CREDIT VALLEY CONSERVATION

LAKE ONTARIO INTEGRATED SHORELINE STRATEGY BACKGROUND REVIEW AND DATA GAP ANALYSIS

APPENDIX C
Coastal Processes
Final Report

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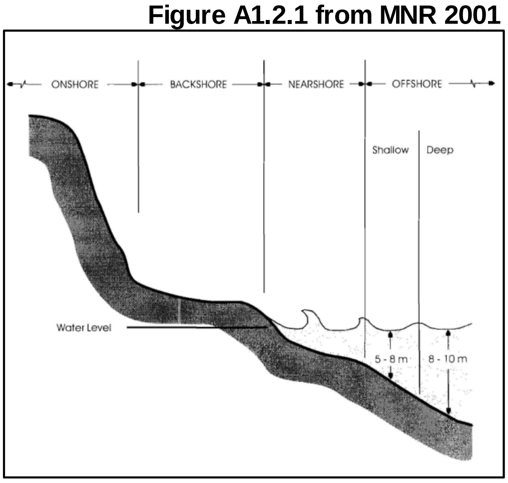
1 INTRODUCTION

This report presents an overview of coastal processes within the limits of Credit Valley Conservation's watershed and identifies gaps in the existing data required for a detailed assessment of those processes. Coastal processes can be generally defined as the natural forces and processes that affect the shoreline zone. Definitions of the shoreline zone vary and can be dependent upon both jurisdiction and context. MNR (2001) provides the following definition of the shoreline zone:

Figure A1.2.1 from MNR 2001



"Lake/land interactions generally occur in an area defined as the shoreline zone (Figure A1.2.1). This zone of interaction is normally divided into three distinct units:

- *The onshore zone is the area landward of and generally beyond the limit of wave action by a particular water body. This may include shoreline bluffs, sand dune fields, wetlands, and areas subject to occasional inundation.*

- *The backshore zone extends from the landward limit of the nearshore to the point of development of vegetation or change in physiography (i.e. where the bluff or dune starts). The backshore zone is typically only affected during severe storms, particularly at high water.*

- *The nearshore zone is an indefinite zone extending from just beyond the breakers zone to the landward limit of the swash zone or the landward limit of the foreshore zone. The swash zone is the portion of the nearshore zone in which the beach face is alternatively covered by the uprush of the wave swash and exposed by the backwash. The foreshore is the sloping portion of the beach profile lying between the berm crest, or in the absence of a berm crest, the upper limit of wave swash, and the lower limit of the backrush of wave swash. The term foreshore is often nearly synonymous with the beach face but is commonly more inclusive, containing also some of the flat portion of the beach profile below the beach face.*

The littoral zone is composed of the backshore, nearshore and shallow offshore (i.e. 5-8 metres) which in total extends from the landward limit of storm wave action on a bluff or beach offshore to the maximum depth at which wave action can effectively transport sediment on the lakebed (i.e. roughly 5-8 metres in the Great Lakes).

The "shoreline" is generally defined as the intersection of the stillwater line with the land. Changes or movement of the "shoreline" lakeward or landward can be influenced by a number of factors. Primarily, the shoreline position is determined by the level of water with respect to the level of the adjacent land and by the erosion and accretion processes which occur."

The current shoreline of Lake Ontario has formed over the last approximately 10,000 years since retreating glaciers allowed Lake Iroquois to outlet through the St. Lawrence River. Erosion from wind, waves and water level fluctuations formed the shoreline zone that exists today. Protection structures have hardened most of the lake shoreline within the CVC watershed and natural processes are generally restricted to the few unprotected reaches of shore and the nearshore lakebed fronting the structures.

2 BACKGROUND REVIEW

We carried out a review of existing background information including various data sources, past study reports, published papers and shoreline work applications. This section of the report presents our relevant findings.

2.1 Water Levels

Water levels on Lake Ontario fluctuate on short-term, seasonal and long-term bases. The causes of these fluctuations are discussed in numerous other reports and need not be described in detail here. Briefly, seasonal fluctuations reflect the annual hydrologic cycle which is characterized by higher net basin supplies during the spring and early part of summer with lower supplies during the remainder of the year. Figure 2.1 is a hydrograph for Lake Ontario showing recent and long-term mean monthly water levels with respect to chart datum. Chart datum for Lake Ontario is 74.2 metres above the 1985 International Great Lakes Datum (IGLD85). To convert IGLD85 datum to Geodetic Datum in the Toronto area, 0.05 metres must be subtracted from the IGLD85 elevation.

The black continuous line in Figure 2.1 shows recently recorded monthly water levels and the grey continuous line shows the long-term mean monthly water levels. The red and blue horizontal lines show the maximum and minimum monthly mean over the period of record from 1918 to 2007. These are mean monthly water levels, not instantaneous levels and therefore do not represent the highest and lowest water levels on record.

It can be seen from Figure 2.1 that water levels generally peak in the summer (June) with the lowest water levels generally occurring in the winter (December). The average annual water level fluctuation is approximately 0.5 metres. Although water levels below chart datum are rare, the lowest monthly mean on record is approximately 73.8 m (IGLD, 1985), or 0.4 metres below chart datum.

Short-term fluctuations last from less than an hour up to several days and are caused by local meteorological conditions. These fluctuations are most noticeable during storm events when barometric pressure differences and surface wind stresses cause temporary imbalances in water levels at different locations on the lake. These storm surges, or wind-setup, are most noticeable at the ends of the Lake, particularly when the wind blows down the length of the Lake. Because of the depth of Lake Ontario, storm surge is not as severe as occurs elsewhere on the Great Lakes (like Lake Erie).

MNR (1989) investigated storm surges throughout the Great Lakes as part of their analysis of extreme water levels for design conditions. They performed a joint probability analysis of static water levels (determined from monthly mean values) and storm-surges to estimate various return periods of instantaneous water levels. Storm surge values were determined from measured water levels at specific recording stations and through the use of a numerical circulation model for locations between the recording stations. Recorded data was used to estimate surges at Toronto and Burlington. Two intermediate reaches were modeled, one for Oakville and one for Mississauga. The boundary between the Oakville and Mississauga reaches was the Clarkson refinery pier, which is actually located in Mississauga. This therefore gives two MNR (1989) shoreline sectors within the boundaries of the CVC watershed. Table 2.1 shows the 1:100-year mean monthly water levels, storm surges and instantaneous water levels for the shoreline reaches relevant to this study. Water levels with a lesser frequency of occurrence were calculated for the Burlington and Toronto shoreline reaches but not for the Oakville and Mississauga reaches.

Table 2.1: 100-Year Water Levels and Storm Surge Heights

MNR (1989) Sector	instantaeous water level (m IGLD85)	storm surge (m)	mean monthly water level (m, IGLD85)
Burlington (sector O-2)	76.06	0.94	75.59
Oakville (sector O-3)	75.96	0.81	
Mississauga (sector O-4)	75.86	0.72	
Toronto (sector O-5)	75.74	0.34	

Long-term water level fluctuations on the Great Lakes are the result of persistently high or low net basin supplies. More than a century of water level records show that there is no consistent or predictable cycle to the long-term water level fluctuations. The intervals between periods of high and low water levels and the duration of those periods vary over the length of record and vary by Lake. As the “lowest” of the Great Lakes, long-term water level fluctuations on Lake

Ontario are affected by fluctuating outflows of the upstream lakes as well as the fluctuating supplies to the Lake Ontario drainage basin. Figure 2.2 shows Lake Ontario's mean monthly water levels from 1918 to 2009. Both long-term and seasonal fluctuations can be seen in Figure 2.2

The International Joint Commission began regulating water levels on Lake Ontario in 1960. They report that water supplies to Lake Ontario have been greater since regulation but regulation has significantly reduced the duration and magnitude of extreme high water levels. Without regulation new record water levels would have been set several times. The effects of regulation can be seen in Figure 2.2 where the fluctuations have been less since 1960.

Some climate change studies that examine the impact of global warming have suggested that long term water levels on the Great Lakes will be lower than they are today. Those changes, however, are expected to have a lesser impact on Lake Ontario than on the upper lakes because the Lake Ontario water levels are regulated. The International Joint Commission has been considering possible changes to those regulations but no final decision has been made. For the time being most approving agencies, including CVC, require that the 100-year instantaneous water level be used for the design and assessment of shoreline protection structures. The 100-year instantaneous water level determined by MNR(1989) is typically used.

Water levels are of major importance to nearshore coastal processes because they dictate, to a large degree, where those processes take place. For example, nearshore waves within the Study Area are generally depth limited, meaning that the waves acting on the shoreline are controlled by the water depth. At lower water levels waves break further offshore. This reduces the stress on shoreline protection structures but leads to downcutting (vertical erosion) of the nearshore profile fronting those structures. At higher water levels that nearshore downcutting allows higher wave heights to reach the structures because the downcutting has effectively increased the water depth. Similar processes take place on unprotected shorelines where higher erosion rates are experienced at high water levels because the backshore bluff is exposed to direct wave attack but the size of those waves is related to the nearshore bottom erosion that occurred at lower water levels.

The Canadian Hydrographic Service (CHS) of Fisheries and Oceans Canada operates a number of permanent water level gauges on Lake Ontario. They do not have any gauges in Mississauga but there are gauges in both Toronto and Burlington. Digital records of hourly water levels are available from 1971 for the Burlington gauge and since 1962 for the Toronto gauge. As of December 2002 both gauges have higher resolution data with records every 3 minutes. It is our experience that the Toronto water level gauge can be taken as representative of the Study Area for most instances. It can be seen from Table 2.1 that storm surges during extreme events will be somewhat higher in Mississauga than in Toronto.

