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Approach to the Physical Assessment of Developments Affecting Fish Habitat in the Great Lakes Nearshore Regions

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ABSTRACT

The Fisheries Act specifies that a development project must not cause a Harmful Alteration, Disruption or Destruction of fish habitat (HADD). The authorization of a HADD is usually conditional on the implementation of certain compensatory measures to achieve a "no net loss" in the productive capacity of fish habitat. Procedures now exist to quantify the impacts of physical changes on productive capacity. These procedures allow the evaluation of pre- and post-development scenarios, including any compensatory measures. Evaluating physical changes requires the determination of areas lost and the assessment of areas modified both directly and indirectly. In this report we outline the methods and techniques available to evaluate the physical changes to fish habitat in the Great Lakes nearshore region. We provide a comprehensive review of information sources and modelling techniques available to assess the impacts of coastal engineering projects on fish habitat. We also present analytical and numerical techniques and models for the prediction of wave action, wind and wave induced circulation patterns, sediment transport, erosion and deposition, change to surficial substrate and the presence or absence of macrophtyes. Finally, we discuss the level of detail that may be required for the assessment of physical impacts for different shore and project combinations.

RÉSUMÉ

La Loi sur les pêches prévoit qu'un projet de développement ne dois pas entraîner de détérioration, de destruction ou de perturbation de l'habitat du poisson (DDPHP). En règle générale, une DDPHP est autorisée à la condition de prendre certaines mesures de compensation pour assurer qu'il n'y aura <<aucune perte nette>> de la capacité de production de l'habitat du poisson. Il est maintenant possible de quantifier les incidences des changements physiques sur la capacité de production. Ces méthods de quantification prévoient l'évaluation de scénarios avant et après le projet de développement de même que toute mesure de compensation. Pour évaluer les changements physiques, il faut déterminer quelles zones ont été perdues et quelles zones ont été modifiées directement et indirectement. Nous présentons dans le présent rapport les méthodes et les techniques d'évaluation des modifications physiques apportées à l'habitat du poisson dans la région littorale des Grands Lacs. Nous faisons un examen complet des sourcs d'information et des techniques de modélisation permettant d'évaluer les conséquences des projets de travaux maritimes sur l'habitat du poisson. De plus, nous présentons des techniques et des modèles analytiques et numériques permettant de prévoir l'action des vagues, les courants de circulation produits par les vents et les vagues, le transport des sédiments, l'érosion et les dépôts, les changements aux couches superficielles ainsi que la présence ou l'absence de macrophytes. Puis, en dernier lieu, nous parlons du niveau de précision pouvant être nécessaire à l'évaluation des incidences physiques sur diverses combinaisons de littoraux et de projets.

1.0 INTRODUCTION

Section 35(1) of the Fisheries Act specifies that a development project must not cause a Harmful Alteration, Disruption or Destruction (HADD) of fish habitat. Section 35(2) of the Act specifies that a HADD can be authorized only at the discretion of the federal minister of the Department of Fisheries and Oceans. The authorization of a HADD is usually conditional on the implementation of certain compensatory measures to achieve a "no net loss" of fish habitat outcome, as stated in the Policy for the Management of Fish Habitat (DFO, 1986).

Recent advances have been made in quantifying the impacts of physical changes on the productive capacity of fish habitat (see Minns et al, 1995). These procedures can be used to evaluate the productive capacity of fish habitat for the pre- and post-development scenarios (the latter including any compensation measures) to determine, in a defensible manner, whether the "no net loss" objective is satisfied.

The first step in assessing the influence of a project on fish habitat is to determine the physical changes to the environment caused by the project. There are three aspects to the evaluation of the physical changes caused by a project: 1) determination of areas lost (i.e. which are no longer submerged in the post-development scenario); 2) the evaluation of directly modified areas (i.e. where the depth and surficial substrate are changed through the placement of a structure); and 3) the evaluation of changes in indirectly modified areas (i.e. where the project modifies the coastal processes which immediately or eventually result in changes to physical habitat characteristics).

These guidelines have been written to assist in the evaluation of the physical changes to fish habitat. Section 2 provides an overview of the Fisheries Act in the context of its implications regarding the impacts caused by development projects. Section 3 presents an introduction to the typical project types and shore types on the Great Lakes. Understanding the natural processes of change (i.e. erosion and deposition) on the fundamentally different Great Lakes shore types is essential for a successful evaluation of the potential influence of a project. Approaches for assessing the physical characteristics of the pre-development habitat conditions and a general discussion of the three aspects of physical changes (i.e. areas lost, directly modified and indirectly modified) are presented in Section 4. Techniques for predicting the influence of projects on local coastal processes, and ultimately the habitat characteristics in the indirectly modified areas, are reviewed in Section 5. A guide for the selection of an evaluation approach commensurate with the potential for impact is provided in Section 6.

2.0 OVERVIEW OF THE *POLICY FOR THE MANAGEMENT OF FISH HABITAT* HABITAT PROTECTION PROVISIONS OF THE *FISHERIES ACT*

The federal Department of Fisheries and Oceans (DFO, 1986) *Policy for the Management of Fish Habitat* recognizes that fish habitats constitute healthy production systems for Canada's fisheries resources and reaffirms the need for their management and protection.

The *Policy* identifies three goals through which the overall objective of a NET GAIN in the productive capacity of fish habitat will be achieved:

I. **Conservation** of existing habitats;
II. **Restoration** of damaged habitat; and
III. **Development** of new habitats.

The first goal, **Conservation**, requires that the current productive capacity of existing habitats be maintained through applying the guiding principle of No Net Loss. Under this principle, existing productive capacity of fish habitats is protected by balancing unavoidable habitat losses with replacement habitat. The No Net Loss principle is in keeping with the global concept of environmentally sustainable economic development and provides for development to proceed while preserving the productive capacity of fish habitats.

The Department of Fisheries and Oceans uses the legislative authority of the *Fisheries Act* to ensure that No Net Loss is achieved. Harmful alteration, disruption or destruction of fish habitat is prohibited by Section 35(1) of the *Fisheries Act*. Failure to comply can lead to fines up to one million dollars or imprisonment.

According to the *Act*, fish habitat is considered to be those parts of the aquatic ecosystem that fish depend on, directly or indirectly, to carry out their life processes. Essentially, these are the physical features that, together with water quality provide the basic life requisites of food, reproduction, cover and the pathways that link them together

The *Fisheries Act*, also provides the Minster of Fisheries and Oceans with the power to authorize the harmful alteration disruption or destruction of fish habitat in cases where adverse effects on fish habitat are unavoidable. In keeping with the principle of No Net Loss, authorizations are issued on the condition that the proponent provides replacement habitat for any losses of fish habitat that result from the project.

The discretionary power of the Minister of Fisheries and Oceans to authorize harmful alteration, disruption or destruction of fish habitat has not, as yet, been delegated to the provincial government. Consequently, the Department of Fisheries and Oceans and the Ontario Ministry of Natural Resources have agreed upon a procedure to review and authorize projects that affect fish habitat. The Ontario Ministry of Natural Resources Area Office is the first step in this procedure. Projects that do not result in the harmful alteration, disruption or destruction of fish habitat or projects that can be modified or relocated such that harmful alteration, disruption or destruction of fish habitat is avoided proceed through Ontario's regulatory process without the involvement of the Department of Fisheries and Oceans. Those projects where harmful alteration disruption or destruction of fish habitat is expected to occur are referred to the Department of Fisheries and Oceans for authorization pursuant to Section 35(2) of the *Fisheries Act*. The *Canadian Environmental Assessment Act* requires the Department of Fisheries and Oceans to screen the project for impacts on areas of federal responsibility before an Authorization can be issued under Section 35(2) of the *Fisheries Act*.

Developments along the shoreline can affect fish habitat directly and indirectly. Frequently, shoreline structures such as groynes or breakwaters change physical processes that can produce negative effects on fish habitat at the site or some distance away. Conversely, placement of offshore structures, such as islands, can alter physical processes to the benefit of fish habitat. The occurrence of negative or positive benefits is dependent on the fish community objectives for the portion of the shoreline affected by a development. For example, a project may destroy habitat for coldwater species while creating habitat for warmwater species. Habitat biologists need to understand the effects of shoreline alterations on physical processes so they can determine if these effects result in harmful alteration disruption or destruction of fish habitat; develop appropriate mitigation and compensation measures, or to plan effective habitat restoration projects.

3.0 PROJECT TYPES AND GREAT LAKES SHORE CONDITIONS

In order to successfully apply a methodology that describes physical characteristics and the associated changes for specific sites, which can often be very complicated, it is important to develop an understanding of the issues. This section provides an overview of the types of projects and conditions that can be encountered on the Great Lakes and connecting channels. References are provided to direct the reader to more detailed descriptions of the coastal processes and conditions along the shorelines of the Great Lakes.

These guidelines have been developed to provide a framework for the assessment of the physical impacts of coastal engineering projects. A description of the function and purpose of the various project types is presented in the first part of this section. The form which these structures take and the construction materials used in their creation is also addressed.

The Great Lakes shoreline is highly diverse and includes: eroding bluffs and banks; rocky shorelines (eroding and erosion resistant); dynamic sand and gravel beaches; and low lying wetland (muddy shores). The nature of the changes produced by coastal engineering projects depends very much on the characteristics of the local and regional shoreline morphology. In the second part of this section, an overview of the different shore types and processes is provided.

3.1 Types and Forms of Projects

Coastal structures are constructed for a large variety of purposes, however, these structures only have four primary functions as follows:

1. to protect and stabilize shoreline (either created or natural) or some marine facility from erosion and damages related to wave action (e.g. revetment, groynes, intakes, outfalls, etc.);
2. to create a sheltered area suitable for mooring, boat launching and navigation and free from sedimentation;
3. to protect an inland area from flooding;
4. to create or enhance fish habitat.

Other miscellaneous coastal structures include: navigation aids, structures to hold ice booms, mooring dolphins, terminals, bridge piers, docks, wharves and terminals.

The purposes of these structures range from the protection (or creation) of a land base for various types of land use (e.g. recreational, residential, institutional, commercial, industrial, etc.) to the development or expansion of mooring facilities for recreational and commercial vessels.

Artificial headlands are "shore perpendicular" structures which are often created to develop protected bays where more accessible and sometimes, less expensive shoreline protection can be implemented such as beaches. In essence, the artificial headland features are created to mimic the function of natural features. The headlands are often seen by the designers to create shoreline diversity (i.e. to break up a long straight section of shore).

Offshore breakwaters or islands are "shore parallel and detached" structures usually constructed to create an area of sheltered water for the mooring of boats or for other recreational purposes such as swimming. These structures also provide shore protection on eroding shorelines.

Most recent marinas that have been constructed consist of two shore connected breakwater arms projecting from the shoreline to create a rectangular "enclosed" basin. The breakwaters are shore connected because they allow access for construction equipment to advance the structure into deeper water. The rectangular shape is a result of an effort to maximize useable mooring area at a minimum cost.

The form of coastal structures has evolved through the last few decades based on a change in the primary construction materials used in their creation. Traditionally, coastal structures on the Great Lakes were built using timbers, concrete and steel sheet piles. While these materials are still in use today, they have mostly given way to the use of quarried stone materials. The reason for this change is that the quarried materials now represent, in most cases, the least expensive construction material to purchase, deliver and place.

As a result of the change in materials, the form of coastal structures has changed accordingly. Whereas timber, concrete and steel sheet pile structures generally were designed and built with vertical faces, larger quarried stone structures must be constructed with a sloping face.

3.2 Shore Types and Processes on the Great Lakes

This section presents an introduction to the shore types and related processes that may be encountered on the Great Lakes.

3.2.1 Overview on Shore Types

Shore types are classified by "controlling substrate" in order to describe both the physical and biological characteristics. The controlling substrate is the most important indicator of how the shore responds to wave action. Generally, the most important part of the controlling substrate is located below the lake level, that is, the nearshore profile. There are four general classes of controlling substrate: rocky shores, cohesive shores, muddy shores (soft sediments with vegetation) and sandy shores (the latter corresponding to dynamic beaches in the MNR Shoreline Policy, 1995). Rocky shores can consist of either erosion resistant or erodible bedrock. In the case of erodible bedrock, such as shale, the shore type characteristics are very similar to those of cohesive shores. On cohesive shores, the controlling substrate consists of a consolidated clay matrix of some form (e.g. glacial till or a lacustrine deposit). The controlling substrate on cohesive shores may be covered with a thin veneer of cohesionless sediment (i.e. sand or gravel) and may even have a significant beach deposit at the shore. Sandy shores are composed of a thick sand deposit such that any underlying bedrock or other consolidated deposit (e.g. till) is never exposed. Muddy shores are often stabilized by the presence of vegetation and usually are associated with embayments or connecting channels (i.e. sheltered shoreline).

There are fundamental differences between the dynamics of rocky, cohesive, sandy and muddy shores. On cohesive shores and erodible rocky shores, the erosion of the material which composes the controlling substrate (i.e. either clay or rock) is irreversible, in other words once the matrix of particles is eroded it cannot be replaced or reconstituted. Therefore, on cohesive shores the controlling substrate is subject to irreversible downcutting which results in continuous long term shore recession. Although there may be some sand overlying the cohesive substrate, it is of insufficient quantity to protect the substrate from exposure to wave action at all times.

In contrast, sandy or muddy shores may either be accreting, eroding or stable depending on the **long term** supply of sediment to the beach or muddy nearshore area. Focusing on a section of beach, if the rate at which sand is delivered to the beach exceeds the rate of removal, the beach will be accreting or growing. The opposite condition leads to erosion and a balance between supply and removal results in a stable beach or muddy shore. However, even stable beaches are susceptible to **short term** (or temporary) erosion during storm events, especially during periods of high water level. In these instances, sand is temporarily eroded from the beach, deposited offshore and will return to the beach in time (i.e. the beach will recover, typically in a period of a few days to a few months).

Rocky shores composed of erosion resistant material exhibit a high degree of stability, both under natural conditions and when influenced by coastal structures.

3.2.2 More on Cohesive Shores

The fundamental process on these shores is the irreversible downcutting of the nearshore part of the controlling substrate. This phenomenon leads to continuous, long term shoreline recession. In other words, bluff erosion along cohesive shores is an effect of the downcutting process, and therefore slope stability issues are only a secondary concern with respect to the rate of shoreline recession (see Figure 3.1). On the Great Lakes the long term recession rates vary between 0.1 and 3 metres/year (Boyd 1981, Environment Canada & OMNR 1976)

It is also important to recognize the role of the sand veneer on cohesive shores. By definition, the quantity of sand is insufficient to protect the underlying substrate from exposure and erosion. In fact, the sand may act as an abrasive agent contributing to the downcutting of the cohesive substratum. The rate of long term recession on a cohesive shore will be influenced by the characteristics of the overlying sand cover. As the sand cover becomes very thick and stable, the frequency of exposure of the erosion susceptible substrate is reduced and, therefore, the downcutting and shore recession rates will also be reduced. Conversely, as the sand cover is reduced and the frequency of exposure of the underlying substrate is increased, downcutting will also increase. However, laboratory tests of wave action on a cohesive profile at the Canada Centre for Inland Waters in Burlington have indicated that the limiting condition of no sand cover results in dramatically reduced erosion rates because of the absence of an abrasive agent on the lake bed (see Skafel and Bishop, 1994). Depending on the quantity of sand covering a cohesive profile in undisturbed conditions, a reduction in the sand cover may or may not result in an increase in erosion rates.

There are two distinct subclasses of the cohesive shore type as pointed out by Boyd (1981). Through an interpretation of the results of the Great Lakes Erosion Monitoring Programme through the 1970's, two types of cohesive profile shapes were identified: a steeply sloping concave profile (Group 3 profiles in Boyd, 1981) and convex profile with a nearshore shelf (Group 4 profiles in Boyd, 1981). Throughout the Great Lakes, cohesive shores fall into one of these two categories. In a recent study of the Lake Huron shoreline, Boyd (1992) developed a figure illustrating the differences in the two profile types (see Figures 3.2), and the Waterfront Regeneration Trust (1995) has completed a similar figure for the north shore of Lake Ontario (see Figures 3.3a and b). The steeply sloping concave profile exists at locations where the eroding glacial till (or other consolidated deposit) is fine grained and devoid of cobbles or boulders. Conversely, the shelf of the convex profiles can be a result of protection by boulder or cobble lag deposits that have formed through the erosion of a stony till. The convex type profile also forms along bedrock shores which are susceptible to erosion. The concave profiles will have little or no beach deposit at the shore, whereas, the convex or shelf profiles may feature a significant beach deposit at the shore, especially during average to low lake level periods when much wave energy is dissipated on the shelf.

3.2.3 More on Sandy Shores or Dynamic Beaches

Changes to sandy shores or dynamic beaches are directly related to the process of sediment transport. Sediment transport occurs in both the alongshore and cross-shore directions. In general, it is cross-shore transport during storms which leads to short term beach erosion. Storms almost always occur in conjunction with an elevated lake level and these conditions result in rapid erosion of the beach deposit, which is carried offshore and deposited as offshore bars. Eventually, as these bars build up through the storm they help to dissipate the waves and slow or halt the beach erosion. Therefore, the beach and backshore dunes act as an important reservoir which is needed to create protective offshore bars during storms. Storm erosion can result in temporary shoreline recession in the order of 10's of metres. In the days, weeks and sometimes years (depending on the intensity of the storm), the beach is slowly restored to its original state through onshore sediment transport (see Figure 3.4).

In contrast, it is generally true that long term changes to beaches are related to gradients in alongshore transport. For example, at a change in shoreline orientation, the capacity of the waves to transport sediment may be reduced. With this scenario there is a gradient in sediment transport where there will be more incoming than outgoing sand, and a growing beach deposit will result. Burlington Beach, Toronto Islands, Long Point and Wasaga Beach are some large examples of these types of deposits on the Great Lakes; there are countless smaller beach deposits. In natural situations, the long term rates of beach growth or erosion related to gradients in alongshore transport are usually quite low in undisturbed situations (less than +/- 0.3 metres per year).

The sediment which makes up a beach deposit is derived from the historical erosion of updrift shores that has occurred over several thousand years. For many of the large beach deposits in urban areas of Lake Ontario, the sediment supply has either been eliminated or significantly reduced (including Burlington Beach, Toronto Islands and the Eastern Beaches in recent years). Where the alongshore transport rates are high (Toronto Islands and Eastern Beaches) the depletion or elimination of sediment supply will result in accelerated erosion rates and management challenges.

With respect to morphological processes, muddy shores represent a special case of sandy shores. The erosion and deposition processes are related to a balance between incoming and outgoing sediment transport at any location. Often, these shore types are associated with delta areas at the mouth of rivers (i.e. where a high sediment load settles out once the flowing river meets a larger water body such as lake).

3.2.4 Modifying Influence of the Backshore Deposit

The topography and geology of the backshore area has a secondary or modifying influence on the shoreline conditions of cohesive shore and erodible bedrock types (i.e. those which feature an inland migrating shore position). In the simplest example, a high backshore will result in high eroding bluffs whereas a low backshore may feature a low or non-existent bluff. Low plain shores are conducive to the development of beach/wetland complexes due to the potential for inundation during elevated lake level periods.

The geology of the backshore may also influence the type of beach that exists locally or downdrift. Often the backshore deposit may differ from the controlling substrate. For example, along the bedrock shores east of Cobourg the backshore often consists of sand and gravel overburden. Therefore, this provides a supply for sand and gravel beaches. In contrast, along parts of the bedrock shore between Burlington and Etobicoke, both the controlling substrate and the backshore geology consist of a thinly bedded shale and the erosion of this shale leads to the creation and maintenance of shingle beaches.

Another important modifying influence of the backshore occurs where high eroding bluffs feature a significant boulder or cobble content. In these cases, the boulders and cobbles can contribute to the creation and maintenance of a lag deposit on the shelf type cohesive profiles. When the backshore topography is undulating, headlands may develop where there are high bluffs due to the lower erosion rates associated with the concentrated contribution of boulders and cobbles to the nearshore lag protected shelf.

3.2.5 Exposed Shoreline Versus Sheltered Shoreline

A large part of the Great Lakes shoreline is exposed to high energy wave conditions generated over fetches of 10's to 100's of km. These shorelines are distinct from the shorelines of sheltered embayments and connecting channels, which for example, can feature extensive macrophyte growth. For the purpose of this report, exposed shorelines are defined as having fetches of greater than 5 km while sheltered shorelines are defined as areas with fetches of less than 5 km.

Sheltered shorelines also arise for the case of deep embayments on an exposed shoreline and for areas where the nearshore zone consists of a very wide and shallow shelf. In both these cases, the shoreline is sheltered from open lake wave conditions.

4.0 APPROACHES TO ASSESSING PHYSICAL CONDITIONS AND PROCESSES

This section presents a review of the available methods for determining impacts of coastal projects in the context of the information required to assess significant changes to fish habitat. A first step for all projects will be the assessment of the existing local and regional conditions. The types of information that are required in this first step and the various sources and methods of acquisition are discussed in Section 4.1. Section 4.2 provides an overview of the relationship between physical impacts and changes to fish habitat including the three areas with different types of impact (i.e. areas lost, areas directly modified and areas indirectly modified). Approaches for defining the areas lost, the areas directly modified and the areas indirectly modified are outlined in Section 4.3. Techniques for evaluating the effects of changes to physical processes on depth, substrate and temperature (i.e. the defining characteristics of habitat) in the areas that are indirectly modified will be presented in Section 5.

Throughout this section, a range of techniques and levels of effort are presented for determining the required information, starting with the simplest approaches and progressing through to more sophisticated and detailed methods. Guidance on the required level of effort to address a particular situation (i.e. project type and shore type) is provided in Section 6 of these guidelines.

4.1 Preparation of Information on Pre-Development Site Conditions

An essential requirement of the assessment of change to the various physical characteristics of fish habitat is a thorough description of the pre-development habitat conditions. This section describes the types of information required, the sources of information and methods of retrieval or generation of data. The data requirements are also compared to the typical requirements for coastal structure design development.

4.1.1 Topographic and Hydrographic Information

For most locations in Ontario, Ontario Base Maps exist. For the shoreline of Lakes Ontario, Erie, St. Clair and the southern parts of Lake Huron and Georgian Bay, the mapping is at 1:10,000 scale; the remaining shoreline on Lake Huron and Lake Superior is mapped at 1:20,000. The contour interval on these maps is 5 m and they are generally only useful in estimating the shoreline position (i.e. the topography near the lake level is not well defined because of the 5 m contour interval). In some locations on the lower Great Lakes, 1:2,000 scale mapping has been completed as part of the Flood Damage Reduction Program (FDRP) being undertaken by Environment Canada and the Ontario Ministry of Natural Resources (MNR). These maps feature a 1 m contour interval and the 1:100 year flood line. About 50% of the Lower Great Lakes (i.e. south of the Severn River on Georgian Bay) have been mapped. These maps are available from MNR (Aquatic Ecosystem Branch), local Conservation Authorities and Environment Canada (Inland Waters Directorate, Canada Centre for Inland Waters, Burlington). A comprehensive discussion of current and historical sources of shoreline mapping in Ontario is presented in Appendix A4.5 of the Technical Guidelines of the Ontario Shoreline Policy produced by MNR (1994).

Hydrographic information is available from Canadian Hydrographic Service offices in the form of published hydrographic charts for navigation and in the form of field sheets which include the raw data used to prepare the navigation charts. The published charts provide contours at regular intervals and some spot depths at scales usually in the range of 1:100,000. Areas in the vicinity of harbours are often covered by charts with smaller scales. The field sheets provide a much greater density of data at smaller scales and digital data should be produced from the field sheets where required. Digital hydrographic data that covers the entire Great Lakes region is also available in CD ROM format from NOAA. Nearshore profile information is available for several sites on the Great Lakes from the Erosion Monitoring Station Programme reported by Boyd (1981). Some Conservation Authorities have continued and/or expanded on the profile monitoring.

For the design of most coastal structures, additional site specific topographic and hydrographic survey information will be required in order to prepare accurate construction drawings and estimates of quantities. The detailed hydrographic information is also required for larger projects in order to apply numerical models of wave transformation and circulation. For example, on larger projects site specific hydrographic information should be based on shore perpendicular profile lines with a spacing in the order of 30 m (see Kana and Andrassy, 1994). Typically, this information is now produced in digital form, and when spliced with the existing sources of topographic and hydrographic information, it provides a description of the pre-development conditions which is adequate to support the required impact assessment investigations.

Mention should be made of the vertical and horizontal datum conventions for mapping. For site specific investigations, establishing a common vertical datum based on the correct conversions is essential. The hydrographic chart information is referenced to either International Great Lakes Datum 1985 (IGLD'85) or IGLD'55. The topographic elevations are generally referenced to the Geodetic Survey of Canada (GSC) datum. Conversions between IGLD ('55 and '85) and GSC vary from location to location and are summarized in "Great Lakes System Flood Levels and Water Related Hazards" prepared by MNR (1989).

The horizontal datum may vary depending on the data source. Recent data, including data derived from Geographic Positioning Systems, is referenced to N.A.D. 1983. Other data may be referenced to the N.A.D. 1927 convention; conversion is required in order to inter-compare these data with recent survey data.

