Geomorphic Shoreline Classification of Prince Edward Island

November 2011 Coldwater Consulting Ltd

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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)) 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.

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
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) 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

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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.
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).
2.5. Tidal constituents
Harmonic tidal constituents were compiled for the 26 available Fisheries & Oceans Canada (DFO) stations around the island. These constituents provide a 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 predicted astronomical tide at any point in time. For the present analysis these have been used to establish the tidal range along the shore. 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 currents. While not presently available, this feature could be incorporated in the future. The use of the tidal constituent database provides the advantage of using a publicly available dataset that is highly accurate and widely employed.

2.6. 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.

![Figure 5 Dataset of nearest MSC50 nodes to the PEI shoreline](image-url)
2.7. **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 Scheme for Cap Lumière-Port Elgin, NB

<table>
<thead>
<tr>
<th>BERUBÉ and THIBAULT (1996) Feature</th>
<th>Type</th>
<th>Attributes</th>
<th>Width and elevation of foreshore, backshore, coast</th>
<th>Qualitative susceptibility to erosion (low, medium, high)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastline</td>
<td></td>
<td>Sediment size and distribution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backshore</td>
<td>Beach</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tidal Salt Marsh</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foreshore</td>
<td>Tidal Flat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tidal Stream</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For the present study, we have characterized the cross-shore profile by the nearshore, foreshore and backshore as illustrated in Figure 6 for cliff/bluff shorelines (upper figure) and for dune shorelines (lower figure).
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\(^2\). 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 7).

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.

\(^2\) This limit is often referred to as the Ordinary High Water Mark however this term has varying technical and legal definitions.
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 Nicholls and Klein, 2005).

