level on the leeward side of a body of water caused by wind stress on the surface of the water.

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* former member

APPENDIX B-4: SHORE PROCESSES WORKSHOP EXECUTIVE SUMMARY
IMPACT OF GREAT LAKES WATER LEVELS ON SHORE PROCESSES
CANADA CENTRE FOR INLAND WATERS, BURLINGTON, OCTOBER 27 AND 28, 1988

A number of common themes and conclusions can be drawn from the review papers presented at the workshop, the summaries of the individual working groups, and from general discussion over the two days of the workshop. The most significant of these can be summarized as follows:

1) There is a wide range of shore types in the Great Lakes, from bedrock shorelines through cohesive bluffs, sandy barriers and protected bays and wetlands. It is recognized that each shore type could be characterized by a different complex set of processes and controlling variables, and that the role of water-level fluctuations on a seasonal and long-term scale would also differ from one shore type to another. From this it follows that the impact of controlling the magnitude of water-level fluctuations or of lowering the mean lake level would also vary from one environment to another.

2) It was generally recognized that the dominant processes controlling coastal erosion and sediment transport are waves and wave-generated currents, particularly during the passage of storms. Water level increases due to wave set-up and storm surge are also significant and may be much larger than seasonal and long-term changes in the mean lake level. These in turn are controlled by shoreline orientation, fetch lengths, wind climate and storm intensities, etc.

3) Wave-generated processes are the primary control on erosion of bluff and sandy shorelines, and in most areas of the Great Lakes, the mean long-term erosion rate is probably independent of water level fluctuations. In both instances, the local beach sediment budget is extremely important in determining the magnitude of erosion and this should be evaluated within the framework of the littoral drift cell.

4) The primary effect of seasonal and long-term water-level fluctuations is to modify the vertical distance over which wave-generated processes operate, but they probably have little effect on long-term erosion and sediment transport rates in most areas. The fluctuations do introduce temporal variations, which are cyclical rather than random, in the rates and intensities of some processes. Thus, rates of toe erosion and bluff recession are higher during periods of high water levels and lower during low water phases (though low water phases may be responsible for inducing large-scale failures in some high bluffs); dune erosion and overwash is also more prevalent during high water periods. In wetland areas, water-level fluctuations may be of greater importance than wave-induced processes, and in this instance the fluctuations are necessary for maintaining the areal extent of the wetlands and the species diversity. Water-level fluctuations also induce cyclicity in foredune development and may thus influence the character of the shoreline development in these areas.

5) Shorelines protected by structures are exposed to the same range of processes as natural shorelines, and in turn modify the natural process. In particular, shore protection may interfere with longshore sediment transport, and along bluff shorelines it may lead to a significant reduction in sediment supply to the littoral drift system.

6) The possible impacts of schemes to (a) reduce the range of lake-level fluctuations, and (b) to lower the overall mean lake levels by up to a metre were seen to vary with shore characteristics. On sandy coasts it was generally felt that the beach and nearshore profile would adjust rapidly to achieve a new equilibrium, and that in erosional areas there would be only a short period of stability before erosion resumed. However, this might vary with different substrate in the nearshore. On erosional bluff shorelines where the erodible material extended throughout the nearshore, the respite from erosion would also be short, but in areas where bedrock is close to the surface or where there is an accumulation of lag deposits, a lowering of water levels could reduce long-term erosion rates. As noted in 4) above, a reduction in the range of long-term fluctuations would reduce the area of coastal marshes and their diversity and productivity. A reduction in the range of lake-level fluctuations might reduce the costs of some protection designs. A 1 metre reduction in mean lake level would drastically reduce the need for existing structures, but in erosional areas new structures would be needed at lower elevations if erosion continued.

7) The workshop identified the need for more research on the coastal processes operating in the Great Lakes, particularly those on cohesive coasts and those involved in sediment transport in the nearshore. It is evident that we still do not know enough about the processes themselves and about the way in which they respond to water-level fluctuations. Studies looking at shoreline response to the extended period of low water levels in the late 1950's and 1960's might shed some additional light on shore response to a permanent lowering of lake levels. Similarly, further insight into the potential effects of reducing the range of fluctuations could be gained from studies comparing shoreline characteristics and erosion rates in Lake Ontario before and after regulation.

8) Finally, it was felt that there was also a need for a compilation of data on the coastal environment as a whole, including wind and wave climates, nearshore morphology and sediments and other shoreline attributes, and for the institution of a systematic programme to monitor coastal erosion and shoreline changes through the establishment of measured profiles and from aerial photographs taken at appropriate scale on a regular and frequent basis. The need for this type of systematic data collection is similar to that for collection of stream discharge and sediment concentrations in rivers and it should be seen as essential to the development of any program of coastal zone management. Such a scheme should continue through both high and low water phases.

