Atlantic Climate Adaptation Solutions Association
Solutions d'adaptation aux changements climatiques pour l'Atlantique

Geomorphic Shoreline Classification of Prince Edward Island

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Coldwater Consulting Ltd.

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This report is also available for download from the ACASA website at: www.atlanticadaptation.ca

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NOTE:
This report and the associated GIS files are a revision of the previous release dated November 2011. Changes from the previous version of this report include:

- Improved definition of the relationship between chart datum and geodetic datum
- Improved definition of extreme tidal level using a nearest neighbour interpolation algorithm
- Inclusion of nearshore tidal currents
- Inclusion of specific climate change scenarios as proposed by Richards & Daigle (2011)

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1. Introduction

This report summarizes work undertaken by Coldwater Consulting Ltd. (Coldwater) to develop shoreline classification and sensitivity mapping for the entire PEI shoreline. This report has been commissioned by the Atlantic Climate Adaptation Solutions Association (ACASA), a non-profit organization formed to coordinate project management and planning for climate change adaptation initiatives in Nova Scotia, New Brunswick, Prince Edward Island and Newfoundland and Labrador and supported through the Regional Adaptation Collaborative, a joint undertaking between the Atlantic provinces, Natural Resources Canada and regional municipalities and other partners. This work presented herein was administered by the Department of Environment, Energy and Forestry (DEEF) of the Province of Prince Edward Island,

This report documents the input data used in developing the shoreline classification, the procedures implemented to classify the shoreline and metocean conditions along the shore and the resulting sensitivity mapping. The results presented herein represent our best estimates based on available data. It is expected that the results of this analysis can be revisited and refined as improved input data becomes available. Automated shoreline delineation algorithms have been employed in the shore classification process making the re-visiting and re-analysis of this data a relatively simple and efficient task.

The GIS files resulting from this work have been provided to DEEF under separate cover. File descriptions and metadata are included in the Appendix of this report.

1.1. Shoreline Classification

Geomorphic shoreline classification involves the description (through both maps and databases) of the location and extent of different shoreline types. Resulting datasets are typically used by resource planners and managers to aid them in evaluating shoreline vulnerability and in delineating coastal hazards as well as for public consumption in improving general understanding of the coastal zone

The development of a shoreline classification system is a key step in being able to assess the effects of coastal hazards on the Island's shorelines. Coastal hazards include: coastal flooding, coastal erosion, and damage to coastal ecosystems. All of these hazards are influenced by the combined actions of sea level rise, tides, storm surge and wave action. To be able to interpret these processes, a clear inventory of the shoreline is required. A geomorphic shoreline classification dataset provides an inventory of the coast: its morphology, geology, ecology and infrastructure.

Two of the key challenges in designing and implementing a shoreline classification scheme are:

1. What scale to use (and is this scale fixed or variable), and
2. How to handle shorelines with multiple characteristics (e.g. an eroding bluff fronted by a sandy shoreline with short stretches of shore protection)

In the past, many schemes have adopted a finite spatial resolution of the shoreline (e.g. 1 km or 100 m long shoreline segments) and have characterized each shoreline segment based on the 'dominant' feature for that segment. In the present analysis we have conducted analysis at scales varying from 1 km to 20m depending on the resolution of the available input data. The resulting shore classification and exposure statistics (waves, water levels and tides) have been mapped onto the high resolution geomorphic shoreline developed in 2010 by Applied Geomatics and provided to us as an input for this analysis.

In using a shore classification dataset for resource management, for evaluation of coastal hazards, or for vulnerability assessments, it is exceedingly useful to have a regional context. In our opinion, the development of a shoreline classification database is just one step in the development of an integrated shoreline management system. The very nature of shorelines is that they are shaped (and re-shaped) by the interactions between land and water. Identification of regional-scale littoral cells and other process-related features is essential in providing a meaningful framework for interpretation of shoreline classification data. Owens (1980) provided an excellent framework for such analysis in his report on sand resources in southern and eastern PEI. Similarly, work by NRCAN (e.g. (Forbes D. , 1999), (Forbes D. P., 2004) (Forbes D. P., 2004)) provides descriptions of sediment processes and the geomorphology of many of the Island's coastlines. Previous investigation of coastal erosion and classification in Stratford, PEI (Geolittoral Consultants, 2010) also provides background for the present work. Prior analysis such as this, combined with our corporate experience on Island shorelines has been used to form a framework for the classification process. As will be shown in the following sections, the littoral compartments originally proposed by Forbes and Owens have been refined and validated through computation of the average annual net alongshore sediment transport and these compartments have been used to group the resulting assessment analysis.

1.2. Approach

Shoreline segments are based on the DEEF 2010 provincial shoreline vector. The proposed classification scheme described in the RFP uses a top-tier classification of exposed or sheltered coasts (selected on the basis of whether the shoreline faces the Gulf/Strait (exposed) or a bay, estuary, lagoon or behind a barrier island (sheltered). As will be shown in the following, we have implemented a somewhat different approach: The response of a shoreline to the winds, waves, tides, river flow and storm surge depends upon many factors. A barrier island may shelter a shoreline under most conditions but not, perhaps, under a severe storm surge. An estuarine shoreline may be sheltered from waves, but not from surge or tidal currents. Rather than group all shorelines on the basis of a somewhat arbitrary distinction between 'exposed' and 'sheltered' conditions, we have assessed shoreline exposure as a key, integral, defining parameter. Each shoreline segment is associated with several characteristics that quantify its exposure to the elements. Namely, the open water fetch to which it is exposed, the water depth near the base of the shoreline, the offshore wave height to which it is exposed, the tidal range at the site, and its exposure to storm surge. Data to quantify these processes has been extracted from regional hydrodynamic and oceanographic datasets at our disposal. This linkage between the geomorphic shore classification and the meteorological and oceanographic conditions to which it is exposed ('metocean conditions') creates a unique database capable of providing excellent insight into the response of the Island's coasts to varying offshore conditions. At the same time this creates a classification scheme that can readily be updated and refined as additional metocean or shoreline data becomes available.

While many of the Island's exposed shorelines appear to be quite sandy, many of them actually have a sandstone bedrock and cobble nearshore that controls shoreline morphology (CCAF A041 Project Team, 2001). Nearshore classification has been used to define the nearshore controlling substrate where possible.

The following steps have been undertaken in this analysis:

1. Kick-off meeting. In-person meeting in Charlottetown to review the study methodology, to discuss the classification scheme and to assemble the constituent input data sets (aerial imagery, shoreline files, topographic contours, etc.). (August 2011)
2. Design of shore classification scheme
3. Data assemblage – Using ArcGIS, a set of working geodatabases were established on the Coldwater server for the classification process.
4. Evaluation of metocean conditions (exposure levels) – using available wave, tide and storm surge data (including in-house operational models), we have characterized metocean conditions around the shore to guide definition of littoral cells and to provide the linkages between the shoreline classification data and the exposure levels. This analysis was undertaken at a relatively coarse scale with the ability to be further refined as resources become available.
5. Algorithms have been developed and applied to extract bluff height and characteristic shoreline geometry data from the available input datasets. These geometric measures were used to assist in preliminary delineation and characterization of individual reaches.
6. Regional-scale assessment – using available data, published literature on coastal geomorphology and coastal processes along Island shorelines, as well as the afore-mentioned metocean data, the entire Island shoreline has been divided into 17 characteristic littoral cells.
7. Selection of representative reaches for classification testing - a suitable set of reference reaches were established that encompass the range of shorelines typical to the Island (open sandy shores, exposed bedrock/till bluffs, spit/barrier systems, large estuaries, smaller tidal inlets, salt marshes). This includes sites where we have detailed site knowledge such as Souris, Basin Head, Savage Harbour, West Point, etc.
8. Trial classification – using the designed numeric classification scheme, classification were undertaken for each of the representative reaches using the available GIS input data.
9. Field verification – site visits to each of the reference reaches were made to 'ground-truth' the classifications and to verify the accuracy and practicality of the classifications.
10. Production phase – using the refined schema, classification was undertaken for the entire Island shoreline

11. QA/QC was undertaken on an ongoing basis to ensure the accuracy and consistency of the classification work.
12. Reporting prepared in the forms of GIS files, maps and a summary technical report. This report documents the data used, the shoreline classification system, the regional sediment framework and provides linkages to metocean forcing functions (updated as of March 2011).

The shoreline classification database and supporting files have been provided in electronic form as an ArcGIS file geodatabase. Shape files and summary excel tables have also be provided for ease of distribution. The PEI CSRS double stereographic projection has been used for all GIS output.

2. Datasets

The datasets assembled for this study are grouped as follows:

- Input Datasets
    - Background datasets – Data that provides context and general background information (bathymetry, shore features, etc.)
    - MetOcean datasets – Data that describes the tides, waves and water levels both offshore and at discrete locations along the shore
    - Physiographic datasets – Data describing the physiographic nature of the Island and its shores (Lidar, orthophotography, land classification data, etc.)
    - Shore protection datasets – Data describing shore protection including georeferenced photography and permitting records
- Derived Datasets
    - Visual classification data – Polygons describing shore features and shore protection
    - Geometric data – Intermediate shoreline data computed by data modeling of the input datasets
    - Exposure data – Summary descriptors of MetOcean conditions along the entire shoreline
    - Shoreline classification data – Descriptors of shore type and geometry along the entire shoreline and identification of littoral cells (shore units)

The following sections provide descriptions of each of these datasets.

2.1. 2010 Provincial Shoreline

This vector shoreline forms the basis for the present analysis. Derived from the 2010 2-m pixel orthophotographic mosaic of the island, this shoreline identifies the geomorphic shoreline around the entire island including all estuaries. The feature attributes for this line identify it as “HHW” indicating that it is the higher high water mark. This is erroneous however since this shoreline vector follows the ‘geomorphic shoreline’ - broadly defined as the landward limit of the influence of the action of waves and water levels. On low-lying coasts this is typically the vegetation line, while on cliffs it is the top of the cliff. As such, the land elevation associated with this feature ranges from a few metres above sea level to tens of metres. As noted in a review by Webster (2011), while there are several segments where this shoreline appears to be well landward of the true geomorphic shoreline. In spite of such errors, this is generally a well-defined and highly detailed dataset.

File format: ESRI Shapefile (vector)
Projection: PEI CSRS double stereographic NAD83
Filename: Coast_2010.shp

Figure 1 2010 Shoreline

The true shoreline is, in fact, not a single clearly defined line in the sand. It is the point at which the sea meets land and, as such, is a constantly moving target. While the 'geomorphic shoreline' is of great use in identifying the landward limit of the combined action of waves and water levels, other shoreline definitions might be more useful when studying the vulnerability to coastal hazards, such as flooding. For coastal hazard studies, it would be preferable to use a shoreline associated with a specific elevation. For example, a shoreline defined by the point at which the sea level at Higher High Water Large Tides (HHWLT[1]) intercepts the shore. Even simpler would be where the Mean Sea Level (MSL) intersects the shore. The disadvantage of using MSL is that it is at a relatively low elevation and is sometimes located quite far offshore of the active beach face (consider for example the beaches along the south shore near Argyle Shore Provincial Park, where there are wide tidal flats exposed when the tide is at MSL and lower). We recommend that in the future a HHWLT shoreline derived from the provincial LIDAR topographic dataset be used for coastal hazard assessments.

2.2. 2010 Orthophoto mosaic

This collection of raster images forms a seamless colour orthophotography layer for the entire island at 0.4 m pixel resolution. This dataset was the basis for the aforementioned 2010 shoreline and provides remarkable detail on shoreline and nearshore conditions. Composed of 214 separate tiles, each tile is 19,000 x 14,000 pixels (7.6 km x 5.6 km) with a file size of roughly 1 GB each.

File format; ESRI raster grids

[1] Used on navigation charts, HHWLT is the expected annual maximum tide level (not including the effects of wave setup or storm surge). It is computed from an 18.6 year long time series of the astronomical tides; the highest tide from each year of the record is selected and the average of those 19 tide levels is the HHWLT. Since tidal ranges vary spatially around the island, the HHWLT elevation also varies.

Projection PEI Double Stereographic NAD83 CSRS
Filename(s): MAP1.tif through MAP214.tif

Figure 2 Example of 2010 Orthophoto and shoreline at Crowbush GC (north shore)

2.3. 2007 LiDAR-derived DEM

This collection of raster images forms a seamless bare earth digital elevation model for the entire island at 1.5 m pixel resolution. This dataset originates from the 2007 LiDAR flights. The tile size and orientation match those of the 2010 Orthophotos with a file size of roughly 72 MB each.

File format; ESRI raster grids
Projection PEI Double Stereographic NAD83; Vertical Datum: CGVD28
Filename(s): DEM1.tif through DEM214.tif

2.4. Bathymetry

Two bathymetric datasets were examined for description of nearshore waters. The first is the General Bathymetric Chart of the Oceans (GEBCO) – an international compilation of bathymetric data largely gleaned from electronic navigation charts. Available at the website www.gebco.net, this dataset provides a grid of water depths at a spatial resolution of 30 arc-seconds (GEBCO_08 grid). As shown in Figure 3, this dataset provides very poor resolution of nearshore conditions along the north shore of the island – notably the barrier islands fronting Malpeque and Cascumpec Bays are missing from the dataset.

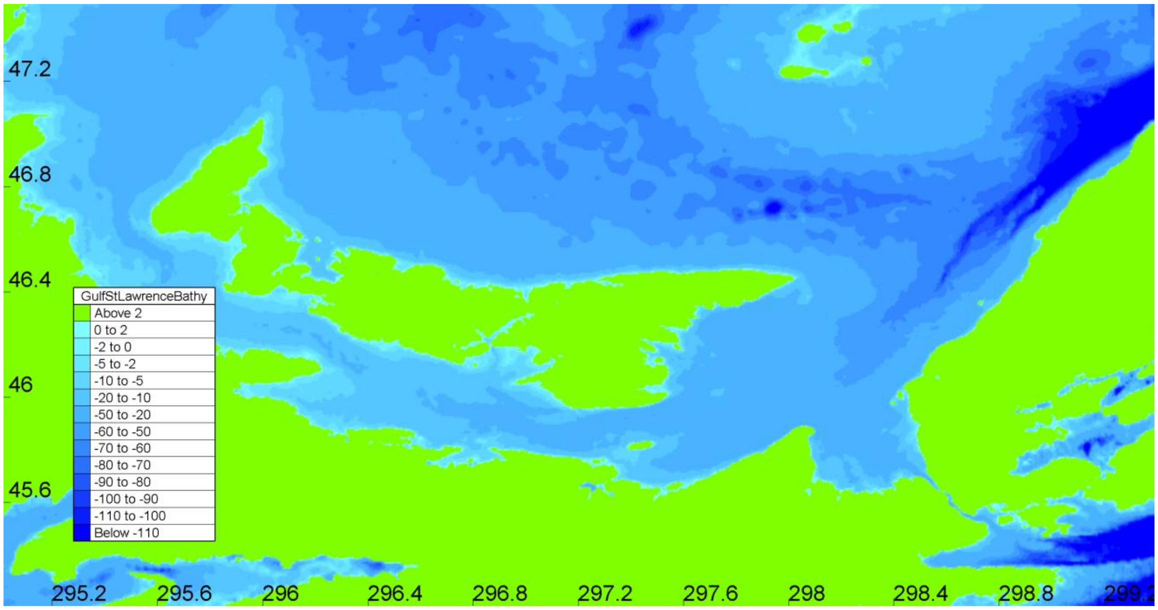


Figure 3 Bathymetry around PEI from GEBCO datast.

Published hydrographic charts from the Canadian Hydrographic Service were accessed to obtain a more realistic representation of nearshore conditions. The 6 m contour (depth relative to chart datum at Charlottetown) was digitized manually from the CHS charts covering Prince Edward Island. The relative proximity of this contour to the shoreline illustrates the relative sheltering of the shoreline (for example, along the south shore the 6m contour is significantly further offshore than along the north shore).

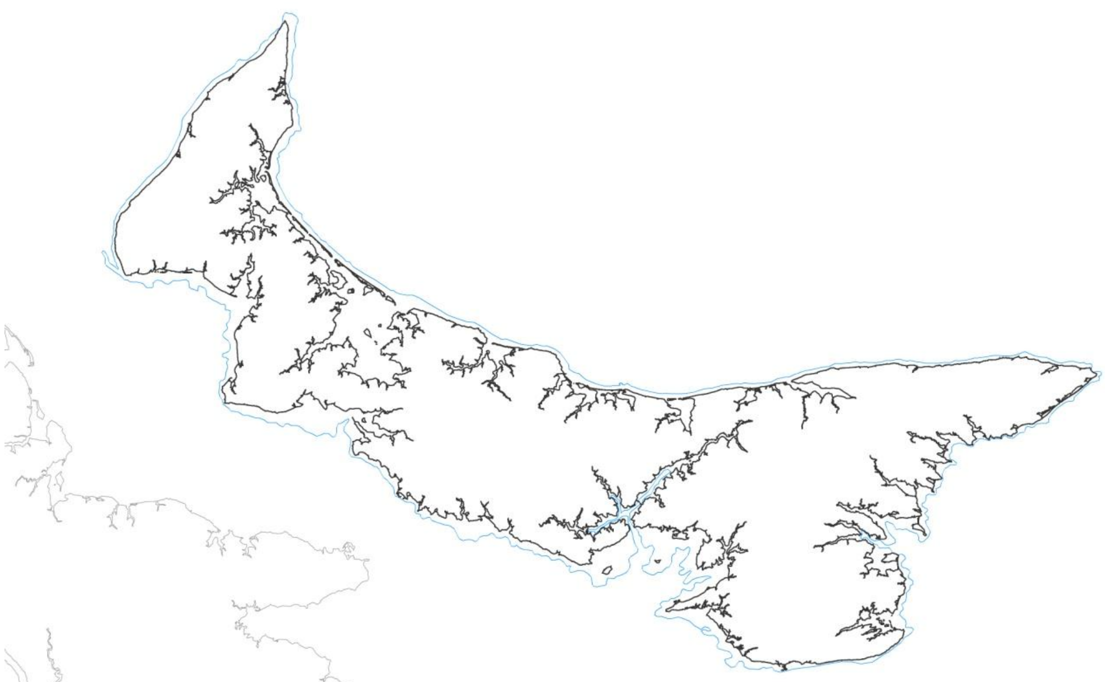


Figure 4 6m contour digitized from CHS charts

2.5. Vertical datums

The simplest common mathematical characterization of the earth is as an ellipsoid (technically an oblate spheroid – a surface of revolution obtained by spinning an ellipse about its short axis). Elevations can be expressed as the distance of a point relative to this ellipsoid. This reference system is widely used nowadays through the application of global positioning systems (GPS). All GPS systems measure location and elevation relative to an ellipsoid known as WGS84.

Mean sea level is a practical and intuitive vertical reference point for maritime regions. The concept of 'mean sea level' becomes challenging, however, when covering a continent the size of North America and when one considers variations of mean sea level over time. Mean sea level is not a horizontal surface but a three-dimensional surface varying with latitude and longitude. In effect, mean sea level is simply a representation of the effects of earth's gravity. The *geoid* is the name given to the complex, smooth but irregular surface that represents a gravitational equipotential equivalent to mean sea level. Nowadays, the geoid is accurately known through detailed mapping of the earth's gravitational potential.

Several vertical datums are widely used in North America:

CGVD28 is notionally, 'height above sea level' based on sea level in 1928. In Canada, land elevations are usually referred to Canadian Geodetic Vertical Datum 1928 (CGVD28) established by Geomatics Canada, Natural Resources Canada (NRCan). This geodetic datum was established as being equal to mean sea level during 1928 as measured at Halifax, Yarmouth, Pointe-au-Père, Vancouver and Prince Rupert. CGVD28 is not based on the geoid but is an imaginary sea level surface extended across the country using conventional levelling techniques.

IGLD85, the International Great Lakes Datum 1985, is a dynamic (geoid-based) vertical datum used to describe water levels in the Great Lakes. Zero for this datum is set to the mean sea level at Rimouski. At the same time that IGLD85 was established, the North American Vertical Datum 1988 (NAVD88) was also established.

NAVD88 is an orthometric vertical datum based on mean sea level at Rimouski, QC (5 km upstream of Pointe-au-Père). Elevations in NAVD88 are given in Helmert orthometric height units (a vertical distance). Notionally, this vertical datum is the same as IGLD85, the difference is that NAVD88 is established through a conventional (spirit-levelling) network while IGLD85 is geoid-based with elevations given in dynamic heights (the gravitational potential at a given location relative to a reference gravitational potential taken). NAVD88 is the standard vertical reference system in the U.S..

WGS84 is the vertical datum for measurements made using GPS equipment. Elevations are expressed as the vertical distance relative to the WGS84 ellipsoid.

Chart Datum (CD) is used mariners and hydrographers to define water depths and water levels. In Canada, Chart Datum is typically defined as Lower Low Water Large Tides (LLWLT) – the average annual lowest astronomical tide. Since tidal ranges vary spatially, Chart Datum varies from station to station around the island of PEI. Historically, there is little to no connection between chart datum and geodetic.

Ongoing Developments: NRCan is presently going through a modernisation process to create a new reference geodetic datum for Canada referred to as the "Height Modernisation System for Canada". This is an equipotential surface that coincides with the mean sea level at Rimouski as observed over the last 19 years. This will result in a new geodetic datum similar to NAVD88 and IGLD85 that will replace CGVD28.

Relating vertical measurements from one datum to another is a challenging task.

- Relationships between geodetic datum and the WGS84 ellipsoid are reasonable accurately defined in Canada. NRCan has developed the Canadian GPS Height Transformation Package (GPS-H) to facilitate the conversion between GPS-based ellipsoid heights (NAD83CSRS98) and geodetic orthometric heights (CGVD28).
- The relationship between chart datum and NAD83 or CGVD28 is not as clearly established. The Canadian Hydrographic Service maintains a network of water level gauges (tide gauges). The reference elevations for these gauges have traditionally been tied in to a series of CHS benchmarks that are not connected to the national geodetic network. Recently, the CHS has been using high resolution GPS survey techniques to establish the elevation of tidal stations relative to the NAD83 vertical datum. Conversion between the NAD83 ellipsoid and CGVD28 is obtained from the afore-mentioned GPS-H package
- The elevation of mean sea level above chart datum is provided by the Canadian Hydrographic Service (CHS) Tide and Water Levels Constituents database (www.meds.dfo-mpo.gc.ca/ISDM) as the variable Z_o.

Due to land subsidence and global sea level rise, mean sea level is a time-varying value. Although not commonly documented, when describing mean sea level one should properly reference the relevant timeframe, e.g. MSL_1928 would refer to mean sea level in 1928, while MSL_2000 would refer to mean sea level in 2000).

Using tidal station elevations in CGVD28 provided to us by CHS (P. MacAulay, pers.comm.) it was determined that while the GPS surveying of tidal stations is complete, there are significant discrepancies in the values of Z_o (the elevation of mean sea level above chart datum) presently available, Using the published Z_o values indicated that mean sea level is on average 5.8 cm below geodetic datum. Given that mean sea level (both at Halifax and at Charlottetown) has risen by some 28 cm since 1928, we expect present-day mean sea level to be roughly 28 cm above geodetic.

In general terms, both mean sea level and CGVD28 are expected to be relatively flat surfaces across PEI. The use of the published Z_o values resulted in spatial variations of MSL (relative to CGVD28) of +/- 30 cm. The reason for this apparent discrepancy is unclear at the moment but appears to be attributable to errors in Z_o since the relative difference between NAD83 and CGVD28 forms a smooth surface varying linearly from one end of the Island to the other. This matter is expected to be resolved in the coming months as CHS continues its work on this matter. In the meantime, an interim method has been developed that provides a smooth and consistent estimate of mean sea level around the Island as described in the following.

For this report, mean sea level (2000) relative to CGVD28 has been approximated under the assumption that CGVD28 is a plane surface represented by mean sea level at Charlottetown in 1928 (based on an average of measured sea levels from 1922 to 1938). Global sea level rise and vertical crust movements have been used to establish an estimate of MSL (2000) relative to CGVD28. Global sea-level rise values were extracted directly from Rahmstorf (2007) which shows a change in global sea-level between 1928 and 2000 of 14.4 cm.

Vertical crustal movement (VCM) contours were extracted directly from Koohzare et al. (2007). The contours were interpolated using a natural neighbour interpolation algorithm to create a map of VCM for the Island as shown in Figure 5. This allows us to obtain the VCM rate for the entire shoreline of the Island and determine the vertical crustal change between 1928 and 2000 (Figure 6). The resulting estimate of MSL (2000) relative to CGVD28 is shown in Figure 7. These values have been used to express the climate change and storm scenarios developed by Richards and Daigle (2011) relative to geodetic datum. It is important to note that this proxy method merely represents our best estimate using available data - review and revision of these estimates are recommended as soon as better numbers are available.

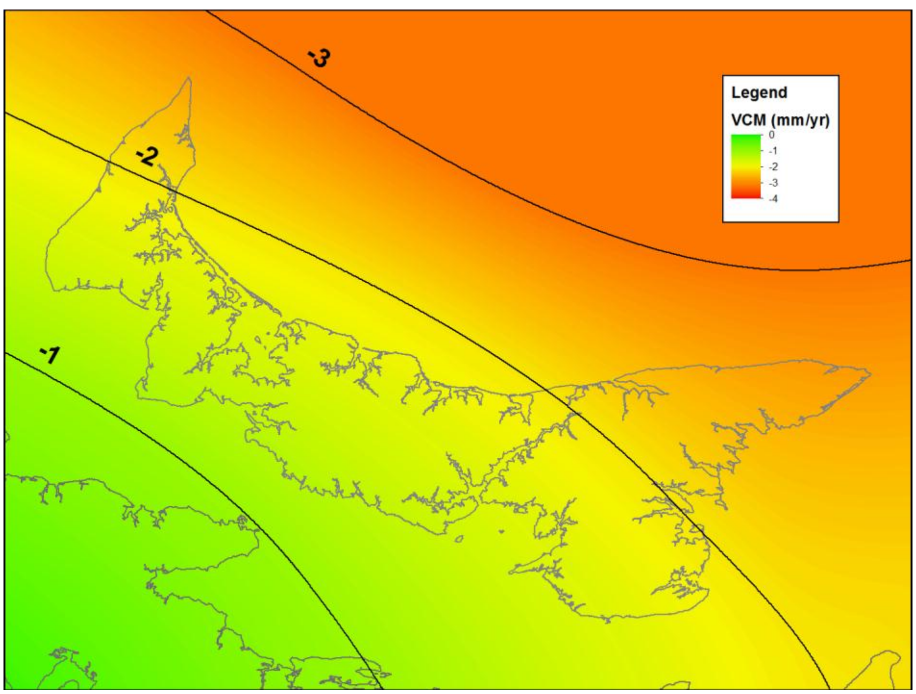


Figure 5 Rate of vertical crustal movements map around PEI. The VCM contour lines were taken directly from Koohzare et al. (2007)

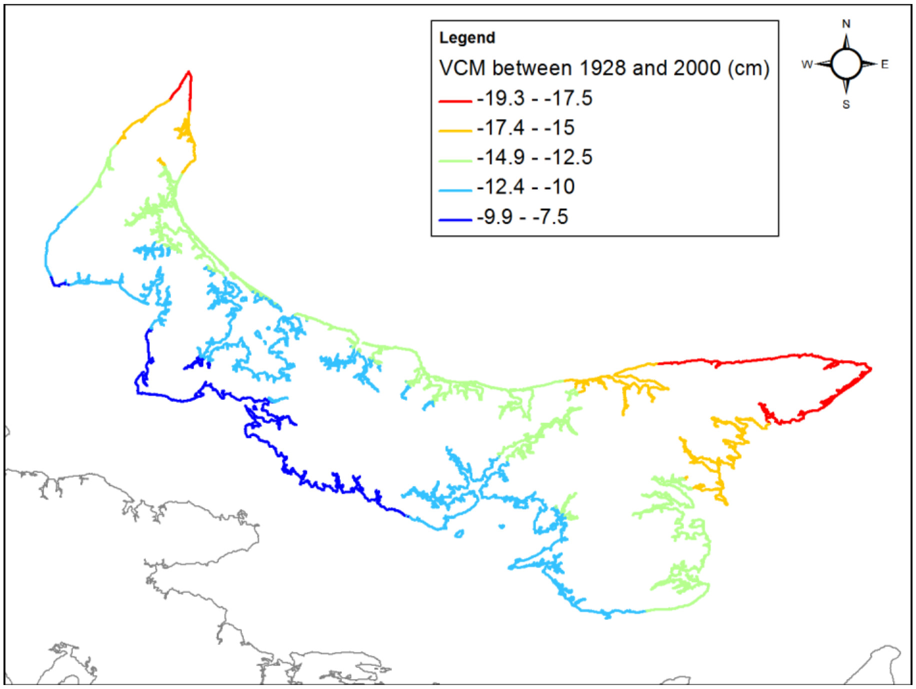


Figure 6 Vertical crustal movements between 1928 and 2000

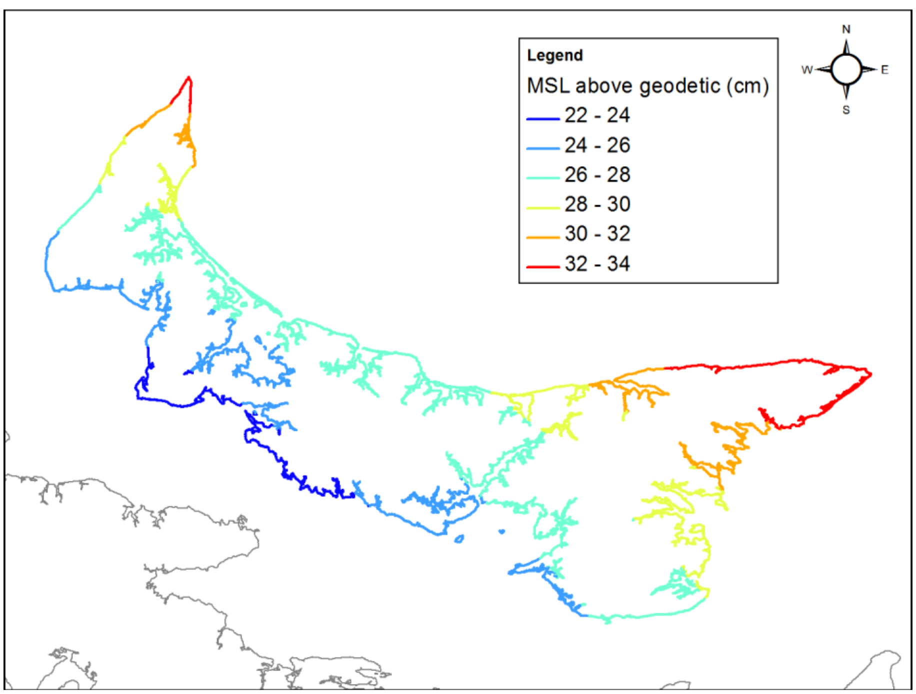


Figure 7 MSL in 2000 above geodetic datum (CGVD28)

2.6. Tidal constituents

Two dataset are available that can provide a description of tidal conditions around the Island:

- Fisheries & Oceans Canada (DFO) provide a definitive set of 73 tidal constituents for each of 26 stations around the Island. These constituents provide an accurate description of the amplitude and phase of the key components of the astronomical tide at each station based on historical measurements and can be used to reconstruct the astronomical tide at any point in time. For the present analysis these have been used to establish the range of tidal water levels along the shore.
- A second dataset consisting of harmonic constituents for tidal currents was compiled from WebTide's northwest Atlantic data set[2]. These harmonic constituents were determined by assimilating Topex-Poseidon tidal observations into a finite element model (Dupont, Hannah, Greenberg, Cherniawsky, & Naimie, 2002). This is a simpler dataset composed of just 5 tidal constituents (compared to the 73 used for water levels) but is the only readily available dataset for tidal currents.