<table>
<thead>
<tr>
<th>Bio-geophysical effect</th>
<th>Other relevant factors</th>
<th>Climate related</th>
<th>Non-climate related</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent inundation</td>
<td>Sea level rise</td>
<td></td>
<td>Vertical land movement (uplift/subsidence), land use and land planning</td>
</tr>
<tr>
<td>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>
<td></td>
</tr>
<tr>
<td>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>
<td></td>
</tr>
<tr>
<td>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></td>
<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>Saltwater intrusion</td>
<td>Surface waters</td>
<td>Sea level rise, runoff</td>
<td>Catchment management and land use</td>
</tr>
<tr>
<td></td>
<td>Groundwater</td>
<td>Sea level rise, rainfall</td>
<td>Land and aquifer use</td>
</tr>
</tbody>
</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 classification scheme for Secondary Coasts (from USACE CEM, 2007 Part IV)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary coasts</td>
<td>Shaped primarily by marine agents or by marine organisms. May or may not</td>
</tr>
<tr>
<td></td>
<td>have been primary coasts before being shaped by the sea.</td>
</tr>
<tr>
<td>A. Wave erosion coasts</td>
<td></td>
</tr>
<tr>
<td>1. Wavestraightened cliffs</td>
<td>bordered by a gently inclined seafloor, in contrast to the steep inclines</td>
</tr>
<tr>
<td></td>
<td>off fault coasts.</td>
</tr>
<tr>
<td>(a) Cut in homogenous materials</td>
<td></td>
</tr>
<tr>
<td>(b) Hogback strike coasts</td>
<td>where hard layers of folded rocks have a strike roughly parallel to the</td>
</tr>
<tr>
<td></td>
<td>coast so that erosion forms a straight shoreline.</td>
</tr>
<tr>
<td>(c) Fault-line coasts</td>
<td>where an old eroded fault brings a hard layer to the surface, allowing</td>
</tr>
<tr>
<td></td>
<td>wave erosion to remove the soft material from one side, leaving a straight</td>
</tr>
<tr>
<td></td>
<td>coast.</td>
</tr>
<tr>
<td>(d) Elevated wave-cut bench coasts</td>
<td>where the cliff and wave-cut bench have been somewhat elevated by recent</td>
</tr>
<tr>
<td></td>
<td>diastrophism above the level of present-day wave erosion.</td>
</tr>
<tr>
<td>(e) Depressed wave-cut bench coasts</td>
<td>where the wave-cut bench has been somewhat depressed by recent diastrophism</td>
</tr>
<tr>
<td></td>
<td>so that it is largely below wave action and the wave-cut cliff plunges</td>
</tr>
<tr>
<td></td>
<td>below sea level.</td>
</tr>
<tr>
<td>2. Made irregular by wave erosion</td>
<td>Unlike rip coasts in that the embayments do not extend deeply into the</td>
</tr>
<tr>
<td></td>
<td>land. Dip coasts where alternating hard and soft layers intersect the</td>
</tr>
<tr>
<td></td>
<td>coast at an angle, cannot always be distinguished from trellis coasts.</td>
</tr>
<tr>
<td>(a) Heterogeneous formation coasts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>where wave erosion has cut back the weaker zones, leaving great</td>
</tr>
<tr>
<td></td>
<td>irregularities.</td>
</tr>
<tr>
<td>B. Marine deposition coasts</td>
<td>Coasts prograded by waves and currents.</td>
</tr>
<tr>
<td>1. Barrier coasts</td>
<td></td>
</tr>
<tr>
<td>(a) Barrier beaches</td>
<td>single ridges.</td>
</tr>
<tr>
<td>(b) Barrier islands</td>
<td>multiple ridges, dunes, and overwash flats.</td>
</tr>
<tr>
<td>(c) Barrier spits</td>
<td>connected to mainland.</td>
</tr>
<tr>
<td>(d) Bay barriers</td>
<td>sand spits that have completely blocked bays.</td>
</tr>
<tr>
<td>(e) Overwash fans</td>
<td>lagoonward extension of barriers due to storm surges.</td>
</tr>
<tr>
<td>2. Cuspate forelands</td>
<td>large projecting points with cusp shape. Examples include Cape Hatteras</td>
</tr>
<tr>
<td></td>
<td>and Cape Canaveral.</td>
</tr>
<tr>
<td>3. Beach plains</td>
<td>sand plains differing from barriers by having no lagoon inside.</td>
</tr>
<tr>
<td>4. Mud flats or salt marshes</td>
<td>formed along deltaic or other low coasts where gradient offshore is</td>
</tr>
<tr>
<td></td>
<td>too small to allow breaking waves.</td>
</tr>
<tr>
<td>C. Coasts built by organisms</td>
<td></td>
</tr>
<tr>
<td>1. Coral reef coasts</td>
<td>include reefs built by coral or algae. Common in tropics. Ordinarily, reefs</td>
</tr>
<tr>
<td></td>
<td>fringing the shore and rampart beaches are found inside piled up by the</td>
</tr>
<tr>
<td></td>
<td>waves.</td>
</tr>
<tr>
<td>(a) Fringing reef coasts</td>
<td>reefs that have built out the coast.</td>
</tr>
<tr>
<td>(b) Barrier reef coasts</td>
<td>reefs separated from the coast by a lagoon.</td>
</tr>
<tr>
<td>(c) Atolls</td>
<td>coral islands surrounding a lagoon.</td>
</tr>
<tr>
<td>(d) Elevated reef coasts</td>
<td>where the reefs form steps or plateaus directly above the coast.</td>
</tr>
<tr>
<td>2. Serpulid reef coasts</td>
<td>small stretches of coast may be built out by the cementing of serpulid</td>
</tr>
<tr>
<td></td>
<td>worm tubes onto the rocks or beaches along the shore. Also found mostly in</td>
</tr>
<tr>
<td></td>
<td>tropics.</td>
</tr>
<tr>
<td>3. Oyster reef coasts</td>
<td>where oyster reefs have built along the shore and the shells have been</td>
</tr>
<tr>
<td></td>
<td>thrown up by the waves as a rampart.</td>
</tr>
<tr>
<td>4. Mangrove coasts</td>
<td>where mangrove plants have rooted in the shallow water of bays, and</td>
</tr>
<tr>
<td></td>
<td>sediments around their roots have been built up to sea level, thus extending</td>
</tr>
<tr>
<td></td>
<td>the coast. Also a tropical and subtropical development.</td>
</tr>
<tr>
<td>5. Marsh grass coasts</td>
<td>in protected areas where salt marsh grass can grow out into the shallow</td>
</tr>
<tr>
<td></td>
<td>sea and, like the mangroves, collect sediment that extends the land. Most</td>
</tr>
<tr>
<td></td>
<td>of these coasts could also be classified as mud flats or salt marshes.</td>
</tr>
</tbody>
</table>