The Surface Water Monitoring Centre of the Ontario Ministry of Natural Resources carries out wave and water level forecasts as part of the Great Lakes Operational Storm Surge System (GLOSS). They currently produce 60 hour forecasts, twice daily, for all of the Great Lakes. The GLOSS is relatively new and is still considered to be operating in "test mode" (as of November 2009). There are not yet any published reports describing the model setup or data product but it is anticipated that there eventually will be. Briefly, GLOSS is a two-dimension circulation model coupled with a two-dimensional wave model. The models are driven by forecast winds and measured water levels assuming static bathymetry and lake boundaries. The bathymetry is represented by a flexible grid that allows the grid spacing to be tailored to specific areas of interest. It is likely, but not confirmed, that the GLOSS bathymetry grid was developed from the NOAA/CHS bathymetry set described in Section 2.6. The current grid has a spacing of approximately 5 kilometers in the offshore and in the order of 200 to 300 metres in the nearshore. It is possible to utilize much finer nearshore grid spacing to better represent significant flow barriers like the large breakwaters and piers found within the Study Area. MNR does not have any specific plans to increase the bathymetric resolution within the Study Area, but they seem willing to incorporate finer grids if they are supplied by others. The benefit of including a more refined GLOSS setup as part of the LOISS should be considered during the shoreline characterization phase of this study.

2.2 Winds

Knowledge of wind conditions is important to an analysis of coastal conditions because it is the winds that generate the waves that drive much of those processes. Winds are also the primary cause of storm surges, which are the short-term water level fluctuations described in Section 2.1. There are many sources of relatively long-term wind data around the lake, including both local and distant sources. Whether or not local or distant wind data is required depends upon how that wind will be used. For a lake-wide wave or circulation model it is preferable that multiple wind sources be used to define the varying conditions across the lake but it is important that the different wind sources be verified as being representative of the over-water winds before they are used. The authors of this report have found that winds measured at the Toronto Island airport are suitable for modeling coastal processes along the western end of Lake Ontario. Toronto Island has suitable wind data measured from 1957 to present although we tend to exclude winds from prior to 1973 due the higher percentage of missing data during that period.

2.3 Waves

There are a number of sources of wave data available in the general Study Area including hindcasts with data within the limits of the CVC jurisdiction and measured wave data from western Lake Ontario. The Marine Environmental Data Service (MEDS) of Environment Canada has online wave data from buoys located at Toronto, Burlington and Grimsby although the Burlington data is limited. While it is outside the CVC jurisdiction the measured wave data is valuable for calibrating hindcast and forecast models that include the immediate Study Area.

Online wave data is also available from a lake-wide hindcast prepared for the International Joint Commission (IJC). That study produced hourly wave data from 1961 to 2000 on a grid encompassing all of Lake Ontario. Data were archived for 307 locations around the perimeter of the Lake. Figure 2.3 shows the location of the archived data sets closest to the Study Area. Some of the measured wave data sites for the western end of the lake are also shown on Figure 2.3. The WIS wave data is offshore data, meaning that it must be transferred inshore if it is to be used in a coastal processes analysis. As waves propagate inshore, changing water depths cause the waves to refract to shoal, which changes both the wave height and wave direction. Waves in the lee of structures or those subjected to strong refraction effects will also undergo diffraction, a lateral transfer of energy along the wave crest. Nearshore wave transformation models typically consider a number of processes including refraction, diffraction, shoaling, wave breaking and bottom friction losses. Depending upon the specific modeling circumstances it may also be necessary for the transformation model to consider wave reflection.

The Great Lakes Operational Storm Surge System (GLOSS), which was described briefly in Section 2.1, includes a 2D wave model that applies from deep-water in to the nearshore. It is both a wave generation and wave transformation model and could be used to produce nearshore waves throughout the study site.

As parts of different studies, Shoreplan has prepared site specific wave hindcasts and estimated nearshore conditions through much of the Study Area. An example of offshore and nearshore wave conditions within the Study Area can be demonstrated using the results of a study for a site on Watersedge Road. Wave hindcasting was used to estimate the wave climate at an offshore location where changes in water depths do not effect wave generation and propagation. Wind data recorded at the Toronto Island Airport was used to predict the wave conditions that would have been generated by those winds.

A 33 year wave climate was produced by hindcasting for the period from January 1973 to December 2005. That is a sufficiently large database to be considered representative of the long term wave conditions. Wind data is available prior to 1973 but it was not utilized due to the high percentage of missing data.

Figure 2.4 shows the highest hindcast wave heights and total wave energy distribution by direction for the 33 year hindcast. The wave energy distribution shows two distinct peaks; one from the east and one from the southwest. Approximately 70% of the total offshore wave energy comes from an easterly direction with the remaining 30% coming from the southwest. Figure 2.5 shows exceedance curves for the hindcast wave heights and wave periods. These curves show the percentage of time that any given wave height or period is exceeded.

A nearshore wave climate at the site was produced by transferring the 33 years of hourly hindcast wave data from deep water into the site using a numerical wave transformation model. Wave transformation models are required to account for the effects that the changing bathymetry has on the waves as they propagate into the site. Figure 2.6 shows the bathymetry covered by the wave transformation model. Figure 2.7 shows the nearshore wave height and wave energy distributions in front of the Watersedge Road site. By examining Figures 2.4 and 2.7 it can be seen that the wave height and energy distributions have narrowed. The offshore and nearshore wave height distributions show similar peaks but the nearshore wave energy distribution is much more weighted towards the easterly peak than the offshore. Approximately 90% of the nearshore wave energy comes from the easterly direction. This is because the easterly waves undergo relatively little refraction compared to the south-westerly waves.

Some studies into the effects of climate change on the Great Lakes have estimated that the frequency of occurrence of severe storms will increase in the coming years. It has also been suggested that there could be an increase in wind speeds and changes in typical storm tracks. As nearshore waves are generally depth limited within the Study Area a small increase in wind speeds is not expected to be significant. Nearshore bathymetry and the overall geometry of the lake play a major role in nearshore wave directions so changing storm tracks are not likely to affect the nearshore wave climate. An increase in the frequency of severe events would be noticeable on any shoreline subject to ongoing erosion.

2.4 Nearshore Sediments

The Great Lakes Sediment Database (also known as the NWRI Sediment Archive) is an archive of data on the sediments of the Great Lakes, their connecting channels, and the St. Lawrence River which was collected by the Environment Canada’s National Water Research Institute (NWRI) and in cooperation with other agencies between 1968 and 2001. It is housed at the NWRI in the Canada Centre for Inland Waters in Burlington, Ontario.

The data has been subdivided into four groups according to location and purpose: contaminated sediments data; Great Lakes basin sediment data; miscellaneous sediment data; and nearshore sediments data. The nearshore sediments data includes descriptions of sediment and core properties, grain-size statistics, sediment patterns and x-radiographs of sediment cores. There is a limited amount of the nearshore sediments data available within the limits of the CVC watershed and that data is located far enough offshore that it will not provide significant benefit to a study of coastal processes. Figure 2.8 shows the location of nearshore sediment samples and cores in the vicinity of the Study Area.

2.5 Shoreline Recession Rates

The vast majority of the shoreline within the CVC watershed has been protected and there is little recession rate data available for the remaining natural shoreline. Environment Canada and MNR (1975) determined shoreline recession rates as part of the Great Lakes Shore Damage Survey, but Shoreplan (2005) found that data to be unsuitable for establishing recession rates within CVC's jurisdiction. CVC (1988) presents a number of shoreline recession rates but a number of those rates seem unrealistically high. The source of that data is not described.

Shoreplan (2005) used three average annual recession rates in their calculations of the erosion component of the Lake Ontario shoreline hazard limits. They used a rate of 0.1 m/yr for all beach shoreline and significant beach deposits that were not long enough to meet the MNR (2001) definition of a dynamic beach. That rate was based in part on the average annual recession rate calculated for Jack Darling Park prior to the construction of the headland beach system (JSW+, 1993).

An average annual recession rate of 0.3 m/yr was used for the large headland areas constructed out of moderately compacted fill material. In reality those sections of shore are unlikely to experience recession because they are well protected and there is sufficient justification to warrant maintaining that protection. However, the erosion hazard assessment process required that an average annual recession rate for unprotected shoreline be used. A rate of 0.3 m/yr is the provincial default for all of the Great Lakes.

An average annual recession rate of 0.2 m/yr was used for the remainder of the shoreline within the CVC jurisdiction. That was selected as a conservative rate for shoreline where bedrock is the controlling substrate, which is the case for all of that shore. A recession rate of 0.1 to 0.15 metres per year is more typically used for bedrock shore but a conservative approach was used because the erosion hazard limits were being determined for use in planning applications.

The average annual recession rates used by Shoreplan (2005) can be used for an initial assessment of the coastal processes along the CVC shoreline. More accurate shoreline recession rate data on the Great Lakes is typically developed from analyses of surveys and aerial photography. Recession rates derived from aerial photography have limitations on beach shorelines without a distinguishable bluff and when recession rates are low. Recession rates derived from surveys are generally more reliable as long as there is confidence in the accuracy of the survey. For example, shorelines and bluff edges shown on legal plans are not always accurate when those features were not considered relevant to the purpose of the survey. The best shoreline recession data is derived from shore perpendicular profiles surveyed for the purpose of documenting the current shoreline position.

2.6 Bathymetry

Figure 2.9 shows nearshore bathymetric contours within the Study Area at a contour interval of 2 metres. This figure was taken from a lake-wide bathymetric map produced as part of a cooperative program by the National Oceanic and Atmospheric Association (NOAA) of the U.S. Department of Commerce and the Canadian Hydrographic Service (CHS) of the Department of Fisheries and Oceans. (http://www.ngdc.noaa.gov/mgg/greatlakes/greatlakes.html). Bathymetric and topographic data is available on a rectangular grid with a resolution of 3 seconds of longitude and latitude. That corresponds to spacing of less than 100 metres for this location. That spacing is sufficient for most wave and circulation modeling as long as details are not required in the vicinity of features with a smaller spatial scale, such as a breakwater. The models may actually require smaller grid sizes but those grids can be generated by interpolating the NOAA data.

The NOAA data was compiled from multiple sources including CHS field sheets. On previous studies in the Toronto area we have found a discrepancy between the NOAA bathymetry and the actual field sheet soundings. We have also noticed significant differences between the shoreline interpolated from the NOAA data and the actual shoreline location. That has led us to question the accuracy of the NOAA data set in some locations. The interpolated shoreline position within this Study Area looks reasonable so there is no specific indication of a problem here, but it should be confirmed before it is used in any critical analyses.