APPENDIX B-5

SHORELINE MANAGEMENT WORKSHOP

EXECUTIVE SUMMARY

The diversity and complexity of shoreline management approaches and programs currently implemented across the Great Lakes Basin is indicative of the principles governing program development and implementation. Three main principles, applied in varying degrees of magnitude and priority, currently govern the direction taken by implementing agencies, namely:

- public health and safety (reduction of risk, damage prevention and welfare)
- ecological and recreational values
- general public benefit (Canada)

The range and complexity of governing principles selected by implementing agencies often dictates how shoreline management problems are defined and influences the range of approaches selected to address identified problems.

Given the current diversity in governing principles across the Great Lakes Basin and the resultant range in definitions of, and approaches to, shoreline management, the general public currently perceives that shoreline management programs are inconsistently applied.

Perceived inconsistencies in program implementation can also be attributed in some degree to variations in the roles and responsibilities of government support agencies (i.e. for policy direction, program implementation, technical support, advisory services), the hierarchy and relationship between government agencies (federal, provincial/state, municipal), existing statutory authority (i.e. does the implementing agency have supporting legislation to administer policy directions), and funding support. All of these have a direct impact on program development and implementation (i.e. the range and feasibility of approaches available to implementing agencies).

Comprehensive shoreline management programs must provide a balance of non-structural approaches to effectively address existing and future shoreline development concerns.

The frequent application of structural measures, often implemented as crisis response measures, are viewed as being short-term, reactive, costly and often ineffective solutions to problems associated with dynamic natural shore processes. In contrast, non-structural preventative approaches are viewed as long-term, proactive, and cost effective solutions, offering long-term benefits to the public at large.

A major limiting factor to effective development and implementation of non-structural programs has been the absence of "political will". Non-structural measures are viewed by many shoreline property owners as a "taking" or "down-zoning" of property values, infringing on the riparian rights of private property owners to use their land as they so wish. Governments have historically been reluctant to promote non-structural programs, despite their acknowledged long-term benefits, in response to public pressure.

Another major limiting factor to effective development, implementation and public acceptance of non-structural measures is the persistent willingness of government to examine lake regulation as a viable solution to shoreline flooding and erosion problems, despite the fact that repeated studies have clearly shown that lake regulation has a maximum impact of lowering water levels only a matter of inches. The real problem is short-term, storm-induced water-level changes which are often measured in feet.

Governments must resolve the issues of full or partial regulation of Great Lakes water-level fluctuations. Only then can resource managers effectively develop and implement non-structural strategies and programs.

The databases used to develop shoreline management policies are often challenged as being unrealistic, incomplete, or unreliable. This is in part due to the lack of continuity in methodologies used by different agencies in the provision of guidelines. These databases, if incomplete, must be improved, standardized and completed.

Comprehensive Great Lakes shoreline management programs currently do not exist. Rather, existing shoreline management programs are designed for specific areas of concern. Some view this as a haphazard application of policy; however, due to the high variability and uniqueness of Great Lake shoreline environments, continued pursuance of this approach is essential to successful implementation and acceptance at the local level.

Non-structural shoreline management measures are often misconstrued as offering permanent solutions to shoreline flooding and erosion problems. For instance, once a setback line has been drawn on a municipal zoning map, there is often strong opposition to its re-evaluation and possible re-drawing. Still, controls such as setback regulations are, in themselves, cost-effective means of transferring information on risks associated with shoreline flooding and erosion. It should be understood that since shore processes are dynamic in nature, declaring any solution, structural or non-structural, as "permanent" is being totally unrealistic and misleading.

Non-structural measures are not innovative approaches to shoreline management. They have existed, and have been applied in varying degrees, throughout the Great Lakes Basin for a number of years. The issue requiring recognition and response is the development of a comprehensive shoreline management program and implementation strategy through government agreements, common understanding of the problems and possible range of non-structural solutions, and public education and acceptance. Programs will succeed where a number of mutually continuous and complimentary non-structural approaches, rather than a single measure, are applied.

APPENDIX B-6: WETLANDS WORKSHOP EXECUTIVE SUMMARY
WATER-LEVEL CRITERIA FOR GREAT LAKES WETLANDS
BUFFALO, NEW YORK JANUARY 24 AND 25, 1989.

Results from the Wetlands Workshop are as follows:

1. Fluctuating water levels, as exhibited in the Great Lakes, have provided conditions for wetlands such that the actual wetland area is significantly larger and more productive than if the water levels had been stable. This is a result of wetland area extension upland due to periodic flooding from high water and also from short term wind set-up. A similar extension can be found at the open-water boundary where periodic low waters support plant growth and reproduction. The impacts of a reduction in the range of fluctuations on wetland area can be quantified, but mitigation would be difficult because of the size of the impacted area.