4.1.2 Shore Type (Controlling Substrate) and Surficial Substrate

A wide range of information is available to help define the shore type, the morphodynamics (i.e. how the shoreline and lake bed positions are changing with time) and the surficial substrate. A correct definition of the shore type is essential to developing an understanding the potential impacts of a coastal project on fish habitat. Information on surficial substrate conditions is required to define the pre-development fish habitat conditions.

As noted in Section 3, the shore type is defined by the controlling substrate which may be determined based on information on the geology and geomorphology for the study area shoreline. It may be recalled that there are four main categories of shore type relating to the sandy, cohesive, rocky and muddy controlling substrates. Valuable references on the general nature of the Great Lakes shoreline morphology include: Boyd (1981), Coleman (1936), Chapman and Putnam (1984), the Waterfront Regeneration Trust (1995) and various Shoreline Management Plans prepared by the local Conservation Authorities. In addition, the Ontario Geological Survey has published large scale maps of Quaternary Geology, Drift Thickness and Bedrock Topography. However, these references often do not provide sufficient detail to confirm the site specific conditions on shore type and controlling substrate. Aside from a review of the surficial conditions (both onshore, and offshore through a diver survey), sometimes the only way of definitively determining the shore type is through subsurface investigations such as boreholes and test pits. For larger coastal engineering projects, where the foundation conditions are uncertain, boreholes will be required anyway to address geotechnical design issues. To determine the thickness of a sand veneer over bedrock, or over cohesive sediment, probing or jetting may be undertaken by divers.

It is essential to determine the historic recession rates for the study shoreline in order to assess the magnitude and geographic extent of the potential impacts of the project. Recession rate information is available from several references including: Boyd (1981), the Coastal Zone Atlas compiled by Environment Canada and MNR (1976), and the available Shoreline Management Plans compiled by the Conservation Authorities. For medium and larger scale projects it is recommended that recession rates be determined through air photo analysis or comparison of recent shoreline positions to those on historic maps. Historic air photos are available from MNR and the National Air Photo Library in Ottawa. It is important to note that aerial photos must be corrected for distortion, a process called orthorectification, if they are to be compared to survey data. Historic shoreline maps are available for site specific areas and also for Lakes Huron, St. Clair and Erie in the form of the Ontario Land Survey (OLS) maps completed in the mid-1930's. The Technical Guidelines of the Shoreline Policy of the Province of Ontario (MNR, 1995) provide valuable information on the sources of information as well as methods to determine long term recession rates.

While the shore type is determined by the controlling (or underlying substrate), the important fish habitat characteristic is surficial substrate. There are some general relationships between controlling and surficial substrate as noted in Table 4.1.

There is limited existing information on surficial sediment for the nearshore regions of the Great Lakes. Investigations have been completed by Lewis and Sly (1971) and by Rukavina (1976) on some parts of Lakes Ontario and Erie. Some jurisdictions such as the Metro Toronto Conservation Authority have compiled littoral habitat mapping based on cursory surveys (see Parkinson et al, 1994). However, there is seldom sufficient detailed information available for the nearshore area where coastal structures are generally constructed. Therefore, site specific investigations are almost always required to determine the surficial substrate conditions. The level of detail required depends mainly on the shore type. For example, on bedrock shores diver videotape of the lake bed may be sufficient. However, on sandy and cohesive shores grab samples and sediment analysis will be required to determine the grain size distribution. From the grain size distribution and a standard nomenclature approach (such as Folk, 1954), the sediment can be classified as mud, silt, sand, gravel/pebbles, cobbles, etc. In more complicated areas, seismic and acoustic remote sensing techniques may be used to provide a more continuous map of the surficial sediment conditions. Remote sensing techniques should be supported by ground truthing (e.g. through the analysis of grab samples).

Diver surveys of the lake bed (preferably with videotape) are recommended for all medium and large scale projects. For smaller scale projects, this information can be gathered through wading or visual observations (from land) of the lake bed conditions in shallow water.

4.1.3 Water Level Fluctuations

For the purposes of evaluating impacts to fish habitat, the 100 year high and record low monthly mean lake levels given in Table 4.2 provide adequate information for most projects. For those projects or shore types (such as wetland) which are sensitive to water level fluctuations (including seasonal variations), more detailed information can be obtained from the water level bulletins issued by the Canadian Hydrographic Service (CHS) or from hard copy summary or digital time series records for the various recordings stations throughout the Great Lakes and St. Lawrence River system (also available from CHS). With the digital time series data, various statistical analyses can be completed to define water level fluctuations. A combined wave and water level data base can then be assembled to consider the combined wave and water level conditions. These combined statistics which may be important when considering the influence of water level on nearshore wave heights.

4.1.4 Wave Climate

An accurate description of the wave climate is critically important to the design development for a coastal structure as well for assessing the impact of a coastal structure. This section consists of a discussion of the available options for developing a description of the deepwater wave conditions. The definition of "deepwater" relates to depths where the largest waves do not interact with or "feel" the bottom. For practical purposes this depth is in the order of 50 m on the exposed coasts of the Great Lakes (i.e. 1/3 to 1/2 of the wave length). The nearshore transformation of the waves (through refraction, diffraction, shoaling, breaking, etc.) is discussed in Section 5.1 since this aspect of the wave climate will be modified with the construction of coastal structures, whereas the offshore wave climate in almost all cases will be unaffected by coastal structures which are constructed well inshore of deepwater on the Great Lakes.

While measured deepwater wave data is available in both the Canadian and U.S. waters of the Great Lakes, the records at any one location are almost always of short duration. Due to the year to year variability in wave climate, a long term description (typically 20 years or more) is required to develop a reasonable estimate of the wave height, period and direction statistics. Therefore, in almost all coastal engineering projects, wave data is derived from some form of wave prediction technique based on a description of the wind climate, for which long records are more generally available, and the "fetch" distances, the open water distances over which wind is able to generate waves from a particular direction sector.

The definition of a long term data set has been generally taken as 10 to 20 years for the purposes of establishing design wave heights, such as the 100 year return period value, in part due to the available wind record lengths used to predict the waves. However, in a recent investigation of coastal processes at the Toronto Islands summarized by Nairn et al. (1994), a 35 year wave climate was used and it was found that there could be significant directional variations in net wave energy over a period of one to two decades. A statistical description of wave direction, while less important for some design issues, may be critical in the assessment of impacts. Wave direction is important in defining the degree of sheltering on either side of the coastal structure. Therefore, wherever possible, the length of the hindcast record should be maximized by using the full length of the available wind data record.

Long term wave climate data has been prepared through the application of numerical wave hindcast models for numerous locations around the Canadian Great Lakes shoreline as part of the a project funded by the Conservation Authorities and Water Management Branch of the Ontario Ministry of Natural Resources in 1988 (see McLaren Plansearch, 1988 for Lakes Ontario and Superior, Sandwell Swan Wooster, 1988 for Lakes Erie and St. Clair, and Philpott Associates, 1988 for Lake Huron and Georgian Bay). Long term wave climate descriptions throughout the Great Lakes have also been prepared by the U.S. Army Corps of Engineers (as described by Hubertz et al., 1991). While this information has been and is useful for smaller projects on the Great Lakes, the design of medium and large scale projects has usually relied on site specific hindcasts (providing site specific information and providing the designer with a known level of confidence in the prepared wave climate).

For almost all medium and large scale projects, numerical wave hindcast models are applied to predict or "hindcast" the hourly wave conditions over a 10 to 35 year period. Either one-dimensional parametric or two-dimensional spectral models are applied. Skafel and Bishop (1991, 1993) have shown through comparisons to measured wave data on the Great Lakes that both the 1D and 2D models in use can provide reasonable estimates of wave height, period and direction. All applications of wave hindcast models require calibration and validation tests against the available measured wave data. Measured wave data is available from the Marine Environmental Data Service (MEDS) for Canadian waters and the National Ocean and Atmospheric Administration (NOAA) for U.S. waters.

The greatest potential for error in wave hindcasting is related to the determination of representative overwater wind speeds. Long term wind data are generally available from recording stations maintained by the Atmospheric Environment Service and NOAA at airports which are often located at some distance from the lake itself. Transfer functions must be developed to translate these land based measurements to overwater winds in an effort to compensate for changes in the wind boundary layer associated with the higher roughness of the land and possible sheltering effects (due to both natural and artificial features), and air-water temperature differences. Considerable research into this issue has produced a wide range in results (for example, refer to Richards and Phillips, 1970, Resio and Vincent, 1976, and Schwab and Morton, 1984). Ideally, the transfer functions should be developed through a comparison of land-based wind data and available overwater wind data, and/or through calibration of trial hindcast results (predicted waves) against any available measured wave data. Therefore, a significant effort should be devoted to the consideration of the applicability of wind data from a particular station and to the transformation of this data to represent overwater conditions.

4.1.5 Ice Climate

An understanding of the ice climate is required for at least two reasons. First, for the period of the year when a nearshore area is frozen over, the lake bed in this area will not be subject to the forces of wave action and, therefore, any impacts related to changes in wave climate will not be experienced during ice cover periods). Also, large areas of all of the lakes freeze over for some period of the year, thereby precluding the generation of waves by restricting or eliminating the open water fetches.

The second issue related to ice concerns possible changes to ice build up patterns and the effects of ice on scouring of the lake bed and shoreline. This issue is particularly relevant on rivers.

The Atmospheric Environment Service publishes weekly ice charts showing the extent and degree of coverage for all of the Great Lakes. Numerical wave hindcasts are generally completed for the average annual open water season based on summary information from the ice charts. An understanding of the local ice build up and scouring issues can be developed through anecdotal evidence, visual observations and through the evidence of ice scour on the lake bed from aerial photographs taken in the spring.

4.1.6 Sediment Transport, Sediment Budget and Erosion Processes

In addition to establishing the local shore type through the determination of the controlling substrate, it is essential to develop an understanding of the pre-development sediment transport processes and the sediment budget for the evaluation of medium and large scale projects. Changes to these conditions and processes caused by the construction of coastal structures can result in significant impacts to the water depth and substrate type.

Information is required on the potential alongshore sediment transport rate, the actual alongshore transport rate (i.e. the rate limited by the rate of supply of sediment to the littoral zone) and the erosion and deposition processes. Estimated rates of potential sediment transport, sediment budgets and limits of littoral cells for the entire Great Lakes are presented in a report by Reinders (1988) prepared for the Conservation Authorities and Water Management Branch of the MNR. While the information in this report provides a valuable general reference, it is of limited use for site specific investigations, particularly for medium to large scale projects. More detailed information is sometimes available where Conservation Authorities have prepared Shoreline Management Plans.

There are no standardized techniques for estimating alongshore sediment transport rates although the science of predicting sediment transport is rapidly evolving. Numerical and analytical models may be applied to estimate erosion and deposition processes in which the long term wave climate is used as input to calculate the average annual rate of sediment transport. The results of this calculation should be presented as the transport components in the two directions along the shore and not just the net or gross value. The adopted technique should be capable of accounting for the influence of wave period and grain size as well as wave height and direction. Two widely applied “bulk” sediment transport predictors are the U.S. Army Corps of Engineers (1984) CERC (Coastal Engineering Research Center) expression and the Queen’s University expression presented by Kamphuis (1991). Both models are strongly empirical and only provide estimates of the total “potential” transport rate moving past a shore normal profile. The Queen’s model has the advantage of being based on a larger data base and having grain size as a variable. It is important to recognize the distinction between “potential” and “actual;” sediment transport rates. The potential transport rate assumes that sediment is mobilized across the entire beach and nearshore profile with no exposed hard substrate.

A few models are available which predict the distribution of sediment transport across a nearshore profile; this information may be valuable as it can be used to approximate the amount of sediment that might be blocked by a coastal structure. Figure 4.1 shows an example of the distribution of alongshore transport across the nearshore zone for several profiles around Toronto Islands (from Baird & Associates, 1994). Figure 4.2 shows the alongshore transport distribution superimposed on a profile cross-section which also includes the position of a coastal structure. Methods which provide the distribution across a profile based on a parametric form (i.e. such as the Fulford, 1982 distribution) are not particularly useful for Great Lakes conditions where the profile shapes vary considerably from location to location and have an important impact on the distribution of alongshore sediment transport. Results from deterministic models of coastal processes, which are based on the actual processes (such as wave breaking and decay, the generation of longshore currents, etc.), are much more reliable for these types of calculations. These types of models are reviewed in Section 5.3.

Most numerical models only predict the "potential" sediment transport. This potential rate is only realized for full sandy beach situations which are not that common on the Great Lakes. On most Great Lakes shorelines, the sand supply is limited, which means that for any profile (or cross-section) extended perpendicular from the shore, the amount of sand on the profile is limited to a relatively thin veneer. At some locations there may be large patches of exposed rocky or cohesive substrate with no sand cover at all as shown in Figure 4.3. The "actual" sediment transport rate is determined from the supply of sediment delivered to the littoral cell through shoreline erosion processes and through sediment loading from creeks and rivers (although the latter is small for almost all sections of exposed Great Lakes shorelines). Therefore, the rate of sediment supply must be determined through a sediment budget for the littoral cell which contains the study site. The sediment budget primarily consists of an estimate of the volume of sand and gravel (i.e. sediment which remains close to shore) yielded in the erosion of the shoreline and lake bed and is based on the product of the long term recession rate and the volume of sand and gravel in the eroded lake bed and bluff. The latter is determined through the height of the eroding section of lake bed and bluff and the sediment characteristics of the eroded material as determined from available borehole information, as shown in Figure 4.4. Along most urbanized sections of shoreline, and for some other sections of shoreline that have come under the scrutiny of coastal engineers, scientists and geomorphologists, there will be existing borehole information and some estimate of the sediment budget. This information is often summarized in the Shoreline Management Plans prepared by the Conservation Authorities.

In addition to determining the alongshore sediment transport rate and the sediment budget, it will be important to describe the pre-development erosion (and deposition) patterns at a site. For example, on eroding cohesive shores, some understanding of the annual rate of nearshore lowering or downcutting can be established quite simply by shifting the nearshore profile shape shorewards at the historic rate of average annual shoreline or bluff retreat. At certain shoreline locations, where the coastal morphology is complex, sophisticated models of morphology, possibly coupled with sediment budget information, may have to be applied. It is essential that an understanding of pre-development morphodynamics be established prior to the implementation of a coastal project. The available techniques for simulating coastal morphodynamics are discussed further in Section 4.3.3.

4.2 Definitions of Physical Habitat Characteristics

This section provides a brief overview of the definition of different areas of impact and the various fish habitat characteristics that can be affected by coastal projects.

Based on Minns et al. (1995), three areas of change are defined as follows and illustrated in Figure 4.5:

1. areas lost defined as areas below the high water level before the project and above the high water level following the project (A_L),
2. areas directly modified defined as areas below the high water level before and after the project but where the original lake bed is covered by the project, habitat characteristics of depth and surficial substrate are affected in these areas (A_{MD}),
3. areas of indirect impact defined as areas where the original lake bed is not covered by the project but where there may be changes to the key fish habitat characteristics including wave energy, surficial substrate, the condition of submerged macrophytes (including the presence or absence of macrophytes), water depth, water temperature and other water quality parameters (A_{MI}).

For the first category, any habitat is totally eliminated and the community production is reduced from its pre-development level to zero. For the second and third categories, changes to production are evaluated based on changes to the characteristics of the physical habitat.

There are important temporal issues regarding the nature of fish habitat impacts. Change in some physical characteristics may only occur during extreme events which are experienced infrequently. Therefore, the impacts of change may not be discernible for some time (i.e. until the extreme event occurs). Also, changes related to erosion and sedimentation processes can result from very slow processes and will only become significant in the long term. These long term erosion processes may also be indefinite (i.e. a state of equilibrium will not be reached in the near future) and therefore, the magnitude of the impact will be a function of the time period under consideration (possibly limited to the design life for the project).

4.3 Assessment of Impacts - Areas Lost, Directly and Indirectly Modified

Some general comments on the assessment of the three areas of impact are presented in this section. Methods for delineating these areas are introduced and methods for completing the evaluation of impacts are reviewed in Section 5.

4.3.1 Areas Lost

The determination of areas lost to habitat is a relatively straightforward exercise. The area lost to fish habitat consists of the area which reverts to "dry land" as a result of the project. An accurate evaluation of the impact of the area lost must be based on an adequate definition of the pre-development depth and substrate conditions within the proposed area lost. Approaches to defining these site characteristics were discussed in Section 4.1. In order to estimate the impact of the project, it will be necessary to have design drawings showing plans and sections of the proposed development. The plans should provide sufficient contours of elevation to define accurately the wet/dry boundary (as defined later in this section).

A critical aspect of the definition of this impact is the specification of a water level (i.e. which defines whether an area is wet or dry). As noted in Section 4.1.3, there is significant seasonal and year to year variation in the Great Lakes water levels. A stringent definition of this impact might rely on an average, or even a low water level (i.e. to maximize the area lost). However, a stringent definition may also lead a proponent to implement undesirable design features. For example, if the average water level is applied in the definition of the wet/dry line, the proponent may be encouraged to create steep sided structures (in the limit, vertical walls) above the defined level where no "credit" is given to a reduction of the area lost at higher lake levels. Figure 4.6 illustrates how the area lost can vary with the selected water level and the slope of a structure for a hypothetical island structure.

It is proposed that the 100 year monthly mean lake level (i.e. not including short duration storm surge effects) should be used to define the wet/dry boundary at the outer edge of the area lost. A summary of the 100 year monthly mean lake levels for each of the Great Lakes is presented in Table 4.2. These levels are referenced to both International Great Lakes Datum 1985 (which is used as the datum for hydrographic charts) and to the Geodetic Survey of Canada Datum (which is used on most topographic maps).

The area immediately outside of, and below, the area lost must be carefully considered in the assessment of direct impacts.

4.3.2 Areas of Direct Impact

The area of direct impact for a coastal structure such as a breakwater is delineated by the wet/dry boundary of the area lost (as defined in Section 4.3.1) and by the outer edge of the "footprint" of the structure. The "footprint" of the structure is defined the area of lake bed covered by the proposed coastal structure. In addition, areas of direct impact may consist of areas of lake bed that have been covered or altered as part of fisheries compensation measures or that have been significantly disturbed by construction activities such as excavation or dredging.

The evaluation of the impact on fish habitat in the directly modified area requires accurate descriptions of the pre-development depth and substrate conditions (as defined in Section 4.1.1 and 4.1.2) as well as the post-development depth and substrate conditions. As with the areas lost, the assessment of the post-development conditions should be based on final design drawings consisting of sufficient detail in the plans and sections to define alterations to depth and substrate over the full directly modified area. In addition, the plans and sections should show any areas where the lake bed will be significantly disturbed (e.g. through excavation or dredging). Provisions for containment of possible construction disturbances, such as silt curtains, should be indicated.

Within the area that is directly modified, two sub-areas should be delineated: 1) areas which are always submerged; and 2) a wet/dry zone. The size, slope and surficial substrate of the wet/dry area may have important implications to the fish habitat impact assessment in relation to the local fish community objectives. Therefore, the plans and sections should also show the 100 year low monthly mean level, which, together with the 100 year high monthly mean level will delineate the wet/dry and always submerged sub-areas of the directly modified area.

4.3.3 Areas of Indirect Impact

Areas of indirect impact of a coastal project in relation to fish habitat are defined as those areas where "significant" changes occur to wave energy, surficial substrate, the condition of submerged macrophytes (including the presence or absence of macrophytes), water depth, water temperature, turbidity and other water quality parameters. The definition of "significant" is continually evolving as the understanding of the relationships between physical fish habitat and community productivity are improved with ongoing research.

Recent work in this area by Minns et al (1995) relates fish community productivity on the Great Lakes to water depth based on 2 m intervals in shallow water and 5 m intervals in depths greater than 5 m. Therefore, "significant" changes in depth relative to fish impact are in the order of 1 m in shallow water and 2.5 m in deeper water at present (i.e. based on Minns et al., 1995). For most coastal projects, this magnitude of significant change only occurs in very close proximity to the project itself, and usually in relatively shallow water, as a result of erosion or deposition processes. Methods for evaluating these types of impacts are presented and discussed in Section 5.3.

The definition of "significant" changes in water temperature relate to changes between the optimum temperature range for warm, cool and cold water fish species. Aside from special cases where hot or cold water is introduced from an external source to the ambient water conditions, significant temperature change only occurs where enclosed basins or significant sheltering is created and flushing is restricted. Techniques are available for enhancing flushing, thus reducing any possibility of significant changes to temperature.

Impacts to water quality and water temperature caused by changes to circulation patterns are generally only "significant" where there is a nearby external source of water (e.g. an outfall or creek) with significantly different temperature or water quality characteristics than the ambient water. Otherwise, and particularly for exposed shore conditions on the Great Lakes, the changes to circulation patterns may not have a significant impact on water quality. However, there are two related issues regarding impairment to water quality: 1) where coastal structures project into the lake, coastal debris including algae may accumulate, sometimes leading to degradation of the local water quality; and 2) in areas sheltered from wave action, algae may accumulate and grow (this is addressed under the discussion of macrophytes in Section 5.4). Methods of evaluating changes to circulation patterns (and the interaction with external sources where they exist) and the impact on water quality and temperature are presented and reviewed in Section 5.2.

Changes to surficial substrate and the local macrophyte conditions are both linked, at least in part, to the changes in wave action and circulation. Coastal development projects which extend into the lake will create areas which are sheltered from some or all directions of wave attack. In addition, the structures may influence circulation patterns (and the related steady current velocities) which are generated by winds and waves or associated with head differences (i.e. river flows). Predictive techniques for evaluating the changes to the hydrodynamic conditions (i.e. the waves and currents) are described and reviewed in Sections 5.1 and 5.2.

Changes to surficial substrate are also determined by the local shore type and sediment supply characteristics. For example, fine sediments will accumulate in a newly created sheltered area only if there is a local supply of fine sediment.

In the Minns et al (1995) method for quantifying fish habitat impacts, the habitat productivity is related to five categories of surficial substrate including rock, gravel, sand, mud and pelagic based on the Folk (1954) system as described in Section 4.1.2. With additional research, the number of categories of surficial substrate will be increased. Nevertheless, these will be based on the median grain diameter determined from a grain size distribution analysis. In most cases, changes to surficial substrate will only be significant in areas of significant erosion and deposition (and depending on the shore type, even in these areas the changes to surficial sediment may not be significant).

The presence of macrophyte cover is defined by Minns et al. (1995) to be a function of water depth, lake bed slope, water clarity, substrate and wave energy. Owing to the strong dependence of the presence or absence of macrophyte growth (including algae) on the magnitude of wave action (or wave exposure), the changes to macrophyte conditions in exposed coast situations are primarily related to changes in wave action. For example, in areas that become sufficiently sheltered, macrophytes may flourish where they were previously absent (providing that the surficial substrate is appropriate). Denny (1995) presents a comprehensive investigation of the influence of wave action on the ecology of wave swept coastlines on the U.S. west coast. Despite the fact that the definition of the dependence of macrophyte growth on the level of wave exposure is only in its infancy on the Great Lakes (compared to the work of Denny, 1995 on the U.S. west coast), there is little doubt that there will be similarly strong dependence of macrophyte survivorship on wave exposure (see Section 5.4).

In summary, the delineation of the indirect area of impact is a function of the anticipated changes in several fish habitat characteristics including: surficial substrate, the presence or absence of macrophytes, water depth, water temperature and other water quality parameters. The changes to these characteristics are almost always linked in some way to changes in the wave and current conditions created by the presence of the planned coastal structures. Therefore, the primary task in evaluating the area of indirect impact will be defining the changes to wave and current patterns. Techniques for describing these changes are presented and reviewed in Sections 5.1 and 5.2.

It is noted that the discussion of indirect impacts is limited to those changes which result in a significant impact to fish habitat. The construction of coastal structures can have far reaching consequences to erosion and sedimentation processes at great distances from the development site as a result of disruption to littoral sand transport and supply. However, unless a project is very large, these types of impacts are cumulative in nature, and therefore, difficult if not impossible to attribute or apportion to any individual project. Therefore, these types of regional impacts on erosion and sedimentation processes (and the related changes to the fish habitat characteristics of substrate and depth) are not considered with respect to fish habitat impacts. These types of impacts should be reviewed and regulated through the enforcement of shoreline management plans and under the Ontario Shoreline Policy (see MNR, 1995).

5.0 TECHNIQUES FOR ASSESSING CHANGES IN AREAS MODIFIED INDIRECTLY BY THE DEVELOPMENT

This section provides a description and review of the techniques available for the assessment of changes to the coastal processes caused by a project. The full range of detail and sophistication is covered from rules of thumb and analytical approaches to numerical and physical models. There are four parts to this section providing a review of techniques for predicting changes to: 1) nearshore waves; 2) currents and circulation patterns; 3) erosion and deposition processes; and 4) surficial substrate and the presence or absence of macrophytes.

5.1 Predicting Modifications to Wave Action

The magnitude of changes to the wave energy and wave-induced circulation patterns created by a coastal development project depends largely on the magnitude of the modifications to the shoreline configuration and nearshore bathymetry. In this section, a variety of approaches for evaluating the changes to waves are presented, ranging from simple "rule of thumb" approximations to the use of sophisticated physical and numerical modelling techniques. The selection of a particular approach depends largely on the nature of the water body under consideration and on the complexity of the shoreline and project.