There is also a significant amount of bathymetric data available from CHS. Digital field sheets are available at different resolutions throughout the Study Area. In some locations the resolution is finer than the resolution available from the NOAA data set. Table 2.2 summarizes the bathymetric data within the Study Area available from the Canadian Hydrographic Service.

Table 2.2: CHS Bathymetric Data

Field Sheet / File Number	Title	Surveyed
8305	Bronte to Port Credit	1986
8306	Lakeview to Mimico	1986
8222	Port Credit Harbour	1984
8223	Credit River	1984
8224	Approaches to Port Credit	1984
8338	Approaches to Petro Canada Refinery Wharf and St. Lawrence Cement Wharf	1987
8282	St. Lawrence Cement Company Wharf	1987
8337	Petro Canada and St. Lawrence Piers	1987
4003190	St. Lawrence Cement Company Wharf	1991
1200132	Petro Canada Refinery Wharf	1995
4012388	Petro Canada and St. Lawrence Piers	2008

2.7 Nearshore Currents

Nearshore currents play a significant role in coastal processes due to their capacity to transport littoral sediments and suspended and dissolved substances. Within a study such as the LOISS the analysis of dissolved and suspended sediments is usually treated as a water quality issue and the transportation of littoral sediments is treated as a coastal process. There is some overlap in dealing with the transportation of suspended sediments such as fine sand, silt and clay. The greatest proportion of sediment transport results from nearshore currents induced by breaking waves but non-wave-generated currents are important to water quality modeling and the transport of fine grained sediments.

A brief overview of the non-wave induced currents on Lake Ontario is presented in the Lake Ontario Collaborative Intake Protection Zone Studies (Stantec, 2008):

> "*The primary factors affecting lakewide circulation patterns are hydraulic currents, wind, and gradients resulting from temperature differences. In Lake Ontario, the hydraulic currents are created by the inflows from Lake Erie (via the Niagara River) and the outflow through the St. Lawrence River.*
>
> *The currents in Lake Ontario vary seasonally. During the winter and early spring, the temperature in the lake is more or less constant, and less than 4 degrees C. This is the temperature of maximum density. The circulation patterns in Lake Ontario are primarily*

driven by wind stress and heat flux at the surface creating a density driven current. In the spring, convective mixing due to heating of the water surface increases the temperature in the lake causing density driven currents near shore; a thermal bar separates the warmer water nearshore from the deep section of the lake that still experiences convection and temperatures less than 4 degrees C, preventing cross-shore circulation. This, combined with the Coriolis force, generates a counter-clockwise circulation pattern throughout the lake.

In summer and fall, the lake becomes stratified with warmer temperatures at the surface and colder water temperatures near the lakebed; a well-developed thermocline reduces the ability for vertical mixing but allows for more cross shore exchange. Prevailing westerly winds cause downwelling along the south shore and upwelling on the north shore where dense cooler water moves to the surface and replaces the warmer surface water.

Pal et al. (1998) analysed data collected from six satellite tracked drifter buoys deployed in western Lake Ontario between 1983 and 1985. The results from the analysis suggested that seasonal and spatial variability in current patterns could have a strong impact on the fate and transport of contaminants. During the spring, contaminants would likely remain near shore due to the thermal bar, and be driven by alongshore currents, while the transport of contaminants offshore is more likely to occur in the summer and fall when stratification has developed throughout the lake.

Beletsky et al. (1999) noted in a study of long-term lake circulation that the annual circulation patterns in 1972-73 resembled a two-gyre pattern consisting of a lakewide large cyclonic (counterclockwise) gyre with a smaller anti-cyclonic (clockwise) gyre in western Lake Ontario. The clockwise circulation pattern was more pronounced in the winter season extending further to the east. The stronger winter patterns were consistent with their findings for all of the Great Lakes.

……

Beletsky, Dmitry, Saylor, James H., Schwab, David J., Mean Circulation in the Great Lakes, Journal of Great Lakes Research, 25(1):78-93. 1999

Pal Badal K., Murthy Raj, Thomson Richard E., Lagrangian Measurements in Lake Ontario, International Association of Great Lakes Research, 24(3):681-697. 1998

To place the above into context we note that Beletsky et al. (1999) (referenced above) reported minimum, maximum and average mean current speeds on Lake Ontario during the summer as 0.1, 2.5, and 1.0 cm/s, respectively. The winter values were 0.4, 9.5, 2.8 cm/s, respectively.

Wave induced mean alongshore currents can exceed 100cm/s from moderate storm events. For most coastal processes studies wave induced nearshore currents are much more relevant than the ambient currents.

A number of field investigations have been carried out on Lake Ontario to collect data as part of investigations into the circulation patterns on the Lake. One such study conducted by the National Water Research Institute (NWRI) of Environment Canada collected temperature and current data from April to October, 2002, at sites offshore of Clarkson. That data could be used in the calibration or verification of nearshore circulation models but should not be expected to provide specific insight into the wave-induced currents.

2.8 Sediment Transport

Assessing littoral sediment transport rates is typically a significant component of a coastal processes analysis but that is not necessarily the case for this study. The shoreline from Burlington to Toronto is generally referred to as a non-drift zone due to the lack of littoral sediments. On many shores of the Great Lakes, littoral sediment supply originates from erosion of shoreline bluffs and the nearshore lakebed. Within the LOISS Study Area the majority of the shoreline has been protected, essentially eliminating bluff erosion, and the nearshore lakebed is erosion resistant bedrock. Some sediment transport does take place because of nearshore bottom deposits, but there is no significant source of new littoral material. Some sediment is introduced via the watercourses that discharge into Lake Ontario, but that sediment is typically fine grained and tends to deposit in deeper water offshore of the nearshore zone. For example, Atria (1994) reports surficial sediment samples on the bed of the Credit River at the site of the Port Credit Marina with a median diameter in the order of 0.02 mm, with 85 to 90% of the sample finer than 0.1 mm. This material can be classified as very fine sand or silt, and either washload or sub-littoral drift, as discussed in Section 3.2.

In the discussion of wave conditions in Section 2.3 we referenced a Shoreplan project for a site on Watersedge Road. As part of that project we also investigated the average sediment transport characteristic at the site by modeling the potential sediment transport rates. Figure 2.10 shows typical results from the alongshore sediment transport modeling. The plots show positive, negative, net and gross transport rates. By definition, sediment transport rates are positive for sediment moving from left to right past the site (when facing offshore) and negative when moving from right to left. At this site sediment moving from north to south is therefore defined as positive transport and sediment moving from south to north is defined as negative transport. The gross transport rate is the sum of the positive and negative transport rates and the net transport rate is the difference between the positive and negative transport rates. The gross transport rate therefore represents the total amount of sediment that is moved past a stationary point, even if it is repeatedly moved back and forth by alternating north and south waves. The net transport rate may be viewed as representing what moves past that point as it enters then leaves the area of interest.

Net transport rates may be either negative or positive, depending on which direction dominates. For the results shown in Figure 2.10 the net transport rate is positive but relatively low when compared to the gross transport rate. This is because the positive and negative transport rates are nearly the same. If the beach contours were aligned slightly more northward then a negative net transport would be predicted. This means that cross-shore processes dominate along this section of shoreline, not alongshore processes.

The bottom plot in Figure 2.10 shows the cumulative distribution of the net and gross transport rates from the top plot in Figure 2.10. The bottom plot therefore shows the total potential transport rates at the site while the top plot shows how the transport is distributed in the cross-shore direction. These are results for a fine to medium sand with a median grain size of 0.2 mm. Different material sizes and gradations of material will produce different transport rates and distributions.

It must be noted that the transport rates shown in Figure 2.10 are potential transport rates and represent the volumes of sediment that could be moved by the available wave energy. Actual transport rates are dictated by the supply of nearshore sediments and the potential rates will not be realized if there is not a sufficient supply. The lack of substantial beach deposits along this section of shore shows that the actual transport rates are much lower than the potential transport rates. When sediment transport is supply limited actual transport rates must be determined using a sediment budget approach. A more detailed description of sediment budgets in presented in Section 3.2.

By examining Figure 2.6 and knowing that the net alongshore transport rate at the Watersedge Road site is close to zero it can be surmised that the net transport direction for the majority of the Study Area will be from northeast to southwest. The shoreline near the Watersedge Road site is generally oriented towards the east but most of the remaining shore within the study site is oriented in a more southeasterly direction. That change in orientation will lead to a net transport direction from northeast to southwest for any new littoral sediment introduced to the nearshore zone. As noted above, however, that supply is very low. That in turn means that the total sediment transport rate will be relatively low along the sections of shore with a net transport direction. Total transport rates will be higher on the section of shoreline with a low net transport rate as the littoral sediments are moved back and forth.

It was noted that the shoreline from Burlington to Toronto is generally referred to as a non-drift zone due to the lack of littoral sediments. That means there will be little sediment supply from the updrift and downdrift shorelines outside the CVC jurisdiction as those shores are also within the non-drift zone. There are significant obstructions to alongshore littoral drift near each of the CVC watershed limits including the breakwaters for the intakes to the old Lakeview Generating station to the east and the St. Lawrence Cement Company wharf to the west. The virtual lack of littoral sediment deposits adjacent to those structures confirms the very low littoral transport rates across the CVC jurisdiction boundaries.

It is important to note, however, that even a small amount of sediment moving along this "non-drift" shore can have significant long-term impacts on the function of outfalls, intakes, and other structures like launch ramps and harbour or marina entrances.

The relationship between sediment transport rates and shoreline erosion is complex and is dependent upon a number of factors including, but not limited to, the nearshore wave energy, the shoreline and nearshore physiography, water levels and shoreline protection. On a fully developed beach shoreline where potential transport rates are realized, both erosion and deposition can take place due to gradients in the transport rates. On supply limited shorelines, deposits tend to be transient and in response to the most recent storm activity. Tendencies towards erosion are higher because there is no beach to protect the shore, but a direct relationship between the available wave energy and the shoreline erosion rate cannot be established without consideration of the other factors.