An alternative approach for describing nearshore tidal conditions would be through the use of a tidal circulation model which would take into account tidal propagation into estuaries and would allow prediction of tidal elevation and tidal currents. While not presently available, this feature could be incorporated in the future. The use of the tidal constituent databases provides the advantage of using publicly available datasets.

2.7. Offshore wave conditions

The Meteorological Service of Canada (MSC) of Environment Canada has developed a long-term hindcast of wind, ice and wave conditions in the northwest Atlantic Ocean (Swail, et al., 2007). Output data from this model is available for gridpoints as shown in the following figure. For the present study hourly wind, wave and ice cover data has been compiled using the gridpoints closest to the PEI shoreline (shown in solid green in the figure). This data has been used to evaluate nearshore wave conditions and resulting sediment transport as described in Section 5.

[2] http://www.bio.gc.ca/science/research-recherche/ocean/webtide/nwatlantic-noatlantique-eng.php

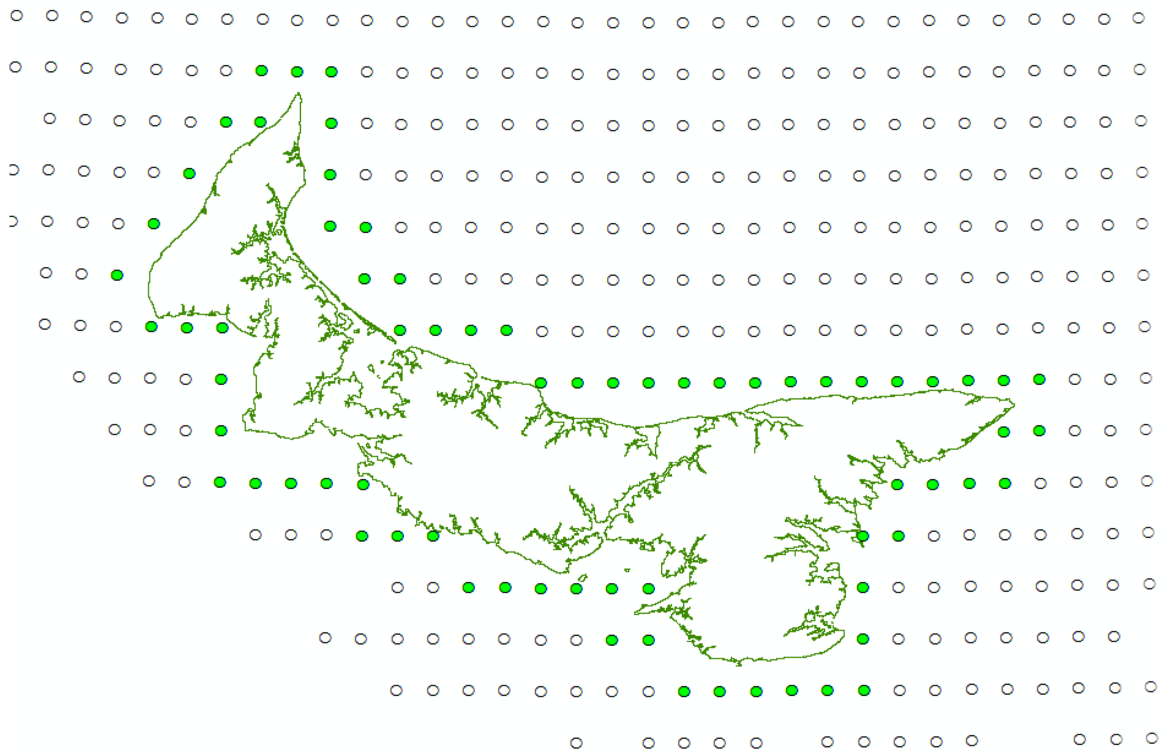


Figure 8 Dataset of nearest MSC50 nodes to the PEI shoreline

2.8. Other GIS Layers

In addition to the air photos, DEM and shoreline mentioned above, the following GIS datasets were used as input for the present study:

- Provincial road network
- Wetlands classification (2000)
- Corporate Land Use Inventory
- 2000 Coastline and 2000 air photo mosaic (black and white, 2m pixels)

3. Geomorphic Shoreline Classification

Coastal geomorphology is the study of the development and evolution of the form and structure (i.e. the morphology) of the coast under the influence of winds, waves, currents, and sea-level changes (CGER, 1994).

Geomorphic shoreline classification refers specifically to a method of classifying (mapping) shoreline features on the basis of their geomorphology – i.e. their physical configuration and their formation. The goal of this classification exercise is to map the coastal landforms of the province in order to support coastal management programs and, in particular, to aid in an assessment of coastal vulnerability to storm damage and the effects of climate change. Alternative classification schemes could be undertaken on the basis of land use, coastal ecosystems, etc.,

A wide range of geomorphic shoreline classification approaches exist in the literature. They vary in scope; ranging from techniques specifically designed for an individual shoreline, through to near-universal systems capable of being applied on a global scale (Finkl, 2004), (Davies J. , 1964).

The starting point for many coastal classification efforts is the system developed by F. Shepard as reproduced in the US Army Corps of Engineers Coastal Engineering Manual (CEM, 2007). This technique splits coasts into being either Primary or Secondary: Primary coasts being formed by non-marine processes (such as plate tectonics); Secondary coasts being those that have been shaped primarily by marine processes (wind, waves, tides, sea levels, etc.). The shorelines of Prince Edward Island fit wholly within this latter category as reproduced in Table 3, below.

This approach works well to generally capture the characteristics of open coastlines, however it lacks detail on coastal wetlands and estuaries. A classification system for rivers and deltas has been developed by Coleman and Wright (1971).

More recently, a comprehensive scheme for classification of Great Lakes shorelines was developed for the International Joint Commission (Stewart & Pope, Erosion Processes Task Group Report, 1992). Further refined in 2003 (Stewart, 2003), this scheme has been successfully applied throughout much of the Great Lakes. This classification scheme is quite similar to the geomorphic classification scheme developed for the Ontario’s Great Lakes (Ontario Ministry of Natural Resources, 2001). A key element of these Great Lakes methodologies is that they emphasize the separate roles that the nearshore, foreshore and backshore have in defining both the form of the shoreline and its response to erosive forces. Notably, consideration of the makeup and erodibility of the nearshore as a controlling factor for overall recession processes has been identified as a key element in understanding the evolution of shorelines throughout much of the Great Lakes – St. Lawrence River system (Davies & MacDonald, 2005), (Davies & MacDonald, 2005), (Baird & Associates, 2010).

Closer to home, one of the few classification studies for Prince Edward Island was conducted by Forward et al in 1959. As reported in Geo-Littoral (2010), Forward’s study covered the entire Northumberland Strait shoreline. Classification was based on the following shore ‘face types’:

1. Steep rock face
2. Undercut rock face

3. Jagged rock face
4. Rock shelf
5. Masked rock face
6. Unconsolidated face, rock based
7. Unconsolidated face (usually over 5 ft)
8. Unconsolidated face (up to 5 ft)
9. Estuarine
10. Depositional beach

The Geo-Littoral report also presents a review of other coastal classification efforts undertaken in Atlantic Canada including works by Catto et al (1999) at Conception Bay, NL, Bérubé and Thibault (1996) in southeastern New Brunswick (Cap Lumière to Port Elgin), This latter study is of interest in that it identified three key shoreline features: The Coastline, the Backshore and the Foreshore and characterized these features independently as summarized in the table below.

Table 1 Shore Classification Schemefor Cap Lumière-Port Elgin, NB

BÉRUBÉ and THIBAULT (1996)				
Feature	**Type**	**Attributes**		
		Sediment size and distribution	Width and elevation of foreshore, backshore, coast	Qualitative susceptibility to erosion (low, medium, high)
Coastline				
	Rocky			
	Unconsolidated			
	Anthropogenic			
Backshore				
	Beach			
	Tidal Salt Marsh			
Foreshore				
	Tidal Flat			
	Tidal Stream			

For the present study, we have characterized the cross-shore profile by the nearshore, foreshore and backshore as illustrated in Figure 9 for cliff/bluff shorelines (upper figure) and for dune shorelines (lower figure).

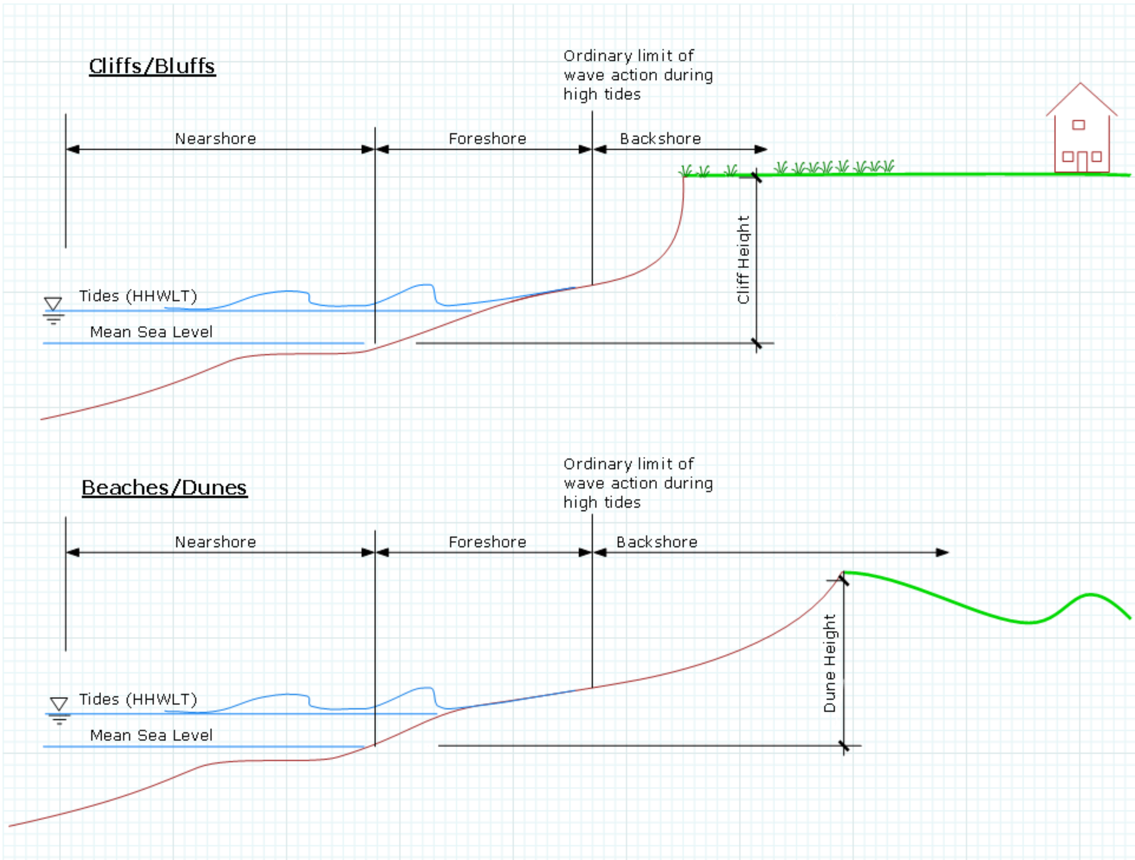


Figure 9 Components of the shoreline.

The nearshore is defined here as the seabed extending seaward from the beach at mean sea level offshore to the limit of influence of wave action.

The foreshore extends from the beach at mean sea level up to the ordinary limit of wave action during high tides[3]. This area is generally void of vegetation. Its landward limit can often be identified by the wrack line or the upper limit of kelp, driftwood and other debris along the shore (see Figure 10).

The backshore extends from the ordinary limit of wave action at high tides landward to the limit of influence of coastal processes – typically to level, stable land away from the cliff face of the landward limit of sand dunes.

[3] This limit is often referred to as the Ordinary High Water Mark however this term has varying technical and legal definitions

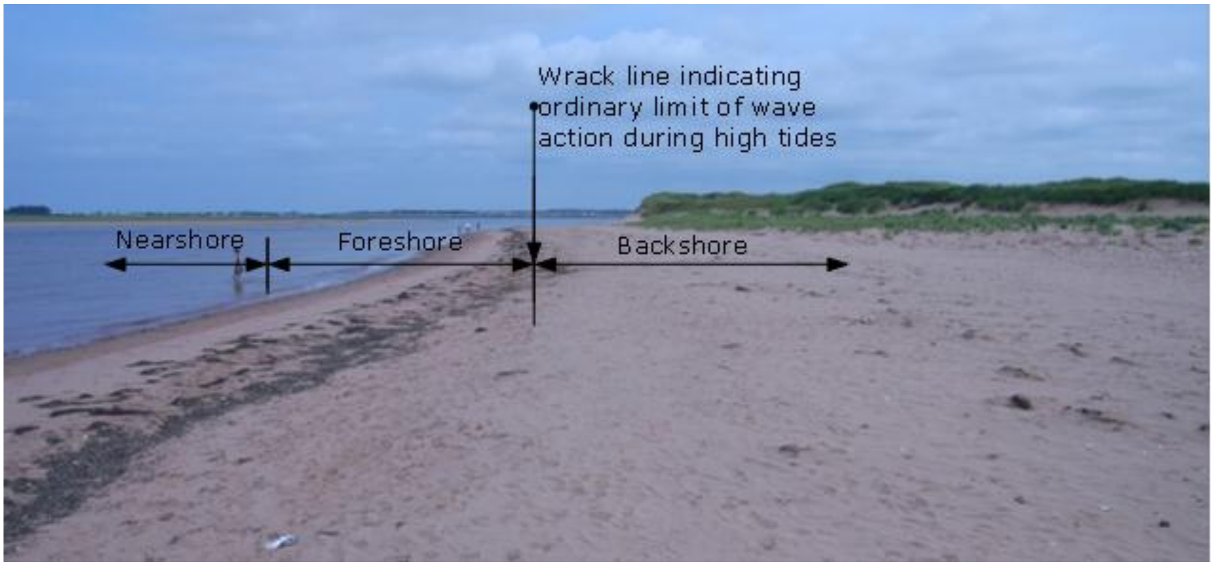


Figure 10 Wrack line defining limit of foreshore (Cabot Beach)

Geo-Littoral, recommended that a shore classification system for PEI would best be based on a system developed by Bernatchez et al. (2008), since, in Geo-Littoral's opinion: in addition to "the simple identification and characterization of selected coastal types: it also includes information on evolutionary trends of the shoreline and proposes scenarios of coastal evolution based on climate change predictions (it offers a look at past trends, present conditions, and probable future evolution)." (Geo-Littoral, p. 36).

The use of historical recession rates to forecast (project) future erosion can be a false and misleading methodology if the physical processes causing erosion are not included in the analysis. In Bernatchez's work, sea level rise / climate change scenarios are represented by assuming that above-average erosion conditions would occur under sea level rise but without justification of the amount by which the erosion rates would increase. An evaluation of the susceptibility of a shoreline to climate change needs to be based on the actual changes expected in water levels and wave conditions and the resulting changes to erosion rates and sediment budgets along the shore. If a defendable and meaningful analysis of the effects of different climate change scenarios is required then a quantitative approach to the problem must be used. Furthermore, erosion is just one of the possible coastal consequences of climate change. As summarized in Ramieri et al. (2011), six key bio-geophysical effects of sea level rise have been identified in relation to climate change (see Table 2). Evaluation of the impacts of climate change needs to be capable of addressing all six of these effects, particularly inundation, flooding and wetland loss/change – not just erosion.

Table 2 Bio-geophysical effects of sea level rise on coastal areas (adapted from Nicchols and Klein, 2005).

<table>
<tr><th colspan="2" rowspan="2">Bio-geophysical effect</th><th colspan="2">Other relevant factors</th></tr>
<tr><th>Climate related</th><th>Non-climate related</th></tr>
<tr><td colspan="2">Permanent inundation</td><td>Sea level rise</td><td>Vertical land movement (uplift/subsidence), land use and land planning</td></tr>
<tr><td rowspan="2">Flooding and storm damage</td><td>Surge (open coast)</td><td>Sea level rise, wave and storm climate, morphological change, sediment supply, ice cover</td><td>Sediment supply, flood management, morphological change, land claim</td></tr>
<tr><td>Backwater effects (rivers and estuaries)</td><td>Sea level rise, wave and storm climate, runoff</td><td>Catchment management and land use</td></tr>
<tr><td colspan="2">Wetland loss / change</td><td>CO2 fertilisation, changes to sediment supply, sea level rise (coastal squeeze), wave and storm climate</td><td>Changes to sediment supply, migration space, direct destruction</td></tr>
<tr><td rowspan="2">Erosion</td><td>Direct effect on open coasts</td><td>Sea level rise, sediment supply, wave and storm climate</td><td>Sediment supply</td></tr>
<tr><td>Indirect effect (inlets and estuaries)</td><td>Sea level rise, sediment supply, wave and storm climate</td><td>Sediment supply</td></tr>
<tr><td rowspan="2">Saltwater intrusion</td><td>Surface waters</td><td>Sea level rise, runoff</td><td>Catchment management and land use</td></tr>
<tr><td>Groundwater</td><td>Sea level rise, rainfall</td><td>Land and aquifer use</td></tr>
</table>

According to Geo-Littoral's review, the Bernatchez system classifies shoreline by type, namely:

> Salt Marshes; Sand Spits; Sand Spits with Salt Marshes; Sand or Gravel Berms (mainland beach); Berms (mainland beach) with adjacent Salt Marshes; Tombolos; Low Unconsolidated Cliffs; Unconsolidated Cliffs of Medium Height; High Unconsolidated Cliffs; Low Rock Cliffs; Rock Cliffs of Medium Height; High Rock Cliffs; Artificial Shoreline. (Geo-Littoral, p. 34).

Such a classification method fails to distinguish between characteristics of the nearshore, foreshore and backshore as is done by the Bérubé-Thibault and Great Lakes methods. For these reasons we have employed a new classification scheme based on the Stewart and Bérubé-Thibault approaches but adapted to suit the specifics of the PEI shoreline as described in the following.

Table 3 Shepard's classifcation scheme for Secondary Coasts (from USACE CEM, 2007 Part IV)

II. *Secondary coasts* Shaped primarily by marine agents or by marine organisms. May or may not have been primary coasts before being shaped by the sea.

A. Wave erosion coasts

1. *Wave-straightened cliffs* Bordered by a gently inclined seafloor, in contrast to the steep inclines off fault coasts.
   - (a) *Cut in homogeneous materials.*
   - (b) *Hogback strike coasts* Where hard layers of folded rocks have a strike roughly parallel to the coast so that erosion forms a straight shoreline.
   - (c) *Fault-line coasts* Where an old eroded fault brings a hard layer to the surface, allowing wave erosion to remove the soft material from one side, leaving a straight coast.
   - (d) *Elevated wave-cut bench coasts* Where the cliff and wave-cut bench have been somewhat elevated by recent diastrophism above the level of present-day wave erosion.
   - (e) *Depressed wave-cut bench coasts* Where the wave-cut bench has been somewhat depressed by recent diastrophism so that it is largely below wave action and the wave-cut cliff plunges below sea level.
2. *Made irregular by wave erosion* Unlike ria coasts in that the embayments do not extend deeply into the land. *Dip coasts* Where alternating hard and soft layers intersect the coast at an angle; cannot always be distinguished from trellis coasts.
   - (a) *Heterogeneous formation coasts* Where wave erosion has cut back the weaker zones, leaving great irregularities.

B. *Marine deposition coasts* Coasts prograded by waves and currents.

1. Barrier coasts.
   - (a) *Barrier beaches* Single ridges.
   - (b) *Barrier islands* Multiple ridges, dunes, and overwash flats.
   - (c) *Barrier spits* Connected to mainland.
   - (d) *Bay barriers* Sand spits that have completely blocked bays.
   - (e) *Overwash fans* Lagoonward extension of barriers due to storm surges.
2. *Cuspate forelands* Large projecting points with cusp shape. Examples include Cape Hatteras and Cape Canaveral.
3. *Beach plains* Sand plains differing from barriers by having no lagoon inside.
4. *Mud flats or salt marshes* Formed along deltaic or other low coasts where gradient offshore is too small to allow breaking waves.

C. *Coasts* built by organisms

1. *Coral reef coasts* Include reefs built by coral or algae. Common in tropics. Ordinarily, reefs fringing the shore and rampart beaches are found inside piled up by the waves.
   - (a) *Fringing reef coasts* Reefs that have built out the coast.
   - (b) *Barrier reef coasts* Reefs separated from the coast by a lagoon.
   - (c) *Atolls* Coral islands surrounding a lagoon.
   - (d) *Elevated reef coasts* Where the reefs form steps or plateaus directly above the coast.
2. *Serpulid reef coasts* Small stretches of coast may be built out by the cementing of serpulid worm tubes onto the rocks or beaches along the shore. Also found mostly in tropics.
3. *Oyster reef coasts* Where oyster reefs have built along the shore and the shells have been thrown up by the waves as a rampart.
4. *Mangrove coasts* Where mangrove plants have rooted in the shallow water of bays, and sediments around their roots have been built up to sea level, thus extending the coast. Also a tropical and subtropical development.
5. *Marsh grass coasts* In protected areas where salt marsh grass can grow out into the shallow sea and, like the mangroves, collect sediment that extends the land. Most of these coasts could also be classified as mud flats or salt marshes.

Broadly speaking, the shorelines of Prince Edward Island can be characterized as follows:

- The nearshore waters are composed on sandstone bedrock frequently overlain by sand which varies in thickness from several meters down to patchy/non-existent cover.
- The foreshores are composed of either sand, sandstone cobble or sandstone bedrock.
- The backshores consist of either sandstone/till bluffs and cliffs, low coastal plains or sand dunes.

Sea levels have been rising around Prince Edward Island for the past 8,000 years (Forbes et al, 2004) as evidenced by Figure 6, below. The upper plot in this figure shows sea level rise at Charlottetown observed over the past century (indicating a fairly steady rate of rise of 3.2mm/yr). The lower figure shows that relative sea levels have been rising around PEI for the past 8,000 years. Broadly speaking, this long-term relative sea level rise has resulted in all coasts around the Island being erosional (transgressive) with only very limited, localized existence of depositional (progradational) shores.

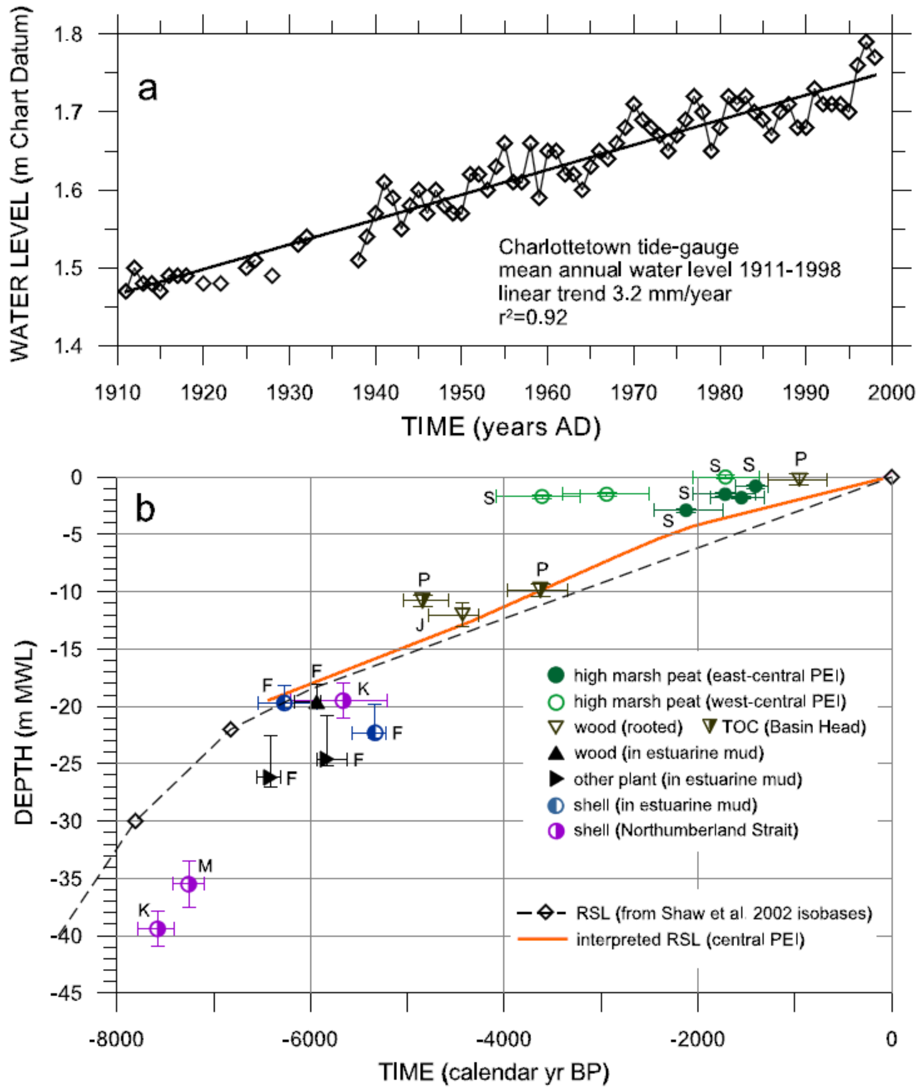


Fig. 6. Relative sea-level changes in central PEI. (a) Trend of annual mean water level from Charlottetown tide-gauge record, 1911 – 1998. (b) Relative sea-level change over past 8000 years from geological and radiocarbon evidence. Broken line is trend from regional isobase analysis (Shaw et al., 2002). Sample data sources are indicated by letters beside data points, as follows: F (Forbes and Manson, 2002); J (Heiner Josenhans, personal communication, 2001); K (Kranck, 1972); M (Medcof et al., 1965); P (Palmer, 1974); S (Scott et al., 1981).

Figure 11 Recent and geologic trends in relative sea level in PEI from Forbes et al, 2004).

Forbes succinctly characterizes the north shore of PEI as follows:

> *The shoreface, nearshore multiple bar complexes, and beaches … are sand-limited. Marine sand seaward of the shoreline is confined to shoreface wedges and as a thin veneer over truncated estuarine deposits within coastal compartments defined in many cases by subtle headlands with limited relief. Sand is transferred landward into multidecadal to century-scale storage in coastal dune, barrier, and flood-tidal delta sinks. (Forbes et al, 2004, p. 198)*

The nature of individual shoreline components along the PEI coast is largely controlled by two factors:

1) The cliff/bluff face (the integrity of the sandstone and the height of the sandstone stratum as well as the overall height of the cliff/bluff).

2) Sandstone outcrops that are relatively erosion-resistant lead to the creation of headlands which support the development of pocket beaches between them.

The response of these shorelines to the actions of wind, waves and tides is largely dictated by the abundance of sand in the nearshore and foreshore. Net sediment supply is perhaps the largest factor in determining the nature of the shore: Shorelines which have a relative abundance of sand behave as a dynamic beach with their position and profile fluctuating in response to waves and weather.

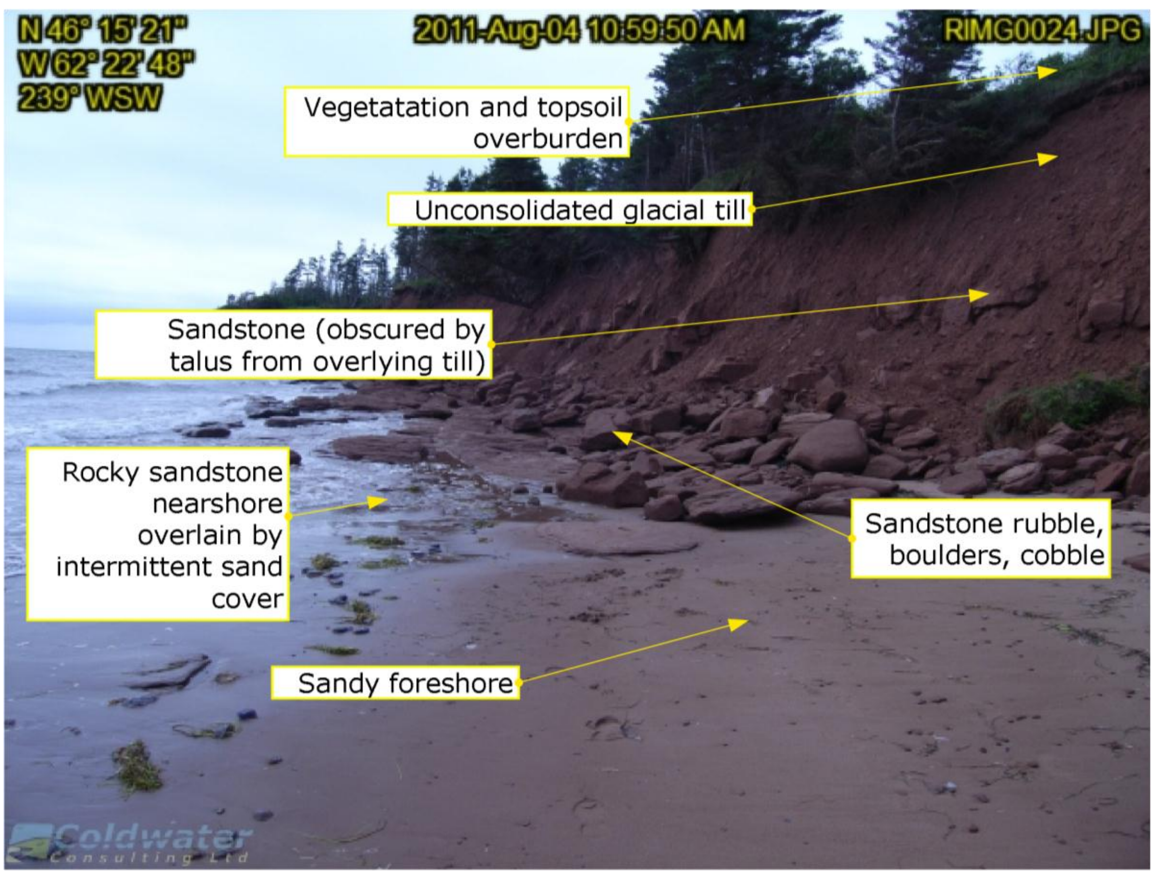


Figure 12 Archetypal cliff/bluff Prince Edward Island shoreline (Sally's Beach Provincial Park, Spry Point)

The shore classification system we have adopted for PEI is presented in the following table.