5.1.1 Simplified Assessment of Impacts on Wave Conditions

Waves generated in deep water undergo significant changes in amplitude (height), length and direction as they propagate towards the shoreline, largely due to the influence of the underlying bathymetry. Some of the processes include:

- Shoaling - The changes in wave height and length due to a decrease in water depth.

- Refraction - The bending of a wave crest due to changes in water depth. A shoal may create an area of wave convergence with high concentrations of wave energy.

- Diffraction - The transfer of wave energy from regions of higher energy concentration to areas of lower concentration. Wave diffraction is the predominant consideration when evaluating the wave climate in a sheltered bay or harbour, or at locations where strong changes in nearshore bathymetry result in wave convergence and in concentrations of wave energy.

- Breaking - The dissipation of wave energy due to breaking processes as waves encounter shallow depths. The presence of wave breaking has a strong effect on the movement of sediments and the level of turbulence in the water column.

- Reflection - The reflection of wave energy due to the presence of structures and/or due to rapid changes in bathymetry is often an important consideration with coastal development. Wave reflections can cause a build-up of wave energy in localized areas. The relative importance of wave reflection is a function of the material characteristics of any surface-piercing structures.

The relative impact of each of the above processes on the transformation of waves as they propagate from deep water to the shoreline depends primarily on the nearshore bathymetry and the arrangement of any coastal structures, although bottom friction may have a limited effect.

An initial review of the site characteristics and deep water wave climate is required to assess the complexity of the problem at hand and to help guide the selection of an appropriate evaluation technique. In certain cases, if various underlying assumptions are met, a simplified assessment of wave transformation may be carried out.

For example, if the nearshore bathymetry may be characterized as having straight, "shore-parallel" contours, the changes in the waves due to refraction and shoaling may be estimated using "Snell's Law", a pocket calculator and tabulated values from the USCOE Shore Protection Manual (1984) or equivalent coastal engineering handbook. The accuracy of this methodology depends largely on the variation of the actual bathymetry from the assumption of straight, parallel contours; such an arrangement is rarely found in nature.

With more complex bathymetries, wave ray-tracing techniques based on the Snell's Law approach have been developed which follow the path of the waves as they move toward shore. In this case, a number of wave rays, defining the direction of wave propagation, are drawn manually on a hydrographic chart of the site with changes in wave direction/height being estimated locally at each contour line of the nearshore bathymetry through solution of Snell's Law. The construction of wave rays is described in many coastal engineering text books (e.g. U.S. Army Corps of Engineers Shore Protection Manual, 1984; Dean and Dalrymple, 1984). Wave ray procedures have also been implemented in computer programs, as described later in this section.

An initial evaluation of wave diffraction around simple coastal structures may be carried out using diffraction diagrams given in various coastal engineering textbooks (e.g. Shore Protection Manual, 1984). These diagrams indicate, in non-dimensional form, the spread in wave energy behind a single, straight breakwater or through a narrow harbour entrance gap for various wave directions, and are typically based on the solution of the equations governing wave diffraction as developed by Penny and Price (1944). It is assumed that the region of wave diffraction has a constant depth.

Wave reflections at a particular site may be initially evaluated through consideration of the shoreline and/or structural materials. Impermeable vertical walls, such as a concrete caisson or a steel pile wall, will reflect most wave energy and may be assumed to cause 100% wave reflection. A sloped, permeable rubble structure will typically reflect 30 to 50% of the incoming wave energy. The wave reflection from a beach face is generally less than that from a structure and may be estimated using simple, empirical equations found in coastal engineering textbooks.

As waves travel into shallow water, there is a limiting steepness for which the wave may remain stable. Once waves reach this limiting steepness, the wave will begin to break and, thereby, dissipate energy. As a rule of thumb, waves will begin to break when their height becomes equal to approximately 0.6 to 0.8 times the local water depth. This is a simplification, however, as the breaking wave height is somewhat dependent on bottom slope, wave steepness and the presence of currents.

Wave overtopping of structures is an inherently complex process and may be evaluated using various empirical formulations (Shore Protection Manual, 1984) based on analysis of physical model test results. There may be large variations (order of magnitude) in the estimates provided by such formulae.

5.1.2 Numerical Models of Wave Processes

Through the use of simplified techniques, such as those outlined above, the assessment of individual wave processes may be carried out. However, the complexity of the bathymetry and the coastal structure layout at many sites often precludes the use of such simplified approaches. In recent years, considerable progress has been made in the development of sophisticated numerical models that simulate wave growth and propagation.

There are a wide range of numerical modelling tools available. The selection of an appropriate tool should be based on an understanding of the dominant wave processes at the project site as there are underlying limitations to each type of model. There is not a single numerical model applicable to all situations.

There can be important distinctions among various numerical models with regard to how waves are characterized. At any point in time, the actual water surface on the Great Lakes is composed of waves of many different heights and periods and coming from different directions. The waves arriving at a particular location are typically characterized through statistical distributions that describe this temporal and directional variability. The simplest wave models make use of "monochromatic" or "regular" waves in which the entire wave train is assumed to be composed of long crested waves of equal period and height, clearly unrealistic for most scenarios. Certain models permit the used of "irregular" waves; that is long crested waves of variable height and period coming from a single direction. The most sophisticated models employ "irregular (or random), multi-directional" waves. In this case, the waves arrive from a range of directions (short crested waves) and are composed of a range of wave heights and periods. Such waves are typically characterized by frequency and directional energy spectra in which the dominant wave height/period and wave direction are identified, respectively.

The use of regular versus irregular waves in a numerical model can lead to varying model results, depending on the site under examination, particularly in diffraction zones. The use of long crested, unidirectional waves tends to create excessive wave focusing and divergence in wave models. The use of long crested waves is more suitable for the simulation of ocean swell waves and not wave conditions on the Great Lakes.

The least sophisticated wave models are numerical implementations of the wave ray tracing procedure previously discussed. Wave ray models have been widely used since the 1970's and may be suitable for an initial evaluation of a particular site. These models are easy to use, require little computational power, and are typically implemented on Personal Computers. The propagation of waves over very large areas (tens of kilometres) may be readily carried out.

The primary disadvantage of wave ray models is that wave diffraction processes are not simulated; therefore, wave ray models should only be used to reproduce wave conditions in regions where water depths vary slowly and where coastal structures are not present. When these conditions are violated, unrealistically large build-ups of wave energy (caustics) may occur at various locations in the model domain, shown visually as a crossing of wave rays. Various numerical techniques have been developed in the past to avoid the development of caustics, including backtracking algorithms, however, it is important to recognize that it is implicitly assumed in all types of the wave ray tracing techniques that the model bathymetry should vary slowly in the horizontal dimensions. In addition, wave reflection characteristics cannot be reproduced in a wave ray model.

A more sophisticated numerical model is the Spectral Nearshore Wave Model. These models are derived by solution of the conservation equation for spectral wave action density and consider a wave energy balance over the model domain (the wave ray model in fact is a type of spectral model in which conservation of wave energy is maintained between the individual wave rays). As the computer requirements are modest for a spectral model, the simulation of wave propagation over very large nearshore regions (tens of kilometres) is possible. Two examples of nearshore models are the HISWA model of Delft Hydraulics (Holthuisssen et al., 1989) and the SHALLWV model of the U.S. Army Corps of Engineers (1991).

The spectral model has similar disadvantages to the wave ray model in that diffraction and reflection processes are not implicitly simulated; these models should ideally be employed in regions where the bathymetry is slowly varying in space. These models should not be utilized to assess the sheltering (diffraction) impacts of a project and are best used to establish wave conditions immediately offshore of a specific project site.

Another group of wave models that are widely employed are based on the solution of the mild-slope equation as derived by Berkhoff (1972). There are generally three formulations of such models: the elliptic, the hyperbolic and the parabolic mild slope models.

The Elliptic Mild Slope Models are based on direct solution of the mild slope equation (an elliptic equation) through use of finite element or finite difference techniques, and can reproduce wave refraction, shoaling, diffraction and reflection. In certain models, wave breaking processes have been implemented in simplistic fashion. The primary disadvantage of the elliptic models is that they are very computationally intensive and, as such, generally only consider regular wave conditions and small modelling regions. Boundary conditions are required around the entire model region. Examples of elliptic models include the model of Berkhoff et al. (1982) and the MIKE21 EMS model of the Danish Hydraulic Institute. These models are typically employed to assess harbour wave disturbance.

Ebersole (1985) developed an efficient numerical scheme for the solution of the mild slope equation in a model called RCPWAVE (U.S. Army Corps of Engineers, 1991). Refractive-diffractive effects are included in the model, although reflection is not. RCPWAVE can only consider the propagation of regular, uni-directional waves. The model has been criticized by others (Kirby, 1988) for causing excessive smoothing of the wave field leading to underprediction of waves in sheltered regions.

The mild slope equations may be re-cast in a different form to give the Parabolic Mild Slope Models. These models are much more computationally efficient than the elliptic models but with the limitation that wave reflections cannot be reproduced and that only limited lateral diffraction effects are taken into account. These models assume that there is a principal direction of wave propagation and the numerical solution begins to deviate when the wave angle relative to the initial wave propagation direction becomes large. Parabolic models do not require the implementation of boundary conditions throughout the model domain and, thus, are more rapidly set up than elliptic models. Wave breaking processes are considered in most of the available parabolic models. Examples of parabolic models include the REFDIF1 model of Dalrymple and Kirby (1986), the MIKE21 PMS model of the Danish Hydraulic Institute, and Tsan and Liu (1982). Due to the limitations on wave angle, parabolic models must be cautiously applied when evaluating the wave sheltering created by coastal structures.

The mild slope equation may be reformulated into a series of hyperbolic equations to yield the hyperbolic mild slope models. An example of this is the model of Copeland (1985). Hyperbolic models are computationally intensive and are not widely employed.

A third category of wave models are the range of Boussinesq Models which have been developed based on the time-dependent, vertically integrated Boussinesq equations of conservation of fluid mass and momentum. Boussinesq models implicitly include the effects of wave refraction, diffraction, reflection and shoaling. Wave breaking has also been implemented in certain models. As many of the models are time dependent, irregular and multi-directional waves can be readily simulated (i.e. very realistic conditions can be reproduced). Boundary conditions must be supplied around the entire modelling region.

A disadvantage of the Boussinesq models is that there is a definite limit on the maximum depth of water that can be incorporated in the model grid. Waves cannot be truly propagated from deep to shallow water. There have been, however, advances in extending the deep water limits of Boussinesq models in recent years (Nwogu, 1993).

Examples of Boussinesq models include the Shoal2d model of the National Research Council of Canada and the MIKE21 BW model of the Danish Hydraulic Institute.

Table 5.1 summarizes the processes that can be reproduced in the various types of numerical wave models. There are some key distinctions among the models. Firstly, the wave ray and spectral models, sometimes referred to as "phase-averaged models" (Battjes, 1994), are not dependent on time and utilize averaged wave properties in the solution process. This implies that the model grid spacing is not linked to either the solution method or the incident wave conditions, and permits the simulation of wave conditions over very large areas, typically tens of kilometres. The difficulty with these models is that only a limited number of wave processes can be simulated. They are most suited to evaluation of wave transformation in deeper regions away from the shoreline where water depth variations have a limited impact on wave propagation.

The mild slope and Boussinesq models, on the other hand, are referred to as "phase-resolving models" and the spacing of the input depth grid must be a function of the input wave conditions (generally 5 to 8 grid points per wave length must be provided). Thus, waves can be simulated over only relatively small regions, typically 4 to 5 kilometres at most, using even a high powered computer workstation. It is often very difficult to simulate the propagation of higher frequency waves (wave periods of less than 4 seconds).

A second important distinction among the models is the requirement for boundary conditions around the model domain. With wave ray, spectral and parabolic models, the user generally only has to specify the wave conditions at the offshore boundary. Full boundary conditions must be supplied around the edges of the model for the elliptic, hyperbolic and Boussinesq models. In the case of structures and shorelines which only partially reflect wave energy, special elements must be introduced into the models to simulate this behaviour. These elements can be time-consuming to implement in the model and must be calibrated to the incident wave conditions in order to provide the correct level of wave reflection. Incorrect definition of these boundaries can lead to insufficient or excessive wave energy in the nearshore region.

5.1.3 Physical Modelling of Wave Processes

Physical scale modelling is one of the best means to simulate wave processes, and may accurately reproduce the physics of the nearshore zone provided appropriate model design and scaling is applied. In such models, a three-dimensional section of the shoreline is created at scale (typically in the range of 1:5 to 1:50, depending on the project size) in an enclosed basin. Physical modelling can be particularly useful in the simulation of the interaction of waves with structures as the effects of wave reflection and diffraction. Three-dimensional wave-induced circulation can also be accurately simulated in these same models. Certain processes such as overtopping can only be accurately reproduced in scale models.

The extent of the region that can be physically modelled is limited (typically to 1 or 2 km at best) due to restrictions on scale selection and basin size.

5.2 Predicting Modifications to Currents and Circulation Patterns

5.2.1 Initial Assessment of Impacts on Currents

Hydrodynamics, the movement of water, is a fundamental feature of nearshore regions, and is an important underlying mechanism affecting the transport and exchange of nutrients, sediment and toxins in water bodies. Flow velocities also influence the survivorship of submerged macrophytes.

An initial assessment of a site should consider the bathymetric conditions in the water body as well as the physical factors, such as wind, inflows and stratification, that induce current motion. This will provide an initial screening as to the complexity of the site and help in the selection of appropriate tools for more detailed analyses.

Often, site specific data must be collected to support the assessment process. This may include the measurement of currents and water levels, as well as the identification of circulation patterns through the use of dye release and/or the tracking of surface floats. It is also useful to undertake vertical temperature profiles during different periods of the year to assess the degree of vertical stratification.

5.2.2 Numerical Models of Currents

Measured current data will provide a certain level of information at a project site but it is often difficult to extrapolate the measured data to scenarios (higher flows, faster wind speeds, different wind directions) which have not been recorded and to develop a full understanding of circulation patterns. Numerical modelling tools allow the user to develop a more complete understanding of the physical interactions at a site.

Significant advances have been made in the field of hydrodynamic modelling in recent years, particularly with the use of three-dimensional models, due to improvements in computer technology. As a result, many of the underlying assumptions and applicability of such modelling are reasonably well understood (Roig, 1994). Numerical models may represent natural phenomena with varying degrees of simplification with respect to the spatial dimensions, ranging from simplistic, one-dimensional models to highly complex three-dimensional models. All of these models start with the generalized Navier-Stokes mathematical equations which describe the motion of fluids in space and vary in the degree of simplification applied to the equations. The selection of an appropriate model and the level of model simplification is largely dependent on the nature of the water body under consideration and the objectives of the assessment.

Three-dimensional models are the most complex of the models and solve for currents and water temperatures in all three spatial dimensions. Inputs to the model consist of a three-dimensional computational mesh or grid which characterizes the geometry and topography of the area under consideration and on which the numerical methods are applied. The grid is fixed in space and at each grid intersection point, the elevation and other relevant computational parameters (for example, bottom roughness, wind stress, eddy viscosity, water temperature) are applied. Boundary conditions, including wind direction and velocity, river inflows/outflows, surface water level and atmospheric thermal exchange must also be applied to the model. A three-dimensional model provides as output a description of current flow, water level, water pressure, water temperature and salinity (if relevant) at each grid point.

Examples of three-dimensional hydrodynamic models include the Princeton Ocean Model (Blumberg and Mellor, 1987), ECOM (Blumberg, 1994), RMA 10 (King, 1993), Trisula (Delft Hydraulics Laboratory) and System 3 (Danish Hydraulics Institute).

In a two-dimensional model, the Navier-Stokes equations are typically averaged in the vertical dimension to yield the "shallow water equations". As a result of the vertical averaging, it is assumed that in similar fashion to a three-dimensional model, the study area is mapped into a computational grid, although this grid extends only in the two horizontal dimensions, not through the vertical. Inputs to the model are less extensive than with the 3D model as 2D models do not resolve vertical density and do not require information on the thermal or density structure of the water body. The output from a 2D model consists of the water level and the vertically averaged current velocity and direction at each grid point.

There are a wide variety of two-dimensional models available. A few of the more common models include RMA 2 (King, 1990), ADCIRC 2D (1992), MIKE21 (Danish Hydraulic Institute), Telemac (Electricte de France) and FESWMS (U.S. Federal Highways Department).

One-dimensional models are typically employed to simulate channel flow in rivers and are not suitable for open coastal regions.

It is important to note that hydrodynamic models should generally be calibrated against measured data, including both recorded water levels and currents. In the calibration process, certain factors such as bottom roughness and turbulence terms are adjusted until the model result match the recorded data. This calibration is particularly important when assessing circulation patterns in sheltered regions where large scale eddies may be established; numerical models vary considerably in their ability to simulate this type of phenomena.

Three-dimensional hydrodynamic models provide the most comprehensive information regarding the currents in a coastal region but are very computationally intensive which limits the practical size and resolution of most model grids. Two-dimensional models are less demanding on computer resources but it is implicitly assumed in the theoretical derivation of such models that vertical currents and density gradients are negligible. This restricts the use of such models to shallow waters (hence the name "shallow water equations") with little or no density stratification. The variation of current velocity with depth cannot be determined from a two-dimensional model - this is a particularly limiting shortcoming for surfzone conditions where the flow is often stratified.

5.2.3 Physical Modelling of Currents

An alternative approach to the numerical simulation of currents is the use of a physical scale model. Physical models can accurately reproduce the physics of many aspects of the nearshore zone provided appropriate design and scaling is applied.

Physical models are less useful for some aspects of the simulation of currents in nearshore regions. Often, current flow is three-dimensional in nature and it difficult to set up conditions such as thermal stratification in a scale model. In addition, it can be troublesome to correctly reproduce boundary conditions in such models.

5.3 Predicting Modifications to Erosion and Deposition Processes

The magnitude of changes to the local erosion and deposition processes, and the related influence of these changes on depth and surficial substrate, depends on the local shore type and on the changes to the nearshore wave and current conditions. In this section, a range of approaches to evaluating changes to erosion and deposition patterns is presented from simple rule of thumb techniques to sophisticated physical and numerical modelling. How changes to erosion and deposition patterns relate to changes to depth and substrate (i.e. fish habitat characteristics) is discussed in Section 5.4.

In order to assure a reasonable prediction of changes to erosion and deposition patterns, the shore type must be correctly evaluated and the pre-development morphodynamics must be well understood. Depending on the shore type, the issue of time scale may be very important; the magnitude of an impact may increase or decrease with time.

Due to the uncertainties related to the complex processes associated with nearshore hydrodynamics, sediment dynamics and the resulting morphodynamics, there are no available techniques to predict accurately the short term and long term changes to erosion and deposition patterns for all situations. However, there are many valuable analytical, numerical and physical modelling tools, that can be applied to assist the investigator in answering "what if" questions regarding potential changes to erosion and deposition processes. Which combination of these tools to use depends very much on the individual confidence of the investigator in the available techniques and the degree of complexity associated with the problem.

A consideration of the shore type, sediment supply conditions and project type provides an initial screening of the complexity of the problem and the basis for applying some rules of thumb.

5.3.1 Perpendicular Obstructions - Rules of Thumb and Analytical Tools for Impact Assessment

For shore attached structures, and where a sediment supply exists there may be localized erosion and/or deposition of sediment on either side of the project.

With respect to deposition, the extent of the fillet beach accumulation that develops will be a function of the shoreline orientation (relative to the wave attack) and the distance that the proposed structure projects into the lake. The fillet beach will take on a long term stable orientation which is normal to an azimuth where there are equal amounts wave energy on either side of the normal (i.e. where the net alongshore sediment transport is zero). This stable beach orientation can be established through:

- a review of nearby beaches with similar orientation and sediment type;
- a review of the directional distribution of wave energy;
- alongshore sediment transport calculations to determine the orientation where there is no net transport.

Referring to Figure 5.1, distance "X" will be determined by the stable beach orientation and may be less than or equal to the distance "Y". When the toe of the beach at the structure falls lakeward of the end of the structure (i.e. as distance "X" approaches distance "Y"), sediment will bypass the structure.

For groins and headland structures, where bypassing of sediment occurs around the end of the obstruction, a shoal may develop off the end of the structure (see Figure 5.1).

Embayments are often created in large lakefill projects. Depending on the potential rate of sediment transport and the available sediment supply, these embayments may be subject to infilling (at a rate determined by the actual sediment transport rate). This type of situation is simply a variation on the fillet beach accumulation as described above (in this case, the accumulation occurs in the embayment instead of updrift of the structure).

With the growth of fillet beaches and the infilling of created embayments, there may be additional areas lost to fish habitat in the future, as well as reductions in water depth. Effects of accumulation updrift of a structure can extend from one to several times the length of the obstruction depending on the shore type and the gradient in alongshore transport (for example, in areas where the net alongshore transport rate is decreasing, the effects may extend updrift more than 5 times the length of the obstruction).

Some examples of fillet beaches and embayment infilling on Lake Ontario are provided in Figures 5.2 to 5.6. Figure 5.2 consists of a survey plan showing the extent of fillet beach development immediately east of the Venture Inn lakefill in downtown Burlington. This fillet beach consists of imported stone and natural shingle material which covers an erodible rock substrate. A very large fillet beach has developed updrift (east) of the Bluffers Park lakefill along a section of cohesive shore in Scarborough (see Figure 5.3). Figure 5.4 shows that on the downdrift (west) side of Bluffer Park, an embayment has been infilled through the growth of spits extending almost perpendicular to the shore. A dramatic example of embayment infilling at the Ashbridges Bay headland is given in Figure 5.5. This embayment has been completely filled, and now a fillet beach is building along the updrift shore, through deposition from sand transported along the Eastern Beaches of Toronto (i.e. a sandy shore). At the R.C. Harris Water Filtration Plant, at the boundary between Toronto and Scarborough, a fillet beach has built to an extent where the maximum width of the fillet is almost equal to the length of the protected intake structure (see Figure 5.6).

For sandy (and muddy) shores, a rule of thumb regarding the magnitude of potential erosion downdrift of a coastal engineering structure (i.e. which acts as a full or partial barrier to alongshore sediment transport) is that the volume of eroded sediment can equal or exceed the volume of sediment accumulated on the updrift side of a structure. The zone of significant erosion is usually confined to one or three times the length of the obstruction (i.e. distance “Y” in Figure 5.1). However, depending on how much of the littoral transport is blocked, and depending on the ratio of net to gross alongshore sediment transport, the area of erosion may extend over a much larger distance. The area of erosion directly offsets areas lost by filling or through indirect deposition.

On erosion resistant rocky shores, by definition, there will be no erosion. On erodible rocky shores, it is likely that there will be little or no discernible erosion impact resulting from the interruption of alongshore sediment transport.

The potential erosion of cohesive shores caused by the interruption of alongshore sediment transport is the least straightforward to estimate. It may be recalled that cohesive shores feature a veneer of sand over a hard cohesive sediment. Where these shores are exposed to waves, they will be eroding naturally at some rate (usually bluff recession rates are in the range of 0.3 to 2 m/year). The removal of some or all of the sand veneer immediately downdrift of a structure (i.e. due to updrift trapping) may or may not result in a measurable increase in the background erosion rate on a cohesive shore. The response depends on the initial conditions and whether the shore has a concave or convex shore profile.

For cohesive shores with concave profiles, if the veneer of sand was initially relatively thick (i.e. providing a certain degree of protection to the underlying cohesive sediment which is prone to irreversible erosion when exposed), then the removal of this sand will result in increased downcutting and shoreline recession; in this case, the long term recession rates could be increased by a factor of two or more. In contrast, in cases where the sand veneer is initially thin (and the underlying till is already frequently exposed to the erosive forces of waves), the interruption of alongshore sediment transport may have little or no effect on the pre-development background erosion rate. The problem in applying these rules of thumb relates to the definition of a thick versus a thin veneer of sand over the underlying cohesive sediment. Nairn (1992) has found that cohesive shores revert to a sandy shore classification (i.e. where the underlying cohesive sediment is seldom, if ever exposed) when the volume of the sand veneer, integrated between the shore and the 4 m depth contour, exceeds 200 m^3/m. Therefore, as a rough guideline, a "thick" sediment veneer will probably feature a sediment cover with a volume in the range of 100 to 200 m^3/m, whereas a thin veneer will correspond to sediment cover volumes of less than 100 m^3/m. Where the potential erosion of the cohesive sediment and shoreline downdrift of a structure is important, it may be necessary to conduct detailed surveys of the thickness of the overlying sand deposit and to apply numerical models to estimate the possible impact of reductions to the thickness of the sand veneer.

On cohesive shores with convex profiles, potential erosion impacts are restricted to an area inshore of the erosion resistant shelf (which usually has a depth of 2 m below datum on the Great Lakes). This sub-category of the cohesive shore type generally features lower long term shoreline or bluff recession rates than cohesive shores with concave profiles (in the range of 0.1 to 0.5 m/year). Nevertheless, there will typically be a beach deposit protecting the shoreline on these types of shores and this deposit would be susceptible to erosion downdrift of a shore perpendicular structure. The removal of all or part of the beach deposit would result in increased erosion rates for the section of the profile above the 2 m depth contour. Determining the extent to which erosion is accelerated would be a difficult task. One approach would be to review the known recession rates for nearby shoreline with convex cohesive profiles to determine if there is any correspondence between the size of the beach deposit and the long term rate of shoreline recession.