2.9 Shoreline Protection

The majority of the shoreline within the LOISS Study Area has been protected with either formal or informal shoreline protection structures. Some sections of shoreline that have not been intentionally protected appear to be experiencing reduced erosion rates due to the influence of adjacent structures. An example of this is the sand beach shoreline fronting the Lorne Park Estates, immediately adjacent to the northern most headland at Jack Darling Park Shoreplan.

As part of the CVC Lake Ontario Shoreline Hazards study (Shoreplan, 2005) defined a total of 87 shoreline reaches within the CVC watershed. Amongst other attributes, a general shoreline type and shoreline protection type were assigned to each reach. Tables 2.3 and 2.4 were developed from that data. The shoreline length values were determined from digital mapping provided by the City of Mississauga and exclude major structures such as piers and breakwaters but include the shoreline within the Port Credit marinas and Lakefront Promenade Park.

Table 2.3: General Shoreline Statistics

Shoreline Type	Length (m)	% of Total Length
all reaches	20,145	
artificial shoreline	9,003	45%
cohesive shore with protection structure	7,779	39%
cobble beach	1,454	7%
sand beach	834	4%
cohesive shore with protective beach or rubble	799	4%
unprotected cohesive bank or bluff	276	1%

Table 2.3: General Shoreline Protection Statistics

Shoreline Protection Type	Length (m)	% of Total Length
revetment	6,072	30%
wall	4,332	22%
beach	3,495	18%
wall and revetment	2,924	15%
rubble	1,417	7%
headland-beach (artificial)	904	4%
none	858	4%
rip-rap berm	143	< 1%

This information is derived from typical characteristics per reach from Shoreplan (2005). A more accurate accounting of the shoreline types and protection types could be obtained from a detailed inventory of the shoreline. Such an inventory could also document the existing condition and expected life span of the shoreline protection structures. Shoreplan (2009) prepared a detailed inventory of all town owned shoreline structures within the Town of Oakville. That inventory included an assessment and scoring system that considered 10 structural and 4 safety related criteria within the assessment scores. A comprehensive Microsoft Access database was produced as part of that assignment. A similar approach could be adopted for the shoreline structures within the CVC watershed although the implications of having a public agency assess the condition of privately owned structures would have to be carefully considered.

The expected life-span of a shoreline protection structure is dependent upon a number of conditions including the structure's material condition and quality, the construction quality, the controlling substrate where the structure is located, and how well the structure is maintained. For a properly designed, constructed and maintained structure the actual type of structure is of secondary importance for the life and risk of failure of that structure.

Maintenance of any structural protection is a fundamental requirement if that structure is to have a significant design life. Even structures designed to withstand 1:100 year design conditions will not last anywhere close to 100 years if they are not maintained. The life expectancy of a typical structure can only be generalized because of the specific nature of the need for maintenance.

The controlling substrate on a shoreline is defined as the dominant underlying material which makes up the lakebed near the shoreline. It plays a key role in the long-term large-scale evolution of the shore and is arguably the most important factor influencing physical processes at the land/water interface. On a non-beach shoreline the strength of the controlling substrate is directly related to the rate of downcutting of the nearshore profile. It is the rate of nearshore downcutting that ultimately determines the life span of many protection structures on the Great Lakes. When the downcutting rate is high, such as occurs on soft till or clay shorelines, the life of seawalls and revetments is relatively short as the structure foundations are ultimately undermined. Long structure lives are common on erosion resistant bedrock shorelines, as those lifecycles are limited by the material and construction quality of the structure, not its foundation.

Material quality can limit the life of a structure in different ways. Steel sheet piling will weaken over time due to both rusting and abrasion. The impact of those effects can be lessened by selecting a thicker pile than required to withstand the design forces at the time of construction. Similarly, weak stone that is susceptible to fracturing due to wave loading and/or freezing and thawing can limit the life span of an amour wall or revetment. Careful selection of the construction material can significantly reduce the potential long-term maintenance needs for armour stone structures.

2.10 Natural Shoreline

There are few significant lengths of natural shoreline within the LOISS study limits. In Table 2.3 it was shown that approximately 1% of the Study Area shoreline is unprotected cohesive bank or bluff, 4% is sand beach and 7% is cobble beach. Of the sand beaches (Cooksville Creek fillet beach, Richard's Memorial Park, Lorne Park Estates and Jack Darling Park) on the Lorne Park Estates beach is natural, the others all require the presence of nearby structures. The cobble beaches at Rattray Marsh, the Petro Canada property and the old Ontario Hydro property are all natural. The cobble beach at Lakeside Park is artificial due to the amount of clay pipe material in the beach. It is likely that significantly more of the shoreline was natural cobble beach prior to the stonehooking that took place from the 1830's until about 1920.

If steps are taken to naturalize the shoreline then careful consideration must be given to both the type of natural shoreline desired and the method used to achieve it. Simply removing protection structures would likely lead to a naturally eroding cohesive bank. Replicating the natural protection provided by a sand or cobble beach is possible but will probably require some retaining structures to keep the beaches in place. Beach fill would be required to achieve the desired shoreline conditions in a reasonable time; allowing the beaches to form naturally would not be practical. These would therefore be different types of artificial shores, but they would more closely represent the natural shore prior to anthropogenic alteration. Detailed study and design would be required to ensure that either the naturalized shore was stable or that the expected erosion rates were accurately quantified.

3 DESCRIPTIVE MODEL OF COASTAL PROCESSES

3.1 Shoreline Reaches

The Lake Ontario shoreline within the CVC watershed is located mainly in the City of Mississauga and has a total length in the order of 13 kilometers. For this study the shoreline was divided into 7 reaches based on littoral transport characteristics. Reach limits were defined where there were either total or near total barriers to the alongshore transport of littoral sediments. Most reaches were further divided into sub-reaches based on shoreline characteristics. Separate sub-reaches were established to differentiate between protected and unprotected sections of shoreline and between publically and privately owned shoreline. The protection and ownership designations were adopted from the CVC Lake Ontario Shoreline Hazards study (Shoreplan, 2005). Within the 7 shoreline reaches a total of 46 sub-reaches were defined. Figure 3.1 shows the location of the 7 reaches and 46 sub-reaches.

Whether or not the 46 sub-reaches provide a sufficiently detailed division of the shoreline within the CVC watershed will ultimately depend upon the Shoreline Characterization phase of the LOISS. A distinction was made between publically and privately owned shoreline because it was assumed that CVC would have to apply different processes or procedures to implement the long-term goals of the LOISS on public and private lands. A distinction was made between protected and unprotected shoreline as it is reasonable to initially assume that there will be no supply of littoral sediments from the erosion of the protected shores. That assumption can be re-examined during the Shoreline Characterization if the quality and longevity of individual protection structures is considered. The shoreline reach attributes, described in Section 3.3, include a protection effectiveness factor to facilitate desired changes.

3.2 Descriptive Model Framework

A framework for a descriptive model of coastal processes within the Study Area was established by emulating the setup for a coastal sediment budget. Sediment budgets are frequently used to estimate littoral sediment transport rates when the littoral transport is supply limited. This occurs when the supply of sediment to the nearshore zone is less than that which could be transported by the available wave energy. When this is the case, alongshore transport rates are estimated through a sediment budget, which is an accounting of the sediment sources and sinks within the nearshore zone.

For a sediment budget the shoreline is divided into a number of segments or reaches and the sediment sources and sinks of each segment are determined. Sources typically include bluff or bank erosion, nearshore bottom erosion, gullying (if present) and watercourse supply of inland soils. Sinks include the offshore losses of fine material, the comminution (breaking-apart) of soft sand grains, which are also lost offshore, and the increase in volume of nearshore sediment deposits. A decrease in nearshore sediment deposit volume would be a source. The volumetric difference between these sources and sinks is assumed to be transported alongshore. The net alongshore sediment transport rate at any point is found by summing the alongshore transport rates from all shoreline segments updrift of that point. Figure 3.2 shows the sources, sinks and inferred transport rates for a typical shoreline segment.

If sufficient data exists the total sediment supply can be subdivided by grain size because the behaviour of nearshore sediments is governed by its size. For example, Figure 3.3 shows the sediment size classifications used in a detailed sediment budget calculated for the north-central shore of Lake Erie by Philpott (1983). The sediment classifications used in that study are also applicable for the LOISS study. The Philpott (1983) sediment budget grouped all grain sizes of sediment entering the nearshore zone into one of four size categories; shingle, littoral drift, sub-littoral drift, and washload. The grain size categories were determined on the basis of the behaviour of that size of material once it enters the nearshore zone. The grain sizes defining the category limits were based on the logarithmic Phi scale where $\Phi=-\log2(d)$ and d is the sediment diameter in millimeters. The relationship between Phi sizes and other commonly used grain size distributions is also shown in Figure 3.3.

Shingle ($\Phi<-1$) consists of cobble, gravel and pebble which, under most conditions, remain close to the toe of the bluff or to the face of a beach.

Littoral drift ($-1 < \Phi < 2$) consists of coarse to medium sand which generally remains within or close to the normal breaker zone. This is the main beach building material for the beaches found on the Great Lakes. Philpott (1983) estimated that approximately 10% of the littoral drift material on Lake Erie is lost through comminution of soft grains which are then transported offshore to deep water.

Sub-littoral drift ($2 < \Phi < 4$) consists of fine and very fine sand which is transported beyond the normal breaker zone. It tends to be deposited during periods of high lake level and transported alongshore at lower lake levels. This material may contribute to, but does not alone form, beaches. It can form a significant proportion of the nearshore sediment deposits noted in the sediment budget (term S in Figure 3.2).

Washload ($\Phi > 4$) consists of silt and clay particles which are too fine to remain permanently in the nearshore zone and are eventually lost to deep water at the Lake centre. This fraction typically forms 80-95% of the total volume of unconsolidated lake sediment and may be ignored in a littoral sediment budget (Philpott, 1983a). During their sediment budget for the Eastern Beaches in Toronto Atria (1993) assumed that sediments with a grain size less than 0.1mm (Φ = 3.3) could be excluded from the sediment budget.