Table 4 PEI Shore Classification Schema

Nearshore Type (3)	Foreshore Type (3)	Backshore Type (5)	Backshore Height (m)
Rocky	Rocky	Cliff	This is a numeric field containing the elevation of the backshore above mean sea level.
Sandy	Sandy	Bluff	
Marsh	Marsh	Low Plain	
		Dune	
		Wetland	

In all, there are 45 possible combinations of Nearshore, Foreshore and Backshore types (3x3x5). If high cliffs were to be distinguished from low cliffs then there would be 54 classes (3x3x6). In the Great Lakes Classification approach, each individual combination and permutation is given a unique numeric identifier code. For example Code 124 might represent a rocky nearshore with a sandy foreshore and a dune backshore, while Code 221 would be a sandy nearshore and foreshore with a cliff backshore. In working with these systems we have generally found that the inclusion of a numeric code identifier does not offer any significant improvement over using the word identifiers (rocky, sandy, etc.) and, in fact, can lead toward confusion. For the PEI shoreline, we have adopted the scheme shown in the above table including the actual elevation of the backshore as a numeric field.

The identification of Nearshore, Foreshore type is based on visual assessment of the 2010 air photos; the backshore type is computed by an algorithm that takes into consideration wetland and dune mapping and backshore slope and elevation (based on LiDAR data). This classification process is described in the following sections.

3.1. Shore Polygons

The entire island shoreline was classified manually at a 1:1,500 scale by visually identifying (from the 2010 air photos) attributes of the nearshore, foreshore and backshore as well as all distinguishable shore protection. Nearshore and foreshore features were classified as sandy, rocky or marsh/wetland. Backshore features were characterized as cliff, dune, marsh or plain. These features were created as three distinct sets (NS, FS and BS) each with their own coverage dependent upon the actual features. The polygons were drawn such that they defined the alongshore limits of each feature and spanned sufficiently far on- and offshore to be overlap both past and present shorelines.

The geological composition of the cliffs and bluffs of the Island's shorelines is complex; some bluffs are composed solely of till, others solely of sandstone. The most common occurrence is a sandstone base overlain by 1-4 metres of unconsolidated till. While the till can generally be characterized as friable and highly susceptible to erosion, the sandstone (and slate) bedrock found along the coast is highly variable with some bedrock eroding almost as rapidly as the overlying till while other bedrock deposits are noticeably more erosion resistant. This is further complicated by the fact that overlying till will often slump down over underlying sandstone covering it from view and giving the impression that the bluff face is composed solely of till. Excavation or boring is required to accurately determine nearshore stratigraphy in such cases. The erosion resistance of bedrock such as the sandstones found around Prince Edward Island is difficult to determine and is typically evaluated by extracting large stone samples and testing their erodibility in a hydraulics laboratory. Overall erodibility of a weathered, jointed rock mass is particularly problematic. Annandale (1995) has developed a method for predicting the erodibility of a wide range of rock materials based on the unconfined compressive strength of the rock, its jointing, block size and bedding plane orientation.

The difficulty in assessing the erodibility of cliffs and bluffs, combined with the near impossibility of determining stratigraphic composition of a cliff face from aerial photography precluded the distinction of bluff/cliff composition within this classification exercise. It is understood (Jardine, pers. Comm.) that the National Parks may have compiled data on bluff stratigraphy for their north shore properties, however this data was not available to us during this study. Future work to delineate bluff composition could be undertaken using analysis of well borehole logs or by an extensive field campaign. Alternatively, the shoreline classification resulting from this report could be combined with analysis of nearshore wave conditions and historical recession rates to compute bluff erodibility. At time of writing this report, this latter approach appears to offer the most promise for developing a useful, quantitative assessment of bluff/cliff erodibility.

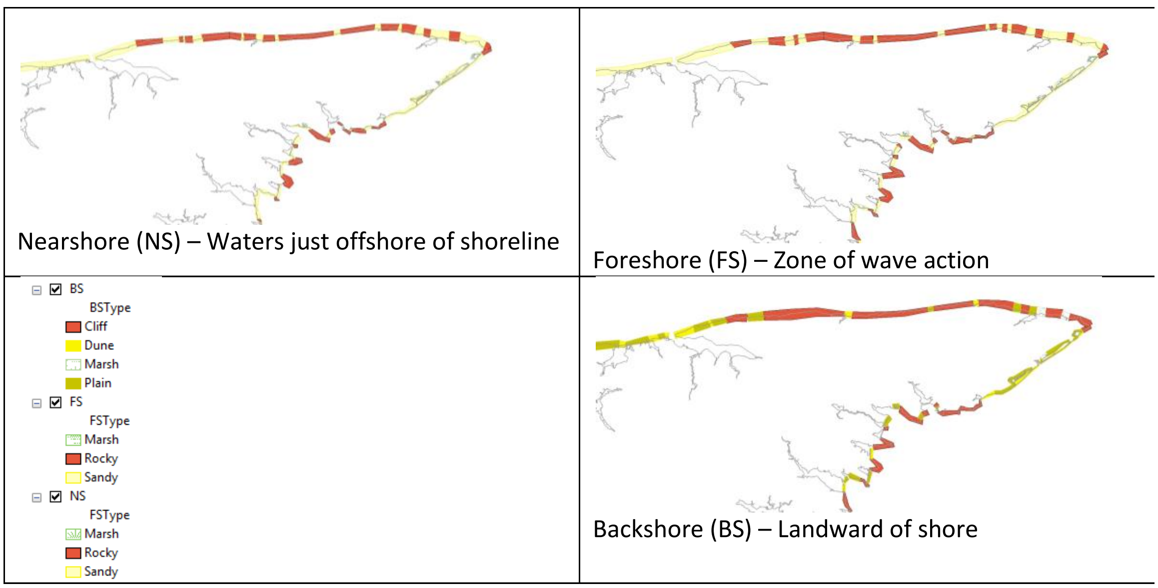


Figure 13 Sample shore polygons

3.2. Slope and Elevation Analysis

This section describes the technique used to compute the shoreline slope and elevation. The technique is divided into three steps: shoreline simplification, slope analysis, and mapping.

<u>Shoreline Simplification</u>

Simplification of the shoreline was undertaken to reduce computational time during the analysis. Since the original shoreline ("coast_2010") has over 600,000 segments, a simplification technique (Douglas and Peucker, 1973) was used to reduce the number of segments. The algorithm is a type of generalization operation that removes small intrusions and extrusions within a certain distance of a line without destroying its essential shape. Here a 10 m distance was used resulting in a simplified shoreline with 38,000 segments.

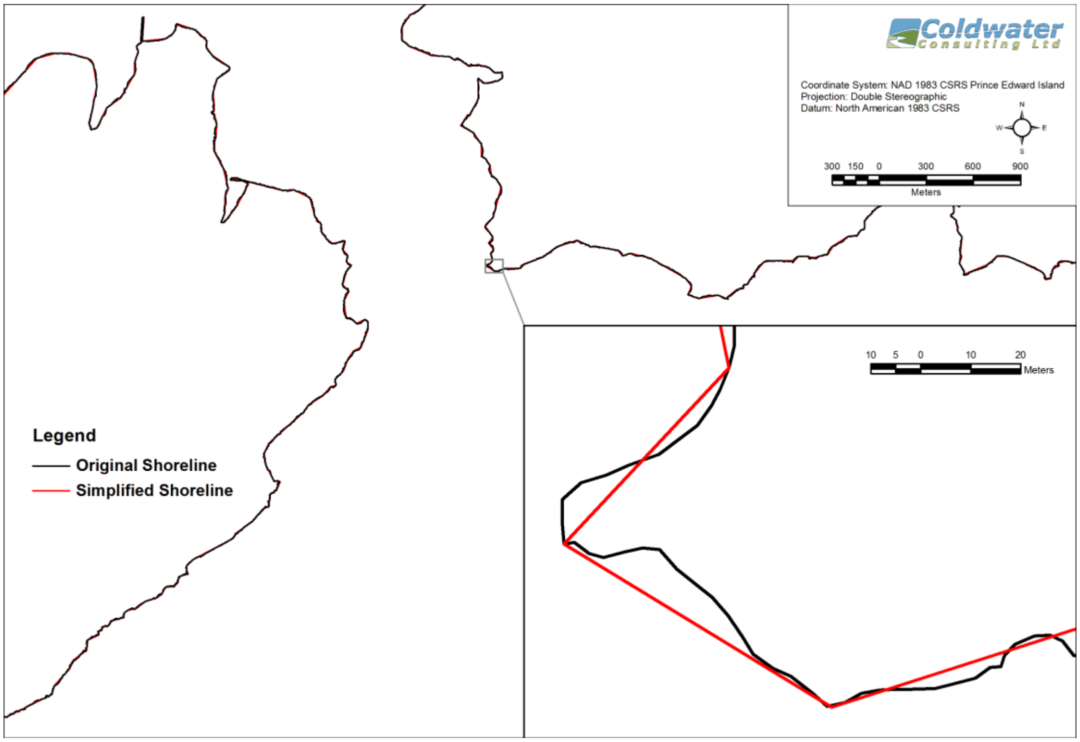


Figure 14 : Example of percent rise slope

<u>Slope Analysis</u>

The slope was calculated from digital elevation maps (DEMs) of PEI based on 2007 LiDAR data. The DEMs have 1.5m cell resolution in the horizontal. For each cell, the slope was calculated as the maximum rate of change in elevation relative to neighbouring cells. Since the DEMs represent quite a smooth surface this selection of the maximum slope was found to provide a realistic characterization of the shore slope. The slope algorithm can be found in Burrough and McDonell (1998). The resulting slope values are expressed as percentage rise as illustrated in Figure 15.

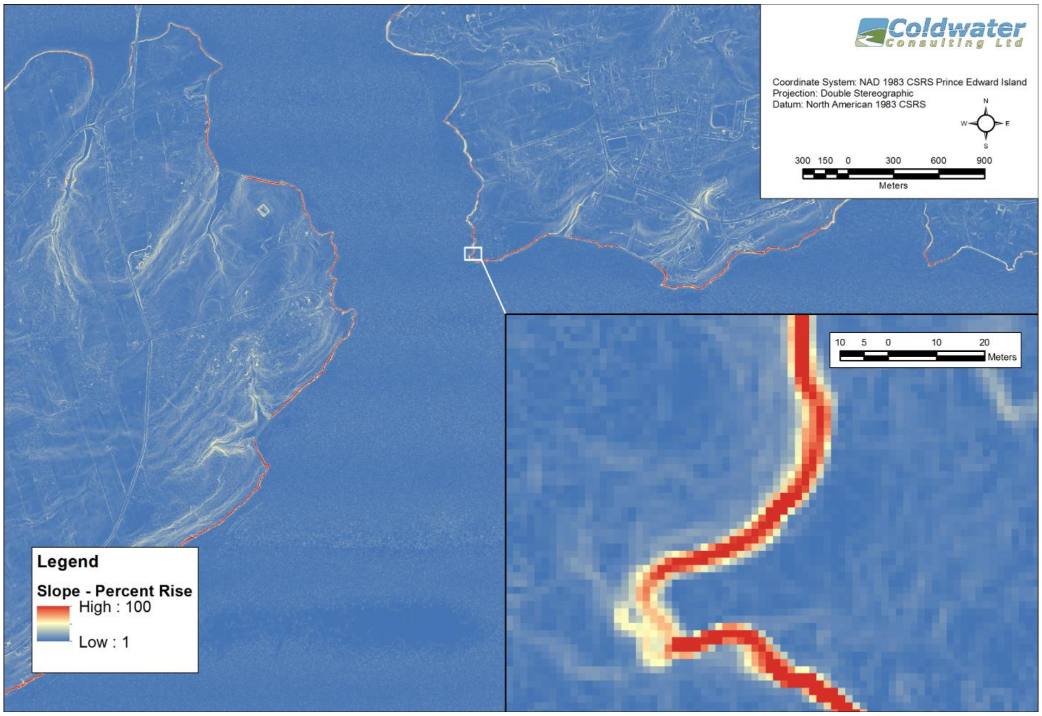


Figure 15 : Example of a digital slope map

The percent rise can be better understood if you consider it as the rise divided by the run, multiplied by 100, as shown in Figure 16. Consider triangle *B* below. When the angle is 45 degrees, the rise is equal to the run, and the percent rise is 100 percent. As the slope angle approaches vertical (90 degrees), as in triangle *C*, the percent rise approaches infinity.

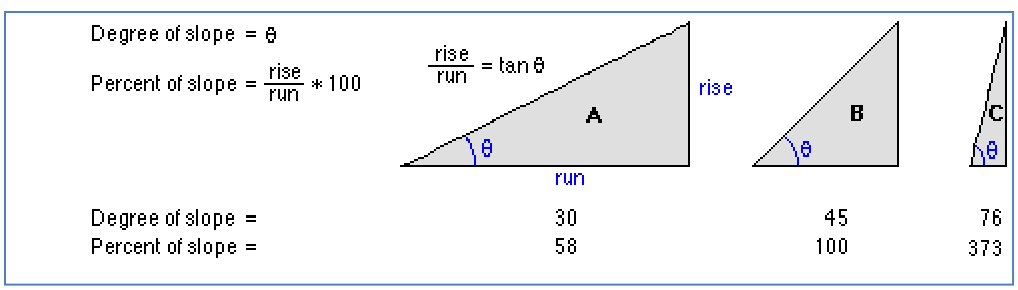


Figure 16 : Example of percent rise slope

<u>Slope and Elevation Mapping</u>

The maximum slope and maximum elevation within 10 meters of the simplified shoreline were mapped onto the simplified shoreline. The analysis was based on the digital elevation maps (DEMs) for elevation and digital slope maps for slope.

As for the shoreline classification: Each shoreline's segment acquired the slope and elevation characteristics from the closest segment from the simplified shoreline, thus mapping the slope and elevation data back to the original (high resolution) shoreline.

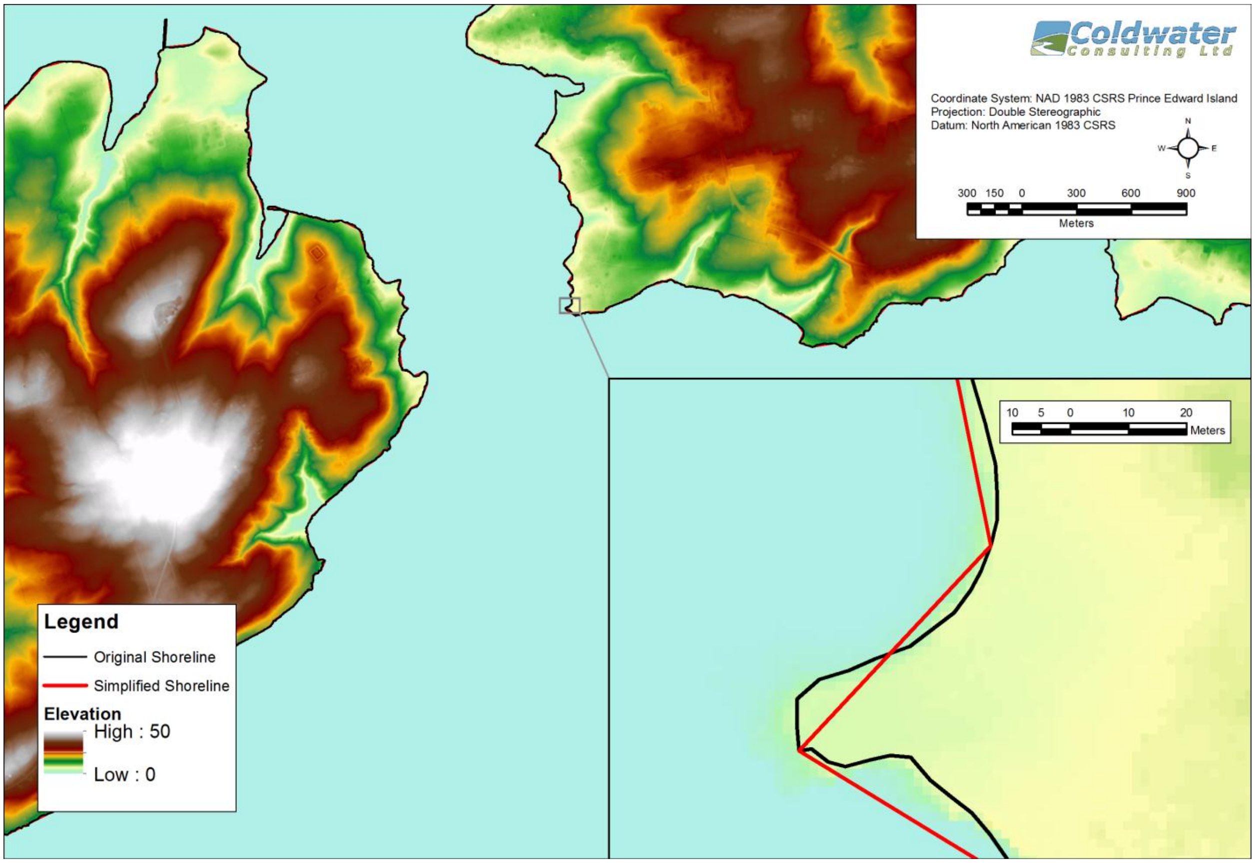


Figure 17 : Example of a digital elevation map

3.3. Shore classification algorithm

The availability of LiDAR-based topography combined with existing mapping of wetlands and sand dunes (2000 Wetlands Classification data) provides the opportunity to derive a systematic shore classification based on quantitative measures. ArcGIS was used to extract land elevations and slopes from the LiDAR-based DEM in a 100 metre wide buffer zone along the shoreline (as defined by the 2010 shoreline vector). The bare earth DEM is a relatively smooth surface at this scale consequently it was determined that the maximum ground elevation and maximum slope worked well as identifiers of cliff and bluff geometry. The slope and elevation was mapped onto the vector shoreline as attributes “Slope” and “Elev”.

The nearshore, foreshore and backshore types from the manual classification polygons were mapped to the vector shorelines as attributes “NSType”, “FSType”, and “BSType”. Wetland type for the nearest wetland feature was mapped to this shoreline along with the distance from the shoreline features to the nearest wetland feature (Attributes “WETL_TYPE” and “Distance”).

The attribute “ShoreType” was assigned to each shoreline feature on the basis of the following algorithm:

```
dim value
value = "Low Plain"
if ([Elev] >= 3) then
    value = "Bluff"
end if
if (([WETL_TYPE] = "SAND DUNE") AND ([Distance] < 20)) then
  value = "Sand Dune"
elseif(([Slope] >= 80) OR ([Elev] >= 8)) then
    value = "Cliff"
elseif (([WETL_TYPE] <> "SAND DUNE") AND ([Distance] < 20) AND ([FSType] <> "Sandy")) then
   value = "Wetland"
end if
```

This algorithm was tuned against the air photo dataset, the shore polygons and against known sites along the shore to optimize the values of slope and elevation and proximity to dunes in order to best capture shoreline characteristics. The only noticeable weakness in this algorithm and the resulting shore classification dataset is that the wetland classification dataset is 10 years out of date and occasionally the dune locations are misrepresented. This is most noticeable at coastal inlets such as at South Lake near Basin Head. Once an updated wetland database becomes available, this automated classification technique can readily be re-run and updated.

3.4. Results

The resulting shoreline classification is presented in the following figures. Figure 18 shows shore type plotted for the entire Island shoreline. This shows the dominance of sand dunes along the beaches of the north shore as well as the predominance of low plains in areas such as Egmont Bay. Cliffs show clearly to be the dominant shoretype overall particularly along the west shore while wetlands are found extensively within the inner estuaries.

The classification database contains data such as foreshore type, nearshore type and land elevation in addition to the overall shore type. GIS queries of various combinations of characteristics can readily be created to identify features of interest. For example, Figure 19 shows regions with cliffs of a height of 10 or more metres combined with a sandy foreshore or nearshore.

This dataset is saved as an ARC Shapefile (.shp) with filename “coast_2010_Coldwater_v2p6.shp” and has been provided to the Province under separate cover. The metadata for this shapefile is included in the Appendix of this report.

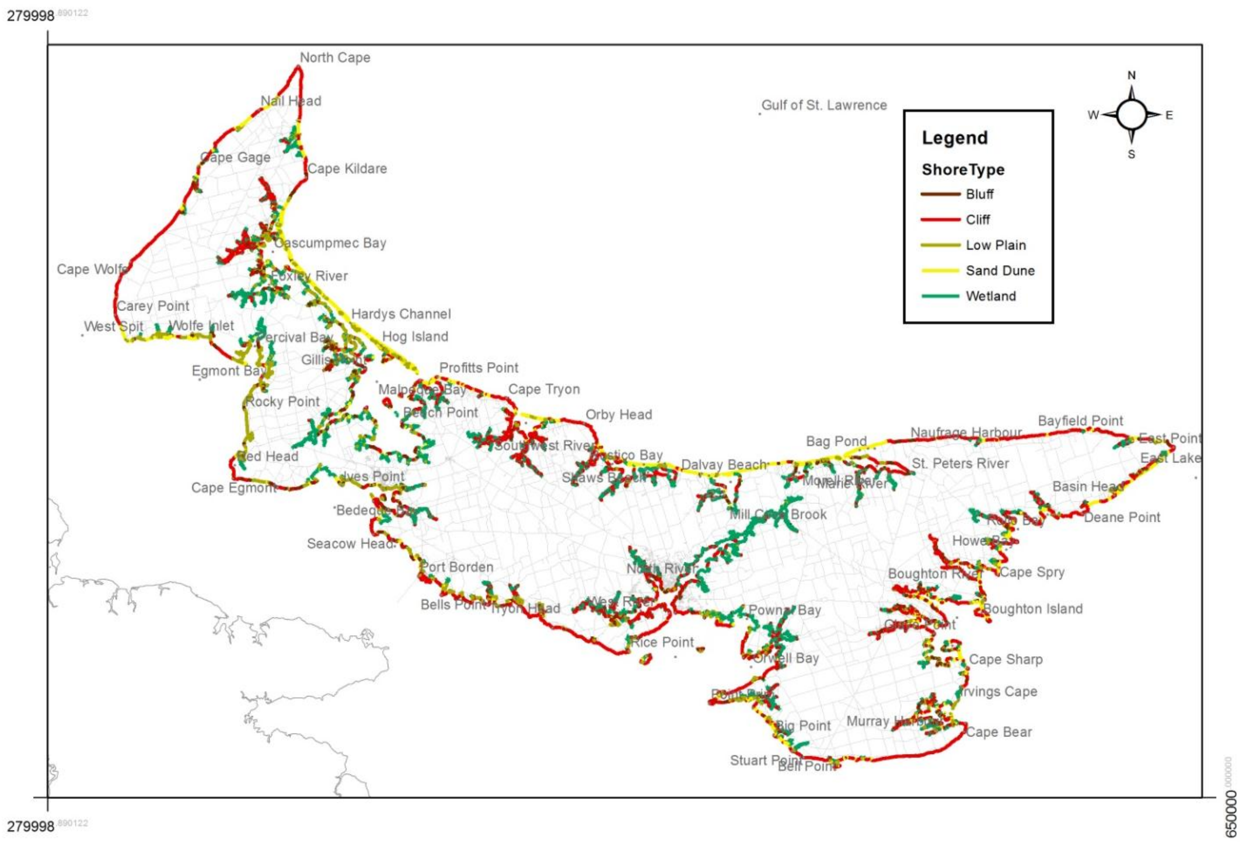


Figure 18 Shore Type

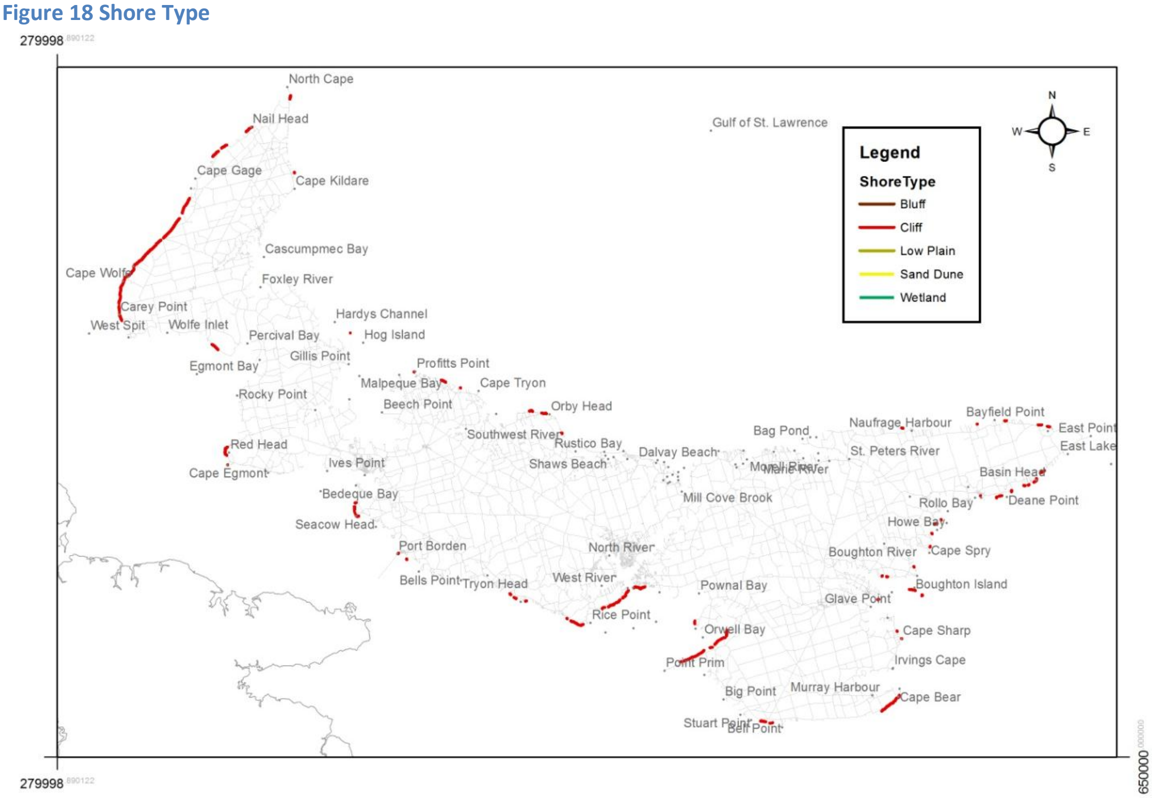


Figure 19 Shorelines with cliffs higher than 10m and sandy foreshores or nearshores.

In this classification exercise, barrier islands and spits have not been identified as unique shoreline features and are classified on the basis of the nearshore, foreshore and backshore types in the same manner as all other shorelines. The distinction between barrier islands and spits can be problematic as is evidenced by the shoreline at Darnley Spit which takes the form of two spits and a barrier island in the CHS navigation charts (see below), while the 2010 air photos (also below), show that the island has subsequently attached to the western shore creating a two-spit system with no barrier island.

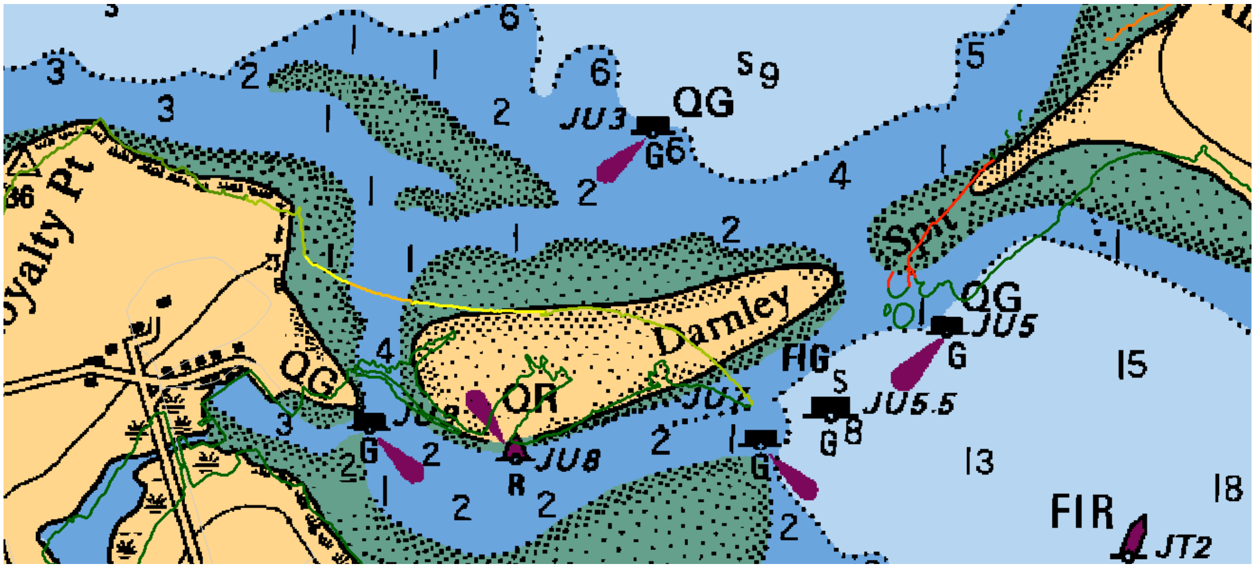


Figure 20 Excerpt from CHS Navigation Chart 4491 showing Darnley Spit as a barrier island/spit complex.

Figure 21 2010 air photo of Darnley Spit.

A similar example comes from Tracadie Bay, which was a barrier spit system in the 2000 air photos (below), but became an island/spit barrier system with the breach of the spit in 2010.

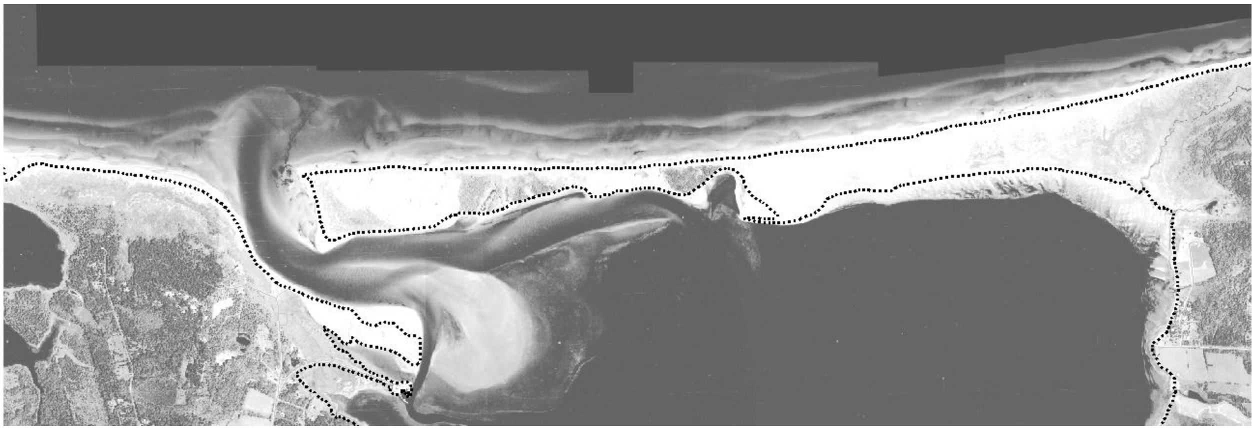


Figure 22 Tracadie Spit in 2000.