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.

Figure 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 8 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 9 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**

<table>
<thead>
<tr>
<th>Nearshore Type (3)</th>
<th>Foreshore Type (3)</th>
<th>Backshore Type (5)</th>
<th>Backshore Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rocky</td>
<td>Rocky</td>
<td>Cliff</td>
<td>This is a numeric field containing the elevation of the backshore above mean sea level.</td>
</tr>
<tr>
<td>Sandy</td>
<td>Sandy</td>
<td>Bluff</td>
<td></td>
</tr>
<tr>
<td>Marsh</td>
<td>Marsh</td>
<td>Low Plain</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dune</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wetland</td>
<td></td>
</tr>
</tbody>
</table>

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 10 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.

**Shoreline Simplification**

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 11: Example of percent rise slope

Slope Analysis

The slope was calculated from digital elevation maps (DEM) 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 12.
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 13. 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.

\[
\text{Degree of slope} = \theta \\
\text{Percent of slope} = \frac{\text{rise}}{\text{run}} \times 100 \\
\text{rise} = \tan \theta \\
\text{run}
\]

<table>
<thead>
<tr>
<th>Degree of slope</th>
<th>Percent of slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>58</td>
</tr>
<tr>
<td>45</td>
<td>100</td>
</tr>
<tr>
<td>76</td>
<td>373</td>
</tr>
</tbody>
</table>

Slope and Elevation Mapping

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.
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:
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 15 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 16 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_v2p5.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 15 Shore Type

Figure 16 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 17 Excerpt from CHS Navigation Chart 4491 showing Darnley Spit as a barrier island/spit complex.](image1)

![Figure 18 2010 air photo of Darnley Spit.](image2)
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 19 Tracadie Spit in 2000.

Figure 20 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 21 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 22 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 23 through Figure 28 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 22 Shore protection permit sites

Figure 23 Shore protection database and site photo - North Lake Harbour.
Figure 24 Shore protection database and site photo - St. Peter's

Figure 25 Shore Protection database and site photo - Lower Montague
Figure 26 Shore Protection database and site photo – Brae Hbr.

Figure 27 Shore Protection and site photos – Charlottetown
Figure 28 Shore Protection and site photos - Summerside.
5. MetOcean conditions

5.1. Tidal conditions

The available Fisheries & Oceans Canada tidal stations near PEI (Figure 29) were used to generate 19-year long time series of water levels (2000-2019). The water level was 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:

- **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.
- **ZoCGVD28** – the elevation of the Canadian Geodetic Vertical Datum (CGVD28) above local chart datum.
- **Name1, Longitude and Latitude** – the name and location of the nearest DFO tidal station.

MHHW, HHWLT, MLLW and LLWLT are all expressed in metres above mean sea level. Zo as published in the DFO tidal statistics is the elevation of mean sea level above chart datum which was computed using the 1970-79 mean sea level. It has been converted here to CGVD28 based on Charlottetown tidal gauge (gauge 1700) to simplify evaluation of the effects of rising sea levels.

Figure 30 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 29 Tidal stations

Figure 30 Elevation of peak tides (HHWLT) above mean sea level.
5.2. 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 2.6, 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.