3.3 Shoreline Reach Attributes

A Microsoft excel spreadsheet was setup to record the attributes of each reach within the descriptive model. At this stage the spreadsheet is considered to be a work in progress because all of the attributes that might eventually be required have not yet been identified. It is anticipated that more attributes will be identified during the shoreline characterization phase of the LOISS as the critical coastal processes are identified.

Table 3.1 presents a list and description of the reach attributes that have been considered to date. The reach attribute list includes all of the elements required to construct a crude sediment budget as described in Section 3.2 but it is acknowledged that much of the sediment budget data does not exist (such as nearshore deposit volume changes) or must be approximated (such as the comminution loss %). It is anticipated that during the shoreline characterization phase of the LOISS decisions can be made about whether to collect that data or to exclude it from the sediment budget analysis.

It is also not uncommon for sediment budgets to divide the supply into different categories based on their grain size, as discussed in Section 3.2. The list of shoreline reach attributes could be modified to allow sediment size distinctions within the reaches where that is relevant. A possible scenario where this could occur is where contaminants have attached to sub-littoral sediments and the behaviour of the littoral and sub-littoral sediments must be tracked separately.

Table 3.1: Shoreline Reach Attributes

REACH ATTRIBUTE	DESCRIPTION
Reach	reach number
Location description	name of shoreline reach, property or nearby street
Reach length	Reach length in metres measured along the lakeward most contour line from the City of Mississauga 2002 digital mapping (taken from Shoreplan 2005)
Controlling substrate	estimated controlling substrate– the controlling substrate is the underlying material which makes up the main body of the lakebed and tends to control the long-term recession of the shoreline
General shore type	estimated shore type – general description of the shoreline includes protected and artificial shores
Surficial substrate	estimate of material that forms the surficial nearshore substrate
Ownership	estimated ownership
Protection status	estimate % of reach length that is protected
Protection effectiveness	estimated effectiveness of existing structures
Bluff height	estimated erodible bluff height for sediment supply volume
Nearshore depth of closure	depth to which erosion of the nearshore bottom profile occurs
Shoreline erosion rate	long term average annual recession rate used in sediment supply volume calculation
Nearshore downcutting rate	rate of vertical erosion of the nearshore bottom
Erosion supply volume	volume of sediment introduced through shoreline erosion calculated from recession rate, bluff height, protection status and protection effectiveness
Nearshore sediment supply rate	volume of sediment introduced through downcutting of the nearshore lakebed calculated from depth of closure and downcutting rate
Watershed supply rate	volume of fluvial sediment introduced to the nearshore zone
Offshore sediment loss rate	estimated % sediment lost to sinks
Comminution loss percentage	estimated % of littoral sediment lost to comminution of soft grains
Nearshore deposit volume change	changes in the volume of nearshore deposits like bypassing shoals
Net sediment transport direction	positive (left to right when facing offshore), negative or neutral

4 DATA GAP CONCLUSIONS

At this stage what does or does not constitute a gap in the required data is somewhat speculative due to the nature of the coastal processes at this site. There is sufficient wind and water level data available to allow long-term simulations of nearshore wave and sediment transport conditions. It is reasonable to assume that nearshore wave conditions will need to be generated for any location subject to further analysis as those analyses tend to be site specific, but within the context of this report we cannot speculate where such analyses may be required.

If sub-littoral sediment movement needs to be modeled then that will have to be done with a nearshore circulation model. The extent to which wave-driven currents and/or general lake hydrodynamics affect the critical circulation patterns will define both the physical extent of the area to be modeled and the type of model that is required. Again, that assessment is expected to be part of the shoreline characterization of the LOISS.

Nearshore sediment samples will be required for any thorough assessment of nearshore sediment transport rates. Samples should be collected for the area of interest as well as updrift and downdrift of the site. Sediment sampling is typically carried out as part of the sediment transport analysis so, although a data gap exists here, it need not be resolved until any actual modeling is planned.

Section 3 presents the initial outline of a coastal processes descriptive model that is based on a sediment budget approach. Not all of the reach attribute data listed in Table 3.1 currently exists so that could be viewed as a data gap. There is a benefit to establishing erosion monitoring stations now, as described below, but it is our opinion that clarification of what other data needs to be collected will be found during the shoreline characterization phase of the LOISS.

The most significant data gap related to coastal processes within the CVC watershed is the lack of shoreline recession rate data. Due to the nature of the unprotected shoreline within the Study Area and the relatively low recession rates, recession rate data is best determined through surveyed profiles. Erosion monitoring stations were established in 1971 and 1972 as part of the Canada/Ontario Shore Damage Survey, but the re-surveying of those profiles was terminated some time ago. New erosion monitoring stations should be established at selected sites on publically owned shoreline within the Study Area. The frequency with which the profiles should be re-surveyed will depend upon the physical characteristics of the site. Dynamic shorelines such as the Rattray barrier beach should be surveyed twice a year for a few years to determine what sort of annual profile shifts take place. Profiles on cohesive shores should be surveyed annually for a few years then less frequently is little erosion is taking place.

A data gap also exists for the exact extent and existing condition of shoreline protection structures within the LOISS Study Area. An inventory and assessment of publically owned shoreline structures could be carried out using the approach recently employed at Oakville (Shoreplan, 2009). Ranking the condition of those structures could help develop priorities for the potential decommissioning of the hardened shoreline. Privately owned shoreline protection structures could also be assessed but the implications of having a public agency assess the condition of privately owned structures would have to be carefully considered.

Recommended actions and timelines to address the data gaps in water quality have been considered and are summarized in Tables 4.1 and 4.2. The items in Table 4.1 are actions that we recommend be carried out to fill the data gaps. The items in Table 4.2 show the actions that will be required if other disciplines show a need to fill those data gaps or if future development plans may alter the nearshore regime.

Table 4.1: Coastal Processes Data Gaps – Recommended Actions

Data Gap	Recommended Action	Time Frame	Estimated Cost
shoreline recession rates	establish new erosion monitoring stations and initial surveys	2010 - 2011	$30,000
	future monitoring	2012 +	$15,000 per year with surveys
Condition and extent of shoreline protection structures	inventory and assessment of publically owned structures	2010	$60,000

Table 4.2: Coastal Processes Data Gaps – Potential Actions

Data Gap	Recommended Action	Estimated Cost
Effects of waves on nearshore currents at a specific location	Local bathymetric survey, if required	$10,000
	Numerical modeling of key storm events	$50,000
Influence of proposed shoreline modifications on littoral sediment regime	Local bathymetric survey, if required	$10,000
	Nearshore bottom sediment sampling and analysis	$10,000
	Profile based modeling of average annual transport conditions	$30,000
Influence of proposed shoreline modifications on sub-littoral sediment regime	Local bathymetric survey, if required	$10,000
	Nearshore bottom sediment sampling and analysis	$10,000
	Sediment sampling and circulation driven 2-D modeling on selected storm events	$60,000
Condition and extent of shoreline protection structures	inventory and possible assessment of privately owned structures	TBD

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Stantec Consulting Ltd., 2008. Lake Ontario Collaborative Intake Protection Zone Studies Volume 2: Peel Water Supply System. Final Report, January 2008. Appendix 3.1. Preliminary In-lake Intake Protection Zone Delineation Region of Peel, City of Toronto and Durham Region. prepared by W.F. Baird & Associates Coastal Engineers Ltd. Unpublished report prepared for the Region of Peel.

Figures

Figure 2.1 Lake Ontario Hydrograph

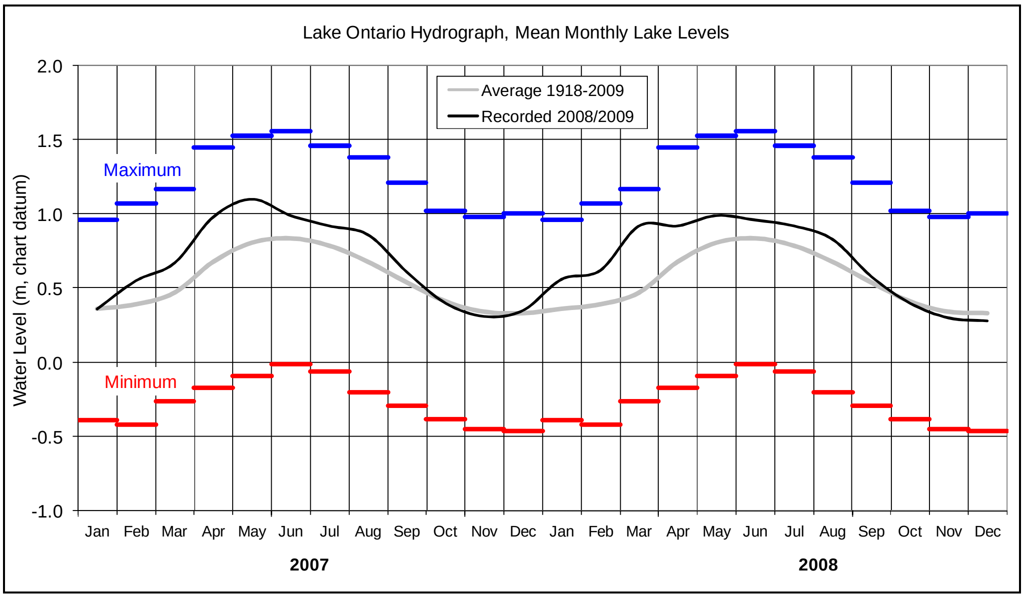


Figure 2.2 Lake Ontario Mean Water Levels, 1918 – 2009. Arrow represents start of water level regulation in 1960.