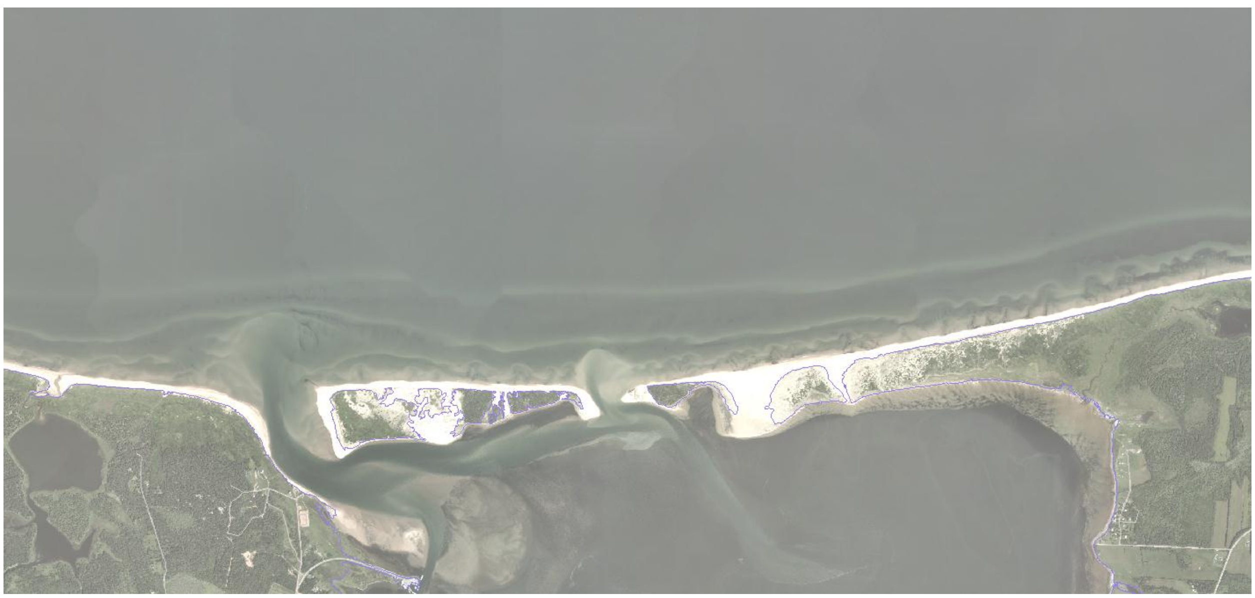


Figure 23 Tracadie Spit (and barrier island) in 2010.

4. Structures

Manual classification was used to visually identify all shore protection at a scale of 1:1500. While this method proved reasonably accurate at delineating larger coastal structures, piers, wharves, bridge abutments, etc. the 0.4 m pixel resolution of the air photos precluded identification of structures smaller than roughly 4m in width (10 pixels). Red island sandstone is commonly used as riprap shore protection. Since this is of the same colour and texture as local bedrock, revetments composed of sandstone could generally only be identified through *a priori* knowledge of their existence from site visits or through inference by land use (e.g. cottage lot), the regularity of the protected shoreline in comparison to adjacent shorelines and the setback of adjacent (eroded) shorelines. Supplemental structure information was obtained from two sources:

- A set of 194 georeferenced site photographs of shore protection taken by D. Jardine – these were imported into the project GIS and used to test whether or not the manual classification process had identified these structures. For the most part they had; approximately 80% of the photos were of sites already identified through the manual classification process. All shore protection identified by these georeferenced photos was subsequently included in the classification dataset. A set of 56 site photos taken by M. Davies were similarly imported and employed. Figure 24 shows the spatial coverage of these site photos.
- A database of shore protection permits issued by the province. Provided in spreadsheet format this dataset identified 1,559 properties where erosion protection permits had been issued. Some properties were located by UTM (Zone 20N) map coordinates (992), some by latitude/longitude (140) and others by parcel identifier (PID) (62). These locations were loaded into the GIS (with exception of those sites identified only by PID since geolocation of those sites was not readily available) and used to support the visual classification as was done for the Jardine photographs. No detail on the exact location, physical configuration or length of any constructions is provided in this database so these records cannot by themselves be used to identify a specific shore protection element. Figure 25 shows the permit locations used in this analysis.

A total of 161 km of shore protection was identified (representing roughly 5% of the total shoreline length). Samples of the shore protection database (with protected shorelines in red, natural shorelines in green) are shown in Figure 26 through Figure 31 including sample site photos.

Based on the limitations of this analysis (photo scale, difficulties in delineating sandstone rubble) we suspect that this under-estimates the actual amount of shore protection in place by as much as a factor of 3 in terms of the number of properties protected. Since most of these properties are small, individual protection schemes that are not visually identifiable in the air photos it is our opinion that the total length of shore protection is likely underestimated by a factor of 2 (i.e. the actual length of shore protection could be as much as 320 km).

The shore protection database has been maintained as a separate dataset, independent of the shore classification database. The shore protection is seen as a separate layer to be viewed on top of, and in conjunction with, the shore classification database. While both lines (shore classification and shore protection) follow the same vector shoreline, the line segments in the two databases are different with the line segments in the shore protection database aligned with individual shore protection features. As a result of this the shore protection database is composed of 1,662 line segments (features) of which 635 are structures and 1033 are natural shorelines. By comparison, the shore classification database consists of 44,780 line segments (features).

This dataset (Filename: "coast_2010_Coldwater_structures_v2p6.shp") and has been provided to the Province under separate cover. The metadata for this shapefile is included in the Appendix of this report.

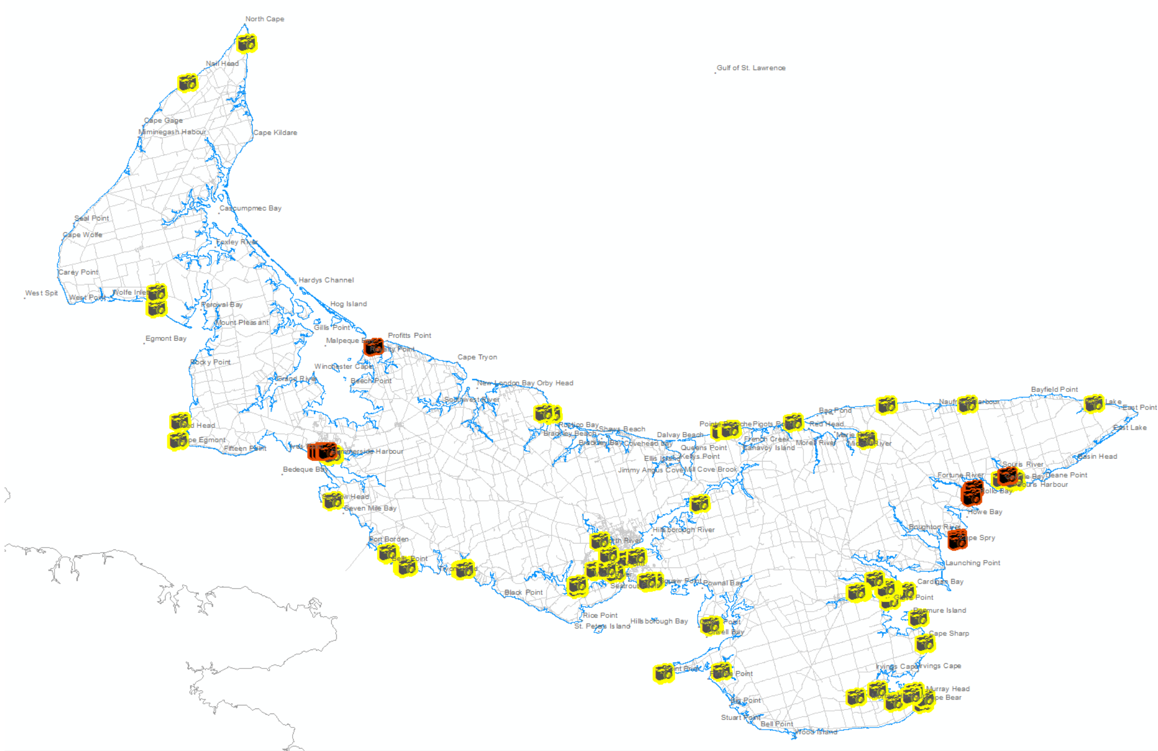


Figure 24 Site photo coverage (yellow icons - D. Jardine; orange - M. Davies)

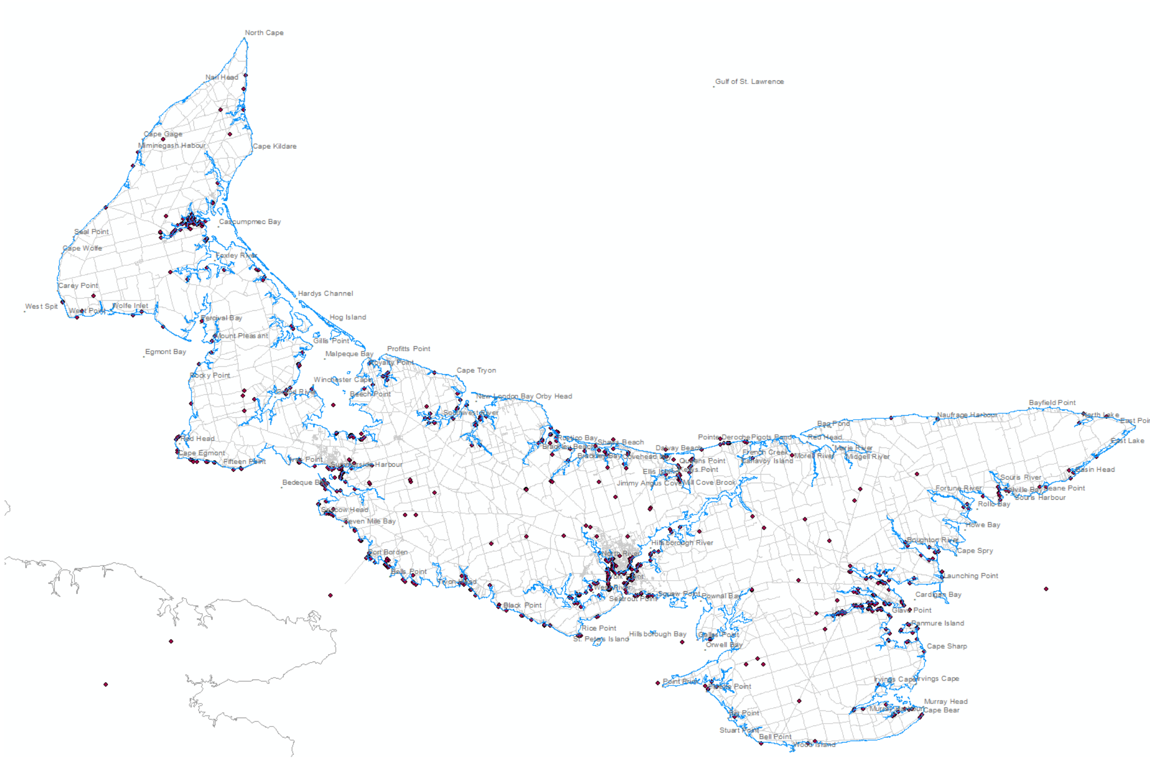


Figure 25 Shore protection permit sites

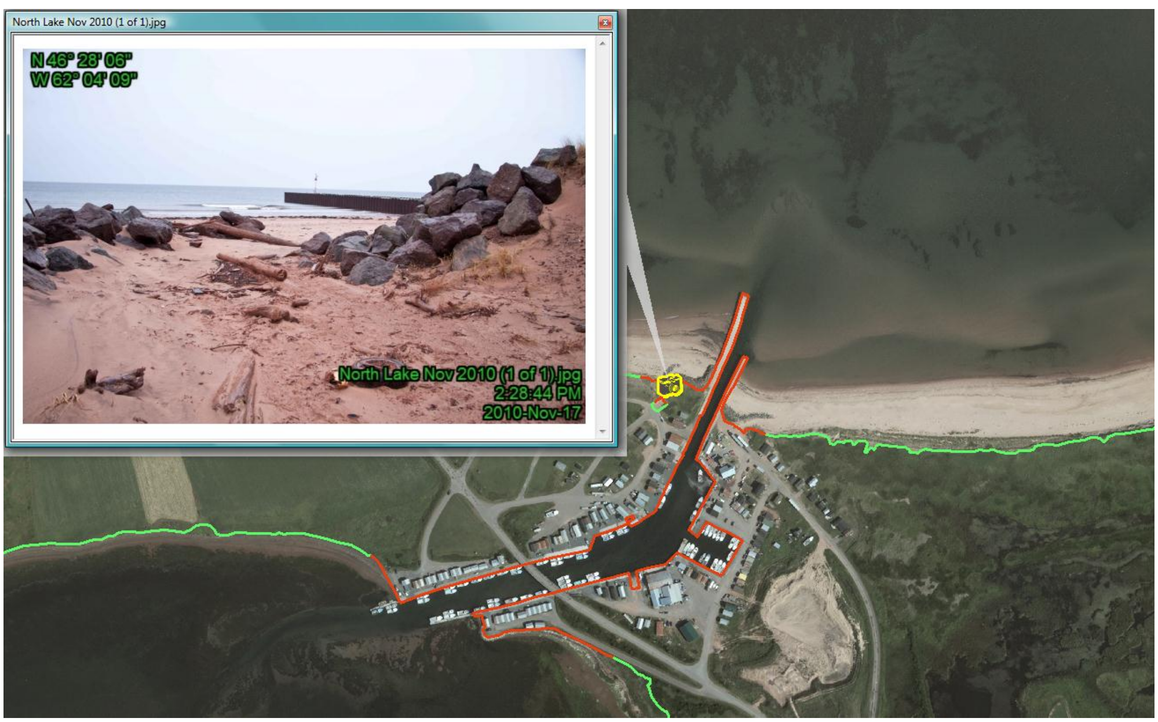


Figure 26 Shore protection database and site photo - North Lake Harbour.

Figure 27 Shore protection database and site photo - St. Peter's

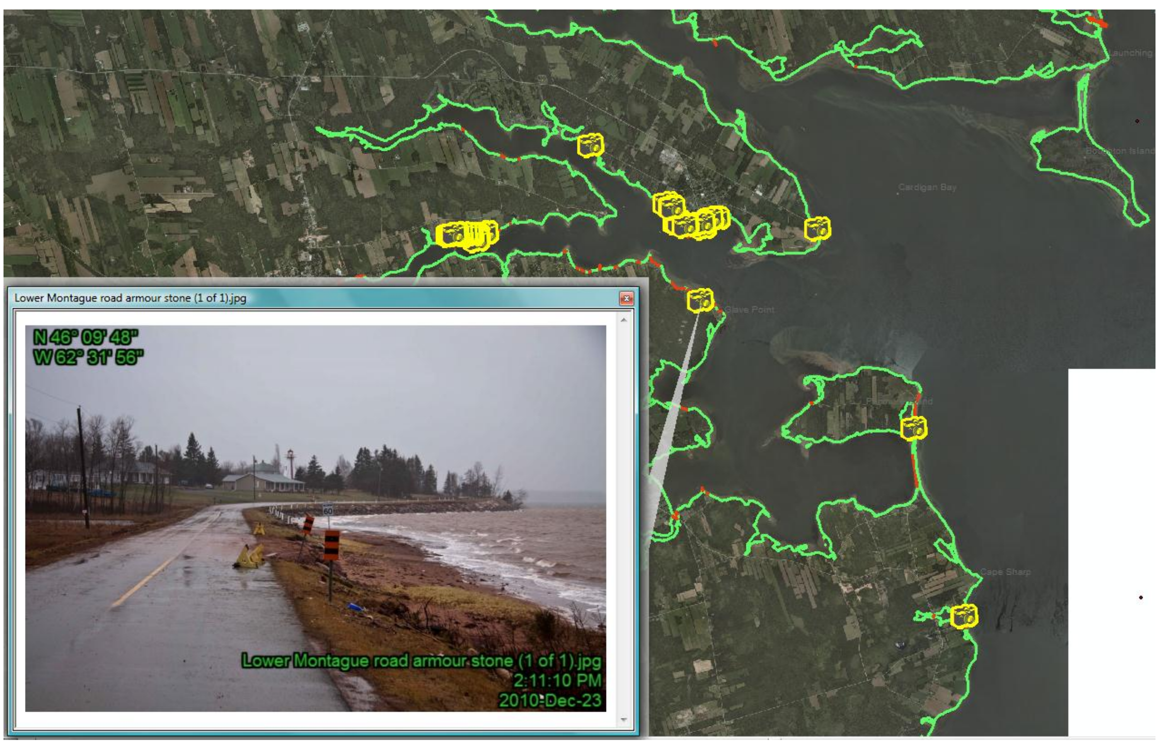


Figure 28 Shore Protection database and site photo - Lower Montague

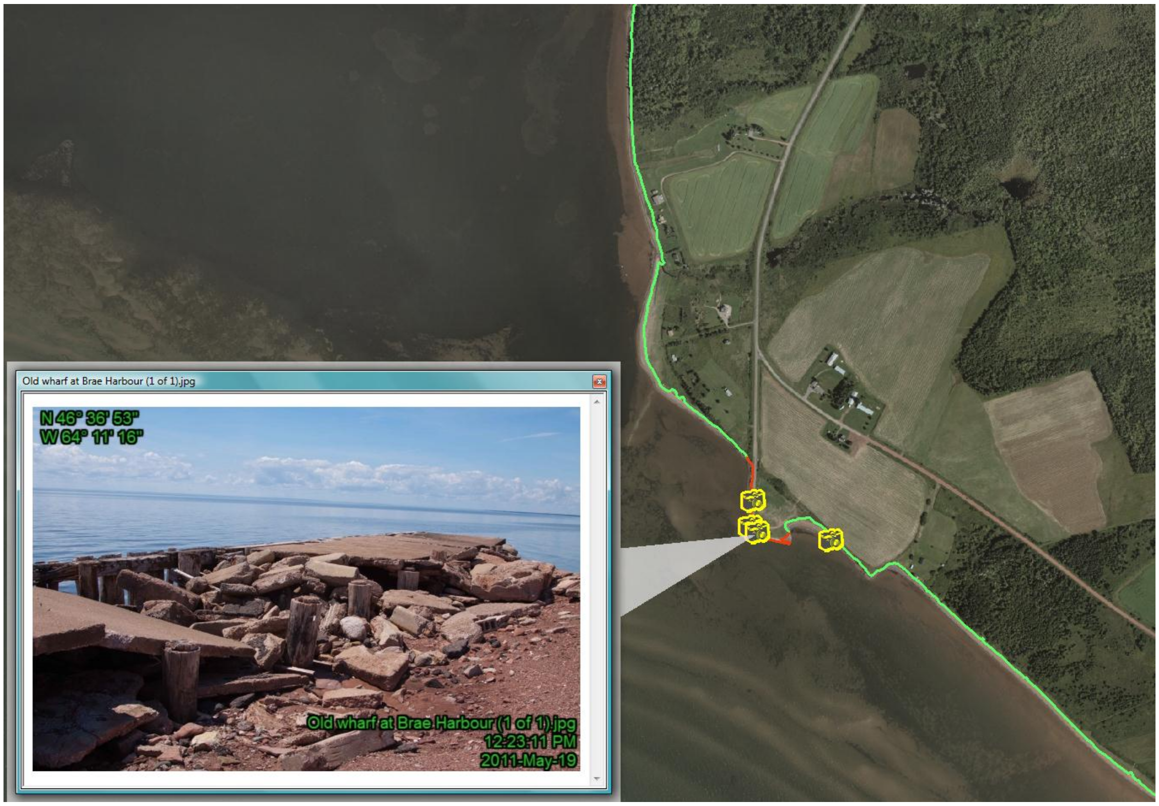


Figure 29 Shore Protection database and site photo - Brae Hbr.

Figure 30 Shore Protection and site photos – Charlottetown

Figure 31 Shore Protection and site photos - Summerside.

5. MetOcean conditions

5.1. Tidal conditions

The available Fisheries & Oceans Canada tidal stations near PEI (Figure 32) were used to generate 19-year long time series of water levels (2000-2019). The water levels were predicted using semi-empirical formulae for harmonic tides (Foreman, 1977; 1978; 1979) involving 73 harmonic constants. The mean water level and harmonic constants were obtained from DFO (Integrated Science Data Management site, ISDM).

These tidal time series were then analyzed to produce the summary tidal statistics. These water level statistics were mapped to the coastal classification shorelines such that each shoreline segment acquired the tidal statistics from the nearest tidal station. The following parameters were added to the coastal classification dataset through this process:

- **ID** – ID of the nearest DFO tidal station.
- **Zo** – the elevation of MSL above local chart datum.
- **MHHW** – higher high waters, mean tide – average of all the higher high water from 19 years of predictions.
- **HHWLT** – higher high water, large tide – average of the annual extreme high water levels.
- **MLLW** – lower low water, mean tide – average of all the lower low water levels.
- **LLWLT** – lower low water, large tide – average of the annual extreme low water levels.

MHHW, HHWLT, MLLW and LLWLT are all expressed in metres above mean sea level. Z_o as published in the DFO tidal statistics is the elevation of mean sea level above chart datum.

In the original report, the coverage of tidal data was segmented into 26 zones around the Island. In this revised report, tidal range data has been interpolated using a natural neighbour interpolation algorithm to create a better spatial representation of tidal conditions. Tidal data for Mt. Stewart at the head of the Hillsborough River has also been included to provide a (simplified) representation of tidal conditions along the Hillsborough River. Using the interpolation algorithm tidal conditions in the Hillsborough now vary linearly from Mt. Stewart to Charlottetown. The data for the tidal range at Mt. Stewart comes from a combination of field measurements and tidal modelling conducted as part of the Environmental Assessment of the Rails-to-Trails Causeway, (JWA, 2001).

Figure 33 shows the distribution of HHWLT around the island. The highest tidal ranges occur on the south shore near Tyron and in Hillsborough Bay. The lowest tidal ranges occur along the northeast shore near Naufrage as well as in Egmont Bay in the southwest.

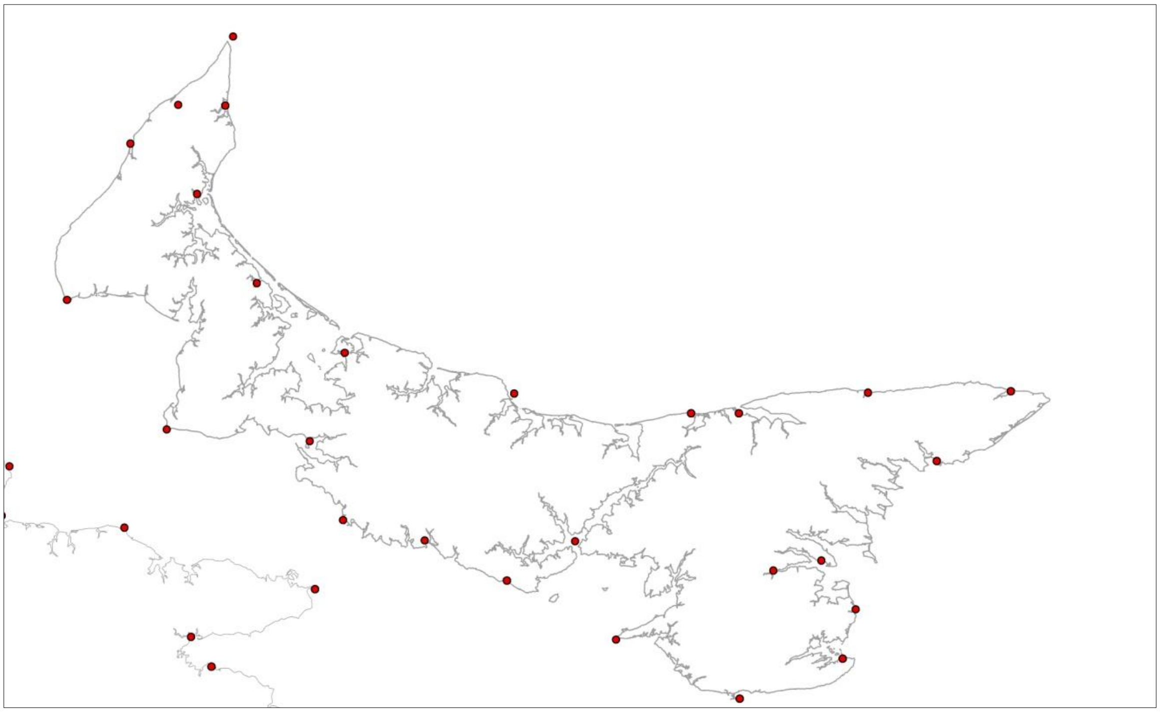


Figure 32 Tidal stations

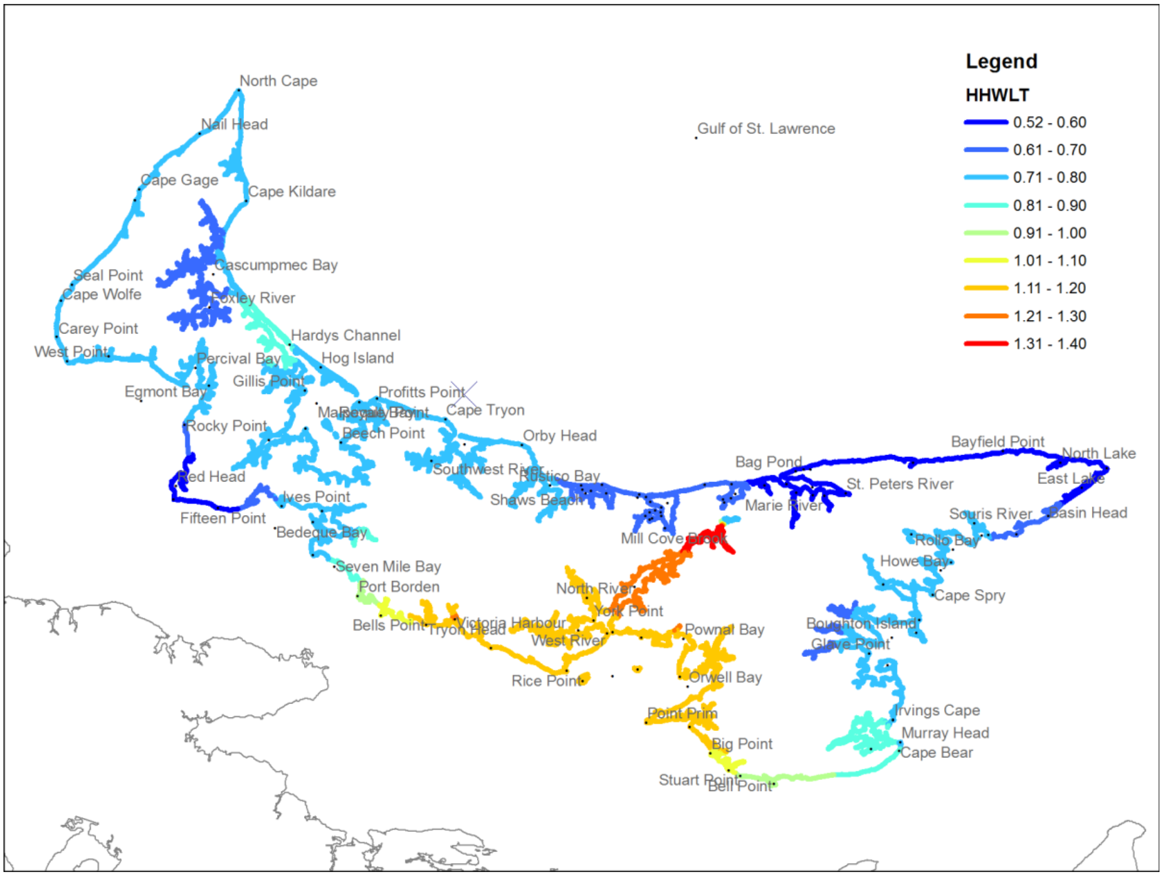


Figure 33 Elevation of peak tides (HHWLT) above mean sea level.

5.2. Tidal currents

The WebTide's Northwest Atlantic data set was used to generate 19-year long time series of tidal currents (2000-2019) around PEI. The tidal currents were predicted using semi-empirical formulae (Foreman, 1977; 1978; 1979) involving 5 harmonic constants; K1, O1, M2, N2 and S2. These tidal time series were then analyzed to produce the averaged tidal currents during the flood and ebb tides as shown in Figure 34 and Figure 35, respectively. Note that since these tidal currents are based on harmonic analysis of tidal conditions, they have a zero mean and hence do not predict any residual currents even though residual currents are known to exist along some of these shores.

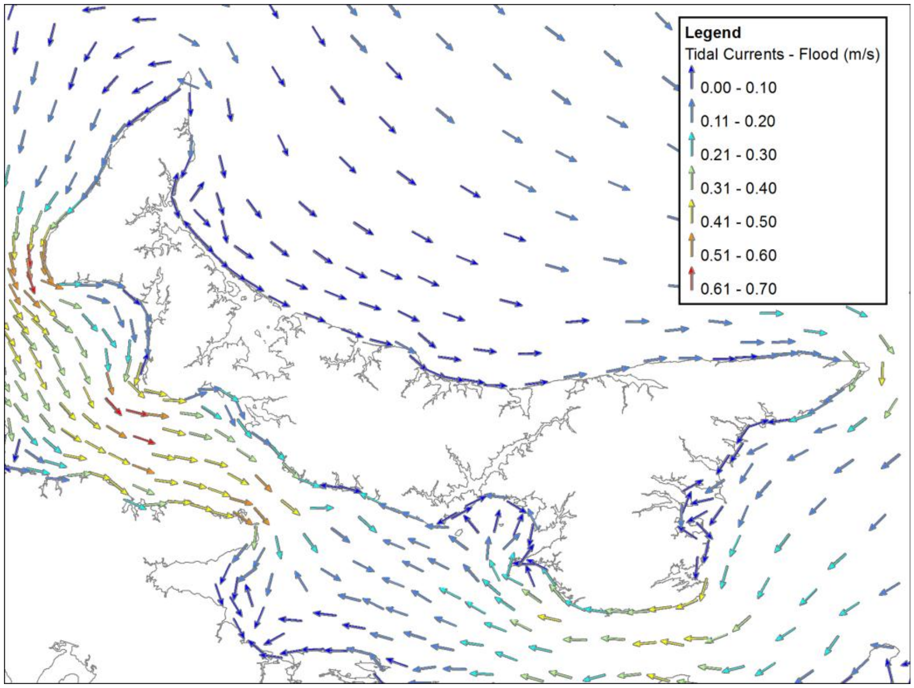


Figure 34 Averaged tidal currents during flood tide around PEI.

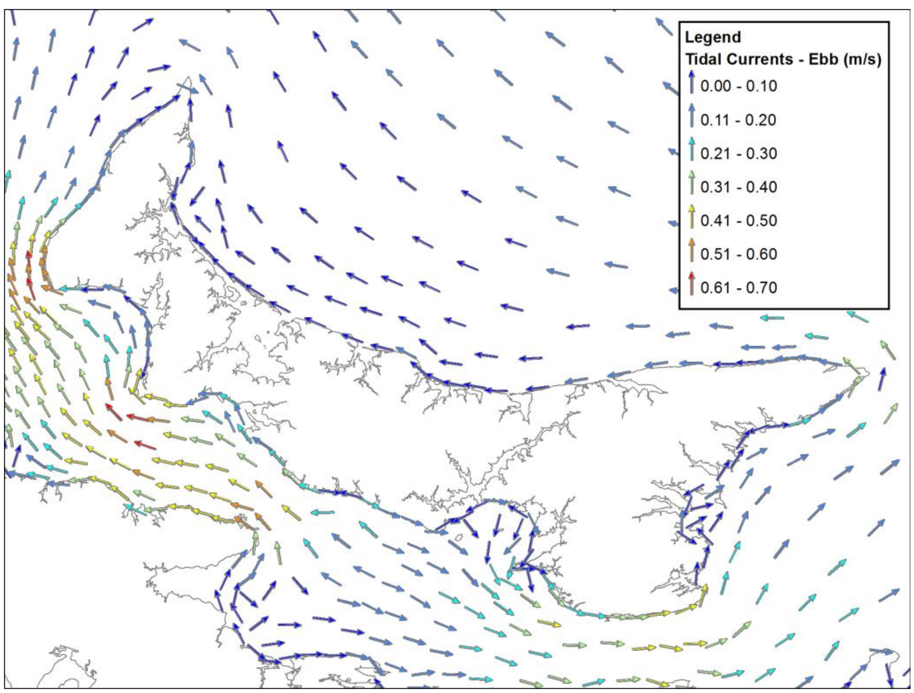


Figure 35 Averaged tidal currents during ebb tide around PEI.