As with sandy shores, erosion impacts related to the obstruction of alongshore transport on cohesive shores may result in areas of fish habitat "gained" (versus areas lost under the Fisheries Act) due to increased bluff and shoreline erosion, as well as increases in the nearshore depths due to accelerated downcutting of the lake bed. The magnitude of areas gained and increases to water depths may be determined by shifting the existing nearshore profile shoreward at the accelerated rate of recession for a period of interest (say the design life of the structure) and comparing these changes to erosion and downcutting anticipated with the pre-development recession rate. Figure 5.7 illustrates this concept for both concave and convex cohesive shore types.

5.3.2 Shore Parallel Structures - Rules of Thumb and Analytical Tools for Impact Assessment

For shores where a sand (or gravel/shingle) supply exists, and one or more offshore breakwaters are constructed, there is a chance that either a tombolo or salient will form. These features consist of a sediment deposit which forms immediately inshore of the breakwater and is either attached to the breakwater (i.e. a tombolo) or detached (i.e. a salient) as illustrated in Figure 5.6. Aside from the immediate impact of changes to the depths in the area of deposition (and additional areas lost to fish habitat), if a tombolo forms, significant erosion may be experienced on the downdrift side of the structures with the partial or complete interruption of alongshore sand transport. Therefore, where downdrift erosion is not acceptable, or where it must be minimized, the design of offshore breakwaters must be completed to avoid the formation of tombolos.

The shoreline response to the construction of single or multiple offshore breakwaters (the latter case is often referred to as a segmented system) is a function of several characteristics as follows:

- the length of the structure (i.e. in the alongshore direction);
- the depth at the structure;
- the local wave conditions (breaker wave height and wave length at the structure);
- the transmission coefficient representing the permeability of the structure to wave action;
- the gap width between breakwaters where more than one is constructed.

Some general guidelines on shoreline response to offshore breakwaters are presented by Rosati et al (1992). The guidelines, consisting of nomographs predicting either limited response, a salient or a tombolo formation, were derived from many applications of the GENESIS numerical model (this model is discussed later in this section). Based on the Rosati et al (1992) findings, for exposed Great Lakes shores, when typical breakwater structures are constructed in water depths of less than 3 m, the development of a tombolo is possible and extreme caution is recommended regarding possible downdrift effects. As a rule of thumb, the tombolo width at the original shoreline will be similar to the length of the breakwater, tapering to almost zero at the structure.

Downdrift erosion may equal or exceed the volume of deposition in the tombolo on sandy beaches. The discussion of erosion impacts on muddy, rocky and cohesive shores downdrift of shore perpendicular structures, presented above, also applies here.

Two examples along the Toronto waterfront of the impacts of shore parallel breakwaters are provided in Figures 5.9 and 5.10. Figure 5.9 shows the armour stone breakwaters recently constructed along the central section of the Eastern Beaches. Tombolos and large salients have developed inshore of the breakwaters. From this figure it is apparent that the extent of tombolo or salient development is related to the length of the structure and the distance from the shore to the structure. The Western Beaches breakwaters shown in Figure 5.10 consist of a concrete superstructure supported by a timber crib foundation. Many of the original gaps between the breakwaters have been filled in with armour stone. As a result, sand transport has been almost completely eliminated, and therefore, the shoreline response has been limited (i.e. only small salients exist).

5.3.3 Numerical Model Application for Impact Assessment

In the last 10 years, dramatic advances have been made in the development of numerical models for the simulation of erosion and deposition. Nevertheless, and particularly for medium to long time scales (i.e. years to decades), these models are by no means accurate and reliable predictors in all situations. Wherever possible, the models require calibration and/or verification against measured changes (i.e. for site specific historic pre-development change or for a similar project with similar local conditions). The most appropriate role of these numerical simulation models is as one tool of many that assist in the design and assessment of impacts of a coastal engineering project.

Earlier models are strongly empirical (i.e. they are based on data from one or more sites), and therefore, rely more heavily on calibration and verification for site specific applications. These models are less transparent with regard to the physics driving the changes to morphology (i.e. they are, to greater degree, "black boxes"). In contrast, much recent development has focused on process-based simulation models of erosion and deposition. To the extent possible, these models rely on the state of the art understanding of the various constituent processes that result in erosion and deposition (i.e. wave generation and transformation, wave-induced currents and detailed sediment transport processes). These models are more transparent and help to develop an understanding of why things happen (with respect to patterns of erosion and deposition). Generally, they require less calibration/verification than the more empirical approaches. Most recently, there has been considerable attention devoted to the prediction of long term coastal behaviour (i.e. over a period of decades or greater). It has been postulated (see Stive and De Vriend, 1995) that predictions for these time scales must take a more parameterized approach where empirical relationships are developed to reflect the understanding derived from the process-based modelling approaches.

It is worth noting that very few modelling approaches are capable of correctly simulating erosion and deposition patterns for shoreline with a limited sand supply (such as rocky or cohesive shores). These shore types are dominant on the Great Lakes.

A brief overview of some of the more well known modelling techniques are presented in the paragraphs below. Some indication of the degree of empiricism (and the associated requirement for calibration) as well as the applicability of the models to the different shore types on the Great Lakes is also provided.

The earliest versions of coastal morphology models were based on the simulation of changes to the shoreline position and are therefore referred to as "one line" models. The change in shoreline shape is determined through a consideration of the gradient in alongshore sediment transport rates and the solution of the continuity equation for the conservation of sediment volume. These models assume that the profile shape (i.e. a cross-section of the beach and nearshore) is unchanging and that cross-shore sediment transport effects can be ignored. With time, these models have been upgraded to consider the effects of groins and offshore breakwaters on shoreline change. Examples of this type of model include: the U.S. Army Corps of Engineers GENESIS model (Hanson and Kraus, 1989); the National Research Council KUST model (Willis, 1978); the Queen's University ONELINE model; and the BPLAN model described by Pinchin and Nairn (1986). These models differ in their numerical computation schemes and in their capabilities with respect to the range of structures that can be considered. Probably, the most versatile with respect to the effects of structures is the GENESIS model which has been extensively applied to predict the influence of groynes and offshore breakwaters on beach morphology.

It is noted that the one line models such as GENESIS are based on an extremely simplified representation of nearshore processes (e.g. the hydrodynamics are not modelled) and their application requires some form of local calibration to establish a basis for tuning the various free parameters in the models. Therefore, the interpretation of results from these models should be approached with great caution and sensitivity analyses should be undertaken to evaluate the possible range of predictions for slightly different assumptions on the free variables. In addition, it is noted that one-line models are generally incapable of considering the limited sediment supply situations that are prevalent on the Great Lakes and are therefore, as a general guideline, these models should be restricted to applications on sandy shores.

The one line models have been extended to consider some cross-shore transport mechanisms (albeit in an empirical manner which is not based on the underlying processes such as hydrodynamics) and these are referred to as "n-line" models (see Perlin and Dean, 1985). These models are cumbersome and are not generally applied.

The COSMOS model has also been extended to describe weakly three dimensional situations by linking several profiles together. This model can be applied to describe the interaction between alongshore and cross-shore processes for situations where the shoreline and the nearshore contours are relatively straight (see Nairn, 1993). In this type of application the model is capable of predicting changes in shoreline position.

A second approach to modelling beach morphology has focused on the changes to the profile shape as a result of gradients in cross-shore sediment transport (i.e. in contrast to the one line models of beach planforms which are based on alongshore sediment transport gradients and which ignore cross-shore processes). The cross-shore models assume longshore uniformity (i.e. parallel contours and infinite shore parallel structures are stipulated). The earliest versions of these models were strongly empirical (i.e. weakly connected to processes) and as a result had several free variables which had to be tuned for each application (see Swart, 1976). EBEACH (also referred to as EDUNE) is a widely used cross-shore sediment transport for predicting dune erosion (see Kriebel, 1990). This model relates cross-shore sediment transport to the rate of wave energy dissipation across the profile; it does not consider the hydrodynamic processes that drive sediment transport and as a result falls into the strongly empirical category. However, it has been extensively applied and the coefficients required to apply the model are relatively well understood. This model has been extended by including bar generating and onshore transport processes (albeit in an empirical manner) to create the U.S. Army Corps of Engineers SBEACH cross-shore model (see Larson and Kraus, 1989). SBEACH has been shown to be an effective tool in predicting profile change. However, its relatively strong empirical nature precludes the possibility of linking the predicted change to hydrodynamic processes. Neither EDUNE nor SBEACH are capable of accurately predicting erosion on cohesive shores where the sand supply is limited.

The next generation of cross-shore sediment transport or profile change models have introduced descriptions of the hydrodynamics based on the wave transformation. The predicted hydrodynamics are used to drive the sediment transport. These models are referred to as "process-based" since they have attempted to incorporate, to the fullest extent possible, the current understanding of nearshore and surfzone processes. The three most widely applied models of this type are: COSMOS (see Nairn and Southgate, 1993); UNIBEST developed by Delft Hydraulics (see Roelvink and Stive, 1989); and the Danish Hydraulic Institute, Broker et al (1991) model which is part of DHI's LITPAK software. These models differ in the manner in which the various processes are described, however, all are relatively transparent and provide the opportunity for linking observed changes in the beach profile to actual processes. In general, they require a minimal amount of calibration or verification in comparison to the more strongly empirical models such as EDUNE and SBEACH.

Schoonees and Theron (1995) present an independent review of the full range of available cross-shore sediment transport and profile change models, including all those mentioned above. The models were rated on two criteria: their theoretical basis and the extent to which they were verified. Considering the combined ratings for these two criteria the COSMOS and UNIBEST models were the mostly highly ranked models. The paper also discusses the important limitations of all available cross-shore models.

Only the COSMOS model is capable of considering profile changes in supply limited situations such as those associated with the prevalent cohesive shore types on the Great Lakes.

Recent development of coastal profile models has focused on predicting long term and large scale "behaviour-oriented" modelling. These models revert to empirical descriptions of processes, which are based on the findings of process-based models, to describe profile changes over a period of many decades to centuries or more (see Stive and deVriend, 1995, Cowell et al, 1995 and Niedoroda et al 1995).

There are many cases where longshore uniformity or a weakly 3D situation is not a reasonable assumption, particularly for coastal engineering projects which will alter the coastal processes in a relatively local area. Process-based "area" models are much less advanced that the coastal profile models owing to the added complexity, and are generally only in "research form" (i.e. the models are not in a form where they can be applied generally by practitioners without an specialized understanding of the modelled processes).

However, this is not to say that the prediction of the physical impacts of coastal structures is beyond the current capabilities. Instead, it must be recognized that the available tools (such as the 2D wave and current models, the one-line models and the profile models) must be appropriately selected and combined to provide a best estimate of the expected changes.

To build an understanding of pre-development conditions, it is important to combine the findings of numerical model simulations with known historic changes to the shoreline and lake bed and an overall sediment budget for the study area. This will provide the basis for a reasonable estimate of future changes as they are influenced by a proposed development.

Table 5.2 provides a summary of the capabilities of the various models of erosion and deposition discussed in this section with respect to representation of coastal processes and particular structure types.

5.3.4 Physical Model Application for Impact Assessment

Physical models provide an important alternative or complementary approach for the assessment of physical impacts of coastal engineering projects. Scale models can provide a more realistic description of the three-dimensional nature of nearshore and surfzone hydrodynamics than numerical models providing that the physical models can be properly designed. Models can either be fixed bed or mobile bed (i.e. the latter include sediment). The most likely source of error in a physical model experiment (and one which is almost always present to some degree) relates to the influence of the boundary conditions. For example, circulation patterns may be more a function of the geometry of a wave basin than an open coast situation. Also, one of the most difficult boundary conditions to properly establish, particularly for smaller models, is the bottom roughness (grain roughness, ripples and other bedforms are almost always distorted in mobile bed models and are difficult to correctly replicate in fixed bed models).

In addition, mobile bed models suffer from sediment transport distortion related to scale effects caused by the grain size scaling. There are many references and schools of thought on the design and application of physical model experiments for coastal engineering projects (see, for example, Dalrymple, 1985, Dean, 1985, Kamphuis, 1985, the Institution of Civil Engineers, 1982). Therefore, while physical model experiments have important advantages over numerical models (i.e. with respect to a description of the 3D flow circulation patterns where the boundary conditions are realistic) they also have important disadvantages (such as complicated scale effects associated with the distorted movement of sediment).

In larger projects, where the physical impacts are expected to be significant and relatively complex, a combination of physical and numerical models should be applied.

5.4 Predicting Modifications to Substrate and Macrophytes

Once the various techniques for describing the waves, currents and changes to morphology have been applied, the findings can be interpreted to determine the changes to the key habitat characteristics of surficial substrate and the presence or absence of macrophytes. Changes to wave energy (and/or current velocity), water quality properties (such as temperature, clarity, etc.) and depth are direct outputs from the wave transformation and circulation models described in Sections 5.1 and 5.2.

In this section, approaches to determining the impact of a project on surficial substrate and macrophyte growth are discussed.

5.4.1 Surficial Substrate

The texture of the surficial substrate may be affected by changes to erosion and deposition patterns caused by the implementation of a coastal engineering project (i.e. in the areas of indirect impact). While numerical model simulation can provide an indication of possible changes to depth as a result of modified erosion and deposition patterns, generally, even the most advanced models are incapable of predicting changes to surficial substrate texture (i.e. as represented by the median grain size of the sediment). Nevertheless, there are some analytical approaches which can be taken in an attempt to define the changes to surficial substrate texture associated with predicted erosion and deposition; these are described in the following paragraphs.

To determine the change to the surficial substrate (i.e. from pre- to post-development conditions), it will be essential to have developed a good description of the pre-development surficial substrate conditions, particularly in areas where erosion and deposition is anticipated (refer to Section 4.1.2).

As alluded to in Section 5.3, there are two general types of deposition related to the construction of coastal engineering structures:

1. deposition updrift of an obstruction in the littoral zone (i.e. a fillet beach) and sometimes a bypassing shoal;
2. deposition in the lee of a structure where wave and current velocities have been reduced.

In the case of a fillet beach, the sediment which accumulates will have a texture similar to that of pre-development beaches, if they exist. Where beaches do not exist at the site prior to development, the textural characteristics of an anticipated fillet beach are best determined by a review of existing beaches at other obstructions nearby the study site and within the littoral cell. Beach sediment may vary in texture within a littoral cell and the variation usually follows a coarsening trend in the updrift direction (i.e. towards the source of the material). A sediment budget, which determines the sediment supply delivered to a section of shoreline from the erosion of updrift shores, may provide some indication of the possible textural make up of a fillet beach; however, depending on the wave exposure, some fraction of the finer sediments derived from updrift erosion may be lost offshore.

It is likely that where a bypassing shoal develops (i.e. as sediment from an updrift accumulation "spills" downdrift), the sediment texture of the surficial substrate will be similar to the sediment texture for updrift nearshore locations with similar water depths.

A situation which falls between the two types of deposition scenarios listed above relates to deposition in a created embayment. An embayment may act as a trap for alongshore sediment transport. Typically, the sediment in the embayment will be slightly finer than sediment on fully exposed beaches located along nearby natural shorelines. Again, the most reliable method of predicting the texture of the deposit is to review similar deposits that may already exist nearby within the littoral cell.

There are two contributing factors to the textural characteristics of deposits which develop in the lee of offshore or detached coastal structures. As with the previously discussed deposition patterns, the first factor relates to the sediment supply conditions. For example, on a long section of sandy beach shoreline the sediment supply will be restricted to a relatively narrow distribution of sand sizes. In contrast, where the updrift shoreline is eroding, the sediment supply may feature a wide sediment distribution (i.e. poorly sorted with a wide range of grain sizes). The texture of a sediment accumulation in the lee of a breakwater structure will also be related, at least partly, to the reduced wave energy and flow velocities in the sheltered area. Sediment may be carried into these sheltered areas and deposited, either temporarily or indefinitely. Therefore, the texture of surficial sediments in these areas may become significantly finer (where there is a fine fraction in the sediment supply delivered to the site). Some indication of "how fine" a deposit could be may be derived from a review of the threshold velocities for different grain sizes under steady current, wave and wave plus current conditions. One of the most widely used approaches for defining the threshold of motion for sediment grains under steady currents is the Shields curve (see for example, Yalin, 1977). For wave action, several of the available incipient motion criteria have been consolidated into a single expression by Losada and Desire (1985). For combined wave and current motion, the combined wave and current shear stress should be determined and input to the steady current and/or the wave action threshold expressions. Soulsby et al (1993) present a review of the available approaches for estimating the combined wave and current shear stress.

Erosion can also result from coastal engineering projects. It was noted in Section 5.3 that the magnitude and extent of this erosion depends very much on the shore type; the same is true for impacts to the textural characteristics of the surficial sediment in eroded the areas. For sandy shores, it is likely that the texture of the surficial sediment in an eroded area will remain relatively unchanged. Exceptions to this general conclusion will include cases where the sediment texture varies significantly with depth below the lake bed; this is usually not the case, at least for the depths of significant erosion typically experienced with coastal engineering structures on the Great Lakes (i.e. in the order of 1 to 5 m).

For both erosion resistant (by definition) and erodible rocky shores, there will be no change to the surficial substrate in erosion areas. For cohesive shores with concave profiles, erosion downdrift of a littoral obstruction will result in the exposure of larger areas of the underlying till (which often consists of some form of hard clay). An estimate of the increase in exposed till areas would have to be based on a prediction of the reduction of the sediment cover volume. On convex profile type cohesive shores, the surficial substrate changes will be restricted to an area inshore of the 2 m depth contour (refer to the Lake Ontario North Shore Descriptive Model of the Waterfront Regeneration Trust, 1995) . The erosion of the beach deposit inshore of this depth will also result in larger areas of exposed glacial till; however, in areas where the shelf exists due to a cobble or boulder lag deposit, the exposed clay may revert to cobble or boulder covered lag as it is eroded (i.e. after it is uncovered). Figure 5.11 illustrates the changes to surficial substrate that can be expected in downdrift erosion areas for both concave and convex cohesive shore types.

5.4.2 Submerged Macrophytes

As noted in Section 4.3.3, the presence of submerged macrophyte cover is defined by Minns et al (1995) to be a function of surficial substrate, water clarity, water depth, wave energy and lake bed slope. The algorithm used by Minns et al (1995) to determine whether the submerged macrophyte cover is greater than 50% (present) or less than 50% (absent) is given below:

If substrate is sand or finer and,
If depth is less than twice the Secchi depth and,
If effective fetch is less than 2 kilometres and,
If maximum slope is less than 15 percent,

Then vegetation is present (i.e. cover greater than 50%),

Else, vegetation is absent (i.e. cover less than 50%).

The most typical indirect impact of a coastal engineering project relates to areas which become at least partially sheltered from wave action. In these areas, the wave energy will be reduced (i.e. fetches will be reduced from greater than 2 km to less than 2 km) and sometimes the substrate may become finer (i.e. from coarser than sand to sand or finer). Both of these influences could trigger the establishment of greater than 50% cover of macrophytes based on the Minns et al (1995) algorithm reproduced above. Typically, in the areas of indirect impact, changes to water clarity and lake bed slope will be of secondary importance compared to changes in wave energy and substrate (the clarity of water inside marina basins may be an exceptional case). Another factor which is probably important to the survivorship of macrophytes is the rate of sediment supply and associated accumulation of sediment in embayments. If rapid and ongoing deposition is occurring it may be difficult for macrophytes to establish (due to both burial and high turbidity).

Changes to surficial substrate have been discussed in Section 5.4.1, while this impact is difficult to accurately establish, changes from coarser than sand to sand or finer are probably predictable. The very simple wave energy trigger for the presence or absence of macrophytes needs to be refined to relate the survivorship of macrophytes to a description of the potential flow velocities (related to both waves orbital velocities and steady currents in the growing season, or for the entire open water season where a disturbed lake bed will reduce the potential for macrophytes to survive).

Denny (1995) presents a comprehensive investigation of the survivorship of various organisms that inhabit the rocky shores of the U.S. west coast. Using descriptions of the resistance of the various organisms to dislodgment, the probability of exceedence for near bed flow velocity, and the lift and drag characteristics of the different organisms, a description of the probability of survivorship was developed. A similar investigation could be undertaken to define the survivorship of submerged macrophytes (and algae) on Great Lakes shores.

For cases where the presence or absence of macrophytes are important to the evaluation of a project, an improvement on the simple approach suggested by Minns et al (1995) is probably warranted. At or near such sites, it is likely that macrophytes will already exist in some form. Some jurisdictions have completed surveys of littoral habitat including macrophyte conditions (e.g. the Metro Toronto Region Conservation Authority have completed a cursory macrophyte survey and the information has been stored in GIS format - see Parkinson et al, 1994). In lieu of a comprehensive physically based description of the absence or presence of macrophytes (e.g. following the approach of Denny, 1995), an empirical approach could be taken which relates the distribution of macrophytes (for nearby pre-development areas or associated with nearby structures) to descriptions of appropriate wave height (or orbital velocity) and/or steady current flow velocities. As noted above, the appropriate descriptor for the wave and current conditions will depend on the manner in which survivorship of an individual species is determined (i.e. related to disturbance of the lake bed at any time of year or to the exceedence of a velocity threshold during part or all of the growing season). Changes to the physical parameters describing the wave and current conditions (i.e. based on the application of wave transformation and circulation models as described in Sections 5.1 and 5.2) could be used to forecast changes to the absence or presence of macrophytes.

Based on a review of large coastal engineering projects at the western end of Lake Ontario and observations of the presence or absence of macrophytes, some qualitative interpretations can be made on where the growth of macrophytes is possible. Surveys of macrophytes have been completed for several waterfront park developments within the jurisdiction of the Metro Toronto and Region Conservation Authority (see Parkinson et al, 1994), and by the Department of Fisheries and Oceans at Bronte Outer Harbour and LaSalle Park. These examples provide a wide range of project and shore types for review.

Importantly, it appears that, at least under exposed shoreline conditions (i.e. not including LaSalle Park on Hamilton Harbour), macrophyte growth is usually restricted to enclosed (or very well protected) bays or basins. Macrophytes generally do not appear to be able to survive in small embayments or semi-sheltered areas created by large shore perpendicular structures. There are three possible reasons for this: 1) that the wave energy in these created bays exceeds the threshold for survival of macrophytes; 2) the sediment supply rate is such that there is a high rate of accumulation which would tend to bury any new growth as well as impairing the water clarity; and 3) the substrate is not conducive to macrophyte growth (e.g. bedrock or glacial till).

The only example of significant macrophyte growth in an embayment on the Toronto Waterfront is in the Humber Bay West (see Figure 5.12). This large lakefill project extends approximately 600 m from shore and the west embayment has an opening approximately 200 m in width. Several factors combine to make this large embayment conducive to macrophyte growth:

- the embayment faces west and is therefore sheltered from easterly wave attack;
- the large extent of the headland (i.e. to a distance of 600 m offshore), offers additional protection from easterly wave attack;
- the water clarity is good since there are no local point sources of runoff and the lake bed and shoreline consist of bedrock.

Created embayments are more apt to provide improved conditions for the growth of *cladophera* and other types of algae particularly where the sediment supply is such that rapid accumulation or frequent shifting of sediment is not occurring. In general, the growth of algae is much more widespread than macrophyte growth, possibly for the following reasons:

- it is more streamlined and therefore able to resist the higher near bed velocities associated with exposed shoreline wave conditions;
- it can grow on rock substrates, whereas larger macrophytes usually require a fine sediment deposit;
- it recolonizes much more quickly after removal by energetic wave conditions.

Most enclosed marina basins have been constructed with steep sides and depths of greater than 2 m. In general, this bathtub-like cross-section is not conducive to macrophyte growth. This is particularly true where turbidity levels are high. For example, the Bluffers Park marina basin along the Scarborough Bluffs has little or no macrophyte growth (see Parkinson et al, 1994), probably due to the high turbidity associated with ongoing bluff and lake bed erosion. In contrast, the marina basin at Sam Smith Park at the west end of Metro Toronto features large macrophyte beds (Gord MacPherson, MTRCA, personal communication). At this location, the lake bed and shoreline consist of bedrock (which does not produce silt and clay when eroded) and the water clarity is much better than that at Bluffers. Similarly, macrophyte growth has been observed in the basins created in the Eastern Headland and extensive growth occurs along the connecting channels between the Toronto Islands. In both cases, the water clarity is reasonably good because the regional substrate consists of fine sand and silt (but little or no clay), and when combined with low levels of wave action, this results in an ideal situation for macrophyte growth.

The LaSalle Park waterfront features extensive macrophyte beds as a result of several factors:

1. the shorelines of Burlington Bay / Hamilton Harbour experience low to moderate wave energy because of the restricted fetch lengths (i.e. these shorelines fall somewhere between the exposed and sheltered shoreline classifications);
2. the area of macrophyte growth is further sheltered from wave action by the lakefill area, the floating tire breakwater and the presence of the floating docks and boats;
3. the water clarity is reasonably good (partly due to the low wave energy in sheltered areas);
4. the muddy/silty/sandy substrate is conducive to macrophyte establishment;
5. there is a 100 to 150 m wide shelf along the shore where depths are less than 2 m which is similar to twice the Secchi depth in this area - the limiting depth for macrophyte growth (Minns, 1995, personal communication).