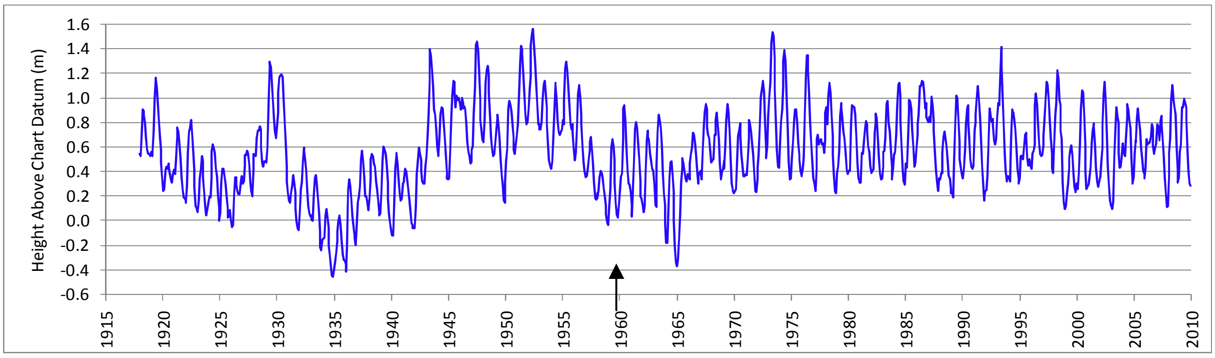


Figure 2.3 Offshore Wave Data Sites

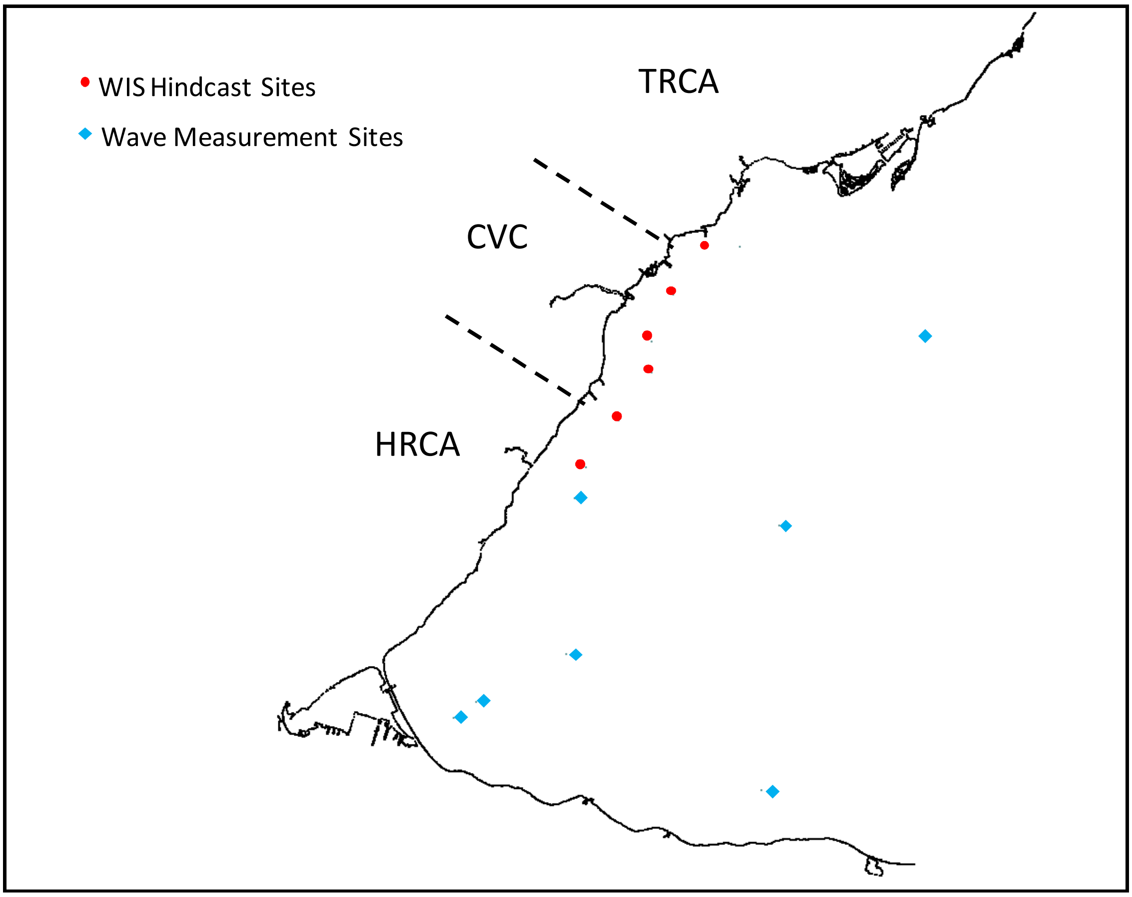


Figure 2.4 Deep-Water Wave Height and Wave Energy Distributions

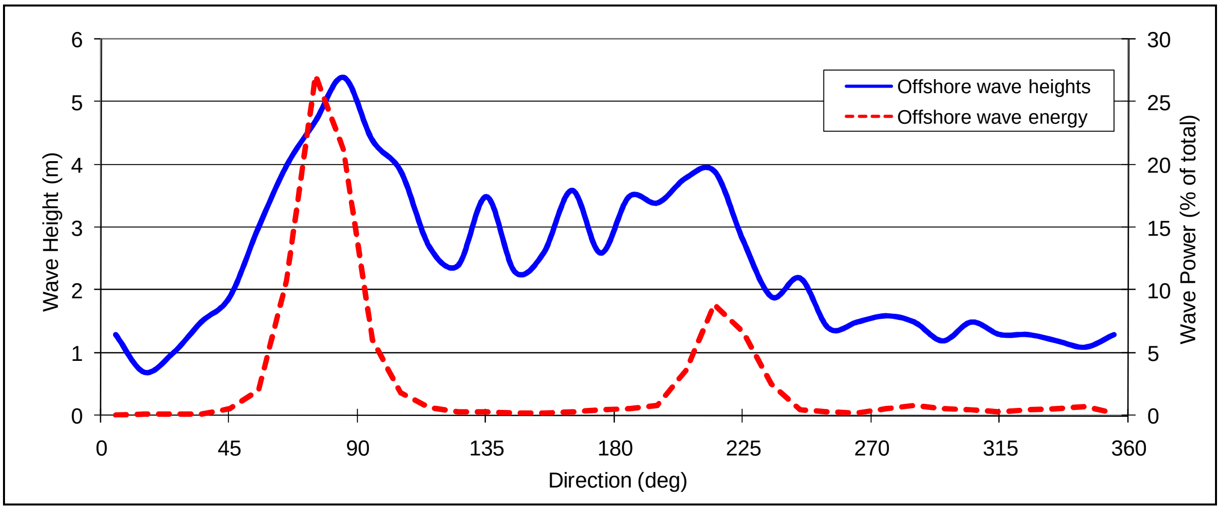


Figure 2.5 Wave Height and Period Exceedance Diagrams

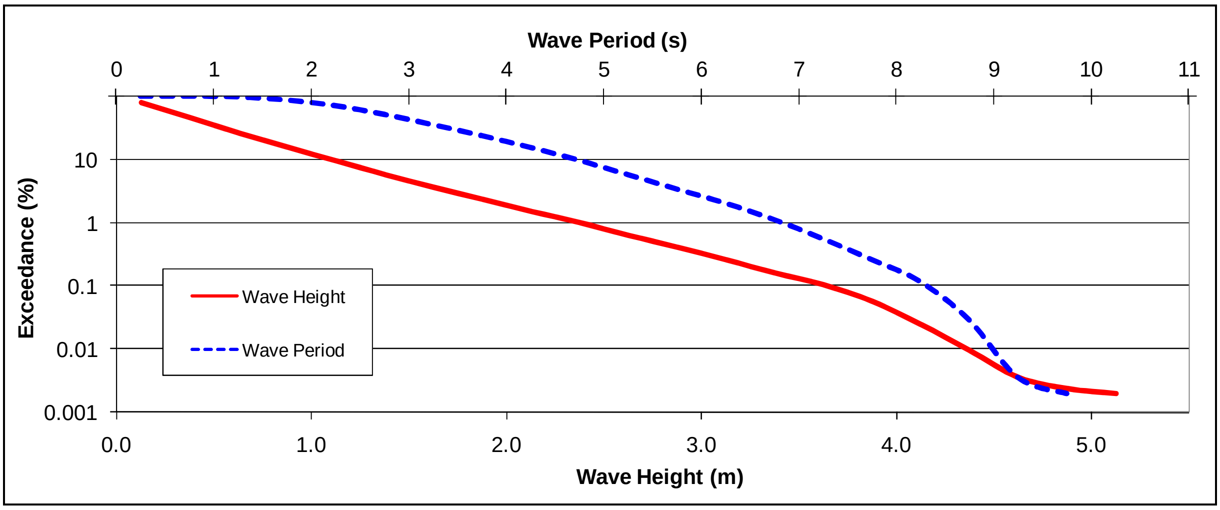


Figure 2.6 Bathymetry Considered in Wave Transformation Model

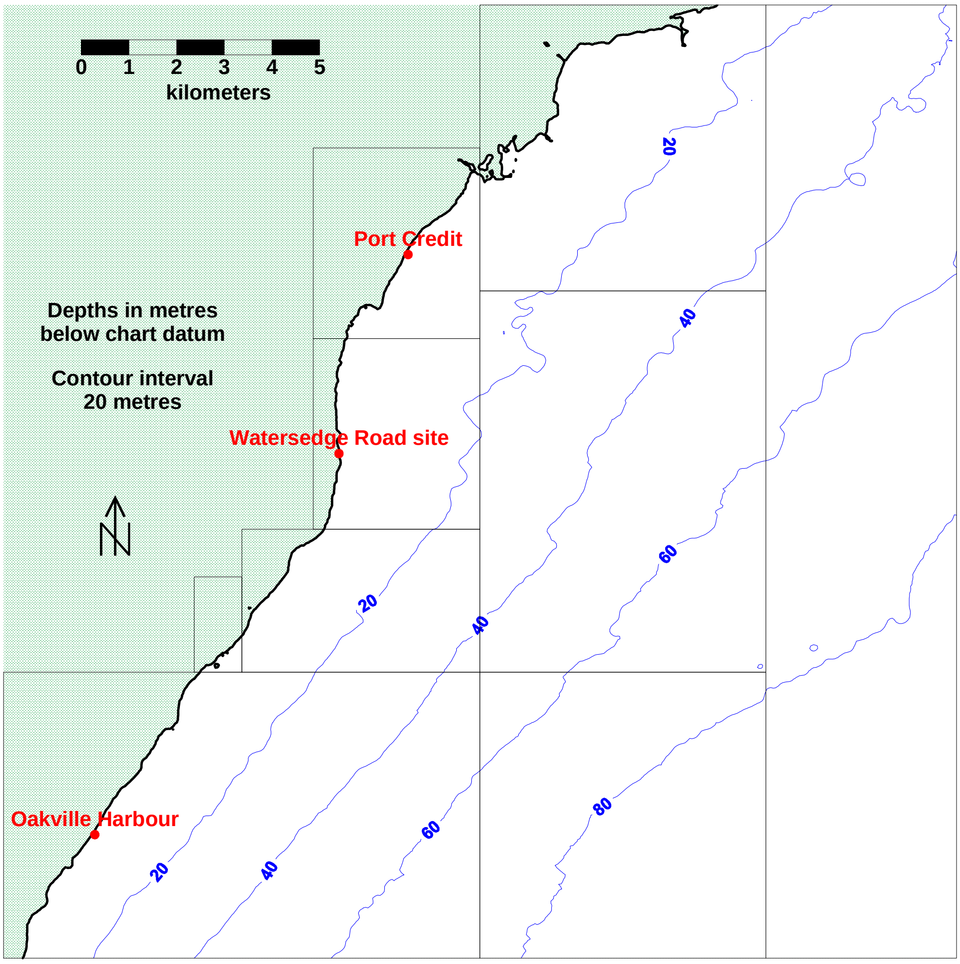


Figure 2.7 Nearshore Wave Height and Wave Energy Distributions

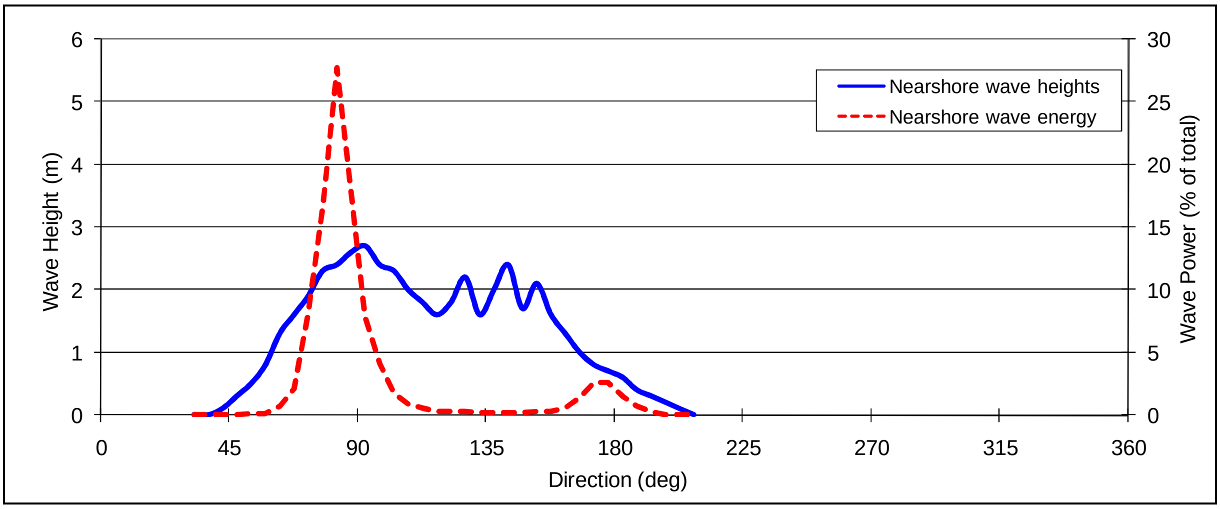


Figure 2.8 Nearshore Sediment Data Locations

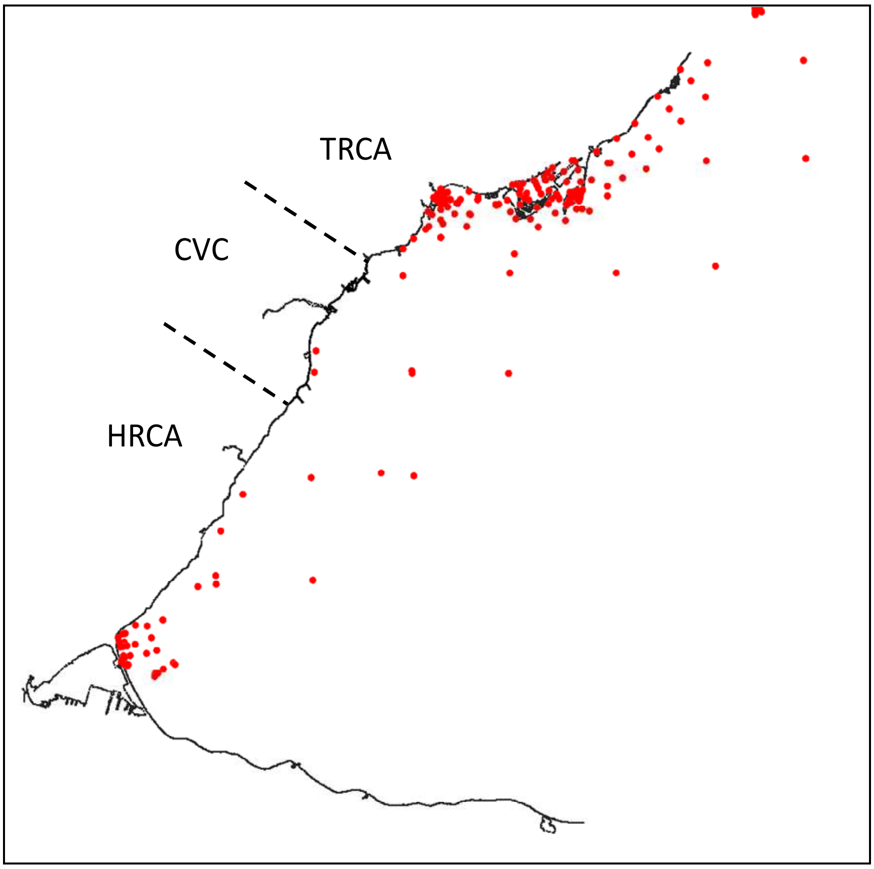


Figure 2.9 Nearshore Bathymetry

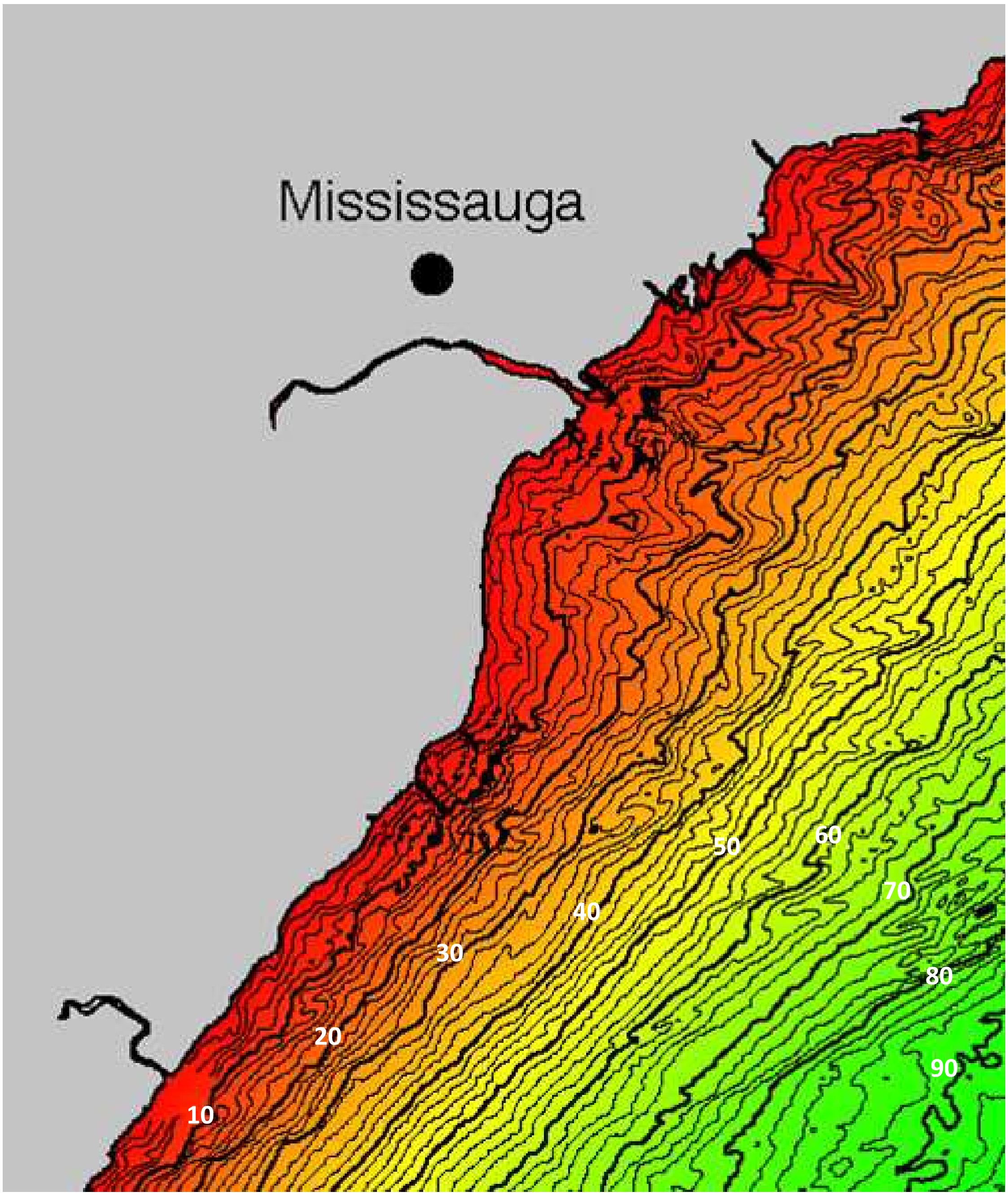