The following parameters were added to the coastal classification dataset through this process:

- **FLOOD_UV** – average tidal current magnitude (m/s) during flood tides.
- **FLOOD_DIR** – corresponding current direction (° Azimuth).
- **EBB_UV**– average tidal current magnitude (m/s) during ebb tides.

- **EBB_DIR** – corresponding flow direction (° Azimuth).

Figure 36 shows the average flood tidal currents around the shoreline of PEI.

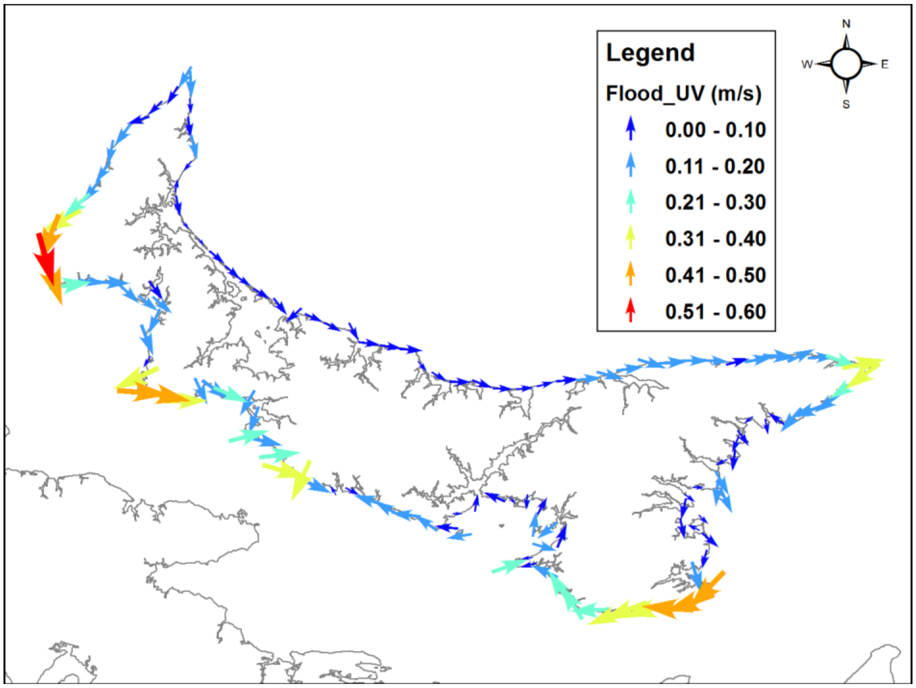


Figure 36 Averaged tidal currents during flood tide around the shoreline of PEI.

5.3. Wind and Wave Analysis

One of the goals of this study is to quantify shoreline exposure to storm conditions in order to be able to evaluate the sensitivity of the shoreline to coastal hazards. As described in Section 2.5, offshore wave conditions were obtained from the MSC50 wave database. For sheltered bays and estuaries that are not directly exposed to these open sea waves, a separate analysis was undertaken to compute the locally-generated wind waves that would be generated over restricted fetches. The following section described the procedures used to develop simplified shorelines for this analysis, and the analysis of the wind and wave conditions.

Shoreline Simplification

The shoreline was again simplified to a scale appropriate to this analysis. Two separate shoreline simplifications were developed in this analysis. One was developed for shorelines exposed to the open sea and the other for shorelines inside major estuaries.

Open-sea

A smoothed outer shoreline was developed that excludes estuaries and small bays. Estuary entrances smaller than 1000 m were excluded from this shoreline. In addition, a simplification technique (Douglas and Peucker, 1973) was used on the shoreline to reduce the number of segments. The algorithm is a type of generalization operation that removes small intrusions and extrusions within 1000 meters of a line without destroying its essential shape. The resulting simplified outer shoreline was composed of 684 line segments.

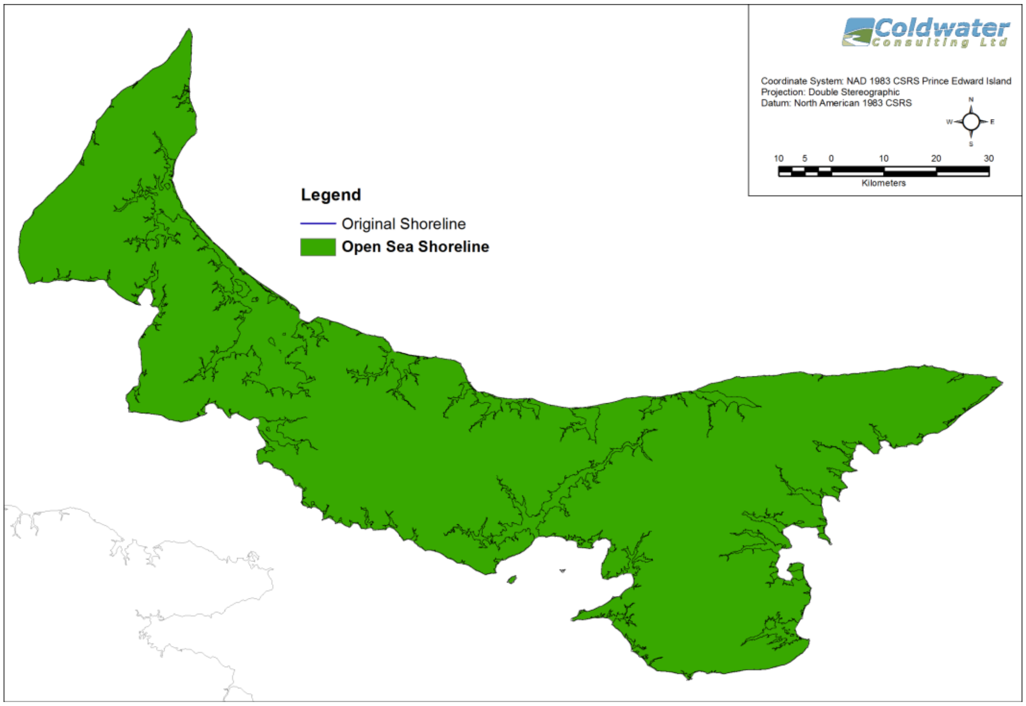


Figure 37 : Open sea shoreline

Estuaries

For estuaries, a second simplified shoreline was developed that covered all major estuaries but excluded small estuaries (estuaries with surface areas less than 10 square-kilometres). In addition to this, the same simplification technique (Douglas and Peucker, 1973) was used to reduce the number of segments. In this case a 500 m exclusion limit was applied. The resulting simplified shoreline was composed of 1435 segments.

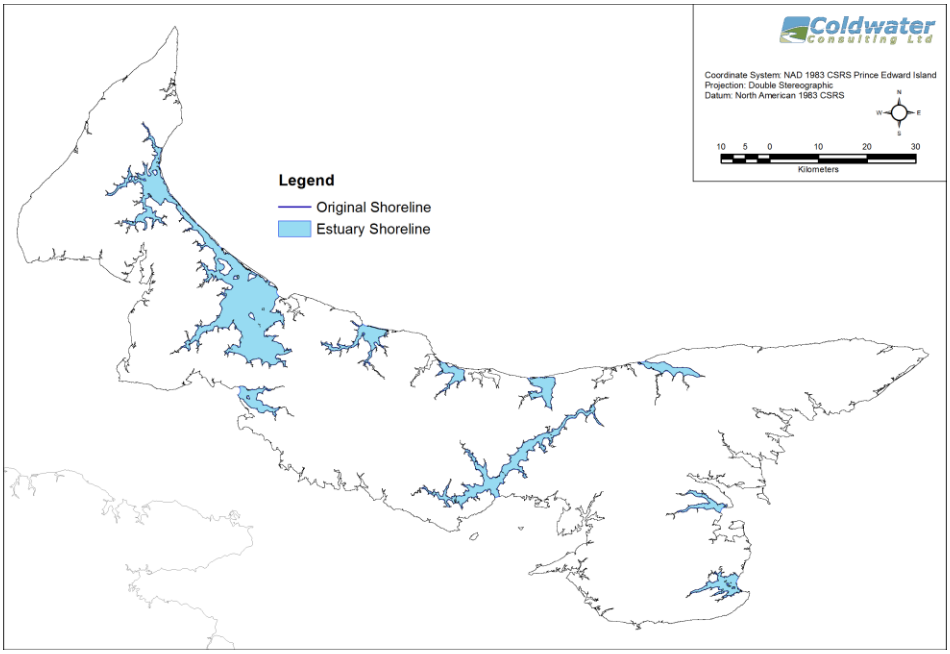


Figure 38 : Estuary shoreline

Wind

Wind fetch is defined as the unobstructed distance that wind can travel over water in a constant direction. Fetch is an important characteristic of open water because longer fetches can result in larger wind-generated waves. The larger waves, in turn, can increase shoreline erosion and sediment re-suspension. At each node along the simplified outer and estuary shorelines, the wind fetches were calculated on a 24-point compass (wind directions between 0^o to 360^o in 15° increments) using the algorithm proposed by Finlayson (2005). Calculated fetches within the estuaries were limited to 15 km (to avoid spurious fetches extending beyond the estuaries to the open Gulf). Fetches exposed to the open sea were assigned a value of -9999; a flag indicating that waves from the MSC50 database are to be used. A fetch of zero is assigned to landbound directions. Figure 39 provides an example of these fetch calculations along the north shore. The exposed northern coast is assigned a fetch value of -9999 indicating that wave conditions are exposed and that the nearest MSC50 hindcast node should be used for wave data. Inside the estuaries the fetch varies according to exposure.

Winds for all shore nodes were based on the nearest MSC50 grid point (which contains 6-hourly wind speed and direction data in addition to offshore wave conditions).

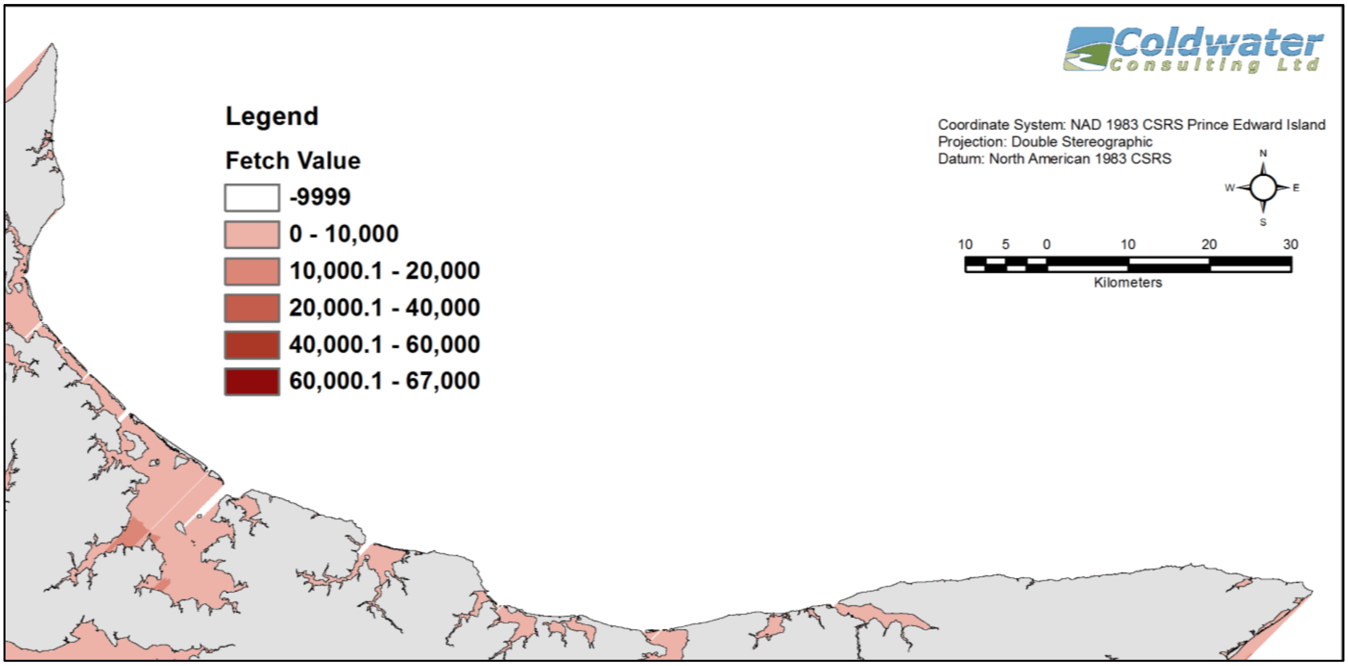


Figure 39 : Example of fetch value for a wind direction of 45° (Azimuth)

Waves

MSC50 Hindcast

The Meteorological Service of Canada (MSC) wave hindcast (MSC50) is a database of offshore (open-sea) wave conditions that has been developed by Environment Canada in conjunction with OceanWeather (Swail, et al., 2007). This hindcast (similar to a forecast, but looking back in time over past storm conditions) covers all of Atlantic Canada giving a comprehensive picture of recent offshore wave conditions. This dataset was developed using the UNIWAVE hindcast model which is a 3rd generation wave model based on the GEBCO-1-arc second bathymetric model of the Atlantic and a 58-yr record of 6-hourly wind and ice cover conditions spanning the time period from July 1954 to January 2010. Output from the wave model is provided on a regular grid. Output points surrounding PEI were extracted from the MSC50 database to provide offshore wave conditions for our analysis. This provides us with a detailed picture of wind and wave conditions in the waters surrounding PEI over the past 58 years.

Exposure

Every segment of shoreline not exposed to open sea is considered to be sheltered. In addition, if the open-sea exposure of a shoreline segment is less than 45°, the shoreline is also considered to be sheltered. Anything else is considered to be on the open coast and fully exposed to the wave conditions described by the MSC50 database.

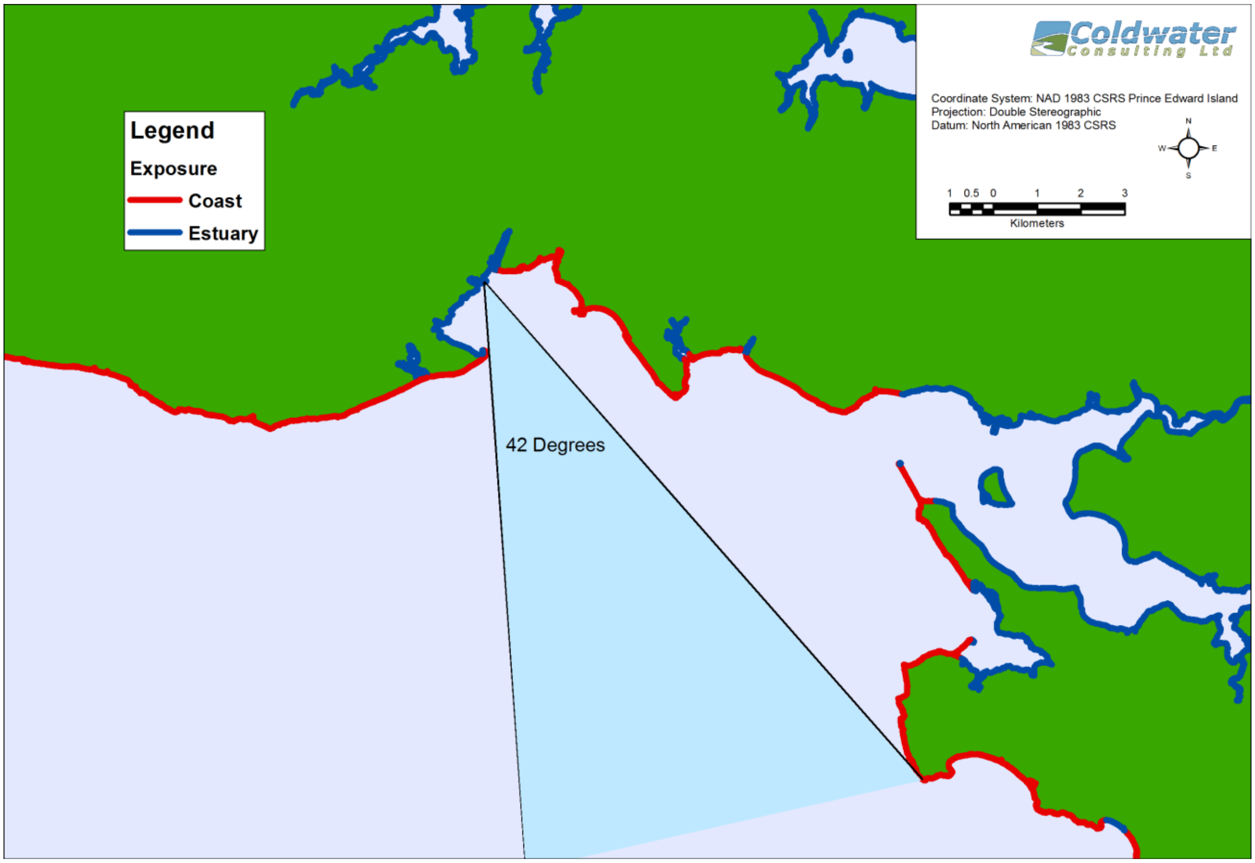


Figure 40 : Exposure example (Segment expose to 42 degrees of open-sea. Since it is less than 45°, it is considered a shoreline with sheltered exposure.

For each direction at each shoreline node a Fortran computer program was then used to compute whether locally-generated (fetch-limited) waves are to be used or the waves from the open water MSC50 hindcast. Locally-generated waves are computed using the wind speeds from the nearest MSC50 grid point. This method results in a continuous hindcast of nearshore wave conditions along the entire provincial shoreline at 6-hour intervals from 1958-2010. These waves are un-refracted and do not include the effects of local bathymetry on wave height or direction. Nearshore wave transformations are subsequently addressed in the following section (Section 5.4) of this report.

Climate change scenarios

The MSC50 hindcast was analysed to examine decadal variations in wave climate to develop scenarios for climate change. Fifty-seven years of hourly wind and wave conditions were acquired from M6010695, located offshore of the northern shoreline near Rustico (see Figure 41).

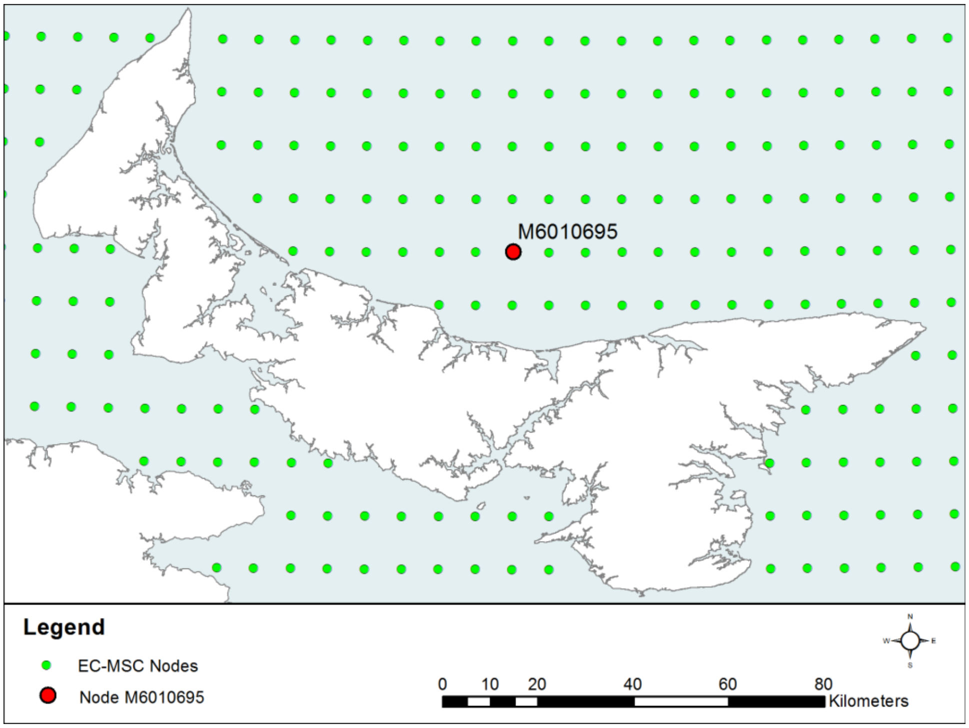


Figure 41 EC-MSC grid and selected node M6010695

The statistics of wind speed and wave height are summarized by direction in the rose plots presented in Figure 42. In this figure, wind and wave conditions are presented for node M6010695 averaged over the entire 57 year hindcast. As can be seen from this figure, winds are predominantly from the west. Wave heights are influenced by the combination of wind speed and open water distances (fetches) for each direction; consequently, waves are dominantly from north-northwest. Waves from the northeast are less frequent and less severe than those from the north, however, they do provide a significant amount of wave activity.

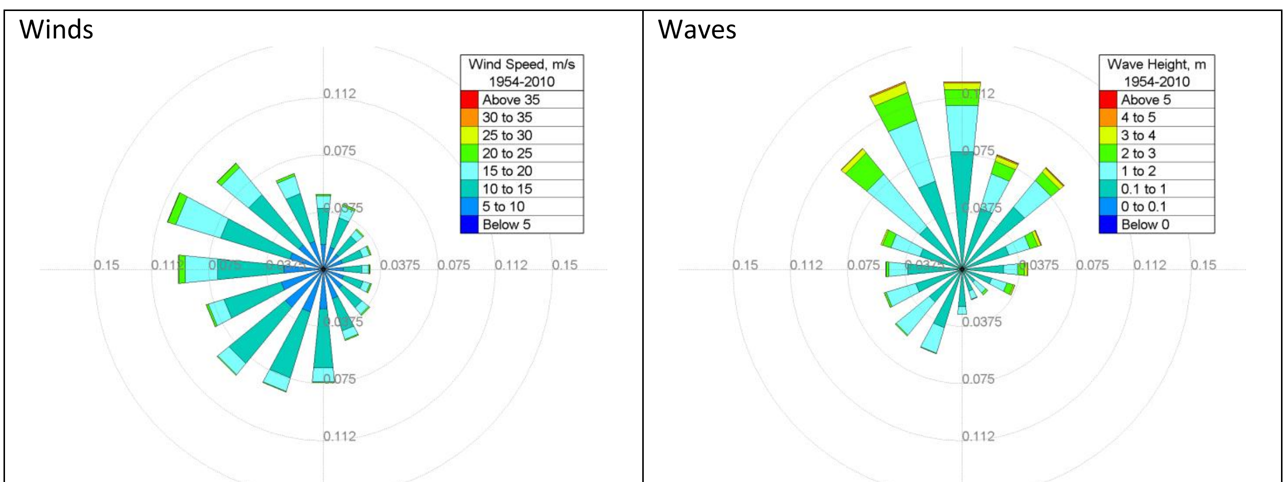


Figure 42 Wind and wave roses 1954-2010 (node M6010695)

Figure 43 shows the total wave energy (by direction) for each decade of the hindcast. There are distinctive variations in wave energy from decade to decade. While there is no long-term trend, it would appear that the 2000s (2000-2009) had more wave energy than other decades.

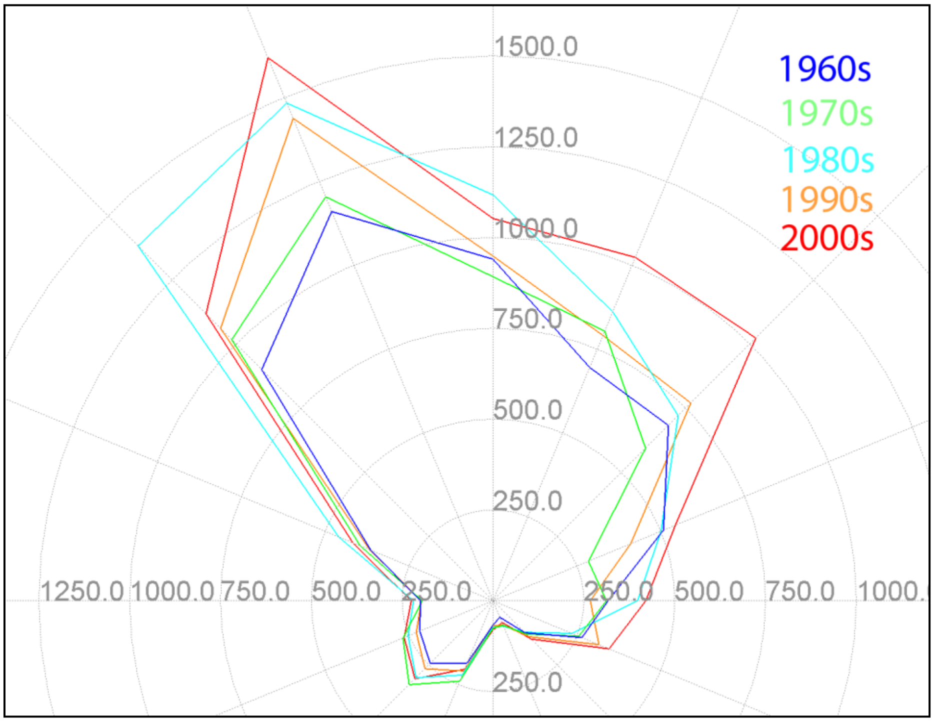
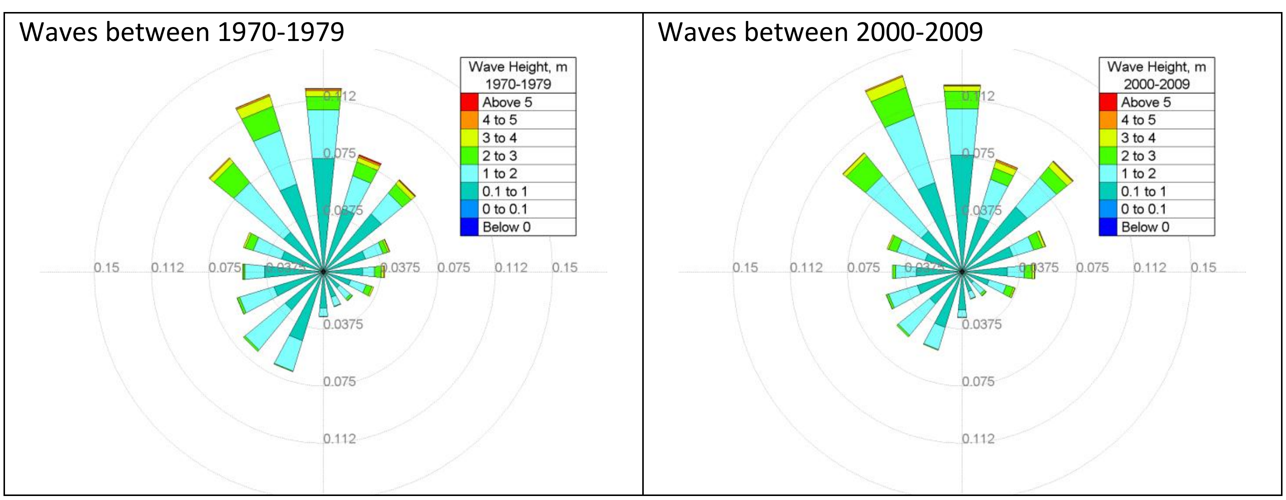


Figure 43 Annual decadal wave energy (node M6010695)

The hindcast data was sorted such that wave roses, ice cover and extreme wave heights could be developed for climate change scenarios. The 1970s were seen to be a period of relatively mild wave conditions while the 2000`s were relatively severe. These two separate data subsets (1970-79 and 2000-10) were used to examine decadal variations in wave climate. Figure 44 shows a breakdown of the wave climates in the 1970s and 2000s. As described in section 6, these wave conditions have been used to create mild and extreme wave climate scenarios.



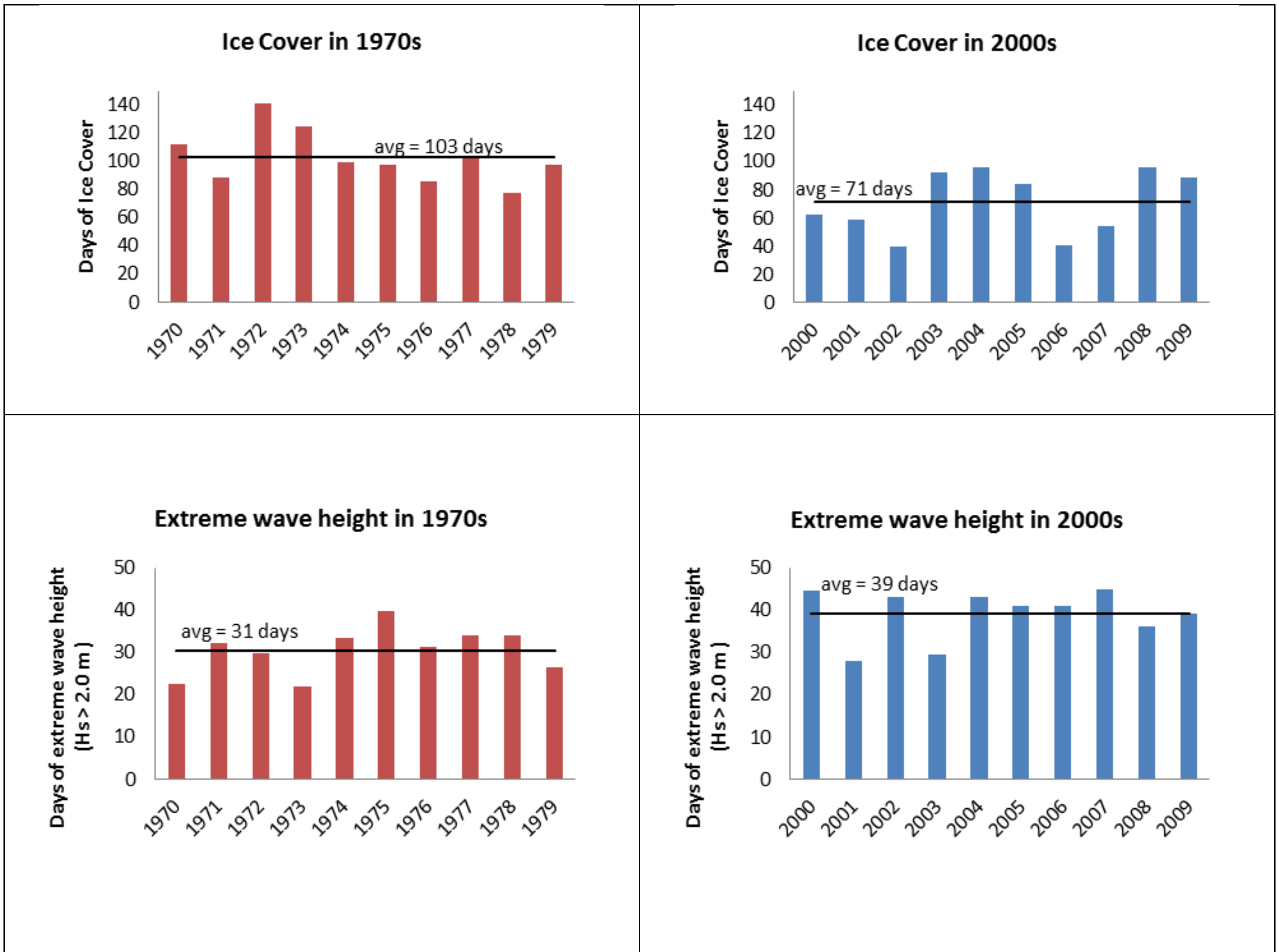


Figure 44 Wave rose, ice cover and extreme wave height for 1970-79 and 2000-10 (node M6010695)

5.4. Sea-Level Rise Scenarios

Sea-level rise scenarios were extracted directly from "*Scenarios and guidance for adaption to climate change and sea level rise – NS and PEI Municipalities*" (Richards & Daigle, 2011). Table 5 shows the estimated total change in sea level (relative to MSL in 2000) for years 2025, 2055, 2085 and 2100. Estimated sea-level rise values were based on global sea-level rise and local crustal subsidence. These scenarios developed by Richards & Daigle assume a single climate change scenario for sea-level rise as shown in Figure 45.