2. Changes in the fluctuations through regulations may change the timing of the highs and lows. Such changes could have very significant detrimental impacts on the wetland vegetation. Some plants have very specific requirements. Plants which need to go through sexual reproduction may not have enough time for sexual maturation before winter sets in. Wild rice, for example, requires mudflats for establishment and increasing water levels for growth and reproduction on an annual basis. Impacts caused by changing the timing of highs and lows can be described but not easily quantified.

3. A generic rule applicable to all the Great Lakes would include:

a) Maintain the seasonal water-level profile for each Great Lake. For seasonal target profiles, the recorded monthly median levels may provide a more meaningful profile than the mean monthly data. Generally, spring and early summer levels should be the highest, followed by a decrease in summer and fall. Winter conditions should be low and stable on the seasonal scale. Mid and late summer highs should be avoided as should major decreases during the winter after ice formation.

b) Changes in the amplitude would have system-wide impacts on plant species diversity and on area. In general, scrub-shrub, _Typha_ and exotics would increase at the expense of other species.

c) Frequency of variability (includes the rate of change, timing, and the duration) are of great importance. These required conditions have not been reduced to detailed numerical parameters. The length of the time frame's periodicity is 10 to 30 years.

In the future, extreme highs or lows could reach levels at which the benefits of fluctuations (needed to maintain current conditions) would be exceeded (physical conditions would change). Using the historic record of fluctuations, an attempt was made to identify possible maximum and minimum levels. As a starting point, the exceeded 10% and exceeded 90% curves were used for the boundaries of the range of fluctuations which must be maintained to protect the ecosystem as it currently exists.

APPENDIX B-7: LIST OF FUNCTIONAL GROUP 2 SUPPORTING DOCUMENTS

Edsall, T. and J. Cleland (1989) Effects of Altered Water Levels and Flows on Fish in the Great Lakes Connecting Channels. U.S. Fish and Wildlife Service, National Fisheries Research Center - Great Lakes, Ann Arbor, Michigan.

Geographic Information System Analysis of Effects of Water-level changes on habitat, Saginaw Bay, Lake Huron (in preparation).

Hatch, R.W. and R.L. Potter (1989) Effects of Fluctuating Water Levels on fish reproduction in the Great Lakes: A Literature Review. U.S. Fish and Wildlife Service, National Fisheries Research Center - Great Lakes, Ann Arbor, Michigan.

International Joint Commission Functional Group 2 (1989a) Impact of Great Lakes Water Levels on Shore Processes: A Workshop Summary, IJC Water Levels Reference Study, 24 pp.

International Joint Commission Functional Group 2 (1989b) Great Lakes Coastal Management - A Workshop Summary, IJC Water Levels Reference Study.

International Joint Commission Functional Group 2 (1989c) Water Level Criteria for Great Lakes Wetlands - Summary of A Wetland Workshop, IJC Water Levels Reference Study, 57 p.

Manny, Bruce (1989) Effects of Water-Level Fluctuations on Great Lakes Water Quality. U.S. Fish and Wildlife Service, National Fisheries Research Center -Great Lakes, Ann Arbor, Michigan.

Stewart, C.J. (1988). Bibliography of Great Lakes coastal process studies and other related research in coastal geomorphology. Environment Canada, Inland Waters Directorate, Internal Report Prepared For Functional Group 2.

Stewart, C.J. (1989). A Review of Previous Methods Used in Evaluating and Estimating Shoreline Erosion of the Great Lakes - St. Lawrence River System. In: IJC Functional Group 2 (1989), "Impact of Great Lakes Water Levels on Shore Processes: A Workshop Summary", IJC Water Levels Reference Study, p. 25-39.

Wilcox, D.A. (1989). Responses of Selected Great Lakes Wetlands to Water Level Fluctuations. In: IJC Functional Group 2 (1989), "Water Level Criteria For Great Lakes Wetlands - Summary of A Wetland & Workshop", IJC Water Level Reference Study, p. 40-56.

APPENDIX B-8

CONVERSION FACTORS

METRIC TO IMPERIAL

1 centimetre = 2.54 inches
1 metre = 3.28 feet
1 kilometre = 0.62 mile
1 square metre = 1.20 square yard
1 square kilometre = 0.39 square mile
1 hectare = 2.47 acres
1 cubic centimetre = 0.061 cubic inch
1 cubic metre = 1.31 cubic yard
1 cubic kilometre = 0.24 cubic mile
1 litre = 0.22 Imperial gallon
1 litre = 0.26 U.S. gallon
1 gram = 0.035 ounce
1 kilogram = 2.21 pounds
1 tonne = 1.10 ton
$^{0}C = (^{0}F - 32)/1.8$

GB 1627 .G8 I64 1989 Annex B
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