One final qualitative observation regarding the presence or absence of macrophytes is that there appears to be an inshore limit for macrophyte growth which may be explained by the fact that growth is inhibited in the wave breaking or surfzone region. The width of this exposed substrate band along the shore may be related to the width of the surfzone which is a function of the nearshore slope, and the wave height and period conditions during the growing season. To some extent the presence of offshore macrophyte beds will dampen or dissipate wave energy, reducing the amplitude of waves and thus the width of the surfzone. The quantitative assessment of wave damping by submerged plant growth is a very complex problem (see Asano et al, 1992).

6.0 SUMMARY, FLAGS AND CONCERNS ON POTENTIAL IMPACTS

In this section, an overview of the potential impacts of coastal engineering projects is presented. The overview is based on a synthesis of the information provided in the previous sections. The potential severity of impacts is addressed and flags are raised for particularly important issues; it is intended that this type of assessment will provide a general indication of the level of effort that might be expected in the evaluation of the potential impacts. This section is subdivided into three sections on: 1) areas lost and directly modified; 2) areas indirectly modified; and 3) a summary.

6.1 Areas Lost and Directly Modified

The evaluation of changes to fish habitat for areas lost and directly modified is relatively straightforward (at least compared to changes in the indirectly modified areas) and the accuracy of the estimates will be high due to the static nature of the changes (i.e. by definition). Some issues and concerns are worth noting and these are described in the following paragraphs.

In the evaluation of the area(s) lost, the definition of the high lake level may be an important factor, particularly for structures with gradual slopes (in Section 4.3.1 it has been suggested that the 100 year monthly mean high lake level should be used). The selected high lake level elevation and the mapping should be referenced to a common datum (i.e. either Geodetic Survey of Canada or the International Great Lakes Datum).

It was noted in Section 4.3.1 that special consideration should be given to the zone between the high and low water levels (i.e. the wet/dry or intermittent beach zone). This zone should be evaluated in a manner which promotes attempts to create gradual slopes (where this is appropriate for the local fish community objectives).

The assessment of changes relies on an accurate survey of the pre-development habitat conditions including depth, substrate and the absence or presence of macrophytes. Some guidelines on these surveys were presented in Section 4.1.

Considering that most coastal structures on the Great Lakes rely at least in part on the use of armour stone, it is important to note that the "textural" characteristics of armour stone can vary considerably depending on the design and construction techniques. Where a slope is protected with a single layer of armour stone, the stones will be placed individually creating a smooth and tightly packed surface with minimal interstitial spaces. In contrast, a slope protected with two layers of armour stone (or with smaller materials such as rip rap) will be constructed in a manner such that the interstitial spaces are much greater than that of a single layer design.

The proposed construction activities should reviewed to determine whether any areas will be directly effected outside of the footprint of the structure. For example, the construction of access roads (which are eventually removed) or the dumping of material that was excavated to "toe in" a structure can temporarily or permanently alter the surficial substrate and/or depth conditions.

Areas of direct impact should also include any habitat compensation measures. However, where these measures are placed on mobile sandy (silty or muddy) substrate, the possibility that these beds may become buried by finer sediment in the future should be investigated using the methods outlined in Section 5.3.

Similarly, there is a possibility that areas which are directly modified by the project may be modified in the future through indirect impacts. For example, parts of an armour stone headland may eventually be buried by sand with the accumulation of a fillet beach. These situations should be flagged in the assessment of areas of indirect impact, and the assessment of direct impacts should be revisited to correct for any changes related to indirect impacts.

6.2 Areas that Are Indirectly Modified

There is much more potential for uncertainty in the evaluation of impacts to fish habitat in indirectly modified areas. These impacts are a result of dynamic processes and may occur quickly or over a long period of time. In this section, an indication of the potential severity or significance of impacts is provided based on a consideration of three groups of variables:

1. the shore type;
2. the project type;
3. and the physical characteristics of fish habitat.

The four primary shore types, as defined by controlling substrate (rocky, cohesive, sandy and muddy shores) were described in Section 3 of this report. Rocky shores can be erosion resistant or erodible. Cohesive shores are subdivided into two distinct subcategories based on whether the profile shape is concave or convex. In general, the shore types can be further classified as exposed coast or sheltered coast with respect to wave action. Exposed shorelines will be relatively straight and will have fetches (open water distances) in the order of 10 km or greater. Sheltered shorelines are characterized by smaller fetches (in the order of 5 km or less), extensive shallow nearshore zones and/or deep bays. The shore type categories are summarized in Figure 6.1. Another important factor that influences how different shore types respond to coastal engineering projects is the sediment supply rate (and the type of sediment supplied) which is primarily determined by alongshore transport processes and a sediment budget (in some areas, sediment loadings from creeks and rivers may be important).

Projects have been divided into three main categories of shore perpendicular obstructions (i.e. that are usually shore attached), shore parallel, offshore structures and enclosed basins (which are usually formed by shore perpendicular structures). The shore perpendicular structures can be subdivided into straight structures (which can result in the accumulation of a fillet beach) and created embayments. Shore parallel structures also have two subcategories of breakwaters (where part of the structure extends above water) and shoals (submerged structures). It should be noted that "enclosed basins" refer here to those areas that are protected from any wave action but still have some form of entrance channel or opening to the lake. The various structure types are illustrated in Figure 6.2.

Fish habitat characteristics have been divided into three main categories consisting of: 1) depth and substrate impacts; 2) macrophyte impacts; and 3) water quality impacts. These groupings have been created to be somewhat independent; however, all are partly dependent on changes to the wave energy and circulation patterns. Depth and substrate changes result from changes to erosion and deposition patterns which, in turn, are a result of modifications to waves and currents caused by a coastal engineering project (refer to Sections 5.3 and 5.4 for a discussion of these impacts and evaluation techniques). Changes to macrophyte coverage are primarily related to changes in wave exposure (and current velocities) and are influenced by depth and water clarity. Water quality can be influenced by modifications to a circulation pattern, but is also dependent on the local water clarity and proximity to point sources (such as creek mouths and storm sewers outfalls). Water clarity is also influenced by the shore type, on eroding clay or cohesive shores the water clarity will be poor for most of the time.

Three tables have been prepared to provide a general indication of the degree of impact to the different habitat characteristics for the different shore type and project type combinations. For impacts which are rated as medium or high, an explanation of the concern is provided in the paragraphs below.

Table 6.1 presents ratings of potential impacts caused by the construction of either shore perpendicular or offshore coastal structures. The impacts range from none to high for depth, substrate and macrophyte changes on exposed shoreline as a function of shore type and the sediment supply conditions. For substrate and depth, the ratings describe the potential for impact and the magnitude and geographic extent of the impact. For example, a high rating on depth indicates that is very likely that a large depth change will occur over a significant part of the indirectly modified area. For macrophytes, a high rating corresponds to a high possibility that macrophytes will be able to flourish in an area that they were previously absent (for exposed shorelines, this rating only applies to projects with enclosed basins or well sheltered embayments).

For exposed shorelines with a moderate to high sediment supply and sediment transport rate, there is medium to high potential for significant depth changes, either in the form of erosion or deposition, for all shore types. For rocky and convex cohesive shores, this will come in the form of a small to moderately sized fillet beach accumulation on one or both sides of a shore perpendicular structure. The extent of the response also depends on the distance that the structure extends into the littoral zone and the rate of sediment supply. A tombolo or salient may develop inshore of a breakwater on rocky and convex cohesive shores. The extent of the response to a breakwater depends on the dimensions and characteristics of the breakwater as discussed in Section 5.3. It is unlikely that there will be a severe erosion response along adjacent rocky and convex cohesive shoreline as a result of the construction of shore perpendicular or offshore structures.

For concave cohesive shores, and for sandy beaches, extensive areas of accumulation on the updrift side of a shore perpendicular structure should be expected (again, depending on the length of the obstruction). A salient or tombolo will develop inshore of an offshore breakwater (again, the extent depends on the breakwater characteristics). The potential for erosion downdrift of either a breakwater or a shore perpendicular structure is greatest on sandy shores. On concave cohesive shores, the erosion will consist of accelerated lake bed downcutting and bluff recession. There may be a moderate impact to depths on muddy shores either through additional accumulation updrift of a shore perpendicular structure or in the lee of a breakwater. Erosion may also occur downdrift of the structures. Generally, accumulation and erosion on muddy shores are very slow processes (by definition the wave energy will be relatively low at these sites - for muddy shores to exist on exposed coasts, there will have to be some offshore shoal or shelf to dissipate the wave energy).

There is a moderate to high probability of significant changes to surficial substrate on exposed rocky and cohesive shorelines with a moderate to high sediment supply and sediment transport rate. On rocky shores, the exposed bedrock substrate will be covered with the sediment which is derived from updrift sources (i.e. mostly from the erosion of the shoreline and lake bed and sometimes from creek and river loadings). This will be true for all three main project type categories including enclosed basins where very fine sediment will slowly accumulate. On convex cohesive shores, the cobble/boulder lag cover on the nearshore shelf may become covered by sand and gravel that is deposited as part of an accumulation associated with one of the three project types (providing that there is a sufficient supply of this type of sediment). In situations where downdrift erosion occurs, there may be some loss of beach material and conversion to glacial till initially, and eventually cobble/boulder lag deposit as the till is eroded. On concave cohesive shores, the primary change to the surficial substrate will be on the downdrift side of a project, where the underlying glacial till may become more exposed.

As noted in Section 5.4, significant changes to macrophyte coverage (as a result of coastal engineering projects) for exposed shoreline sites will be limited to marina basins or sheltered embayments that do not experience high turbidity or sediment accumulation. For rocky shores and convex cohesive shores with a sediment supply that features some fine sediments (i.e. silt and clay), there is a medium to high probability that macrophytes would eventually colonize a newly created protected basin (the relatively clear water conditions of these shores will promote growth, but first, a fine sediment substrate must be deposited over the rocky substrate). The potential for macrophyte growth within a marina basin on a concave profile cohesive shore is less likely due to the high turbidity associated with these shore types (due to the ongoing erosion of the lake bed and backshore bluff). Macrophytes will colonize enclosed basins in areas with a sandy controlling substrate, providing that the potential for sediment accumulation is not high (this will always be true for enclosed basins, but may not be the case for sheltered embayments open to the direction of net sediment transport). There is a high possibility of changes to macrophyte coverage on exposed muddy shores because the appropriate substrate already exists and all that is required to promote growth is a reduction in wave energy.

Table 6.2 provides a summary of the anticipated degree of impacts to depth, substrate and macrophytes in response to coastal engineering projects that are constructed on a sheltered shoreline. For sheltered shoreline (i.e. as exists in partly or fully enclosed embayments or connecting channels or rivers), it has been assumed that the sediment transport rate is relatively low (due to the low wave energy associated with the short fetches of sheltered shoreline). For these types of conditions, depth and substrate changes are generally anticipated to be insignificant to low for all shore types. However, the potential for changes to the macrophyte coverage are expected to be moderate to high for all shore types. The reason for this is that the survivorship of macrophytes is very sensitive to wave energy at the levels expected on sheltered shorelines. Recalling that the Minns et al (1995) algorithm indicates that macrophytes will be present where fetches are less than 2 km, and that we have defined sheltered shoreline as conditions with fetches of less than about 5 km, changes to wave energy caused by sheltering in the lee of structures may result in significant changes to the macrophyte coverage. In other words, in contrast to exposed shoreline, macrophyte growth on sheltered shorelines may be promoted both within and outside enclosed basins.

Although not included as part of the Minns et al (1995) algorithms for the evaluation of habitat changes caused by a project, impairment of local water quality (e.g. the bacterial, chemical or physical properties) may be an important consideration with respect to the altered quality of the fish habitat as a result of a project. The most important consideration with respect to changes in water quality caused by a project is the proximity to a source of contaminated water (or water with undesirable physical properties such as high temperature or high turbidity). Where a project is constructed near to a source of contaminant loading (e.g. creek and river mouths, storm sewer outfalls, treatment plant outfalls or industrial plant outfalls), and depending on the project type, the quality of sheltered water may be adversely affected. Table 6.3 provides an indication for the influence of different project types on the potential for water quality impacts. The extent of impact depends on the degree and nature of changes to local circulation patterns caused by projects. Also included in Table 6.3 is a rating of the potential for a project to trap coastal debris of natural (such as cladophera or algae) and human origin, and contaminated sediments (where they exist). Water quality is most likely to be impaired within large created embayments or sheltered areas, and for marina basins (the influence on basins depends on the flushing characteristics and the existence of any direct inputs to the basin itself).

6.3 Summary

An indication of the potential importance of physical impacts on fish habitat for different combinations of project type, shore type and habitat characteristic have been presented in this section. General guidance on the required level of effort to assess a potential impact may be derived from the ratings provided in Tables 6.1 to 6.3. However, it is important to note that coastal engineering projects are very difficult to generalize owing to the wide variety of possible project types and shoreline characteristics. Nevertheless, for combinations of project type and shore type that have a medium to high rating for the significance of a potential impact, the responsibility should rest with the proponent to undertake an investigation with a commensurate level of sophistication and detail or to explain why local conditions make such an investigation unnecessary.

It is advisable to apply rules of thumb to perform an initial evaluation of the extent and nature of possible impacts to fish habitat caused by physical changes associated with projects. In many cases, this initial assessment will provide an indication of which issues require focused investigation.

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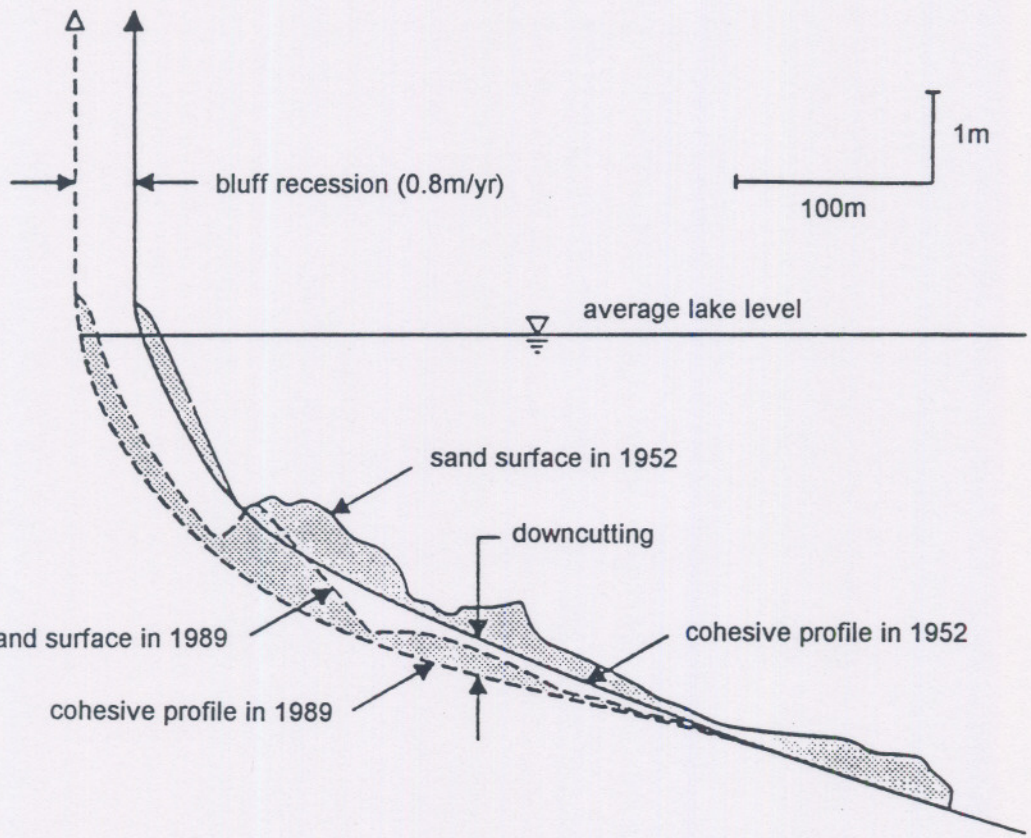


Figure 3.1 Cohesive Profile Recession and Irreversible Downcutting, Scarborough Bluffs, Lake Ontario

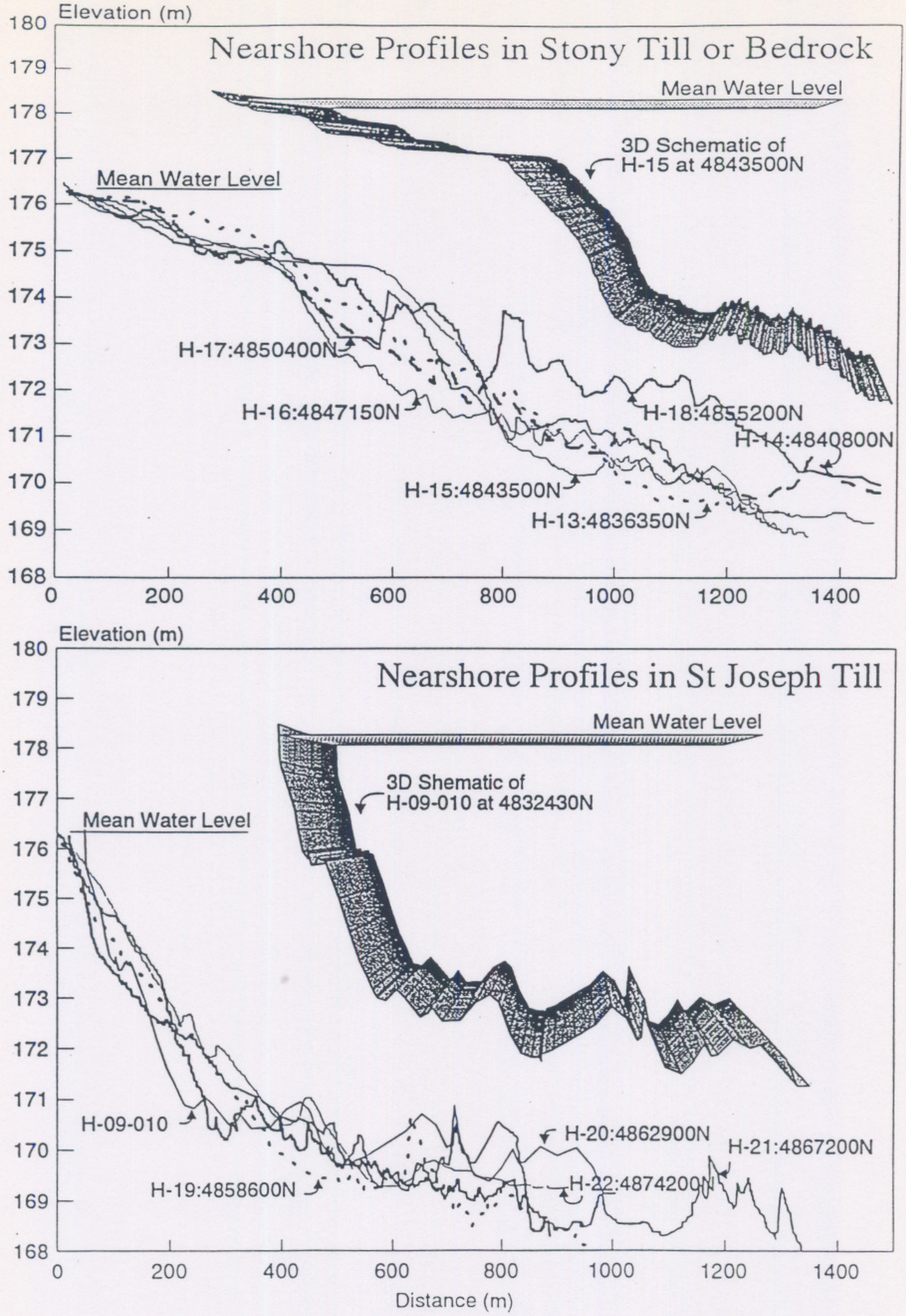


Figure 3.2 Concave and Convex Nearshore Profiles, Lake Huron
From Boyd, 1992 (Ph.D. Thesis, University of Waterloo)

Figure 3.3a Nearshore Concave Profiles North Shore, Lake Ontario

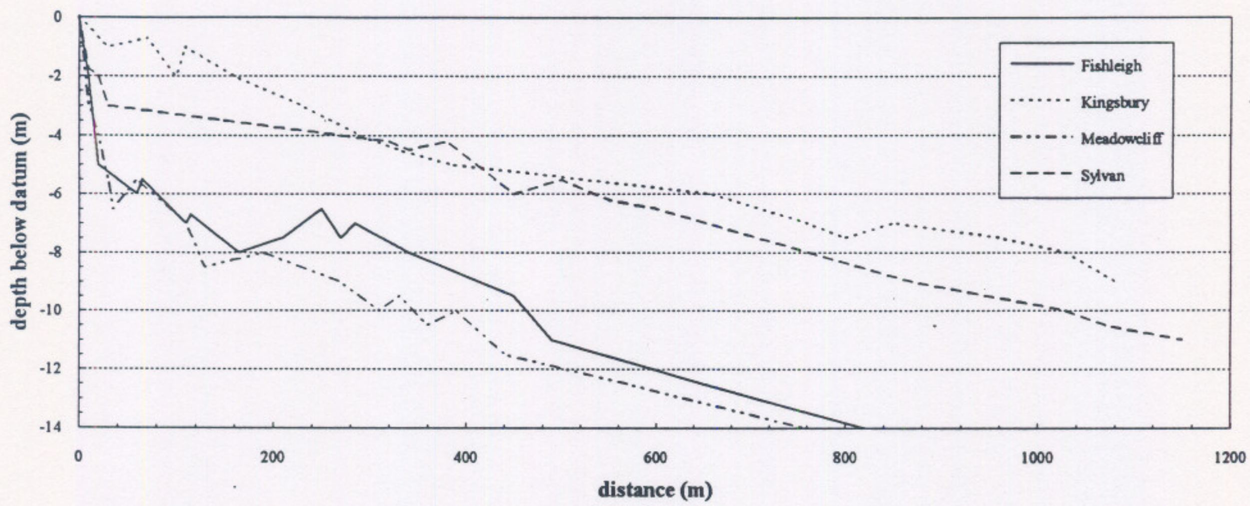
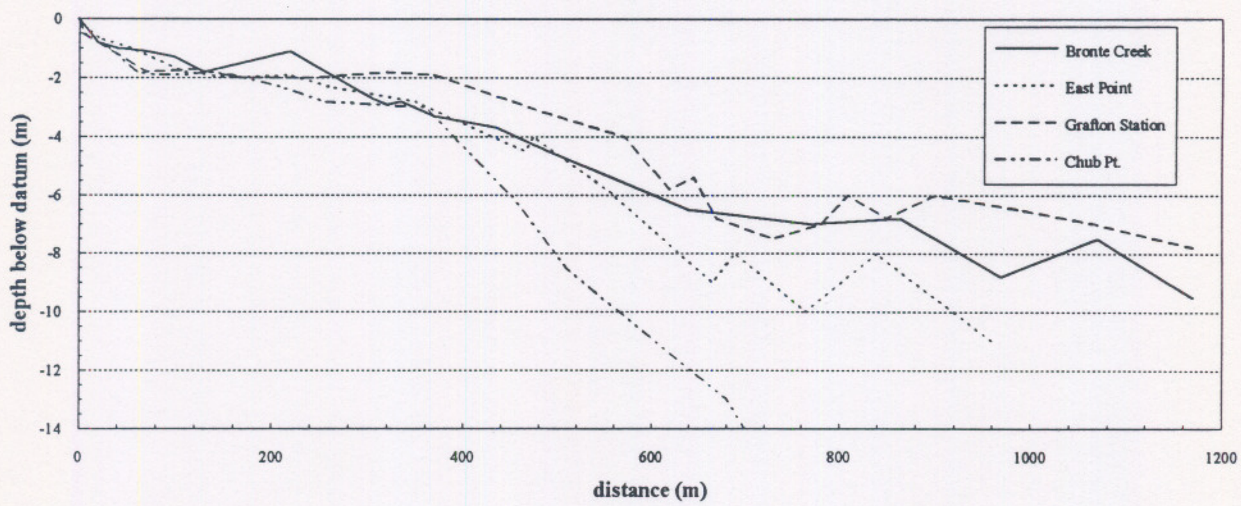