Table 5 Estimates of anticipated changes in total sea level for the years 2025, 2055, 2085 and 2010 (Richards & Daigle, 2011)

Municipality or Area	Total Change[1] (2025), m	Total Change[1] (2055), m	Total Change[1] (2085), m	Total Change[1] (2100), m
Nova Scotia				
Burncoat Head	0.15 ± 0.03	0.42 ± 0.15	0.82 ± 0.36	1.05 ± 0.48
Joggins	0.15 ± 0.03	0.42 ± 0.15	0.82 ± 0.36	1.05 ± 0.48
Pictou	0.15 ± 0.03	0.42 ± 0.15	0.82 ± 0.36	1.05 ± 0.48
Cheticamp	0.16 ± 0.03	0.45 ± 0.15	0.86 ± 0.36	1.10 ± 0.48
Sydney	0.16 ± 0.03	0.45 ± 0.15	0.86 ± 0.36	1.10 ± 0.48
Canso Harbour	0.16 ± 0.03	0.45 ± 0.15	0.86 ± 0.36	1.10 ± 0.48

Halifax	0.15 ± 0.03	0.43 ± 0.15	0.83 ± 0.36	1.06 ± 0.48
Lunenburg	0.15 ± 0.03	0.43 ± 0.15	0.83 ± 0.36	1.06 ± 0.48
Liverpool	0.15 ± 0.03	0.43 ± 0.15	0.83 ± 0.36	1.06 ± 0.48
Yarmouth	0.15 ± 0.03	0.43 ± 0.15	0.83 ± 0.36	1.06 ± 0.48
Digby	0.15 ± 0.03	0.42 ± 0.15	0.82 ± 0.36	1.05 ± 0.48
Hantsport	0.16 ± 0.03	0.45 ± 0.15	0.86 ± 0.36	1.10 ± 0.48
Prince Edward Island				
Alberton	0.16 ± 0.03	0.44 ± 0.15	0.84 ± 0.36	1.08 ± 0.48
West Point	0.14 ± 0.03	0.40 ± 0.15	0.78 ± 0.36	1.00 ± 0.48
Summerside	0.14 ± 0.03	0.40 ± 0.15	0.78 ± 0.36	1.00 ± 0.48
Rustico	0.16 ± 0.03	0.44 ± 0.15	0.84 ± 0.36	1.08 ± 0.48
Charlottetown	0.15 ± 0.03	0.43 ± 0.15	0.83 ± 0.36	1.06 ± 0.48
St Peter's	0.15 ± 0.03	0.42 ± 0.15	0.82 ± 0.36	1.05 ± 0.48
North Lake Harbour	0.16 ± 0.03	0.45 ± 0.15	0.86 ± 0.36	1.10 ± 0.48
Naufrage	0.16 ± 0.03	0.45 ± 0.15	0.86 ± 0.36	1.10 ± 0.48
Georgetown	0.16 ± 0.03	0.45 ± 0.15	0.86 ± 0.36	1.10 ± 0.48

[1] Relative to MSL in 2000

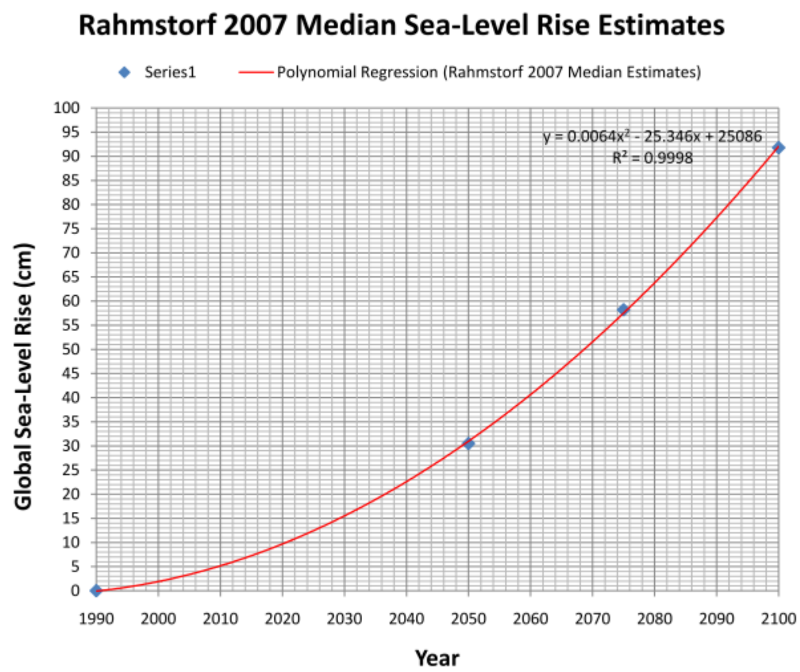


Figure 45 Sea-level rise estimates based on Rahmstorf (2007) as presented in Richards & Daigle (2011).

5.5. Storm-Surge Scenarios

Storm-surge scenarios are based on 10-, 25-, 50-, 100-yr return period and were extracted directly from Richards & Daigle (2011) (see Table 6).

Table 6 Return period surge levels (Richards & Daigle, 2011)

Municipality or Area	10-yr return period surge, m	25-yr return period surge, m	50-yr return period surge, m	100-yr return period surge, m
Nova Scotia				
Burncoat Head	0.89 ± 0.20	1.01 ± 0.20	1.10 ± 0.20	1.20 ± 0.20
Joggins	0.85 ± 0.20	0.96 ± 0.20	1.04 ± 0.20	1.13 ± 0.20
Pictou	1.12 ± 0.10	1.27 ± 0.10	1.38 ± 0.10	1.49 ± 0.10

Cheticamp	0.96 ± 0.20	1.10 ± 0.20	1.20 ± 0.20	1.31 ± 0.20
Sydney	0.63 ± 0.10	0.72 ± 0.10	0.78 ± 0.10	0.85 ± 0.10
Canso Harbour	0.71± 0.20	0.81± 0.20	0.88± 0.20	0.95± 0.20
Halifax	0.71 ± 0.10	0.81 ± 0.10	0.88 ± 0.10	0.95 ± 0.10
Lunenburg	0.71 ± 0.20	0.81 ± 0.20	0.88 ± 0.20	0.95 ± 0.20
Liverpool	0.71± 0.20	0.81 ± 0.20	0.88 ± 0.20	0.95 ± 0.20
Yarmouth	0.68 ± 0.10	0.75 ± 0.10	0.81 ± 0.10	0.87 ± 0.10
Digby	0.68 ± 0.20	0.75 ± 0.20	0.81 ± 0.20	0.87 ± 0.20
Hantsport	0.85 ± 0.20	0.96 ± 0.20	1.04 ± 0.20	1.13 ± 0.20
Prince Edward Island				
Alberton	1.07 ± 0.20	1.22 ± 0.20	1.33 ± 0.20	1.45 ± 0.20
West Point	1.35 ± 0.20	1.58 ± 0.20	1.76 ± 0.20	1.93 ± 0.20
Summerside	1.13 ± 0.20	1.3 ± 0.20	1.42 ± 0.20	1.55 ± 0.20
Rustico	1.07 ± 0.10	1.22 ± 0.10	1.33 ± 0.10	1.45 ± 0.10
Charlottetown	1.13 ± 0.10	1.30 ± 0.10	1.42 ± 0.10	1.55 ± 0.10
St Peter's	1.07 ± 0.20	1.22 ± 0.20	1.33 ± 0.20	1.45 ± 0.20
North Lake Harbour	1.07 ± 0.20	1.22 ± 0.20	1.33 ± 0.20	1.45 ± 0.20
Naufrage	1.07 ± 0.20	1.22 ± 0.20	1.33 ± 0.20	1.45 ± 0.20
Georgetown	1.18 ± 0.20	1.32 ± 0.20	1.46 ± 0.20	1.60 ± 0.20

6. Longshore Transport and Nearshore Waves

Using the wave conditions described in the foregoing section, nearshore wave conditions and longshore sediment transport rates were computed along the entire provincial coastline. This analysis provides a basis for interpretation of shoreline change (erosion and accretion) and also facilitates the identification of littoral cells – those shoreline units within which sediment transport processes are either partially of completely contained (analogous to a drainage basin in hydrology). The longshore transport analysis was conducted on the same simplified shoreline used for the wave climate analysis and then mapped onto the coastal classification shoreline. This resulted in the following fields being added to the database:

- **Hs**: The annual average significant breaking wave height (m). This is computed by refracting the offshore waves toward shore under the assumption of parallel offshore contours and determining the significant wave height as the wave starts to break.
- **MaxHs**: Similarly, MaxH_s is the average of the annual maximum significant breaking wave heights (m). (Similar to HHWLT, this is computed by selecting the largest wave height in each of year of the hindcast and then computing the average over the 58-years of the hindcast.)
- **Qn**: The net longshore sediment transport rate (m^3/yr) based on the long-term average rate over the 58 year duration of the wave hindcast. This is computed from the breaking wave height at each time step and its angle relative to the shoreline.
- **Ang**: The alongshore direction of the net rate (° Azimuth). This direction is always shore-parallel and simply indicates the direction of transport (to the left or right) in a manner suitable for mapping.

Figure 46 shows the distribution of annual average wave heights (H_s) around the island shorelines while Figure 47 shows the distribution of the annual maximum wave height (Max H_s). These plots show that both wave statistics are generally much higher along the north and west shores than elsewhere and that the peak storm heights (Max H_s) along the south shore are typically 1-2m while waves reach 4-6m along the north shore.

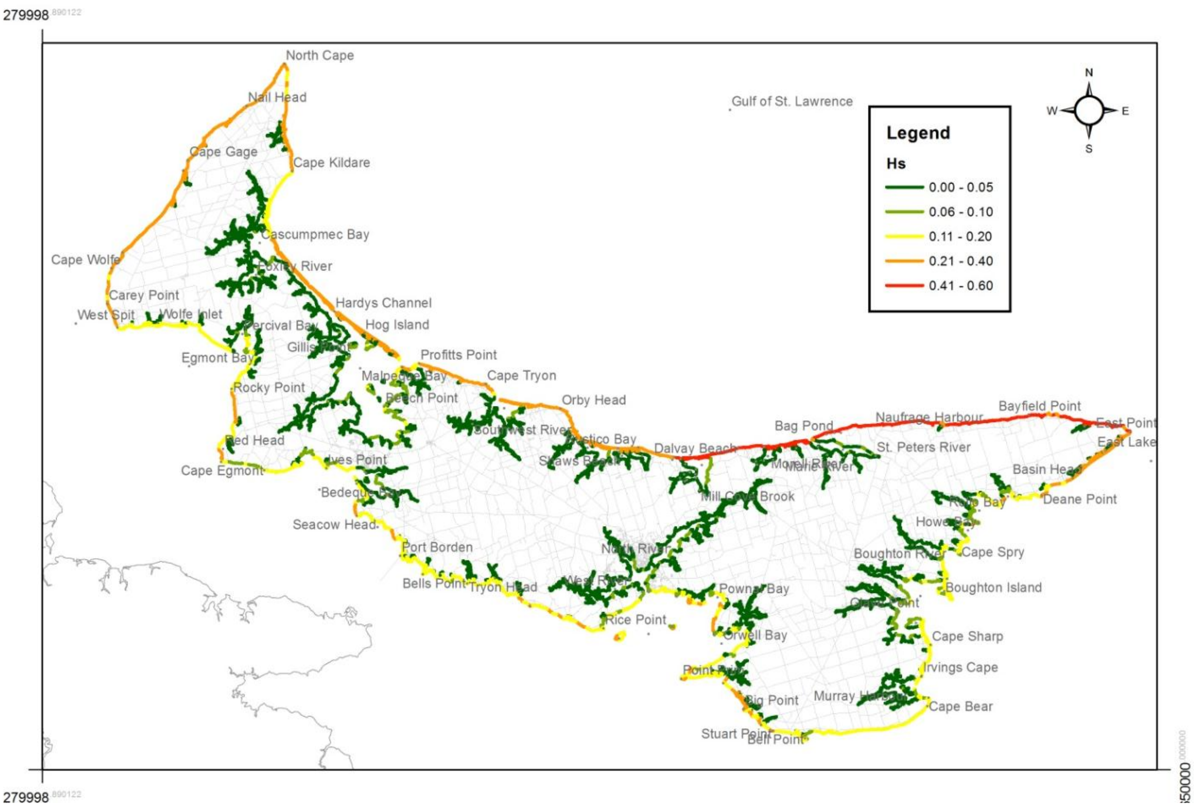


Figure 46 Annual average Hs at shore.

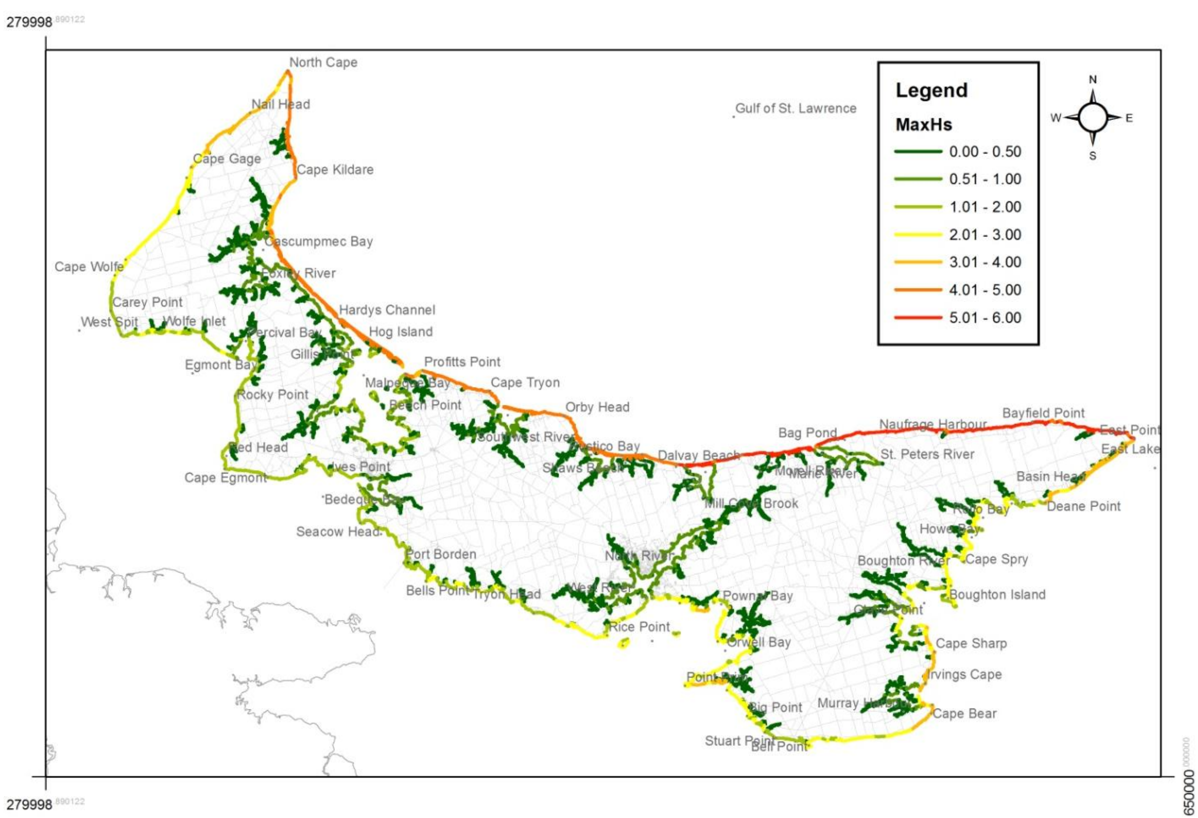


Figure 47 Annual maximum H_s at shore.

It is important to note here that the transport rate computed here is the potential transport rate due to wave action; that is, the amount of sand that waves would move along the shore if the supply of sediment were unlimited. The presence of cliffs and rock outcrops can limit the supply of sediment so that the potential rate represents an upper bound of the actual rate. This analysis does not consider the effects of complex nearshore bathymetry (shore parallel offshore contours are assumed) nor does it consider the effects of tidal or river currents which tend to dominate transport in inlets and estuaries.

The longshore transport rate calculations were conducted for each 6 hour timestep of the 58 year long wave hindcast. Transport rates were computed using the Queen's University Expression for Sediment Transport (Kamphuis, 2010) which is largely based on work undertaken by (Davies M. , Littoral Sand Transport Prediction, 1984). Field data upon which this predictor is based include longshore transport measurements from the Canadian Coastal Sediment Study (C2S2) conducted in the 1980s at Stanhope Beach and at Pointe Sapin, NB.

Review of published sediment grain size analysis for PEI beaches supported selection of 0.3 mm as a representative mean grain size for this broad-scale analysis. The algorithm used to compute sediment transport uses a bimodal energy analysis to separately compute the transport rates due to the sea and swell components of the wave climate. As a future development, the resulting transport rates could be combined with historical erosion rates based on shoreline change analysis to create a calibrated sediment budget for the province.

6.1. Decadal Variability

Nearshore wave conditions and longshore sediment transport rates were computed along the entire provincial coastline using the 1970s and 2000s datasets as describe in Section 5. This analysis provides a basis for interpretation of shoreline change (erosion and accretion) for two different climate conditions. The longshore transport analysis was conducted on the same simplified shoreline used for the wave climate analysis and then mapped onto the coastal classification shoreline. This resulted in the following fields being added to the database:

- **Hs_70**: The annual average significant breaking wave height (m) in the 1970s.
- **MaxHs_70**: The average of the annual maximum significant breaking wave heights (m) in the 1970s.
- **Qn_70**: The net longshore sediment transport rate (m^3/yr) based on the long-term average rate over the 10 year duration (1970-79) of the wave hindcast.
- **Ang_70**: The alongshore direction of the net rate (° Azimuth) based on the long-term average rate over the 10 year duration (1970-79) of the wave hindcast.
- **Hs_00**: The annual average significant breaking wave height (m) in the 2000s.
- **MaxHs_00**: The average of the annual maximum significant breaking wave heights (m) in the 2000s.
- **Qn_00**: The net longshore sediment transport rate (m^3/yr) based on the long-term average rate over the 10 year duration (2000-09) of the wave hindcast.
- **Ang_00**: The alongshore direction of the net rate (° Azimuth) based on the long-term average rate over the 10 year duration (2000-09) of the wave hindcast.

7. Interpretation

The resulting shore classification dataset provides a wealth of information about the shoreline and its exposure to the elements. This section provides some preliminary explorations of this dataset to illustrate its potential application.

Data interpretation is undertaken using maps (ArcGIS shapefiles) as well as charts and tables. For ease of use, the databases built into the ArcGIS shapefiles have been extracted into an Excel spreadsheet.

The scale and extent of the dataset favours the use of regional and sub-regional groupings in order to consolidate the dataset. The longshore transport analysis provides technical support for the adoption of the following littoral cell classification system.

The four shorelines of the province (North, East, West and South) provide the first-order of this classification. The north shore is delineated by the North Cape at its western limit and East Point at its eastern limit. The North shore consists of 259.5 km of open shoreline facing the Gulf of St. Lawrence and 1,192.7 km of estuarine shoreline.

The north shore is subdivided into several coastal compartments controlled by the presence of large estuaries and coastal headlands. Sediment is generally carried from west to east along this shore. The main sources for sediments along this shoreline are the eroding sandstone cliffs and bluffs that make up 40% of the Gulf shoreline. Major sediment sinks include the flood deltas of the major estuaries and the shoals of Milne Bank offshore of East Point which forms the terminal depositional feature for this shore.

Seven coastal compartments have been identified along the north shore:

- Tignish bounded by North Cape to the west and Cape Kildare to the east.
- Malpeque which comprises the shoreline from Cape Kildare to Cape Tryon as well as the Cascumpec and Malpeque estuaries.
- Cavendish which extends from Cape Tryon to Orby Head and includes the estuary of New London Bay.
- Brackley which extends from Orby Head to Cape Stanhope and includes both the Rustico and Brackley estuaries.
- Tracadie which extends from Cape Stanhope to Pointe Deroche and includes the Tracadie estuary.
- St. Peter's which extends from Pointe Deroche to Cable Head and includes the Savage Harbour and St. Peter's Bay estuaries.
- Naufrage which extends from Cable Head to the eastern terminus at East Point.

The East shore extends from East Point in the north to Cape Bear in the south and has been divided into the following four coastal compartments:

- Northeast extending from East Point to Howe Point including the South Lake, Basin Head, Souris and Fortune Bay estuaries.
- Boughton extending from Howe Point to Boughton Island including the Boughton river estuary.
- Cardigan extending from Boughton Island to Gaspereaux including the shorelines of Cardigan Bay, Brudenell and Panmure Island.

- Murray Harbour extending from Cape Sharp to Cape Bear including the Murray River estuary

The south shore extends from Cape Bear in the east to West Point in the west and has been divided into 5 coastal compartments:

- Southeast shore extends from Cape Bear past Wood Islands to Prim Point
- Hillsborough extends from Prim Point to Rice Point and includes the Charlottetown shoreline and the waters of the Hillsborough estuary.
- Tryon extends from Rice Point to Seacow Head and includes the depositional shoal at Tryon Head.
- Bedeque extends from Seacow Head to Cape Egmont and includes the Summerside shoreline.
- Egmont extends from Cape Egmont to West Point

The West shoreline is considered one contiguous coastal compartment extending from North Cape to West Point.

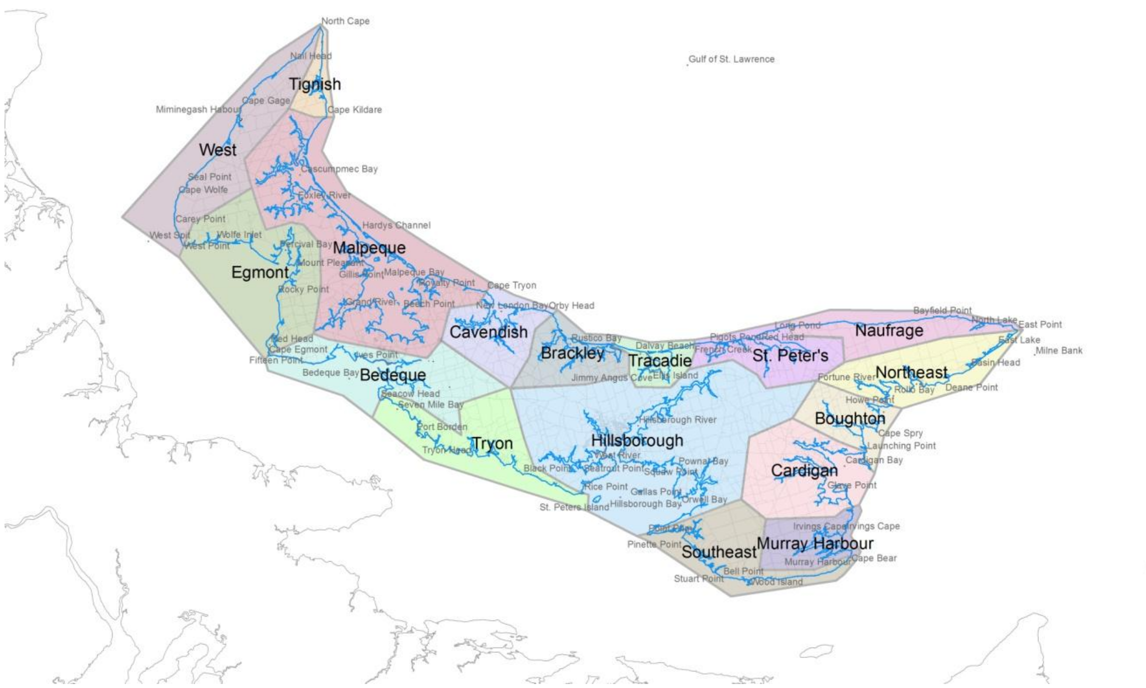
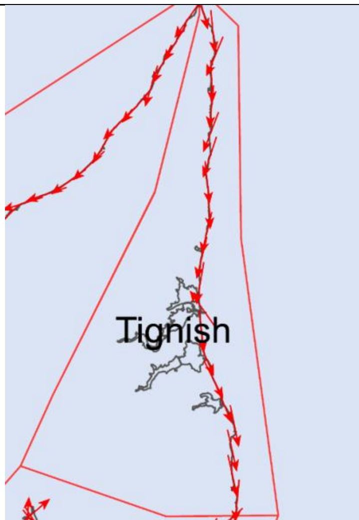
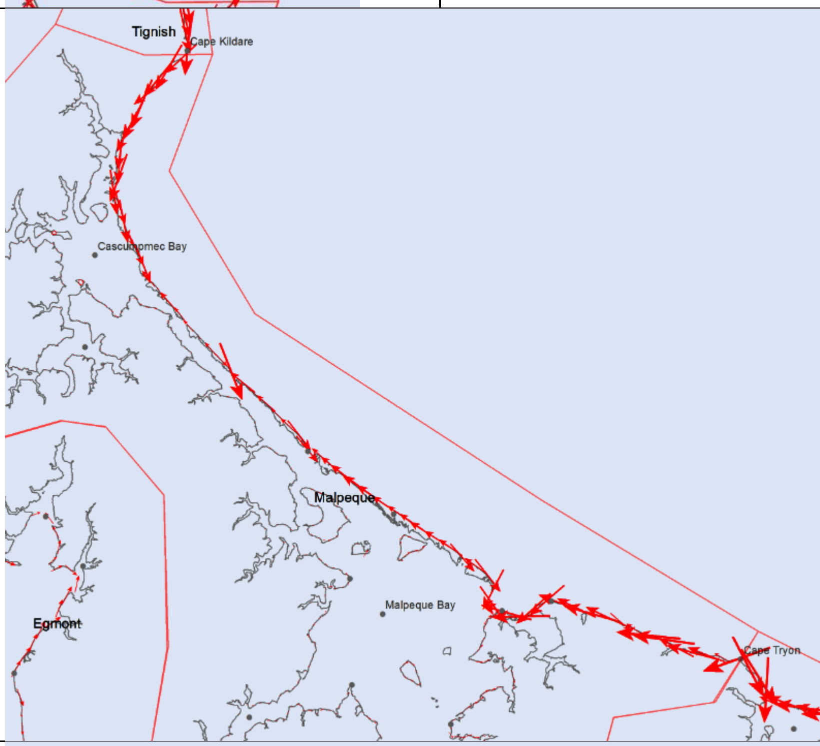


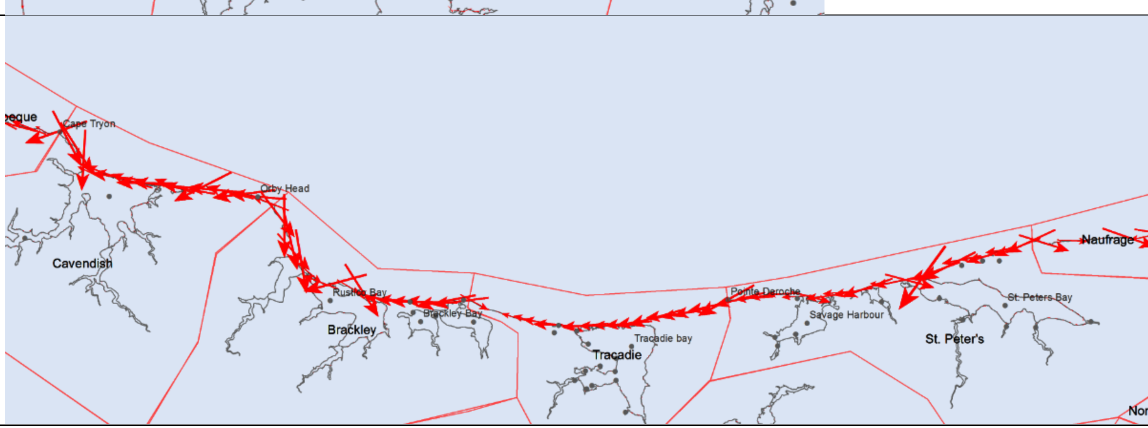
Figure 48 Shore Units

The following figures show plots of the annual average net longshore transport rates within each of these coastal compartments.

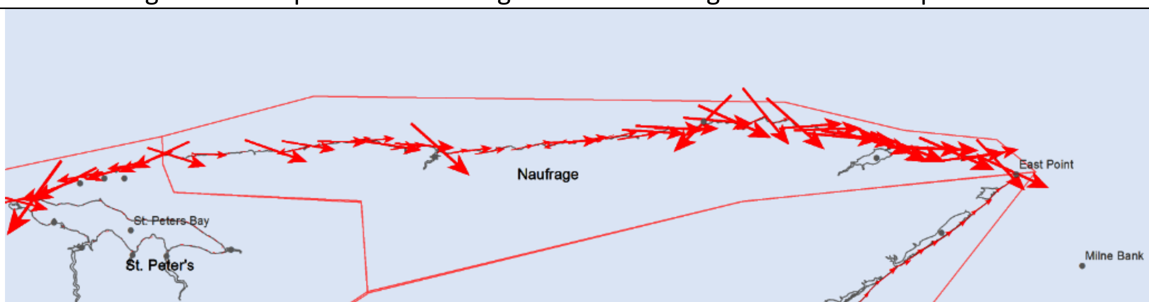


Top left: Tignish cell extending from North Cape to Cape Kildare – net transport is all to the south.
Middle: The shorelines of Cascumspec Bay and Malpeque Bay form a littoral cell confined by Cape Kildare and Cape Tyron. Sediment is supplied to this cell by the Tignish cell to the northwest. Cape Tyron is a divergent point with transport to the west of Cape Tyron heading west while sediments to the east head east.
Lower: The Cavendish, Brackley and Tracadie and St. Peter's littoral cells along the north shore are are relatively shallow embayments (bights).