Figure 2.10 Potential Alongshore Sediment Transport Rates

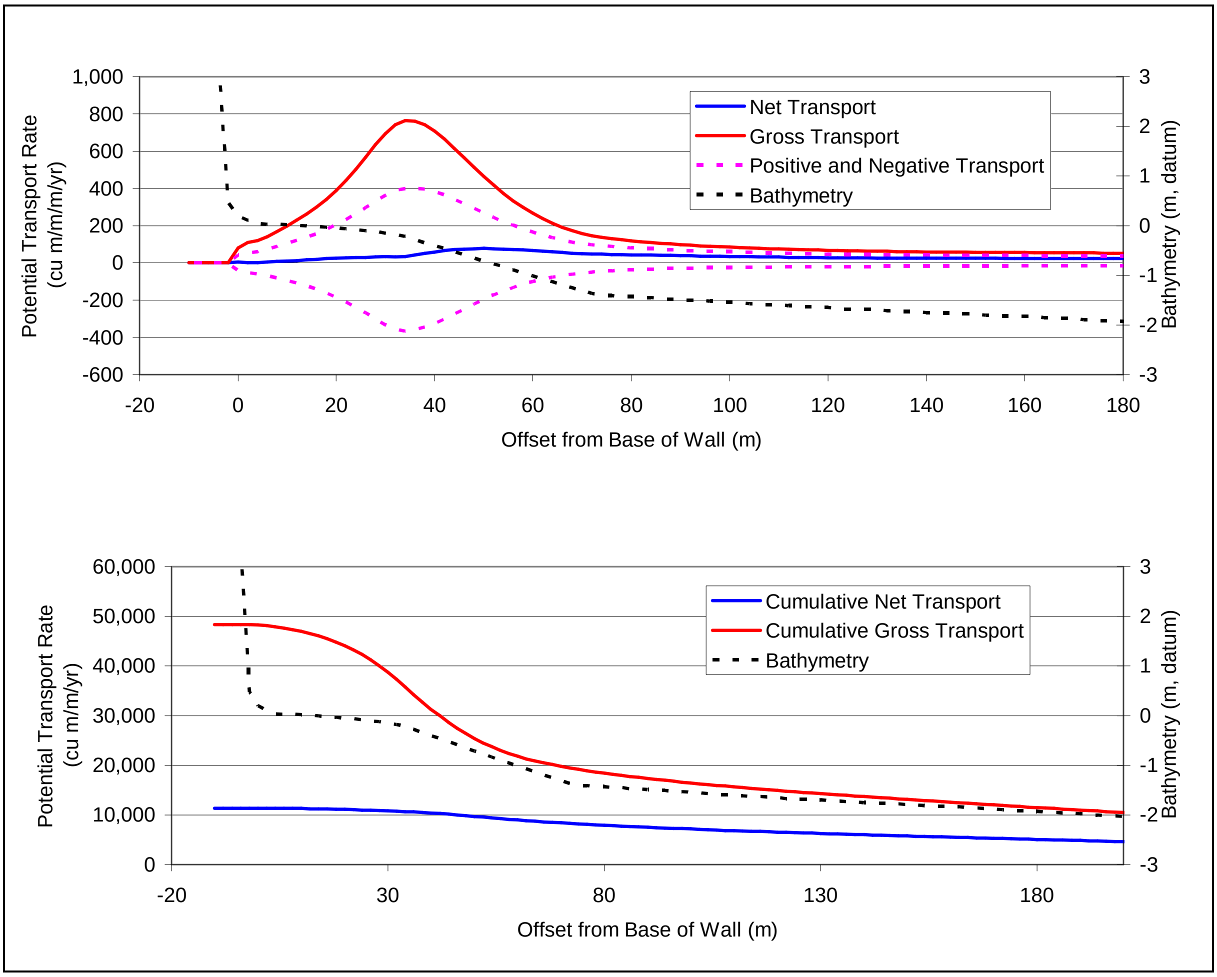


Figure 3.1 Shoreline Reaches and Sub-Reaches

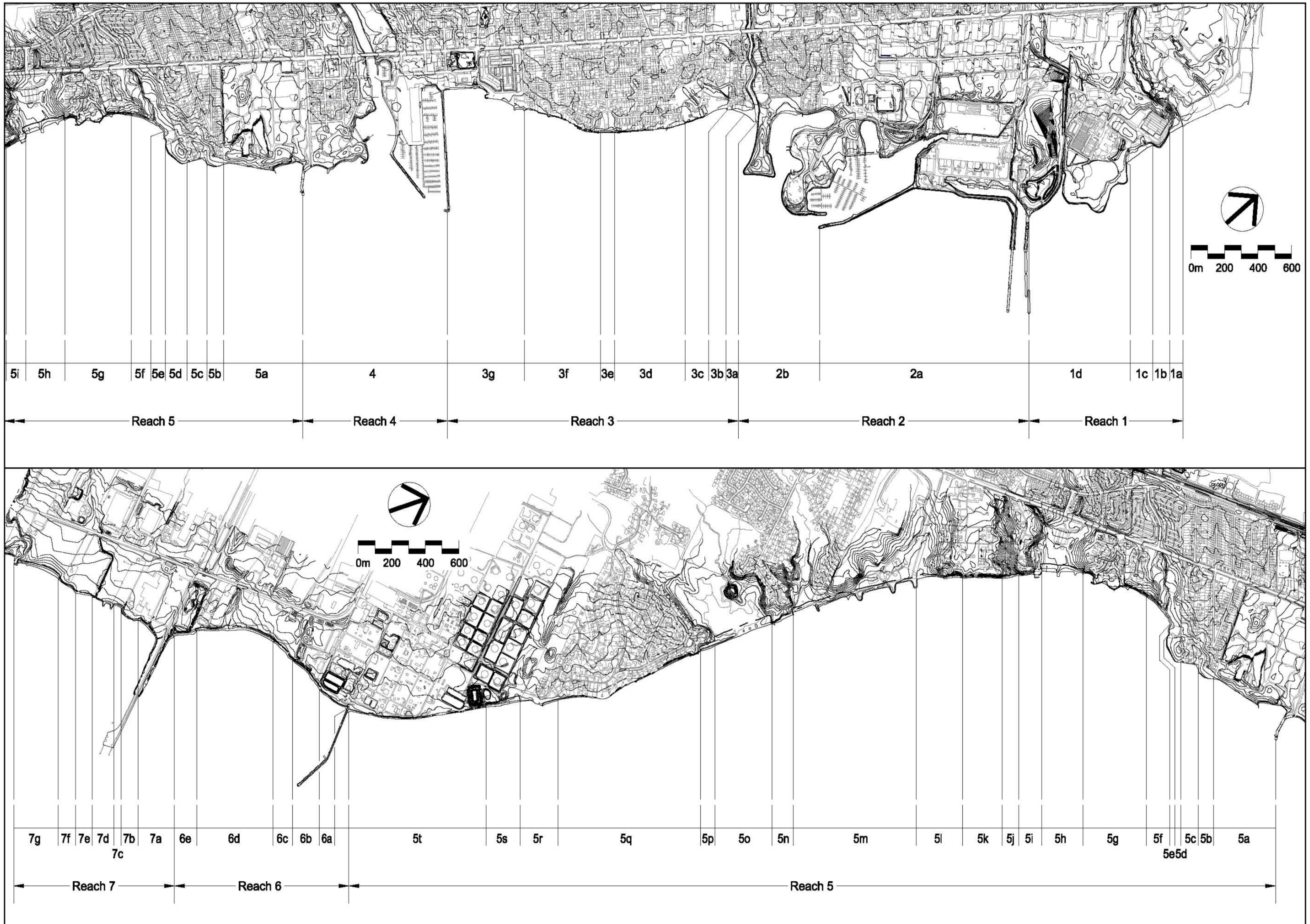
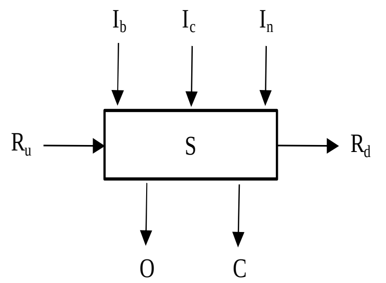


Figure 3.2 Typical Sediment Budget Cell



$$Rd = I_b + I_c + I_n - S - O - C$$

$$R_N = -R_u + R_d$$

Where:

I_b = input from bluff erosion
I_c = input from creeks and rivers
I_n = input from nearshore bottom erosion

O = offshore losses
C = comminution of soft grains (also lost offshore)
S = gain in nearshore deposit (negative for loss)

R_u = sediment transport rates from updrift segments
R_d = sediment transport rate to downdrift segment
R_N = net alongshore sediment transport rate

Figure 3.3 Sediment Size Classifications

	from U.S. Army (1977)				
from Philpott (1983a)	Wentworth Scale (Size Description)	Phi Units ϕ *	Grain Diameter, D (mm)	U.S. Std. Sieve Size	Unified Soil Classification (USC)
	Boulder				
		-8	256		Cobble
Shingle	Cobble		76.2	3"	
		-6	64.0		Coarse Gravel
	Pebble		19.0	3/4"	Fine Gravel
			4.76	No. 4	Coarse Sand
	Granule	-2	4.0		
		-1	2.0	No. 10	Medium Sand
Littoral Drift	Sand – Very Coarse	0	1.0		
	Sand – Coarse	1	0.5		
	Sand – Medium		0.42	No. 40	Fine Sand
		2	0.25		
	Sand – Fine	3	0.125		
Sub-littoral Drift	Sand – Very Fine		0.074	No. 200	Silt or Clay
		4	0.0625		
Washload	Silt	8	0.00391		
	Clay	12	0.00024		
	Colloid				

* $\phi = -\log_2 D$ (mm)