Figure 3.3b Nearshore Convex Profiles North Shore, Lake Ontario



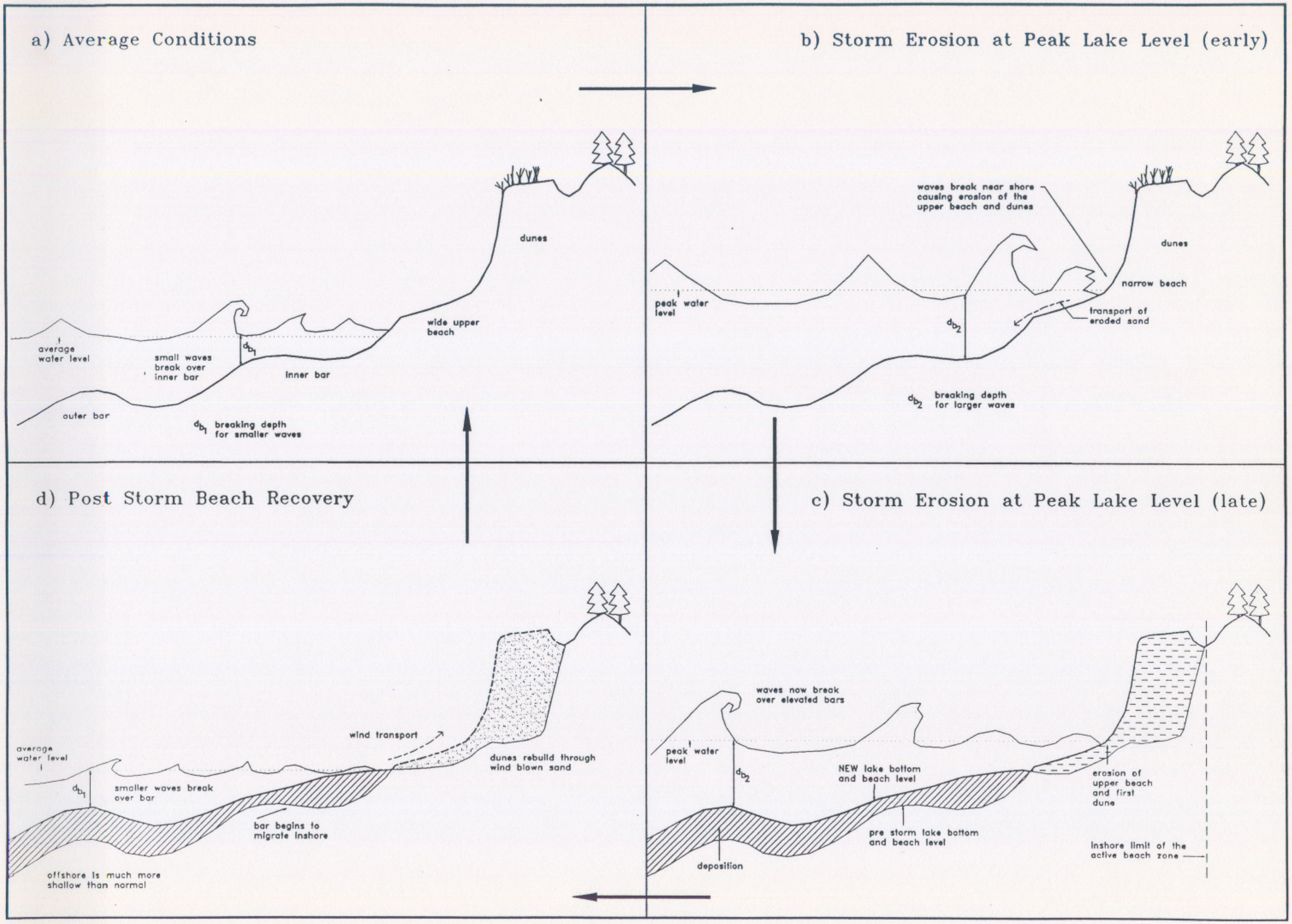
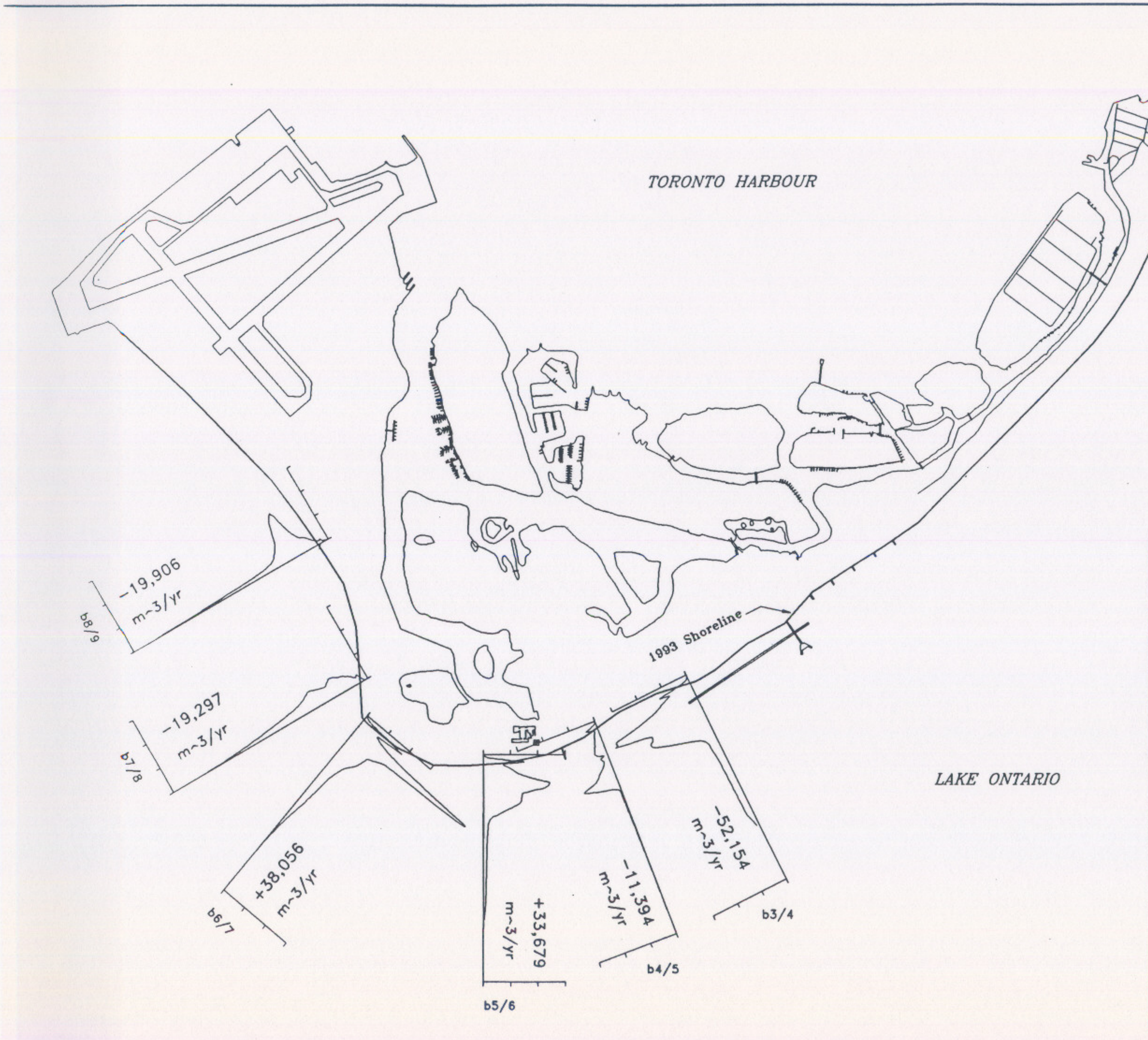


Figure 3.4 Recovery Stages of Beach and Dune Erosion (from Nairn, 1992 IJC Report)



THE TORONTO ISLANDS NATURE SCHOOL

Prediction of Average Annual Alongshore Sediment Transport

d50 = 0.20mm

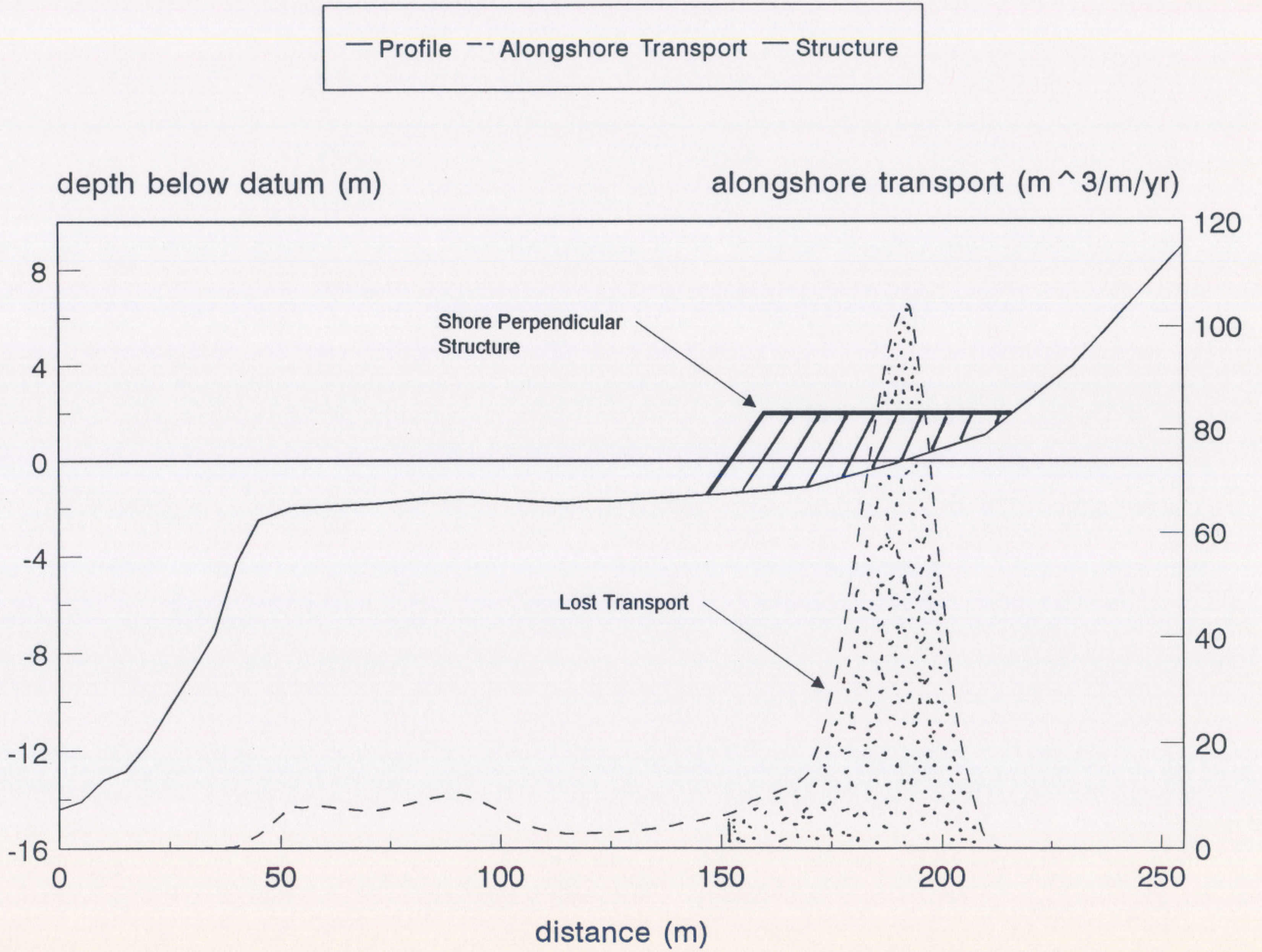
Figure 4.1

Baird & Associates

Map Scale 1:20000

Figure 4.2 Shore Perpendicular Structure and Influence on Alongshore Transport

Convex Cohesive Profile



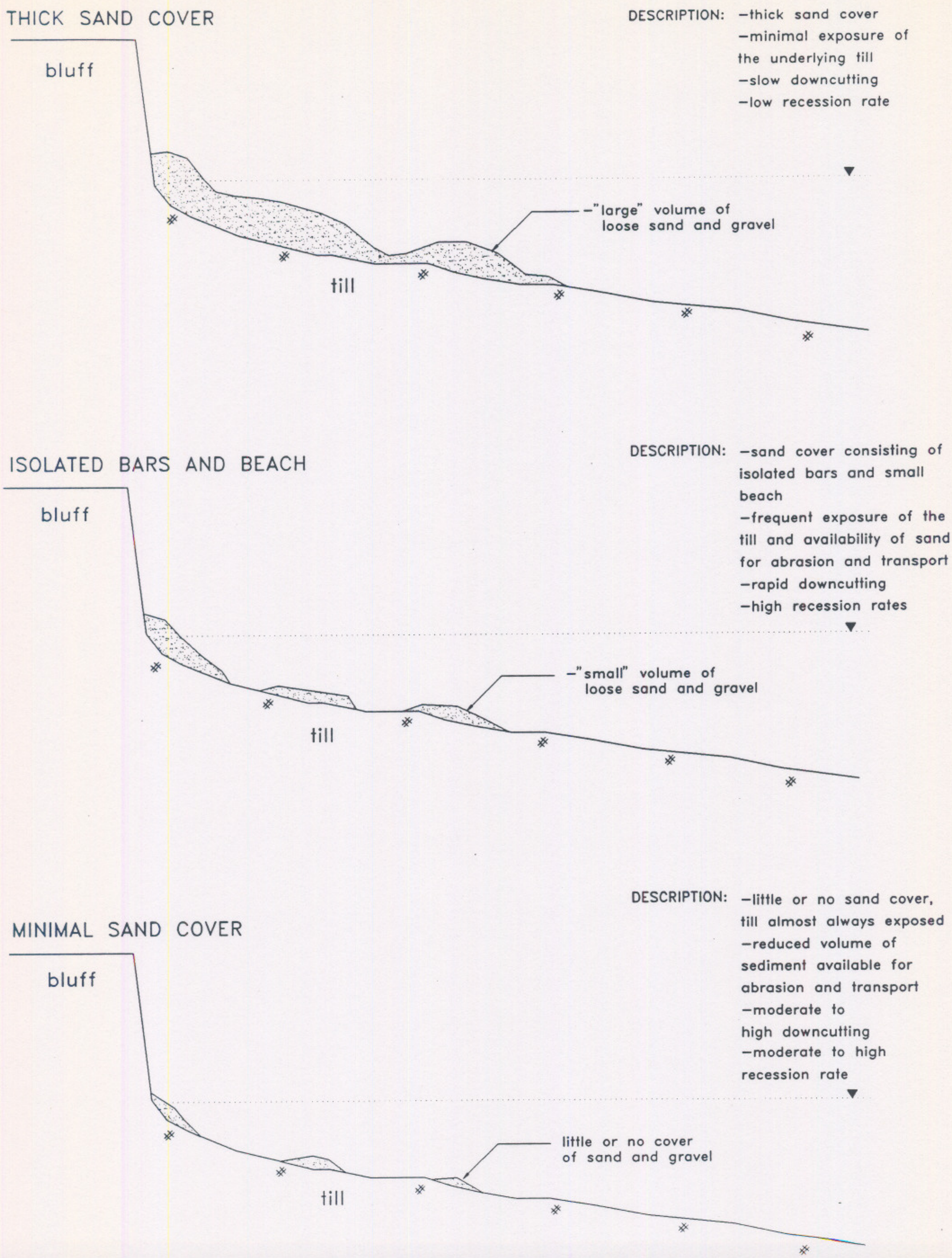


Figure 4.3 Sediment Cover on Rocky and Cohesive Profiles (Three levels of sediment supply)

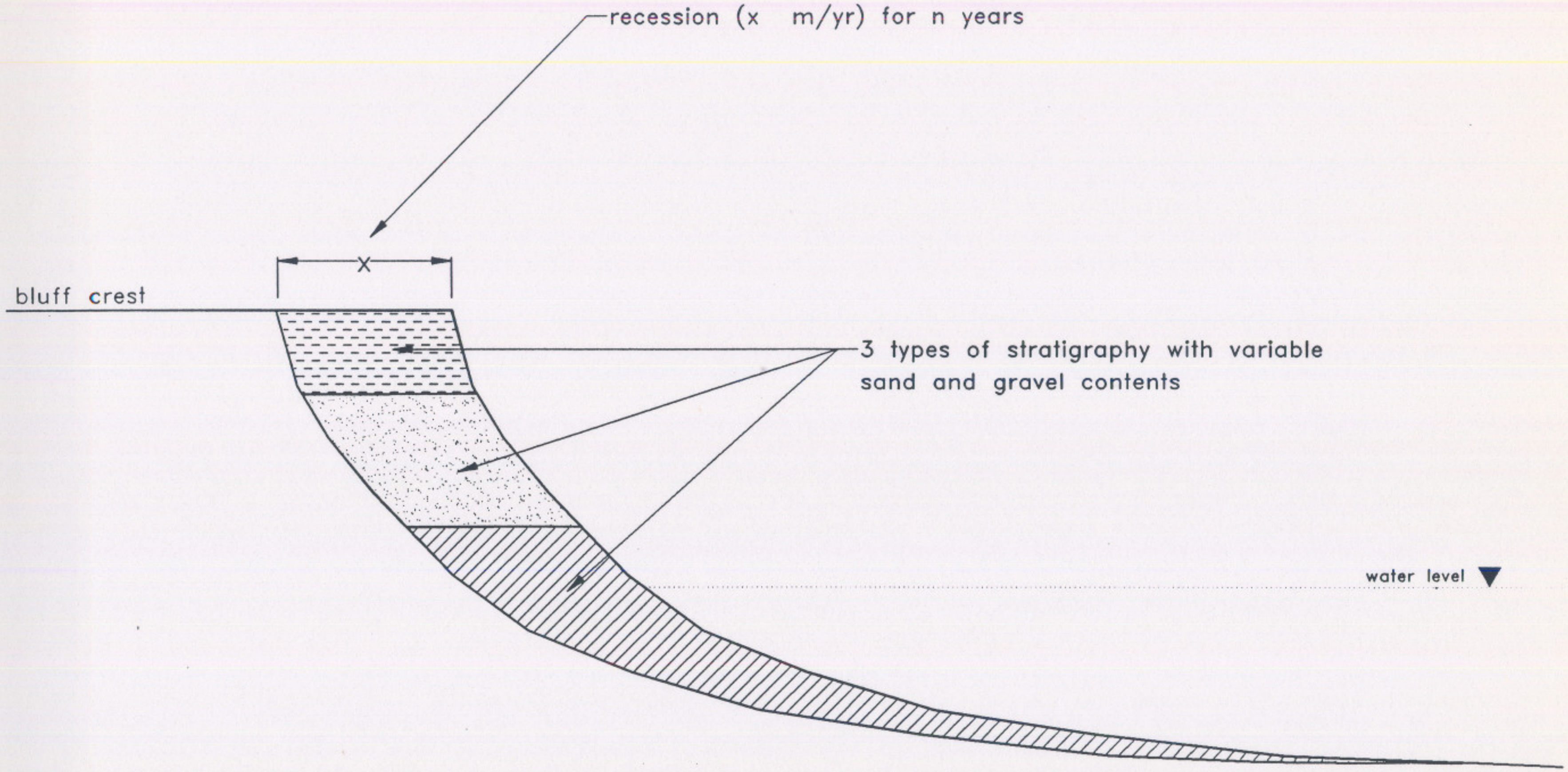


Figure 4.4 Cross-Section Showing Basis for Sediment Budget Calculations

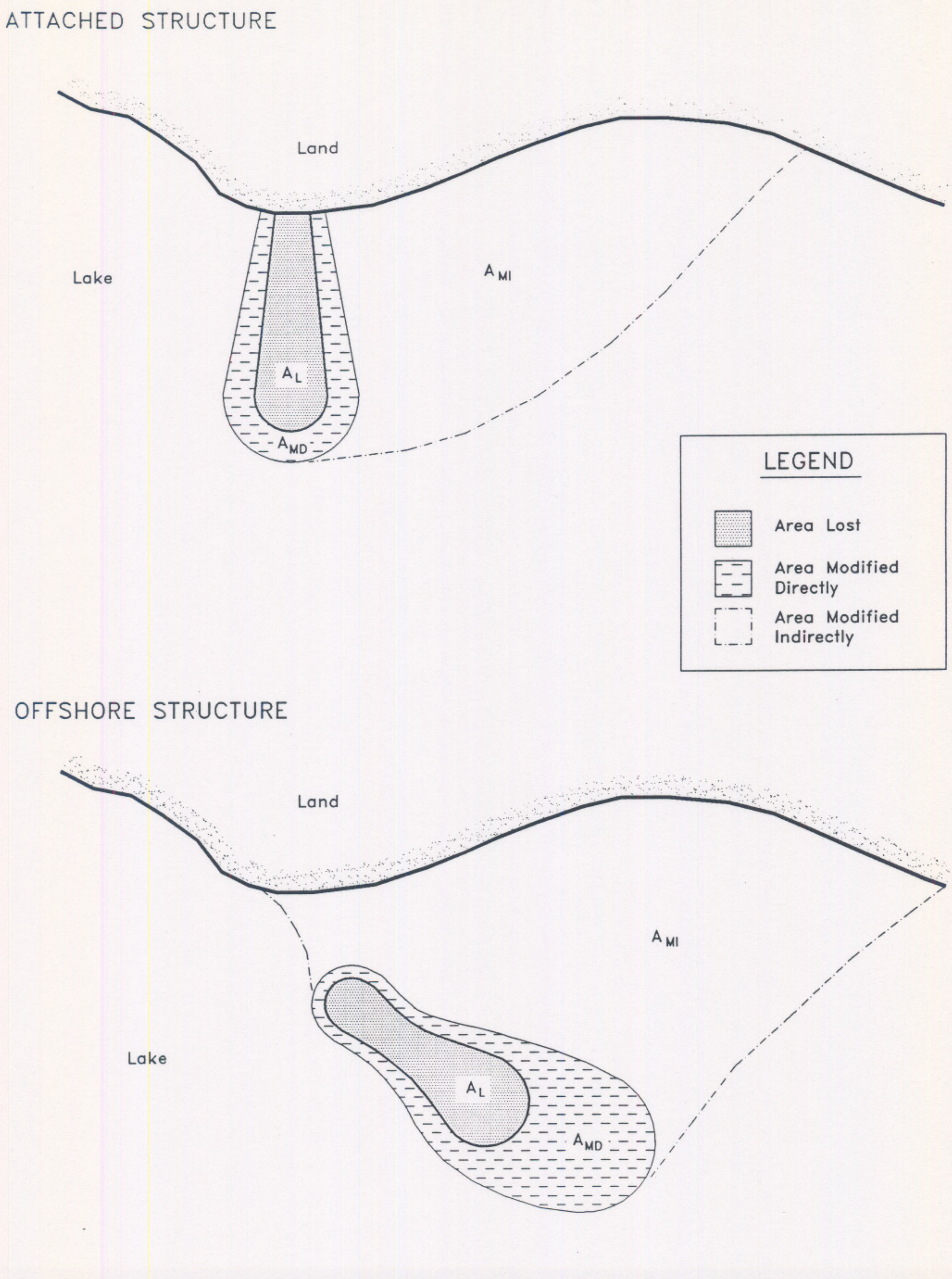
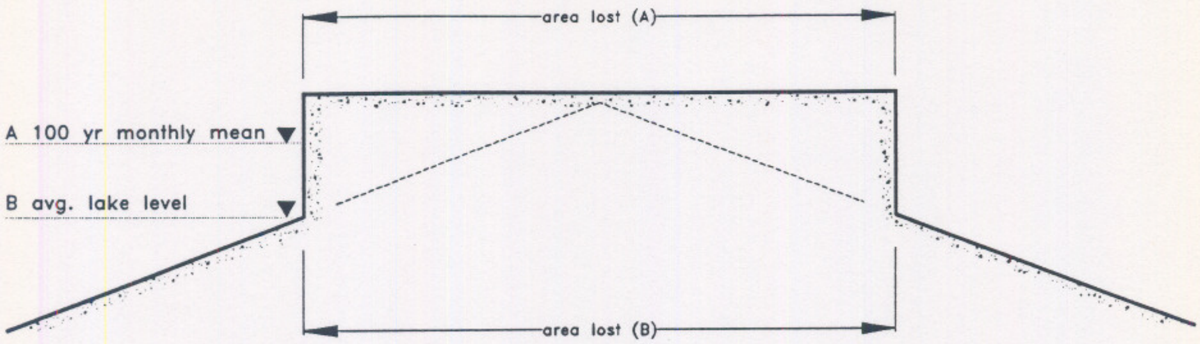