Top: The Naufrage littoral cell (described as the 'eastern conveyor' by Shaw et al (2009) carries sediments eastward to East Point and Milne Bank with very few reversals.
Bottom: The northeast cell is sand-rich along the northern half. Wave-driven transport (shown here) is to the north for the reach north of Colville Bay. The inlets along this northern stretch are all offset to the south suggesting net southward transport. Wave diffraction, tidal currents and interactions with Milne Bank likely drive transport southward along this shore in contradiction to these wave-transport predictions. From Colville Bay to Howe Point, there are deep embayments with spit barriers generally indicating southward transport. South of Howe Point, net patterns appear to be northward. (See next page).
The littoral cells for Boughton Bay, Cardigan Bay and Murray Harbour are more clearly defined with the longshore transport vectors being consistent with general shoreline patterns.



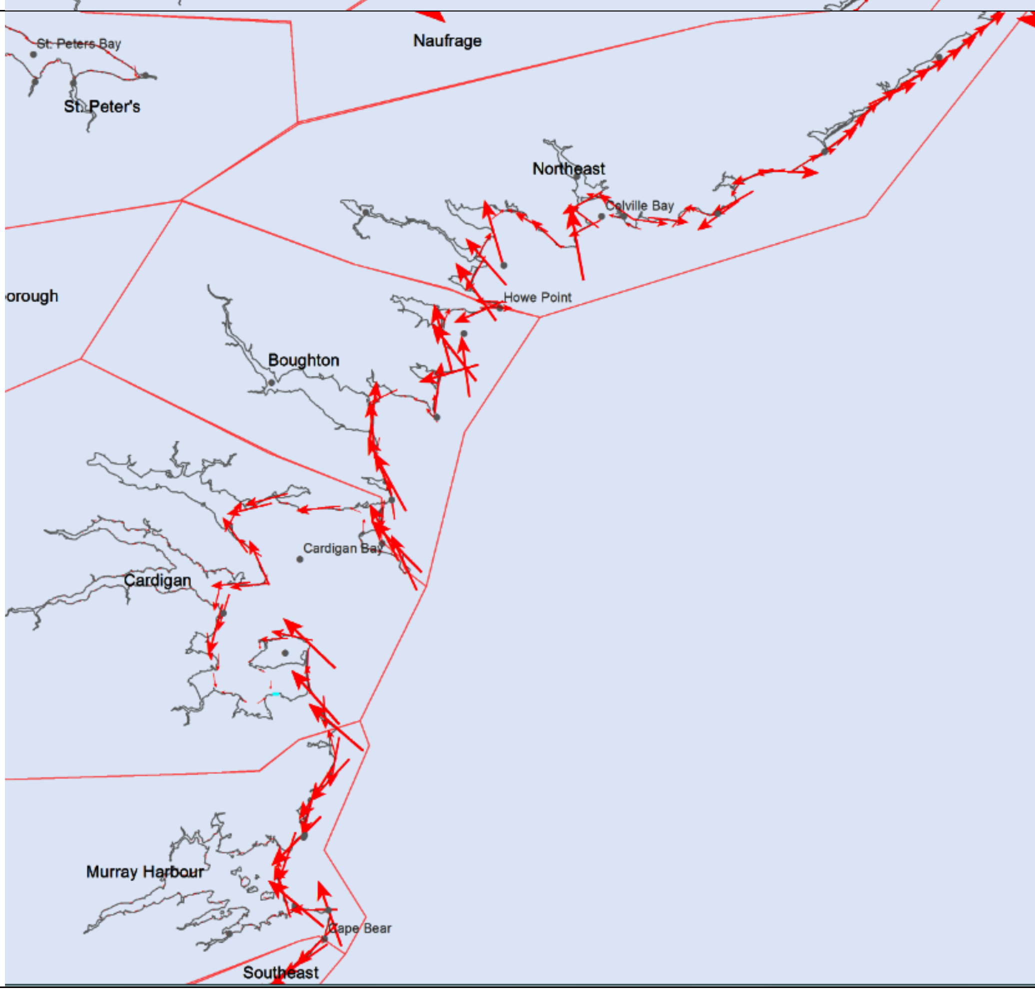


Figure 49 Southward offset inlets at South Lake and Basin Head.

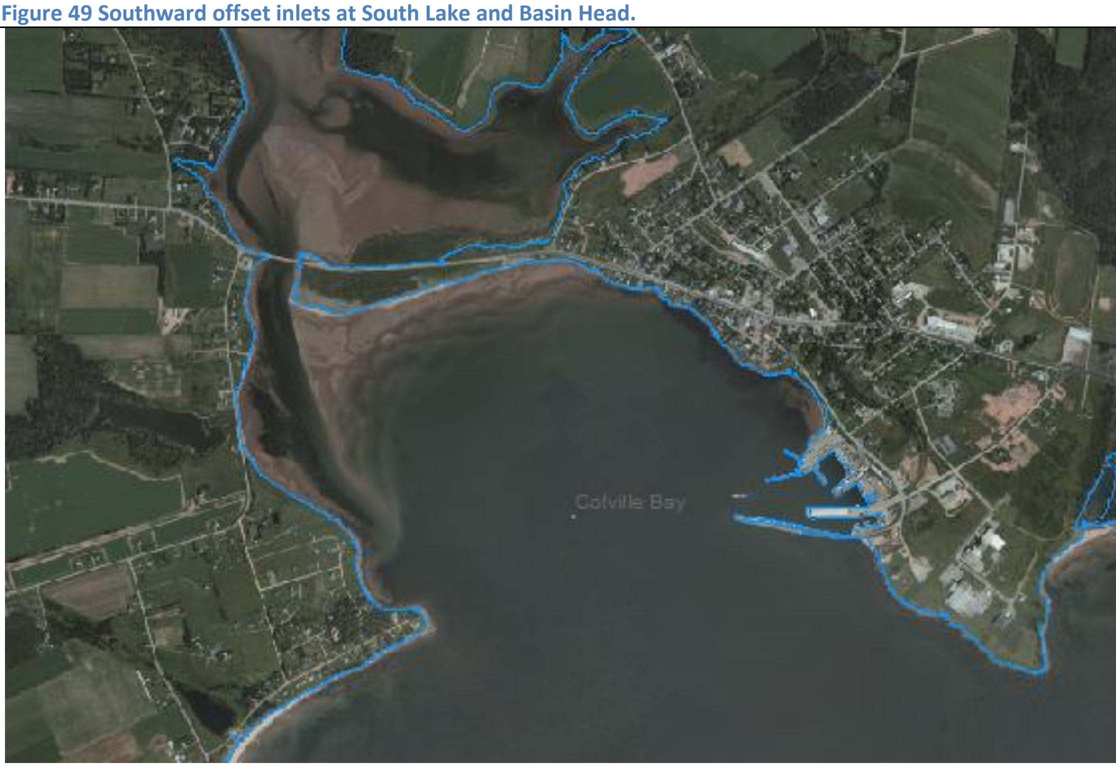
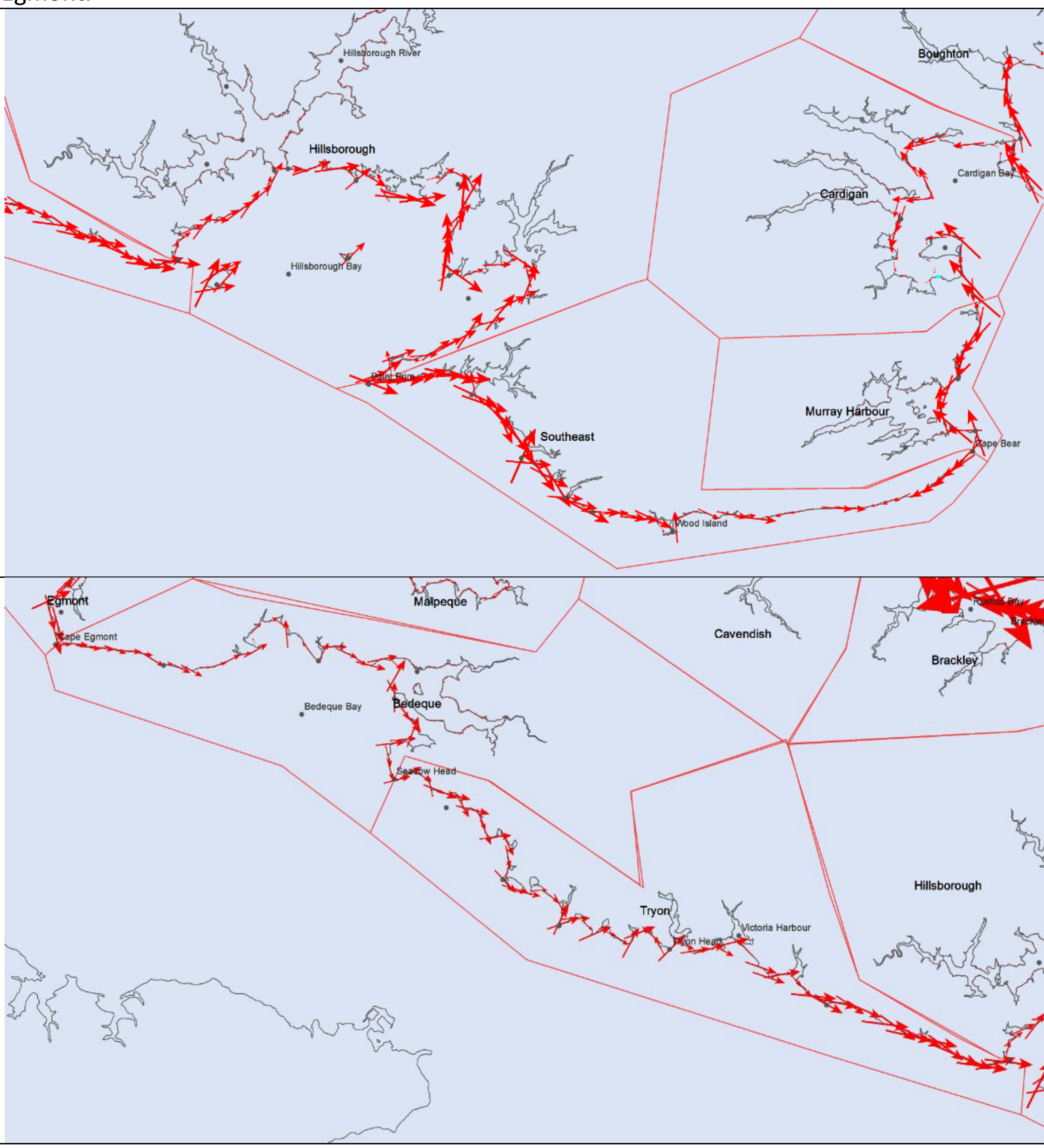


Figure 50 Southward offset spit at Souris, Colville BaY.

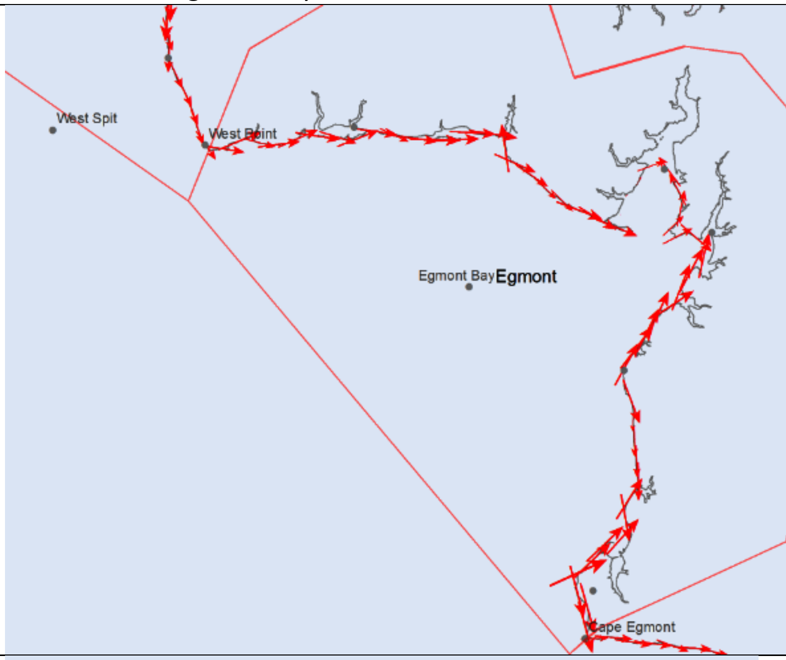
Top: The Southeast shoreline cell is defined by Cape Bear just below Murray Harbour to Point Prim . Net transport along the entire shore is toward Wood Islands. Net transport east of Wood Islands is weakly toward the west but the presence of a large offshore shoal at Cape Bear (Fisherman's Shoal) indicates that net transport might actually be to the east from Wood Islands to Cape Bear.

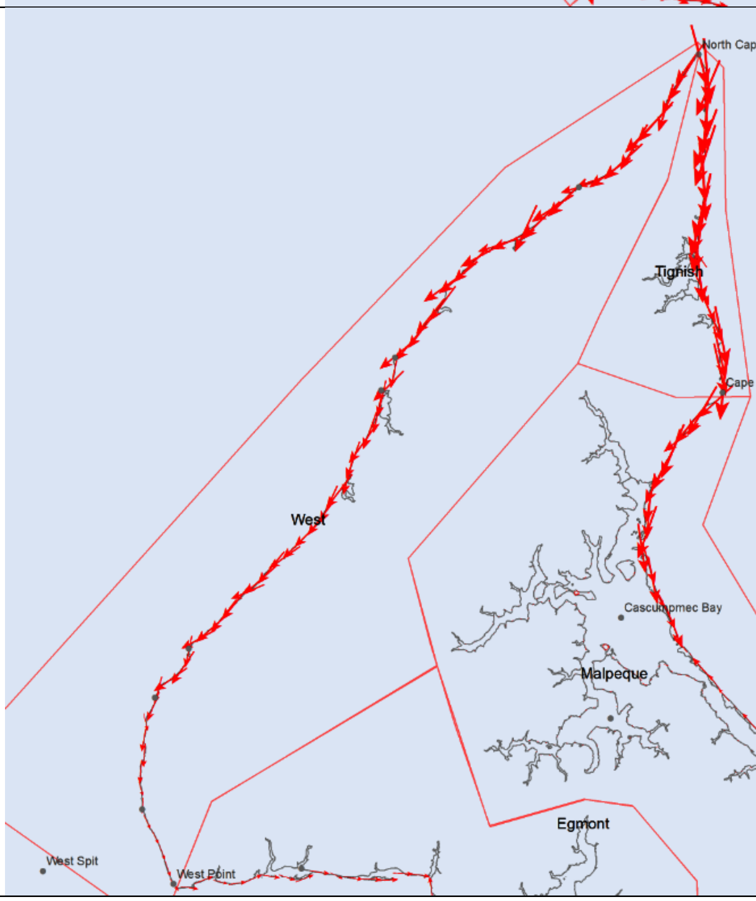
In Hillsborough Bay net transport is toward the centre of the bay away from both Point Prim and Rice Point Tidal flows from the Hillsborough estuary likely dominate over longshore transport within this reach.

Bottom:The Tryon littoral cell between Seacow Head and Rice Point shows a general trend of eastward transport. The Bedeque cell is defined by a divergence point at Seacow Head and Cape Egmont.



Top: The Egmont cell is clearly defined by west-flowing sediment transport at West Point and north-easterly transport from Cape Egmont
Bottom: The western shore is defined by a single littoral cell extending from North Point to West Point. Sediment from West Point is split between heading offshore to West Spit and eastward into Egmont Bay.





The following table (Table 7) provides a statistical summary of shore types along the provincial shoreline grouped by coastal (exposed) and estuarine (inshore) regional and by each of the coastal compartments listed in the foregoing. Highlights from this data include the following:

- Along the province's open coasts bluffs and cliffs compose 47% of the shoreline while 31% is sand dune.
- Along the Island's estuarine shorelines wetlands dominate (54% of the shoreline) and there are more cliffs (19%) than low plains (12%).
- Within the estuaries, the shores are on average 54% wetlands.

Table 7 Shore classification summaries

	Length of shore type (m)						Percentages				
	Bluff	Cliff	Low Plain	Sand Dune	Wetland	Grand Total	Bluff	Cliff	Low Plain	Sand Dune	Wetland
Coast	**47,604**	**373,705**	**89,345**	**249,531**	**42,102**	**802,286**	**5.9%**	**46.6%**	**11.1%**	**31.1%**	**5.2%**
East Shore	**7,950**	**60,957**	**9,223**	**49,208**	**9,179**	**136,517**	**5.8%**	**44.7%**	**6.8%**	**36.0%**	**6.7%**
Boughton	416	15,520	815	10,335	1,048	28,134	1.5%	55.2%	2.9%	36.7%	3.7%
Cardigan	3,749	12,651	3,706	9,506	5,606	35,218	10.6%	35.9%	10.5%	27.0%	15.9%
Murray Harbour	1,981	7,083	2,078	5,236	1,656	18,032	11.0%	39.3%	11.5%	29.0%	9.2%
Northeast	1,805	25,704	2,624	24,131	869	55,133	3.3%	46.6%	4.8%	43.8%	1.6%
North Shore	**9,325**	**96,274**	**3,465**	**147,212**	**3,459**	**259,734**	**3.6%**	**37.1%**	**1.3%**	**56.7%**	**1.3%**
Brackley	620	4,921	49	18,235		23,824	2.6%	20.7%	0.2%	76.5%	0.0%
Cavendish		10,864		12,035		22,899	0.0%	47.4%	0.0%	52.6%	0.0%
Malpeque	1,465	14,615	1,473	52,103	373	70,028	2.1%	20.9%	2.1%	74.4%	0.5%
Naufrage	4,750	45,838	246	13,311	2,663	66,807	7.1%	68.6%	0.4%	19.9%	4.0%
St. Peter's	873	557	371	23,917		25,718	3.4%	2.2%	1.4%	93.0%	0.0%
Tignish	1,493	18,868	1,264	5,307	75	27,008	5.5%	69.9%	4.7%	19.6%	0.3%
Tracadie	124	612	62	22,305	348	23,451	0.5%	2.6%	0.3%	95.1%	1.5%
South Shore	**27,788**	**163,923**	**75,699**	**36,371**	**29,093**	**332,874**	**8.3%**	**49.2%**	**22.7%**	**10.9%**	**8.7%**
Bedeque	7,267	13,896	13,323	4,411	9,061	47,959	15.2%	29.0%	27.8%	9.2%	18.9%
Egmont	3,179	11,958	34,277	11,941	879	62,234	5.1%	19.2%	55.1%	19.2%	1.4%
Hillsborough	7,390	44,999	11,688	4,995	17,679	86,751	8.5%	51.9%	13.5%	5.8%	20.4%
Southeast	3,647	43,326	5,126	12,159	1,205	65,464	5.6%	66.2%	7.8%	18.6%	1.8%
Tryon	6,305	49,743	11,285	2,865	269	70,466	8.9%	70.6%	16.0%	4.1%	0.4%
West Shore	**2,541**	**52,551**	**958**	**16,740**	**372**	**73,162**	**3.5%**	**71.8%**	**1.3%**	**22.9%**	**0.5%**
West	2,541	52,551	958	16,740	372	73,162	3.5%	71.8%	1.3%	22.9%	0.5%
Estuary	**129,530**	**472,518**	**302,793**	**231,182**	**1,340,632**	**2,476,655**	**5.2%**	**19.1%**	**12.2%**	**9.3%**	**54.1%**
East Shore	**29,318**	**140,308**	**33,605**	**78,401**	**173,407**	**455,039**	**6.4%**	**30.8%**	**7.4%**	**17.2%**	**38.1%**
Boughton	5,417	30,382	5,601	6,022	23,739	71,161	7.6%	42.7%	7.9%	8.5%	33.4%
Cardigan	13,551	55,308	14,582	28,995	52,527	164,964	8.2%	33.5%	8.8%	17.6%	31.8%
Murray Harbour	5,391	25,537	8,407	15,603	49,471	104,408	5.2%	24.5%	8.1%	14.9%	47.4%
Northeast	4,959	29,081	5,016	27,780	47,670	114,505	4.3%	25.4%	4.4%	24.3%	41.6%
North Shore	**61,236**	**212,558**	**134,122**	**124,655**	**659,869**	**1,192,441**	**5.1%**	**17.8%**	**11.2%**	**10.5%**	**55.3%**
Brackley	2,595	33,895	6,351	7,670	73,952	124,462	2.1%	27.2%	5.1%	6.2%	59.4%
Cavendish	4,196	54,274	4,827	8,032	64,789	136,118	3.1%	39.9%	3.5%	5.9%	47.6%
Malpeque	41,572	89,726	107,975	82,708	380,969	702,949	5.9%	12.8%	15.4%	11.8%	54.2%
Naufrage	289	1,475	856	929	13,345	16,896	1.7%	8.7%	5.1%	5.5%	79.0%
St. Peter's	8,886	22,728	9,708	16,542	59,946	117,810	7.5%	19.3%	8.2%	14.0%	50.9%
Tignish	1,047	1,015	2,753	1,135	33,296	39,247	2.7%	2.6%	7.0%	2.9%	84.8%
Tracadie	2,651	9,445	1,654	7,638	33,572	54,960	4.8%	17.2%	3.0%	13.9%	61.1%
South Shore	**36,958**	**116,672**	**130,694**	**24,972**	**494,560**	**803,857**	**4.6%**	**14.5%**	**16.3%**	**3.1%**	**61.5%**
Bedeque	10,766	11,028	19,069	2,952	43,074	86,889	12.4%	12.7%	21.9%	3.4%	49.6%
Egmont	3,789	1,631	49,665	10,519	62,893	128,495	2.9%	1.3%	38.7%	8.2%	48.9%
Hillsborough	13,134	80,003	19,289	1,539	307,864	421,830	3.1%	19.0%	4.6%	0.4%	73.0%
Southeast	2,654	12,089	15,500	6,768	59,232	96,243	2.8%	12.6%	16.1%	7.0%	61.5%
Tryon	6,616	11,922	27,172	3,193	21,497	70,399	9.4%	16.9%	38.6%	4.5%	30.5%
West Shore	**2,018**	**2,980**	**4,371**	**3,154**	**12,795**	**25,318**	**8.0%**	**11.8%**	**17.3%**	**12.5%**	**50.5%**
West	2,018	2,980	4,371	3,154	12,795	25,318	8.0%	11.8%	17.3%	12.5%	50.5%
Grand Total	**177,134**	**846,223**	**392,138**	**480,713**	**1,382,734**	**3,278,941**	**5.4%**	**25.8%**	**12.0%**	**14.7%**	**42.2%**

Table 8 provides similar statistics for coastal and estuarine shorelines combined. This compilation indicates that:

- Wetlands are by far the dominant overall shore type composing some 42% of the total shore compared to cliffs (26%), bluffs (5%), low plains (12%) and sand dunes (15%).
- The Hillsborough littoral cell contains 325 km of wetland shores while Malpeque contains 381 km.
- There are 206 km of low plain along the south shore compared to 138 km along the north shore.
- 772 km of the Island's total shoreline length rests within the Malpeque coastal compartment as compared to 98 km along the entire west shore (owing to the relatively straight cliff/bluff shoreline of the western shore compared to the fractal estuarine shoreline at Malpeque).

Table 8 Summary shoreline statistics for coast and estuarine shorelines combined.

Estuary and coasts combined							Percentages				
	Bluff	Cliff	Low Plain	Sand Dune	Wetland	Grand Total	Bluff	Cliff	Low Plain	Sand Dune	Wetland
Coast & Estuaries	**177,134**	**846,223**	**392,138**	**480,713**	**1,382,734**	**3,278,941**	**5.4%**	**25.8%**	**12.0%**	**14.7%**	**42.2%**
East Shore	**37,268**	**201,265**	**42,828**	**127,609**	**182,586**	**591,555**	**6.3%**	**34.0%**	**7.2%**	**21.6%**	**30.9%**
Boughton	5,833	45,902	6,416	16,358	24,787	99,295	5.9%	46.2%	6.5%	16.5%	25.0%
Cardigan	17,301	67,959	18,288	38,502	58,133	200,182	8.6%	33.9%	9.1%	19.2%	29.0%
Murray Harbour	7,371	32,619	10,484	20,838	51,127	122,440	6.0%	26.6%	8.6%	17.0%	41.8%
Northeast	6,764	54,785	7,640	51,911	48,539	169,639	4.0%	32.3%	4.5%	30.6%	28.6%
North Shore	**70,561**	**308,832**	**137,587**	**271,867**	**663,328**	**1,452,175**	**4.9%**	**21.3%**	**9.5%**	**18.7%**	**45.7%**
Brackley	3,215	38,815	6,400	25,904	73,952	148,286	2.2%	26.2%	4.3%	17.5%	49.9%
Cavendish	4,196	65,138	4,827	20,067	64,789	159,017	2.6%	41.0%	3.0%	12.6%	40.7%
Malpeque	43,036	104,342	109,448	134,810	381,342	772,978	5.6%	13.5%	14.2%	17.4%	49.3%
Naufrage	5,039	47,313	1,102	14,240	16,008	83,702	6.0%	56.5%	1.3%	17.0%	19.1%
St. Peter's	9,759	23,285	10,079	40,459	59,946	143,527	6.8%	16.2%	7.0%	28.2%	41.8%
Tignish	2,540	19,883	4,017	6,442	33,372	66,255	3.8%	30.0%	6.1%	9.7%	50.4%
Tracadie	2,775	10,057	1,716	29,943	33,919	78,410	3.5%	12.8%	2.2%	38.2%	43.3%
South Shore	**64,746**	**280,595**	**206,394**	**61,343**	**523,654**	**1,136,731**	**5.7%**	**24.7%**	**18.2%**	**5.4%**	**46.1%**
Bedeque	18,033	24,924	32,392	7,364	52,135	134,848	13.4%	18.5%	24.0%	5.5%	38.7%
Egmont	6,968	13,589	83,941	22,460	63,772	190,730	3.7%	7.1%	44.0%	11.8%	33.4%
Hillsborough	20,524	125,002	30,977	6,534	325,543	508,580	4.0%	24.6%	6.1%	1.3%	64.0%
Southeast	6,301	55,415	20,626	18,928	60,438	161,707	3.9%	34.3%	12.8%	11.7%	37.4%
Tryon	12,920	61,665	38,457	6,058	21,766	140,865	9.2%	43.8%	27.3%	4.3%	15.5%
West Shore	**4,559**	**55,531**	**5,329**	**19,894**	**13,167**	**98,480**	**4.6%**	**56.4%**	**5.4%**	**20.2%**	**13.4%**
West	4,559	55,531	5,329	19,894	13,167	98,480	4.6%	56.4%	5.4%	20.2%	13.4%

With GIS datasets that describe the shoreline, the existing shore protection infrastructure and the exposure of the shoreline to metocean conditions opens up a wide range of possibilities for assessing and examining the vulnerability of the shore to present and future hazards. This is not meant to be a definitive assessment of shoreline vulnerability and further work should be undertaken to refine the statistical framework for this analysis as well as more detailed analysis of wave-shoreline interactions.

Decadal Variation

The following two figures show the decadal variations in average annual net alongshore sediment transport rates around the Island of PEI. It shows that the potential sediment transport rates were relatively lower for most of the shoreline in the 1970s. This is due to the mild wave conditions compared to the relatively severe wave conditions in 2000's. Figure 53 shows an example of the sediment transport rate computed using the full 57 years of hindcast and that based on the 2000s hindcast. In some locations the overall net transport direction is reversed in the 2000s dataset. This points to one of the more interesting possibilities from climate change - a change in offshore wave climate could result in dramatic changes to sediment budgets and sediment pathways – possibly some erosional areas may become depositional while depositional areas may become erosional.

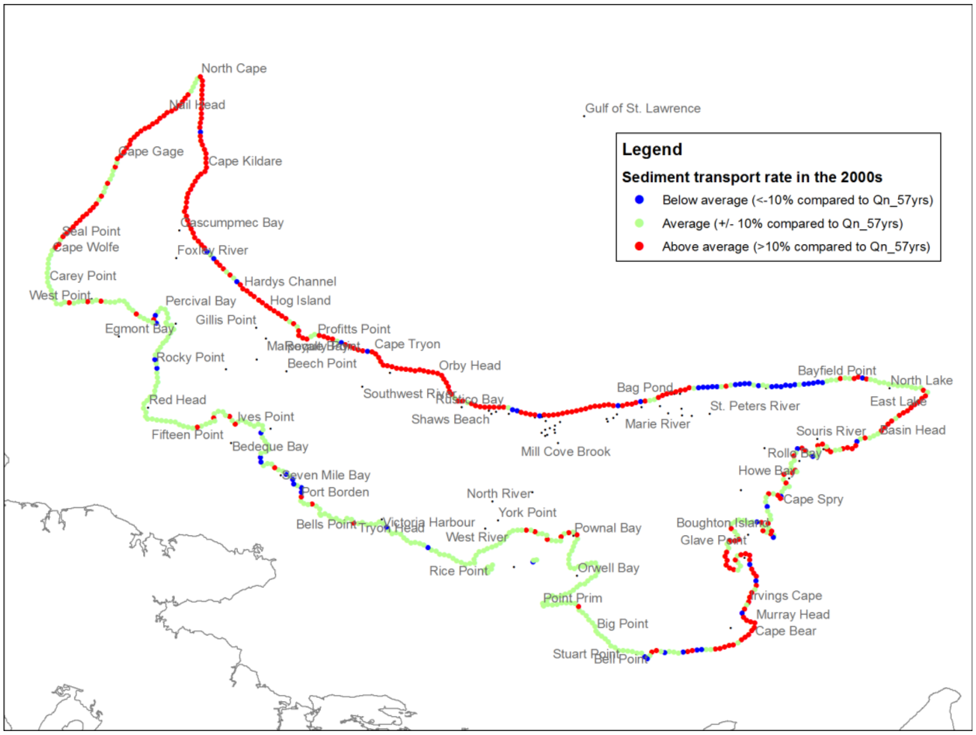


Figure 51 Sediment transport rate based on the 2000s wind and wave conditions

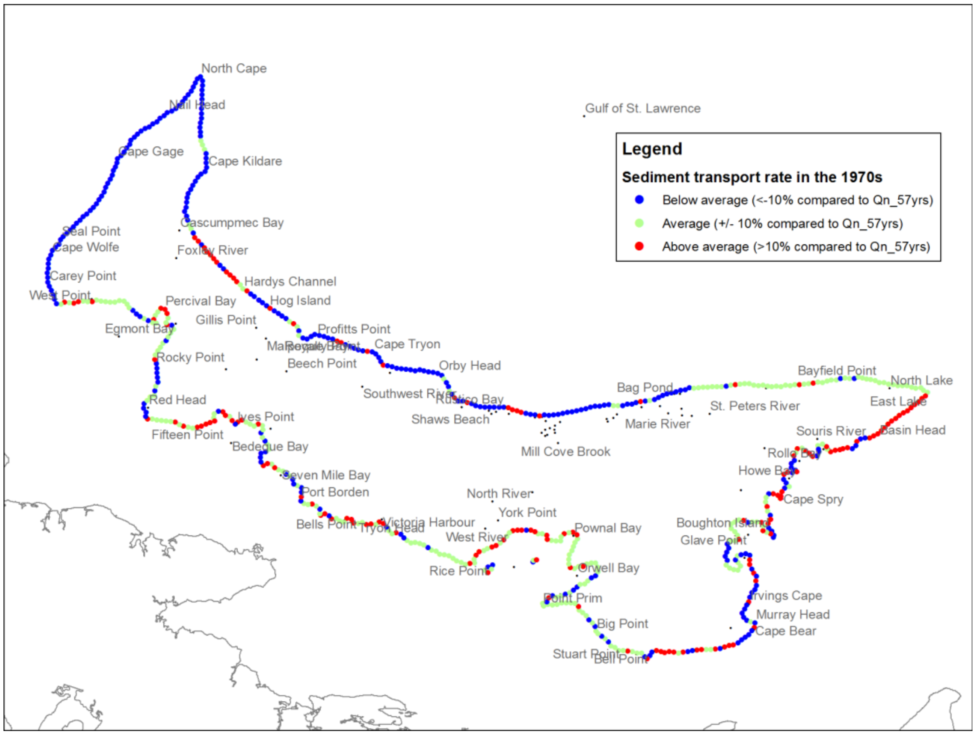


Figure 52 Sediment transport rate based on the 1970s wind and wave conditions

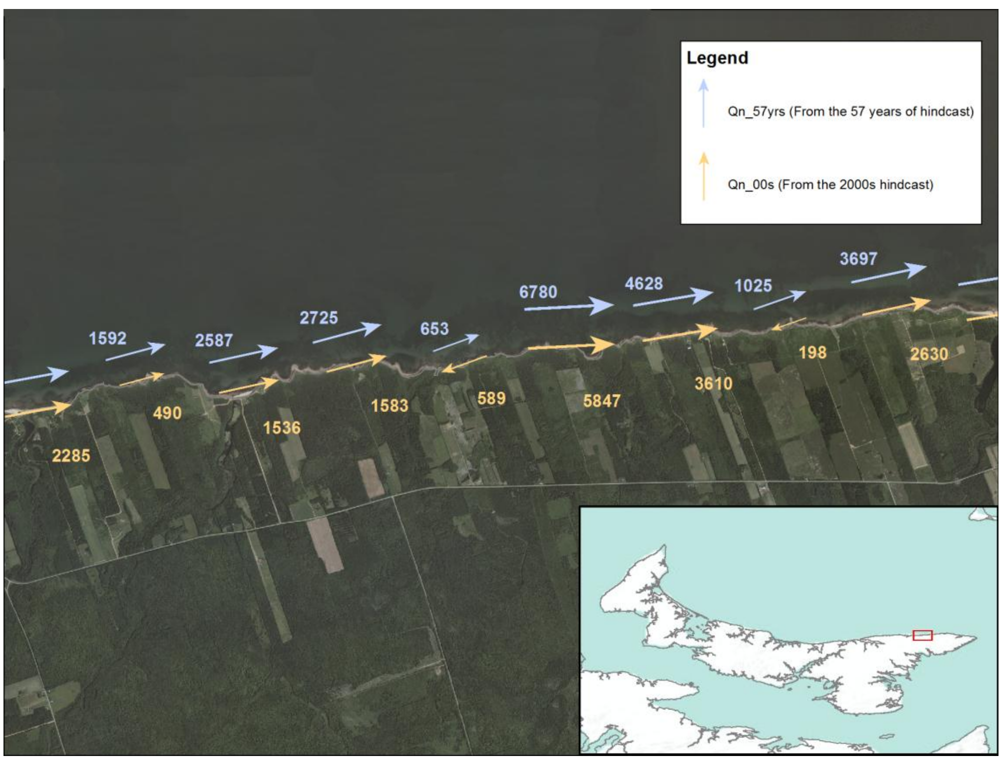


Figure 53 Sediment transport rate based on the 57 years hindcast and based on the hincast in the 2000s

Vulnerability to Coastal Erosion

The exposure of a shore unit to the erosive forces of wave action can be characterized by the magnitude of net potential transport rate along that shore. The magnitude of the longshore transport rate is primarily a function of the offshore wave height and its angle relative to the shoreline. Areas that are exposed to an equal distribution of wave energy from both directions (left and right) may have large amounts of sediment moving in the nearshore but this sediment will tend to remain in the nearshore. A strong directional signal in the transport rate (i.e. dominantly to either the left, or right) with infrequent reversals will result in a strong NET transport rate. A complete picture of nearshore erosion comes from examining the gradients of longshore transport. Areas that have more sediment moving toward them than away experience accretion while areas with more sediment moving away experience erosion. The development of sediment budgets along the shore based on transport rates, gradients and on historical rates of shoreline change is recommended as the next step in refining this analysis.

In the absence of sediment budgeting and without the benefit of historical transport rates, the maps of net longshore transport do provide an illustration of the vulnerability of various shorelines to erosion. A hazard index could be developed based on a combination of the magnitude of the net alongshore transport rate, shore type and shore height. This is beyond the present scope of work. As an interim measure the following plot of the magnitude of QsNET provide an indication of the relative severity of wave erosional forces along the coast (Figure 54).

In this figure the open coast shows as having much larger transport rates than in any of the estuaries (as would be expected due to wave exposure). Transport rates along the north shore are generally an order of magnitude higher than along other shores. Along the north shore, rates are relatively lowest along the barrier beaches fronting Malpeque Bay and near the Greenwich Dunes just east of St. Peter’s Bay. Along the south shore, the shoreline near Wood Islands shows a near zero net transport rate indicating that the wave energy from the east is in close balance to wave energy from the west along this reach.

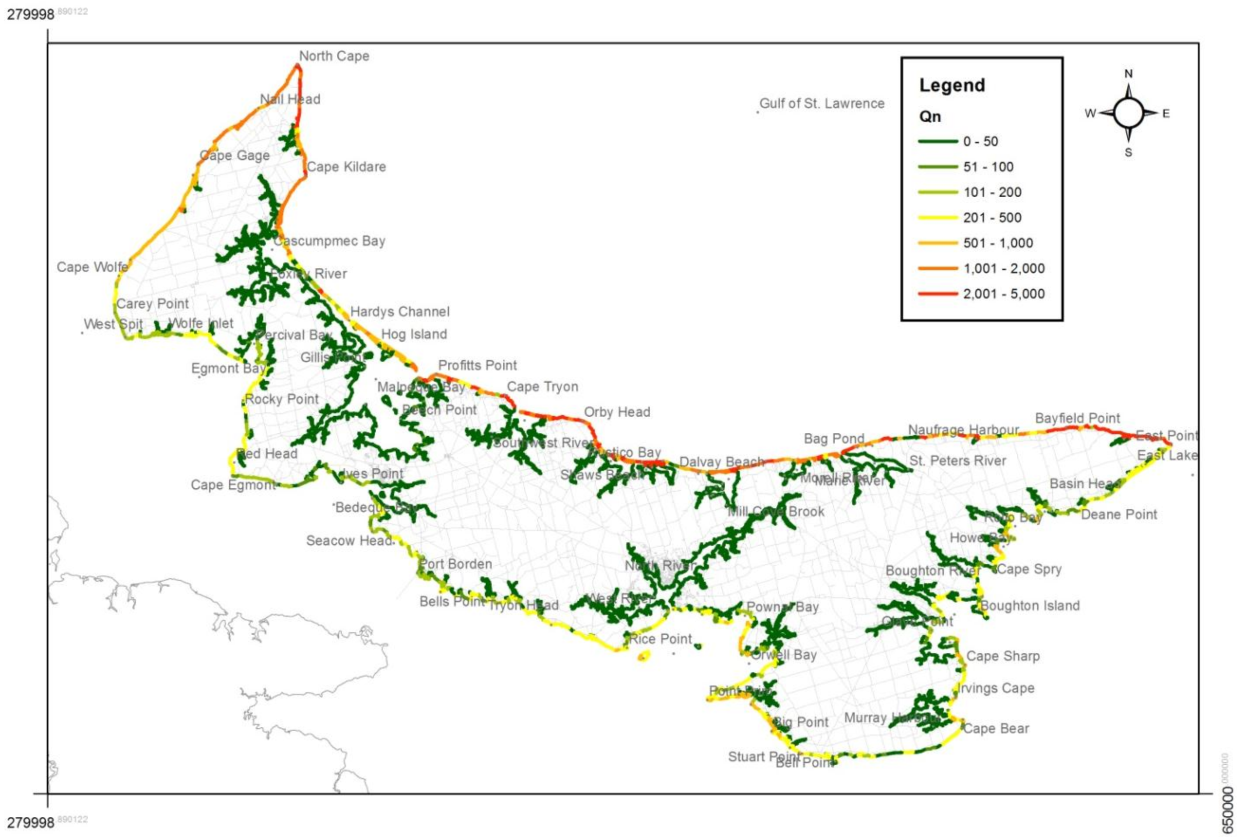


Figure 54 Average annual net alongshore sediment transport rates.

Vulnerability to Coastal Flooding

The hazard of coastal flooding is dependent upon storm water levels, wave action and the elevation, composition and level of development of the coast. Using the datasets compiled for this study the following section presents a provisional index for quantifying vulnerability to coastal flooding.

The mechanisms considered for this flooding index are illustrated in Figure 55. Wave runup carries flood waters up the shore profile. Wave runup is dependent upon the local wave height and the water level both of which are influenced by tide and surge conditions. The susceptibility to coastal flooding is described by the ratio of the freeboard of the shoreline (elevation of land above the storm water level).

Detailed predictors of wave runup for given wave conditions, nearshore geometry and structure characteristics have been developed in recent years (Pullen, Allsop, Bruce, Kortenhaud, Schuttrumpf, & van der Meer, 2007) (US Army Corps of Engineers, 2007) (MacDonald, Davies, & Wiebe, 2010). For the present analysis a simpler approximation of wave runup has been employed:

$$R_u=1.8\ H_s$$

Here the input wave height is the average annual maximum significant wave height at breaking. A local depth-limited breaking criteria is then applied at the shore using the HHWLT tidal level and an assumed surge level of 0.5m (typical of severe storm surges throughout the Island).

The shoreline freeboard, F is computed as the vertical elevation of the backshore above the storm water level (mean sea level plus tide plus surge).

The vulnerability to coastal flooding, VCF is the ratio of runup to freeboard:

$$VCF = R_u / F$$

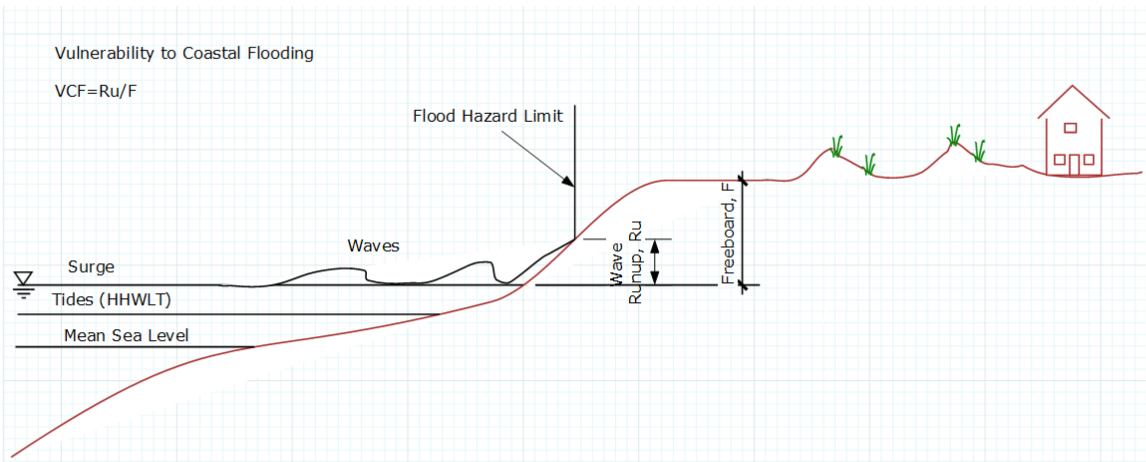


Figure 55 Vulnerability to Coastal Flooding (Schematic)

It is important to note here that this is a very broad generalization of the physical processes involved in coastal flooding; it is, however, a pragmatic approach that provides a first take on a province-wide characterization of vulnerability to coastal flooding.

Clearly, varying the storm surge and tide assumptions as well as more detailed wave runup and overtopping analysis should be explored in the ongoing refinement of this approach. This approach is particularly suitable for evaluating the effects of increased relative sea levels due to climate change, which reduces the freeboard of the backshore.

The following figure shows a map of the VCF parameter. Low-lying areas, particularly barrier islands show as being susceptible to flooding as do large portions of the Hillsborough estuary and Egmont Bay. This VCF parameter is an indicator of coastal flooding risk based on an assumed surge of 0.5 m and no sea level rise. Other scenarios need to be considered and the database has been provided in Excel format with a macro to compute VCF in order to facilitate exploration of this parameter.

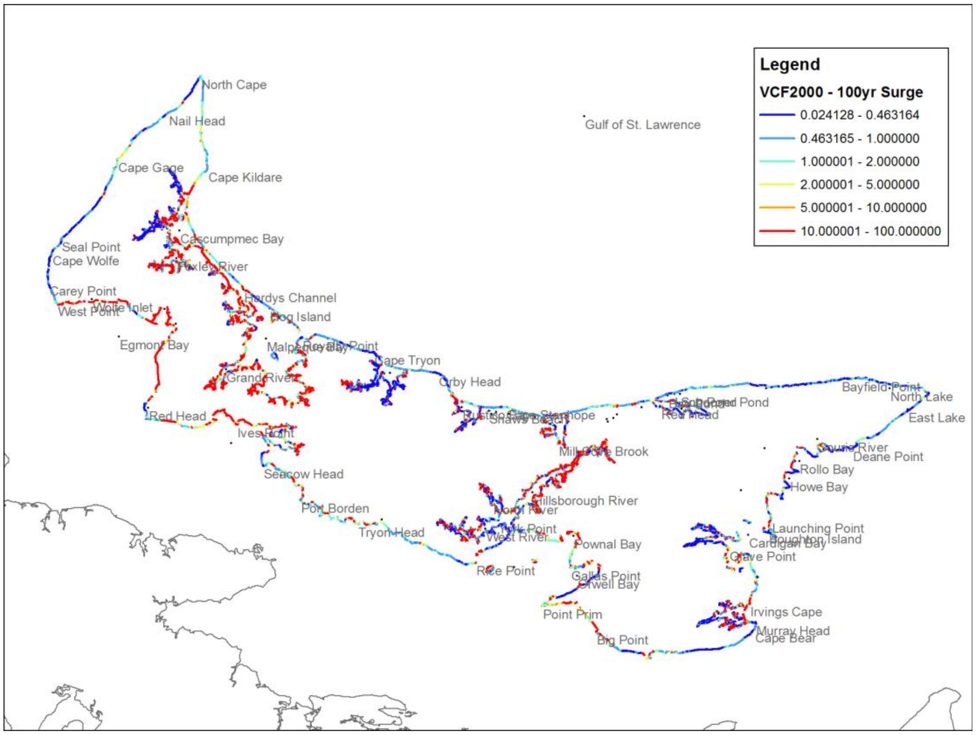


Figure 56 Vulnerability to Coastal Flooding (100-year surge, mean sea level in 2000).

The algorithms for computing VCF with user-defined values of the mean sea level (as an elevation above the CGVD28 datum) and the storm surge level (super-elevation of the still water level above the atmospheric tide) have been implemented both as ArcGIS calculation algorithm and as a Microsoft Excel intrinsic function (using a Visual Basic macro). Details on these algorithms are provided in the Appendix of this report.

In this revised report, 25 combinations of sea-level rise and storm-surge were used to compute the VCF. Each scenario (see Table 9) can be viewed in ArcExplorer or ArcGIS with the layer (.lyr) file as given in the data products.

Table 9 Scenarios for vulnerability to coastal flooding

	No surge	10-yr return period surge	25-yr return period surge	50-yr return period surge	100-yr return period surge
Sea Level (2000)	VCF2000_0yr.lyr	VCF2000_10yr.lyr	VCF2000_25yr.lyr	VCF2000_50yr.lyr	VCF2000_100yr.lyr
Sea Level (2025)	VCF2025_0yr.lyr	VCF2025_10yr.lyr	VCF2025_25yr.lyr	VCF2025_50yr.lyr	VCF2025_100yr.lyr
Sea Level (2055)	VCF2055_0yr.lyr	VCF2055_10yr.lyr	VCF2055_25yr.lyr	VCF2055_50yr.lyr	VCF2055_100yr.lyr
Sea Level (2085)	VCF2085_0yr.lyr	VCF2085_10yr.lyr	VCF2085_25yr.lyr	VCF2085_50yr.lyr	VCF2085_100yr.lyr
Sea Level (2100)	VCF2100_0yr.lyr	VCF2100_10yr.lyr	VCF2100_25yr.lyr	VCF2100_50yr.lyr	VCF2100_100yr.lyr

8. Closure

The provincial shoreline classification and the supporting tools presented here represent a major step forward in our ability to visualize and analyze coastal hazards. It is important to note that the ongoing refinement and analysis of this dataset is seen to be a critical factor in further improving the usefulness of both the classification database and the supporting tools. The classification system presented here, along with the climate and transport analysis, represent an important and valuable initial step in this direction but significant further work is required to extend, refine and validate this system.

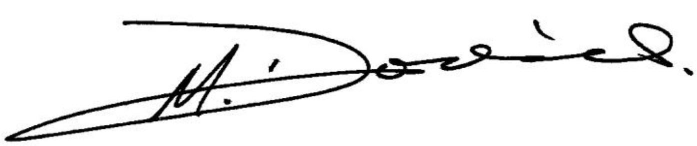
The sediment transport rates and wave conditions presented in this report are meant to be used to support the quantitative evaluation of coastal processes and coastal hazards. They are not intended (nor are they suitable) for the design of coastal structures, shore protection or other engineering applications.

The dataset and analysis presented herein provides a comprehensive picture of shoreline characteristics throughout the Island along with a characterization of the waves, water levels and transport conditions to which the shoreline is exposed.

This report has been prepared by Coldwater Consulting Ltd. for the benefit of the Province of Prince Edward Island. The data, information and recommendations contained in this report represent our professional judgment based on available information and within time and budgetary constraints.

Submitted October 28th, 2011

Revised report submitted March 14th, 2011



M.H. Davies, Ph.D., P.Eng.
Coldwater Consulting Ltd.

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Appendices

Related Data Products

The following files form a companion dataset to this report and have been submitted to PEI DEEF for their use and retention.

PEI_CstlClassn_Map_v6.mxd	ArcGIS 10.0 map file
Coast_2010_Coldwater_v2p6_shp	Geomorphic Classification Database
Qn_v3p1	Qn, Hs, Hsmax and Ang from Class'n database as points
Coast_2010_Coldwater_Structures_v2p6_shp	Structures Database
Features_shp	File containing names of key shore features
6mContour_shp	Offshore contour at 6m depth
Shore_Units_shp	Polygons identifying shore units
PEI_Coastal_shp	Geotagged photos of coastal structures (D. Jardine)
PEI_Structures_shp	Geotagged photos of the PEI shoreline (M. Davies)
NBandNS_shoreline.shp	New Brunswick and Nova Scotia shoreline
Classn_v2p5.xlsm	An Excel spreadsheet containing Geomorphic Classification Database along with macro calculator for coastal hazards
Note that the shape files listed each exist in their own folder, containing: Shape files (.shp, .dbf, .shx), projection file (.prj), and metadata file (.xml) layer files (.lyr) accompany many of these files to assist in viewing and presentation in ArcGIS and ArcExplorer	

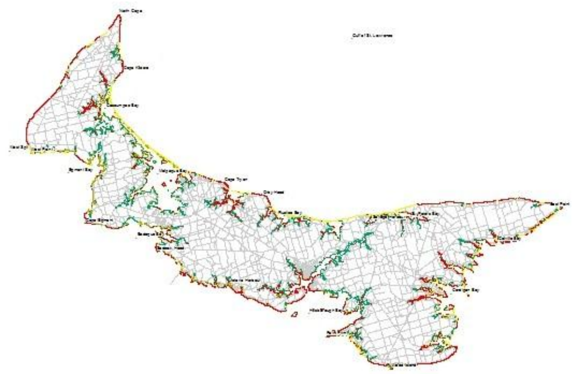
Geographic coordinate system for all GIS files is:

NAD_1983_CSRS_Prince_Edward_Island Projection: Double_Stereographic False_Easting: 400000.000000 False_Northing: 800000.000000 Central_Meridian: -63.000000 Scale_Factor: 0.999912 Latitude_Of_Origin: 47.250000 Linear Unit: Meter (1.000000)	Geographic Coordinate System: GCS_North_American_1983_CSRS Angular Unit: Degree (0.0174532925199433295) Prime Meridian: Greenwich (0.000) Datum: D_North_American_1983_CSRS Spheroid: GRS_1980 Semimajor Axis: 6378137.00 Semiminor Axis: 6356752.31 Inverse Flattening: 298.2572

Metadata for these files has been compiled using the ArcGIS "Item Description" metadata style. The .xml metadata files accompanying the shape files contain this information along with full FGDC-compliant metadata (projection, spatial extents, topology, geoprocessing history, etc.). The Item Description metadata for the Shore Classification and Structures datasets is presented on the following pages.

Geomorphic Shore Classification for Prince Edward Island

Shapefile



Tags

Geomorphic, shoreline, classification, PEI, Prince Edward Island, Bluff, Cliff, Low Plain, Sand Dune, Wetland

Summary

Shoreline Classification Database describing the Prince Edward Island shoreline mapped onto the Provincial 2010 vector shoreline. Shore types include: Bluff, Cliff, Low Plain, Sand Dune and Wetland

Description

Prepared in 2012 by Coldwater Consulting Ltd., this dataset provides a description of shore types for the entire PEI shoreline.

Documentation is provided in the accompanying report:

Davies, M.H. (2012). Geomorphic Shore Classification of Prince Edward Island, Report prepared for the PEI Dep't of Environment, Energy and Forestry.

Dataset contains 44,780 records. Fields in this dataset include:

FSTypeis a character string describing the nature of the foreshore based on visual assessment of 2010 (0.4m pixel) orthophoto mosaic at a scale of 1:1,500

NSTypeis a character string describing the nature of the nearshore based on visual assessment of 2010 (0.4m pixel) orthophoto mosaic at a scale of 1:1,500

BSTypeis a character string describing the nature of the backshore based on visual assessment of 2010 (0.4m pixel) orthophoto mosaic at a scale of 1:1,500

Longitude, Latitude, MHHW, HHWLT, MLLW, LLWLT are numeric (float) descriptors of tidal conditions along that shore segment. These are elevations in metres above Mean Sea Level (MSL) and are based on data from the DFO tidal constituents database.

Zois the mean sea level above chart datum (based on data from the DFO tidal constituents database).

Elev is a numeric (float) value representing the elevation in metres of the backshore (cliff/dune/plain, etc.) based on the Provincial contour dataset from the LiDAR topography and is in metres above the CGVD28 vertical datum.

Slope is a numeric (float) value representing the maximum slope of the backshore (rise/run) used in delineating cliffs and bluffs.

WETL_TYPE is a character string identifying the nearest wetland polygon based on the 2000 Provincial Wetland Maps.

Distance is a numeric (float) value signifying the minimum distance between the shore segment and its closest wetland polygon.

ShoreType is a character string identifying the backshore type based on the shore classification algorithm described in Davies (2012).

ShoreUnit is a character string identifying the "Shore Unit" or "Littoral Cell" within which the shore segment resides.

Qn is a numeric (float) value signifying the annual average net alongshore transport (m3/yr) computed as described in Davies (2012).

Ang is a numeric (float) value signifying the direction of the net transport in degrees Azimuth.

Hs is a numeric (float) value signifying the annual average significant wave height at breaking for that shore segment based on the offshore wave conditions from the MSC50 hindcast (Swail et al, 2009) as described in Davies (2012).

Hsmax is a numeric (float) value signifying the annual average maximum significant wave height at breaking for that shore segment based on the offshore wave conditions from the MSC50 hindcast (Swail et al, 2009) as described in Davies (2012).2

Qn_00s, Ang_00s, Hs_00s, MaxHs_00s are the net longshore transport, direction, average Hs and Maximum annual Hs for the 2000's decade (representative of climate change storminess?)

While Qn_70s, Ang_70s, etc. are the corresponding fields for the 1970s - a period of low storminess and high ice cover.

VCF iis a numeric (float) value signifying the Vulnerability to Coastal Flooding as per Davies (2012). This field is computed for user-defined values of storm surge and mean sea level using the calculation algorithm "VCF.CAL".

Surge_10, Surge_25, Surge_50 and Surge_100 are numeric (float) values representing storm surge heights (anomolies) for the 10, 25, 50 and 100-yr return periods (ref: Daigle and Richards, 2012).

Total_2025, Total_2055, Total_2085 and Total_2100 are the expected total increases in sea level (subsidence plus sea level rise) relative to mean sea level (Richards & Daigle, 2012).

MSL_2000, MSL_2025...MSL_21000 are the expected mean sea levels relative to geodetic datum (CGVD28) for the Richards & Daigle (2012) climate change scenarios.

V2000_0, V2000_10, V2000_25...V2100_100 are the computed Vulnerability to Coastal Flooding for each year (2000, 2025, 2055, 2100) and for each storm return period (0, 10, 25, 50, 100 yr).

Flood_UV and Flood_DIR are the mean current magnitude and direction for the flood tidal current, respectively

Ebb_UV and Ebb_DIR are the mean current magnitude and direction for the ebb tidal current, respectively.

Credits

Dataset was created by Coldwater Consulting Ltd., Ottawa. Project Lead: M. Davies, Ph.D., P.Eng. [info@coldwater-consulting.com]. Point of contact at PEI DEEF: Erin Taylor [etaylor@gov.pe.ca] This work was commissioned by the Atlantic Climate Adaptation Solutions Association (ACASA), a non-profit **organization** formed to coordinate project management and planning for climate change adaptation initiatives in Nova Scotia, New Brunswick, Prince Edward Island and Newfoundland and Labrador and supported through the Regional Adaptation Collaborative, a joint undertaking between the Atlantic provinces, Natural Resources Canada and regional municipalities and other partners. This work presented herein was administered by the Department of Environment, Energy and Forestry (DEEF) of the Province of Prince Edward Island.

Use limitations

There are no access and use limitations for this item.

Shore Protection Database for Prince Edward Island

Shapefile

Tags

Shore Protection, revetment, armouring, riprap

Summary

This is a database of shore protection structures along the Prince Edward Island shoreline compiled in 2011 by Coldwater Consulting Ltd. Data was collected by visual examination of the 2010 (0.4m pixel) aerial photomosaic of PEI (PEI Dept' Environment, Energy and Forestry). Results are mapped onto the 2010 Provincial vector geomorphic shoreline.

Description

Prepared in 2012 by Coldwater Consulting Ltd., this dataset identifies shore protection along the PEI shoreline.

Documentation is provided in the accompanying report:

Davies, M.H. (2012). Geomorphic Shore Classification of Prince Edward Island, Report prepared for the PEI Dep't of Environment, Energy and Forestry.

Dataset contains 1,662records.Each record is a length of shoreline that is either protected or in its natural state.

Field "Struct" is a character string identifying shoreline as either protected ("Structure"), or natural ("Natural")

Length is a numeric field (float) listing the length of the shore segment.

ShoreUnit is a character string identifying the "Shore Unit" or "Littoral Cell" within which the shore segment resides.

NSEW is a character string identifying the shore within which the segment resides (North, South, East or West).

Credits

Dataset was created by Coldwater Consulting Ltd., Ottawa. Project Lead: M. Davies, Ph.D., P.Eng. [info@coldwater-consulting.com]. Point of contact at PEI DEEF: Erin Taylor [etaylor@gov.pe.ca] This work was commissioned by the Atlantic Climate Adaptation Solutions Association (ACASA), a non-profit organization formed to coordinate project management and planning for climate change adaptation initiatives in Nova Scotia, New Brunswick, Prince Edward Island and Newfoundland and Labrador and

supported through the Regional Adaptation Collaborative, a joint undertaking between the Atlantic provinces, Natural Resources Canada and regional municipalities and other partners. This work presented herein was administered by the Department of Environment, Energy and Forestry (DEEF) of the Province of Prince Edward Island.

Use limitations

There are no access and use limitations for this item.

Vulnerability to Coastal Flooding (VCF)

This parameter (as described in Section 7, on page 67 of this report) is a computed parameter based on user-input values of the storm surge and mean sea level.
Users of ARCGIS can use the following VCF.CAL function to compute VCF:

```
Contents of file VCF.CAL
surge=0.5
MSL=0.274
depth= [HHWLT] + surge
Elev_MSL=[Elev]-MSL
if([MaxHs]>0) then
  H=[MaxHs]
  if([MaxHs]>depth) then
    H=depth
  end if
  Ru=1.8*H
  F= Elev_MSL-depth
  if (F>0.) then
    ratio = Ru/F
    if (ratio>100.) then
      ratio=100.
    end if
    v=ratio
  else
    v=0.
  end if
else
  v=-1.
end if

__esri_field_calculator_splitter__
v
```

Users of the Excel workbook "Class_v2p5.xlsm" can input values for Surge and MSL in the named cells of the worksheet (AG1 and AG2) and the built-in Excel macro "VCF" will automatically update the values in the VCF column.

A	AB	AC	AD	AE	AF	AG	AH	AI
					Surge:	0.5		
	MaxHs	ShoreUnits	VCF		MSL:	0.274		
0.19	1.672	West	0.61					
0.19	1.672	West	0.66					
0.19	1.672	West	0.87					
0.19	1.672	West	1.19					
0.19	1.672	West	0.58					
0.19	1.672	West	0.58					
0.19	1.672	West	0.66					
0.21	1.709	West	0.55					
0.21	1.709	West	0.66					
0.21	1.709	West	0.66					
0.21	1.709	West	0.54					
.208	1.699	West	0.88					
.208	1.699	West	0.59					
.208	1.699	West	0.59					

Note:
The "VCF" column is a calculation using the embedded macro function "VCF" which computes Vulnerability to Coastal Flooding for a given Surge and sea level. Examination of the effects of various surge levels and of increasing sea levels can be obtained by changing the values for "Surge" and "MSL" in column AG

Screen shot of the VCF function column.

The macro for these calculations is as follows.

```
Function vcf(HHWLT, MaxHs, Elev, MSL, Surge)
' VCF is the Vulnerability to Coastal Flooding
' Key input parameters WITHIN this function are:
'  (1)  MSL - the elevation of Mean Sea Level above CGVD28
'           CGVD28 is the Canadian Geodetic Vertical Datum
'           which is based on MSL in 1928
'       e.g. MSL for 2011 is 0.274m
' One of the effects of climate change is higher sea levels, this
' can be assessed by increasing the value of used in this algorithm
'
' (2) Surge - the surge elevation at which VCF is to be evaluated
'           The choice of surge is critical to this analysis,
'           a value of surge=0.5 has been set here as the default
'           value. Surge heights range from 0 to almost 1.0m depending
'            upon storm severity.
'
' Note: Elev is the elevation of the backshore above the CGVD28 datum
' The elevation of the backshore above mean sea level is Elev_MSL (=Elev-MSL)
' The Freeboard, F is the vertical distance between the storm stage (=Depth)
' and the height of the backshore (ELEV_MSL)
'
Depth = HHWLT + Surge
Elev_MSL = Elev - MSL

If (MaxHs > 0) Then
  H = MaxHs
  If (MaxHs > Depth) Then
    H = Depth   ' Wave height is limited to local depth above MSL
  End If
  Ru = 1.8 * H
  F = Elev_MSL - Depth
  If (F > 0#) Then
    ratio = Ru / F
    If (ratio > 100#) Then
      ratio = 100#
    End If
    v = ratio
  Else
    v = 0#
  End If
Else
  v = -1#
End If
vcf = v
End Function
```