Figure 4.5 Plan View of Attached and Offshore Structures

CASE I Island With Vertical Edges Above the Average Lake Level



CASE II Island With Gently Sloping Edges Above the Average Lake Level

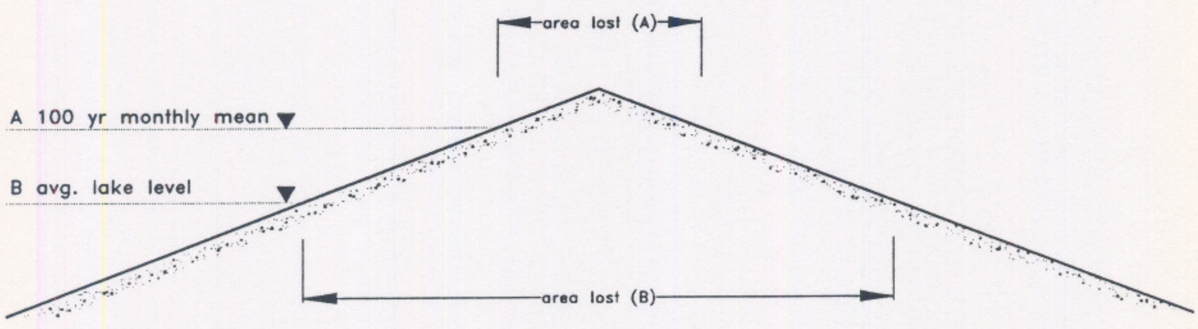


Figure 4.6 Area Lost and the Importance of Defining Water Levels

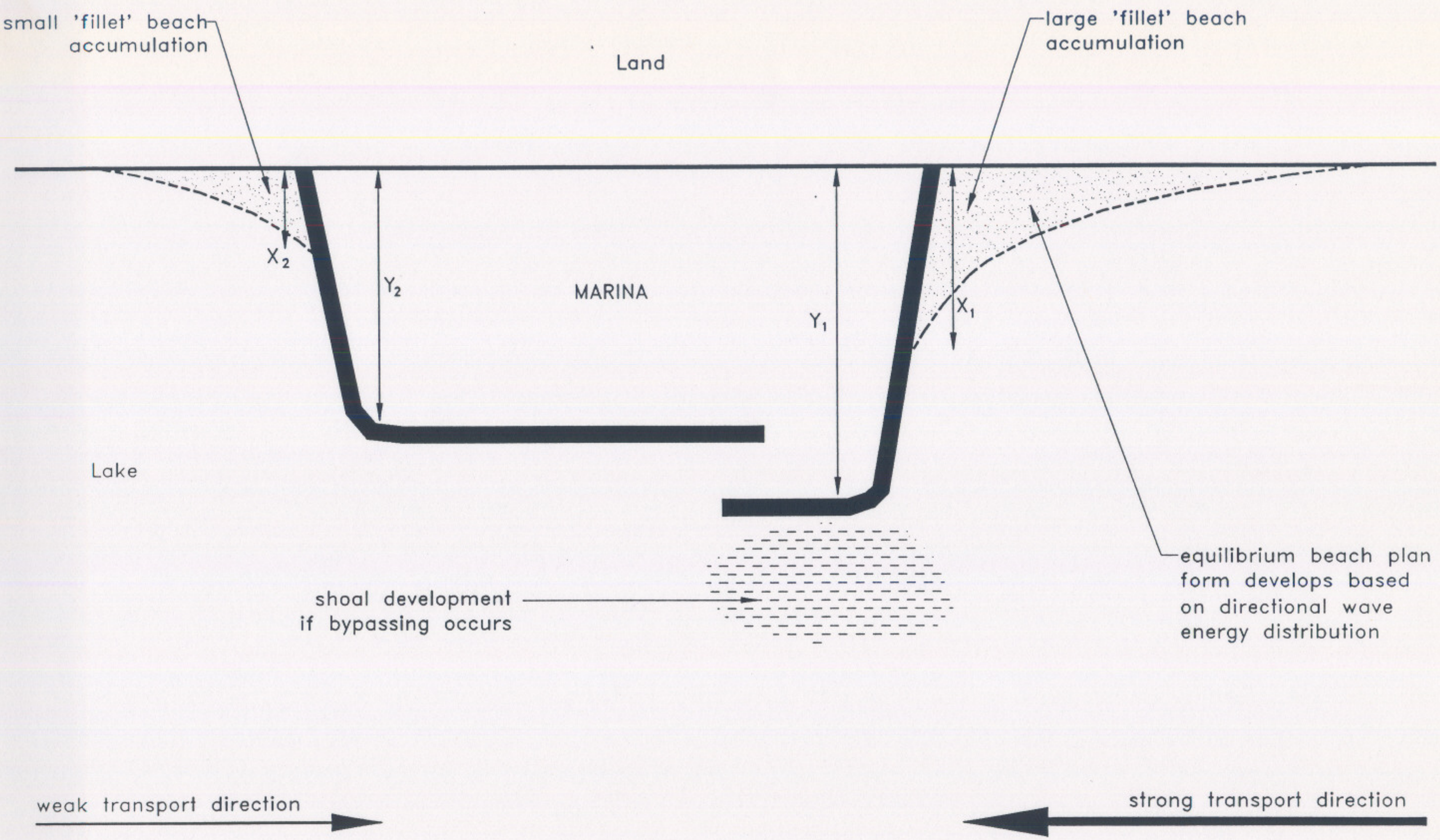


Figure 5.1 Fillet Beach and Shoal Development for Shore Normal Structures

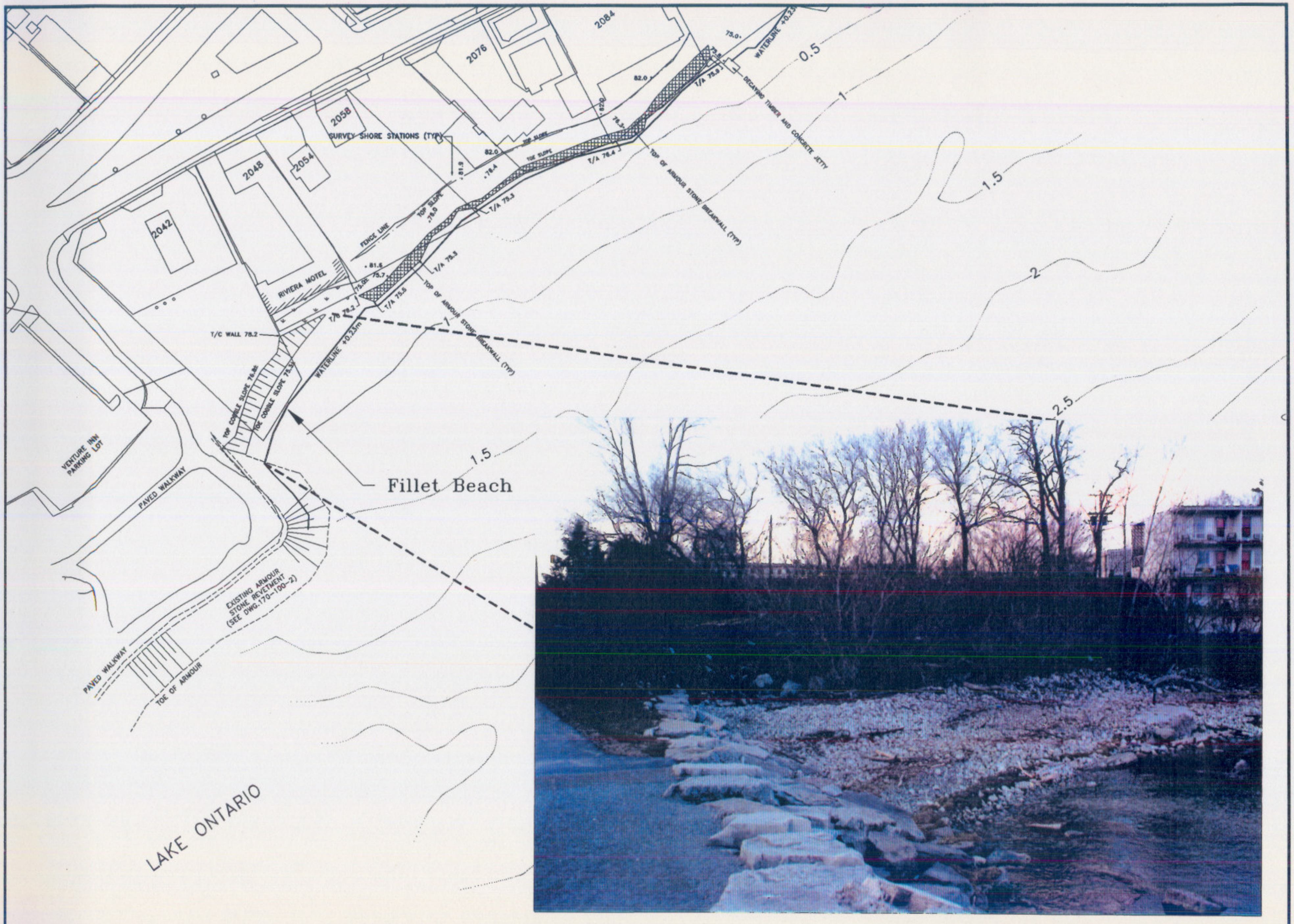


Figure 5.2 Fillet Beach Updrift of the Venture Inn Lakefill, Burlington, Ontario

Figure 5.3 **Bluffers Park, Scarborough. Fillet Beach at East Side of Development. September 1989.**

Figure 5.4 **Bluffers Park, Scarborough. Infilled West Embayment. July 1988.**

Figure 5.5 Ashbridges Bay, Toronto. Infilling of East Embayment. April 1992.

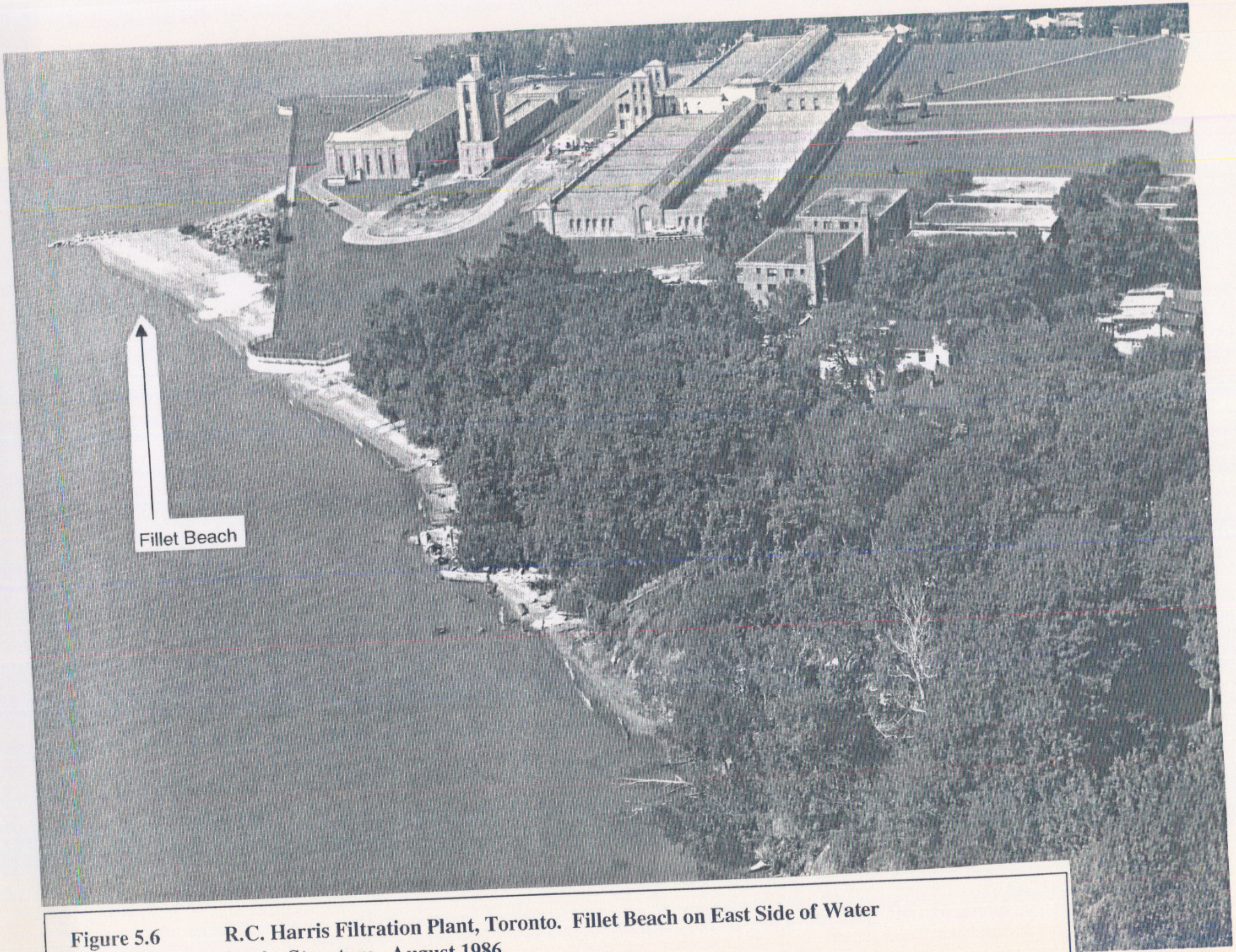


Figure 5.6 R.C. Harris Filtration Plant, Toronto. Fillet Beach on East Side of Water Intake Structure. August 1986.

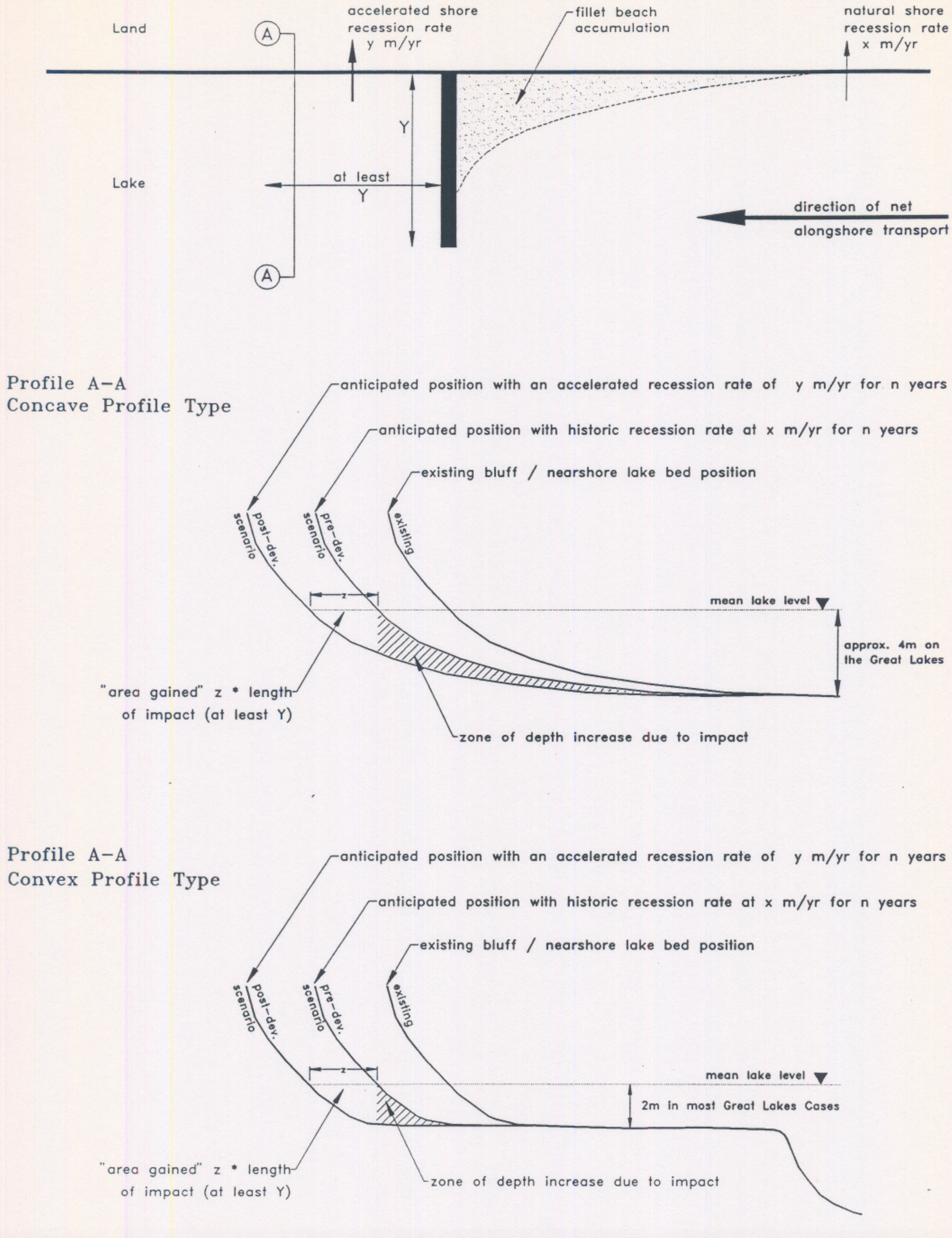


Figure 5.7 Influence of Increased Erosion and Downcutting on a Cohesive Shore Downdrift of a Littoral Obstruction

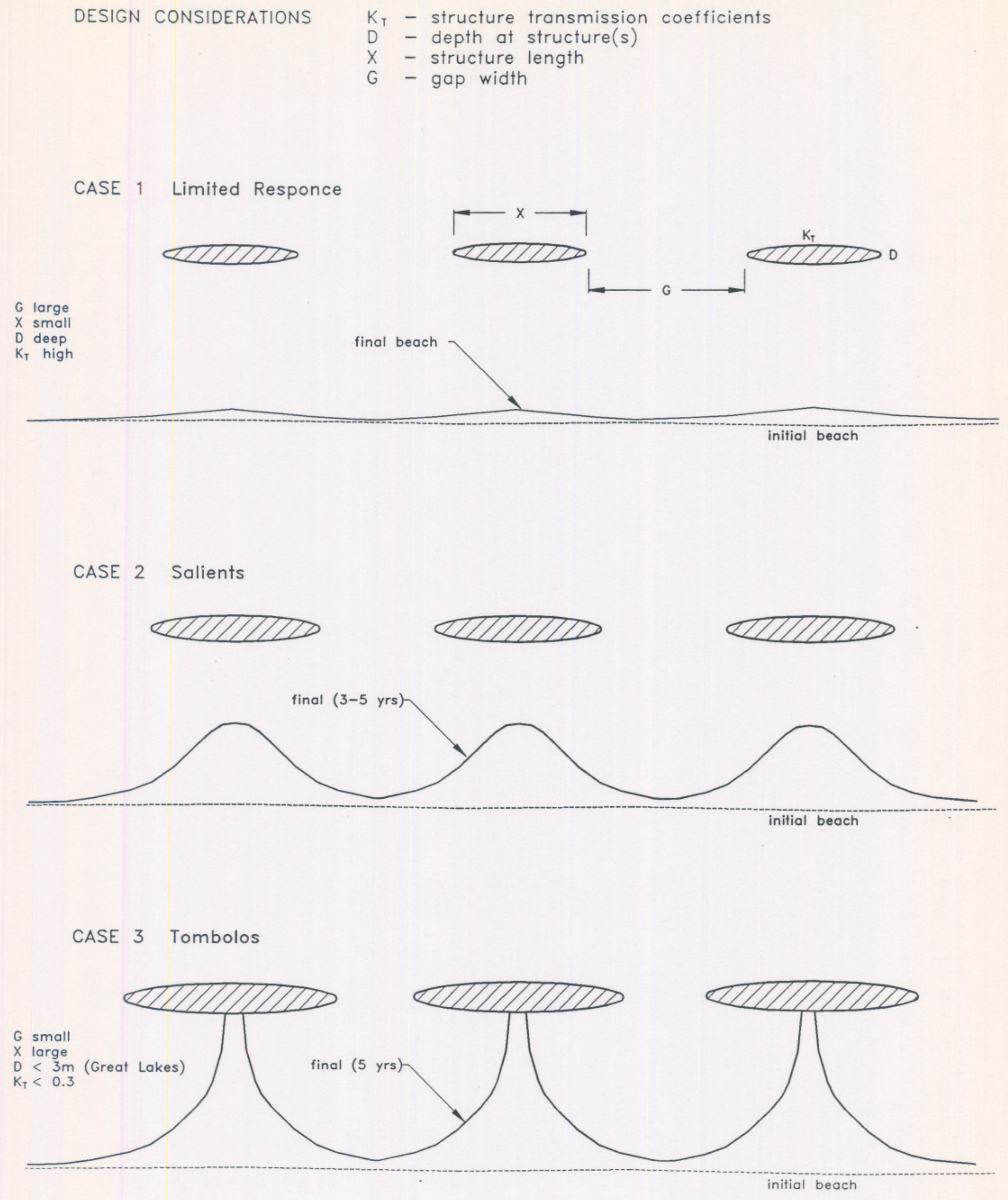


Figure 5.8 Schematic Diagram of Salients and Tombolos Associated with Offshore Breakwaters

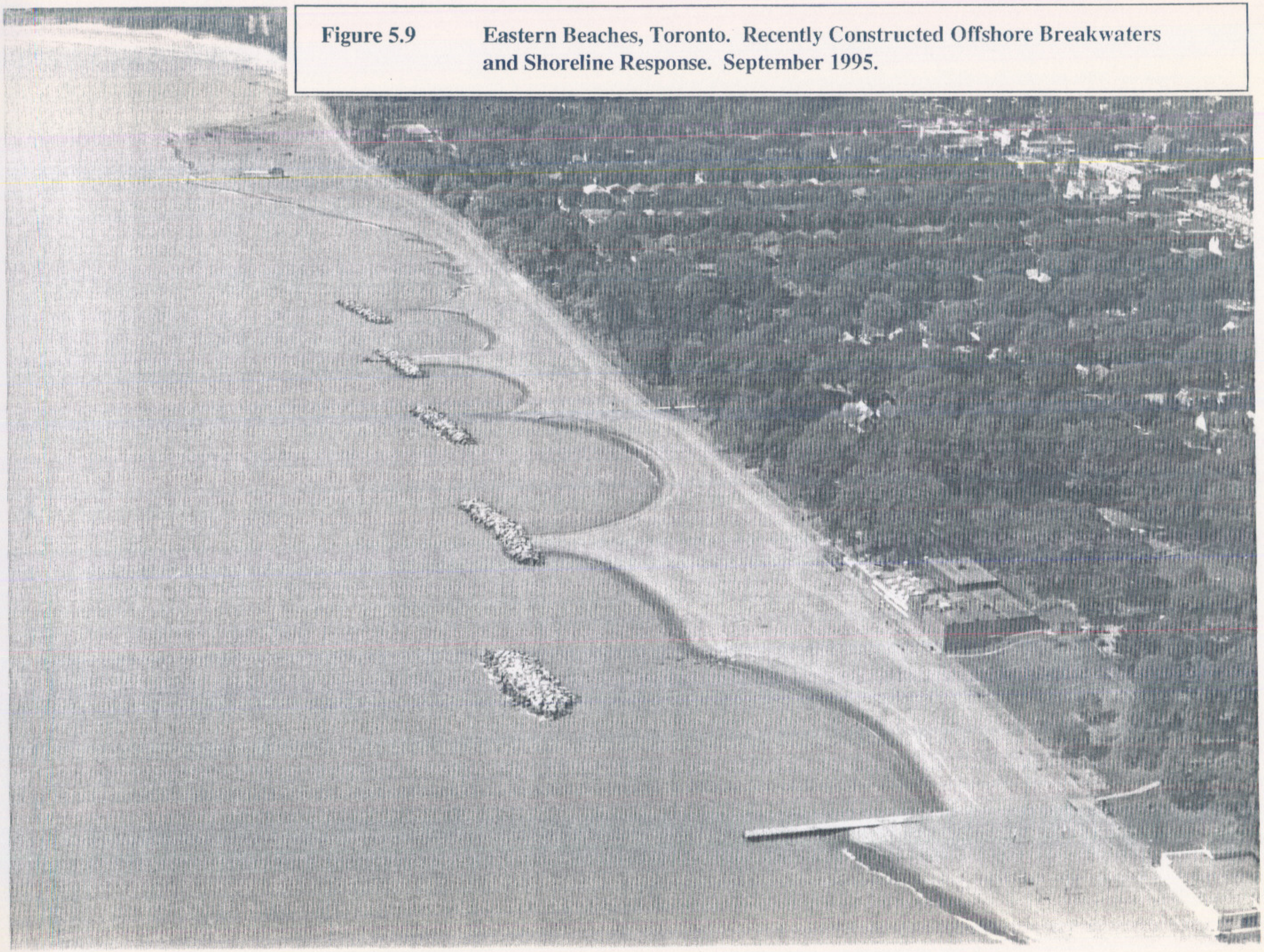


Figure 5.9 Eastern Beaches, Toronto. Recently Constructed Offshore Breakwaters and Shoreline Response. September 1995.

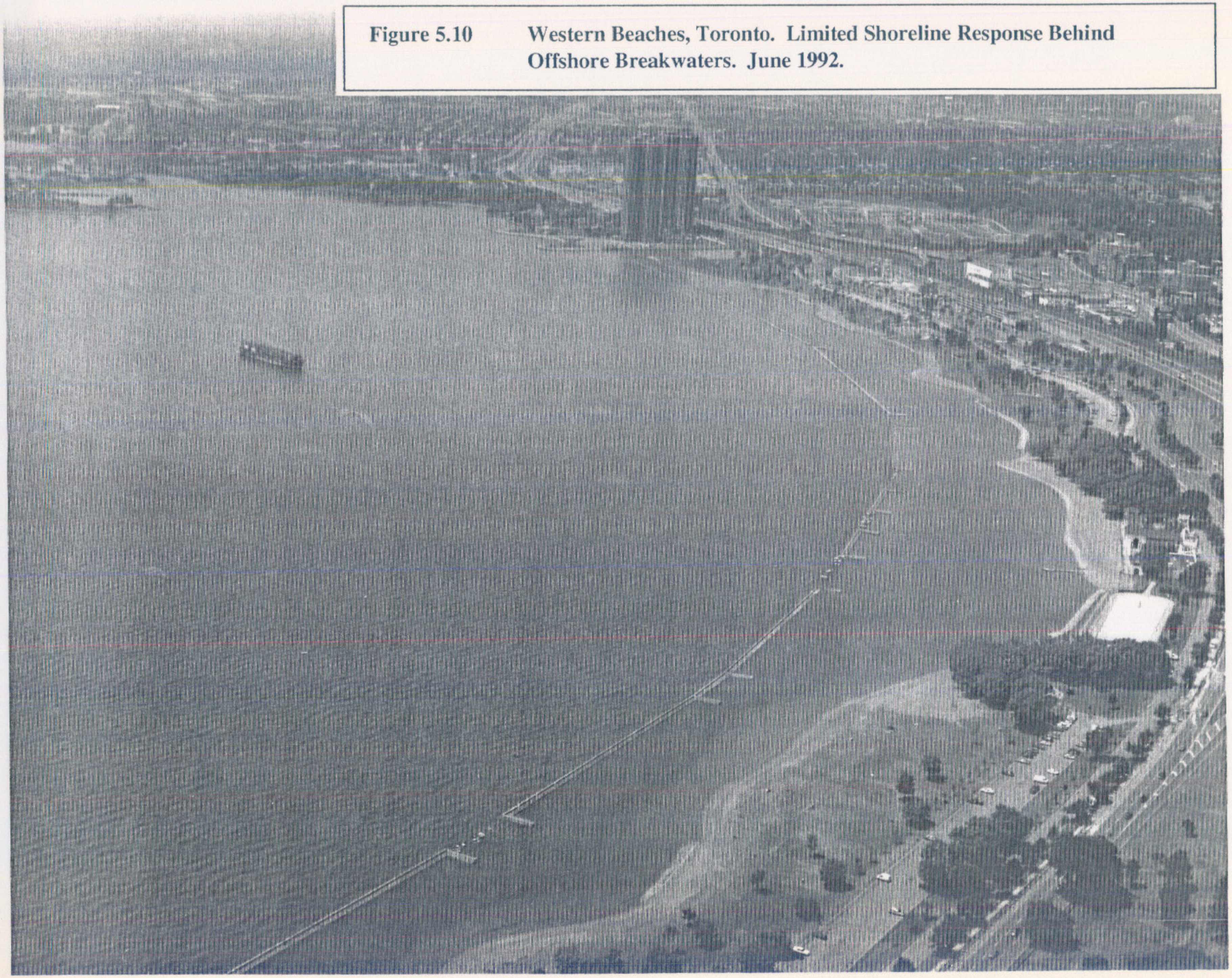
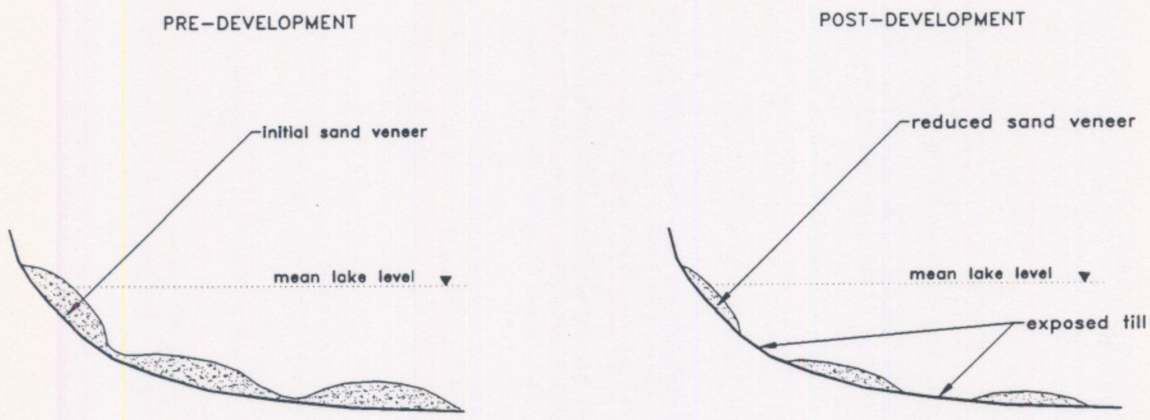


Figure 5.10 Western Beaches, Toronto. Limited Shoreline Response Behind Offshore Breakwaters. June 1992.

a) Concave Profiles (typical)



b) Convex Profiles (typical)

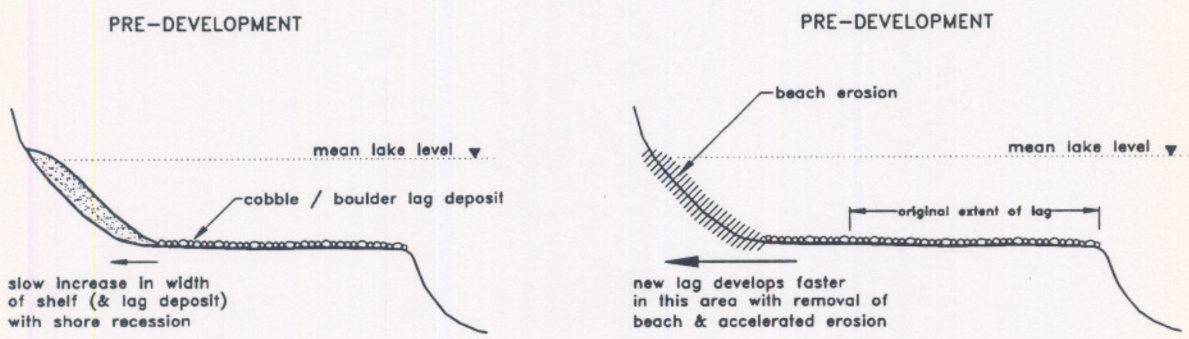


Figure 5.11 Cohesive Shores and Changes to Surficial Substrates in Downdrift Erosion Areas

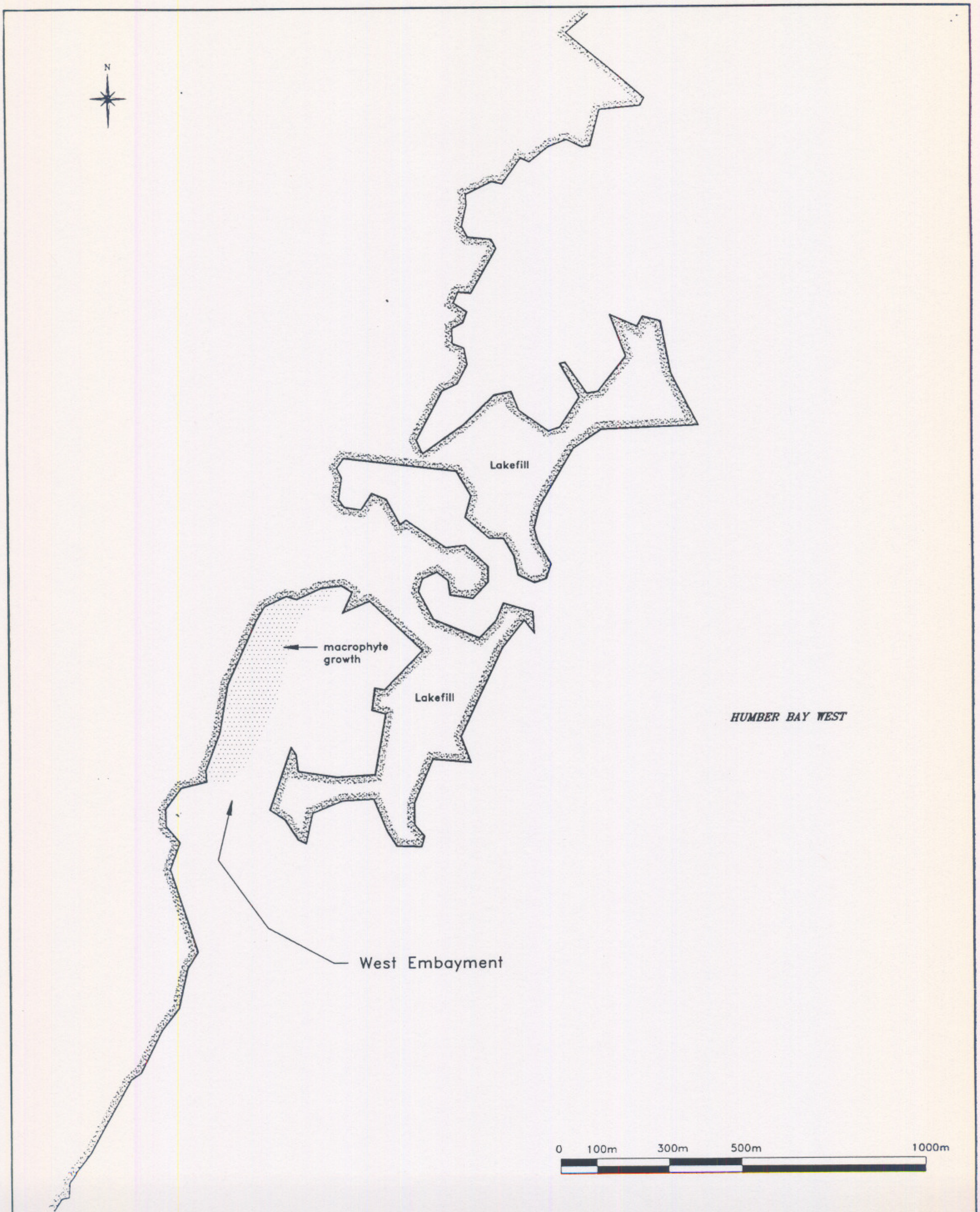


Figure 5.12 Humber Bay West, Toronto, Ontario
(digital file courtesy of MTRCA)

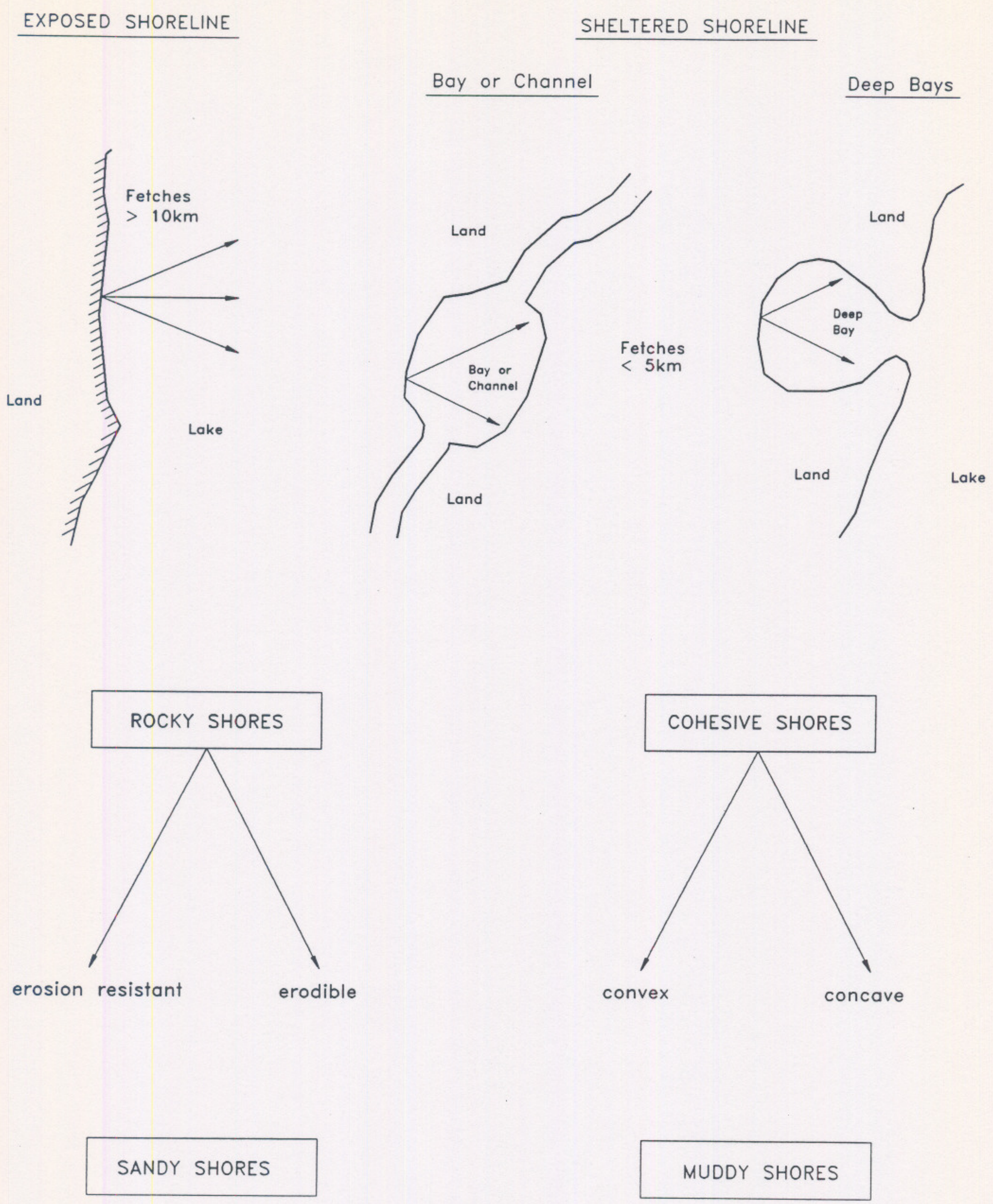


Figure 6.1 Shore Types

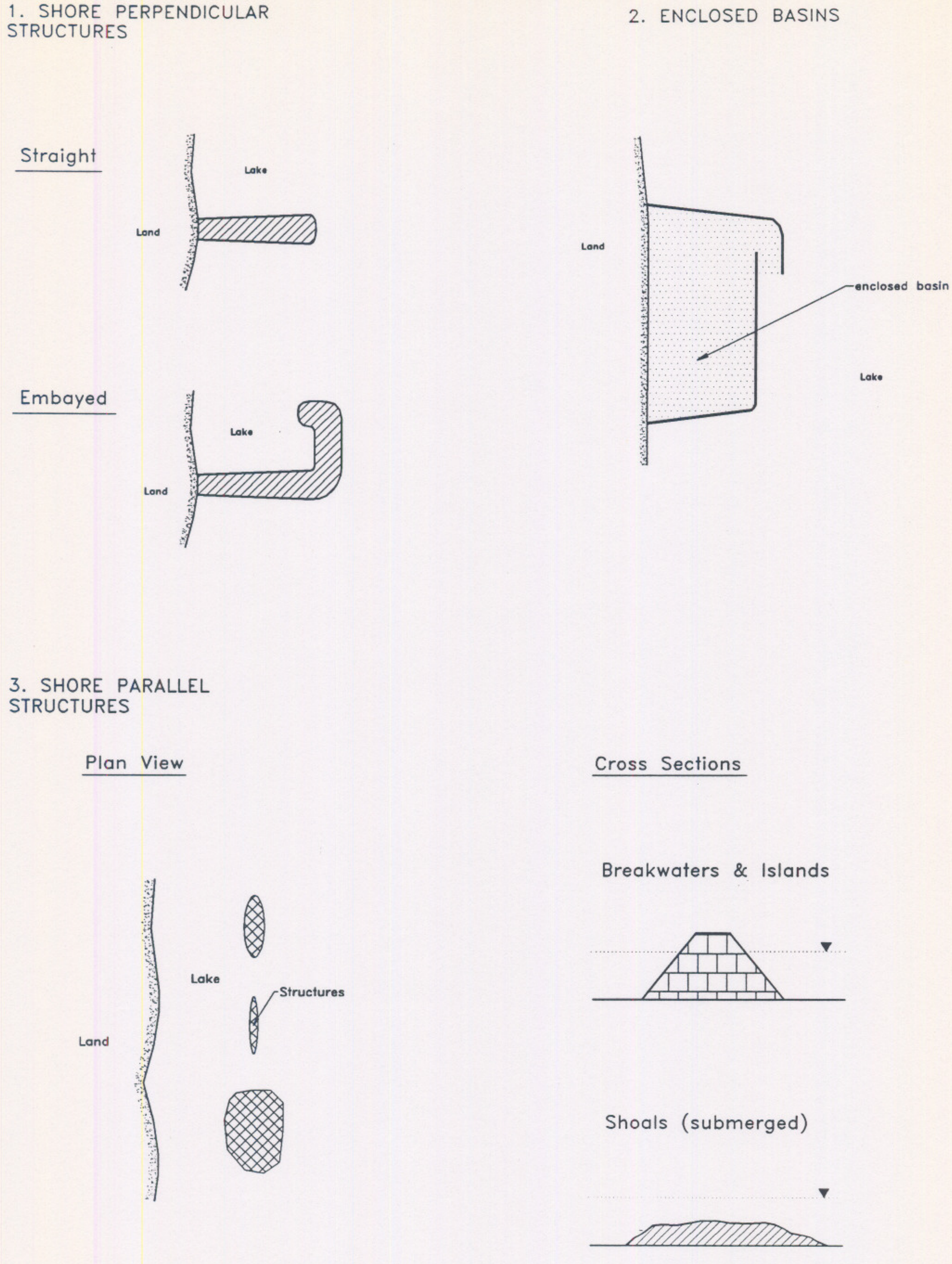


Figure 6.2 Project Types

Table 4.1 Controlling and Surficial Substrate

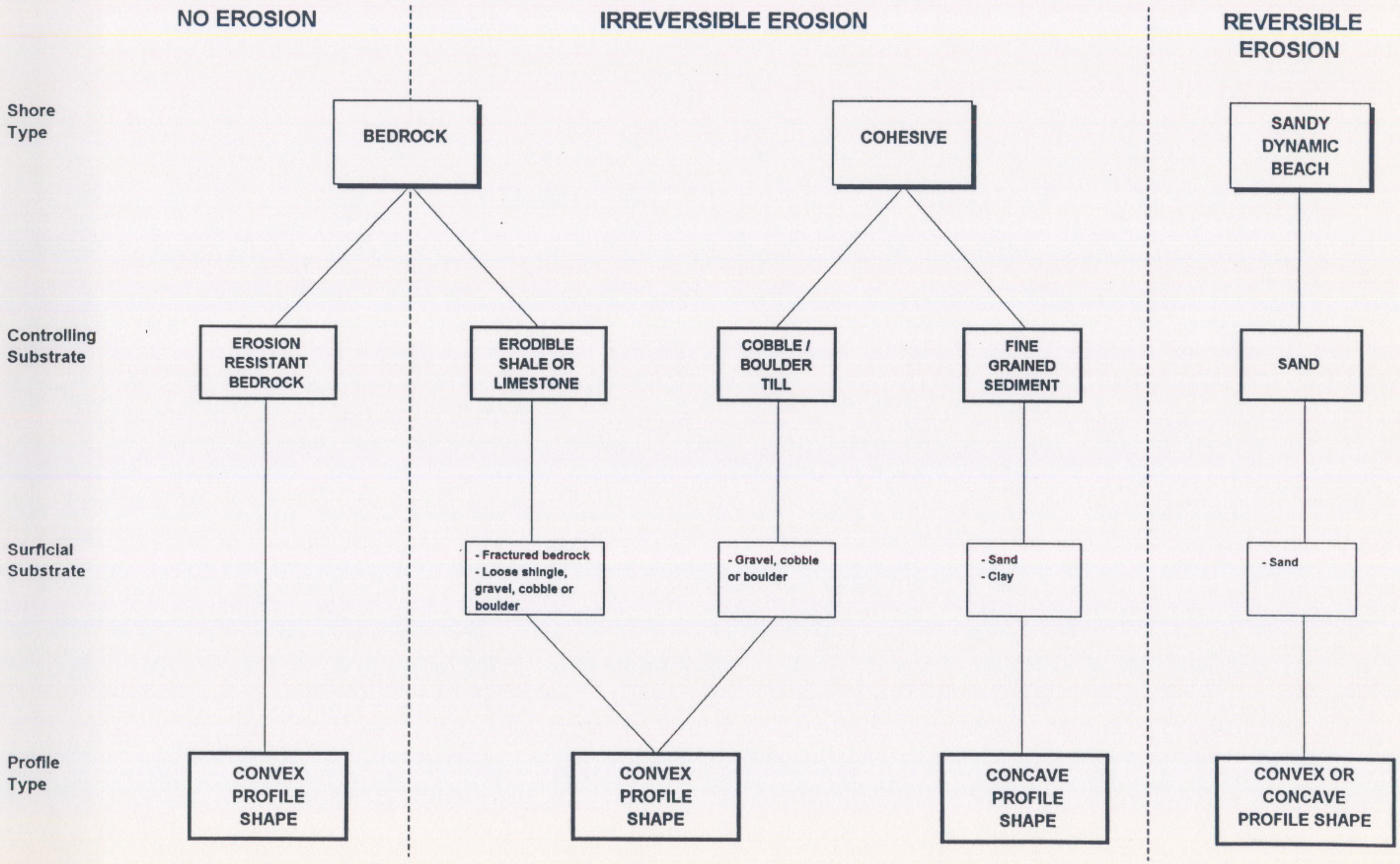


Table 4.2 100 Year Record High and Low Monthly Mean Water Levels for the Great Lakes

100 Year Record High Monthly Means

LAKE \ MONTH	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
LAKE ONTARIO	75.20	75.27	75.37	75.65	75.73	75.76	75.66	75.58	75.41	75.22	75.18	75.20
LAKE ERIE	174.90	174.78	174.88	174.98	174.97	175.04	175.03	174.94	174.83	174.94	174.85	174.90
LAKE HURON	177.26	177.11	177.12	177.23	177.28	177.33	177.39	177.39	177.38	177.50	177.38	177.26
LAKE SUPERIOR	183.81	183.63	183.61	183.68	183.74	183.76	183.82	183.86	183.86	183.91	183.89	183.81

100 Year Record Low Monthly Means

LAKE \ MONTH	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
LAKE ONTARIO	73.74	73.78	73.94	74.03	74.11	74.19	74.14	74.00	73.91	73.82	73.75	73.74
LAKE ERIE	173.19	173.18	173.20	173.38	173.44	173.45	173.45	173.43	173.38	173.30	173.20	173.19
LAKE HURON	175.62	175.59	175.58	175.61	175.74	175.76	175.78	175.77	175.76	175.70	175.65	175.62
LAKE SUPERIOR	182.92	182.76	182.74	182.72	182.76	182.85	182.96	183.02	183.12	183.10	183.01	182.92

LAKE	Chart Datum (IGLD '85)
LAKE ONTARIO	74.20
LAKE ERIE	173.50
LAKE HURON	176.00
LAKE SUPERIOR	183.20

Note: Water Levels in Metres Referred to IGLD '85
(Source: Canadian Hydrographic Service, Monthly Bulletin)

Table 5.1
Processes Simulated in Numerical Wave Models

MODEL	Shoaling	Refraction	Diffraction	Reflection	Breaking	Bottom Friction	Wave-current Interaction	Irregular Waves	Multi-directional Waves	Time Domain Solution
Wave Ray	●	●			●	●				
Nearshore Spectral	●	●			●	●	●	●	●	
Mild Slope Parabolic	●	●	○		●	●	●	●	●	
Mild Slope Elliptic	●	●	●	●	●	●	●			
Boussinesq	●	●	●	●	●	●	●	●	●	●

● Process Included
○ Process Partially Included

Table 5.2
Processes Simulated in Numerical Models of Erosion / Deposition

	← PROCESSES →			← STRUCTURE / SHORE TYPE →			
	Wave Transformation	**Wave Generated Currents**	**Sediment Transport**	**Revetment**	**Breakwaters ***	**Groins / Headlands**	**Cohesive / Rocky Shores (thin veneer)**
BEACH PLAN MODELS							
GENESIS	○		○	○	●	●	
KUST	○		○			●	
ONELINE	○		○	○		●	
BPLAN	○		○			●	
COSMOS-3D	○	○	●	●		●	●
BEACH PROFILE MODELS							
EDUNE or EBEACH	○		○				
SBEACH	○		○	○	●		
DHI LITPAK	●	●	●		●		
UNIBEST	●	●	●		●		
COSMOS-2D	●	●	●	●	●		●

● Process Included
○ Process Partially Included
* Submerged only for Beach Profile Models

Table 6.1 Indirect Impacts to Depth, Substrate and Macrophytes Based on Shore Type and Sediment Supply
EXPOSED SHORELINE

SHORE TYPE	Rocky		Cohesive Convex		Cohesive Concave		Sandy		Muddy	
SEDIMENT SUPPLY	no	yes	low	med.	low	high	no	yes	no	yes
Depth *	none	low to med.	low	med.	med.	high	low	high	low	med.
Substrate *	none	low to med.	low	med.	low	med.	none	low	none	none to low
Macrophytes •	low	med. to high	low	med. to high	low	low	high	low	high	high

* impacts relate to either deposition or erosion
• for enclosed basins and well sheltered bays

Table 6.2 Indirect Impacts to Depth, Substrate and Macrophytes Based on Shore Types SHELTERED SHORELINE (sediment transport / supply assumed to be low)

HABITAT CHARACTERISTIC \ SHORE TYPE	Rocky	Cohesive Convex	Cohesive Concave	Sandy	Muddy
Depth	none	low	low	low	low
Substrate	none	low	low	low	low
Macrophytes	med.	high	high	high	high

* impacts relate to either deposition or erosion

• for enclosed basins and well sheltered bays

Table 6.3 **Indirect Impacts to Circulation Patterns and Water Quality for Different Shore Types**

PROJECT TYPE / CONDITION	Shore Perpendicular Obstruction		Shore Parallel Structure(s)		Enclosed Basin
	Straight	**Embayed**	**Breakwater(s)**	**Shoal(s)**	**(within basin only)**
Near a Source of Contaminant Loading (Water Quality)	med.	high	med.	low	med. to high
Far from a Source of Contaminant Loading (Water Quality)	low	low	low	low	med.
Potential for Debris Build Up	med.	high	med.	low	n/a