![Open sea shoreline](image)

Figure 31: 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.

![Estuary shoreline](image)

Figure 32: 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 resuspension. At each node along the simplified outer and estuary shorelines, wind fetches were calculated on a 24-point compass (wind directions between $0^\circ$ to $360^\circ$ in $15^\circ$ 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 33 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).
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 34: 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 6) of this report.
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 or 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:

- **Hₜ**: 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.
- **MaxHₜ**: Similarly, MaxHₜ 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 (m³/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 35 shows the distribution of annual average wave heights (Hₜ) around the island shorelines while Figure 36 shows the distribution of the annual maximum wave height (Max Hₜ). 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 Hₜ) along the south shore are typically 1-2m while waves reach 4-6m along the north shore.
Figure 35 Annual average Hs at shore.

Figure 36 Annual maximum Hs 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.
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 37 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 Cascumscap 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 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 38 Southward offset inlets at South Lake and Basin Head.

Figure 39 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 5) 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 shore are on average 54% wetlands.

Table 5 Shore classification summaries

<table>
<thead>
<tr>
<th>Coast</th>
<th>Bluff Length (m)</th>
<th>Low Plain</th>
<th>Sand Dune</th>
<th>Wetland</th>
<th>Grand Total</th>
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<td>958</td>
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<td>856</td>
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Table 6 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 fratal estuarine shoreline at Malpeque).

Table 6 Summary shoreline statistics for coast and estuarine shorelines combined.

<table>
<thead>
<tr>
<th>Estuary and coasts combined</th>
<th>Percentages</th>
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</thead>
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<tr>
<td></td>
<td>Bluff</td>
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<tr>
<td>Bluff</td>
<td>4.6%</td>
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<td>Cardigan</td>
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<tr>
<td>Murray Harbour</td>
<td>7,371</td>
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<td>Northeast</td>
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<td>Tryon</td>
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<td>West Shore</td>
<td>4,559</td>
</tr>
<tr>
<td>West</td>
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</tr>
</tbody>
</table>

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.

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 40).

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.
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 41. 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:

\[ VCF = \frac{R_u}{F} \]

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 42 Vulnerability to Coastal Flooding (0.5m surge, no sea level rise).

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.
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

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


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.

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<tr>
<th>File Name</th>
<th>Description</th>
</tr>
</thead>
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<td>ArcGIS 10.0 map file</td>
</tr>
<tr>
<td>Coast_2010_Coldwater_v2p5_shp</td>
<td>Geomorphic Classification Database</td>
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<tr>
<td>Qn_v3p0</td>
<td>Qn, Hs, Hmax and Ang from Class’n database as points</td>
</tr>
<tr>
<td>Coast_2010_Coldwater_Structures_v2p6_shp</td>
<td>Structures Database</td>
</tr>
<tr>
<td>Features_shp</td>
<td>File containing names of key shore features</td>
</tr>
<tr>
<td>6mContour_shp</td>
<td>Offshore contour at 6m depth</td>
</tr>
<tr>
<td>Shore_Units_shp</td>
<td>Polygons identifying shore units</td>
</tr>
<tr>
<td>PEI_Coastal_shp</td>
<td>Geotagged photos of coastal structures (D. Jardine)</td>
</tr>
<tr>
<td>PEI_Structures_shp</td>
<td>Geotagged photos of the PEI shoreline (M. Davies)</td>
</tr>
<tr>
<td>Classn_v2p5.xlsm</td>
<td>An Excel spreadsheet containing Geomorphic Classification Database along with macro calculator for coastal hazards</td>
</tr>
</tbody>
</table>

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)

Geographic coordinate system for all GIS files is:

<table>
<thead>
<tr>
<th>NAD_1983_CSR5_Prince_Edward_Island</th>
<th>Geographic Coordinate System: GCS_North_American_1983_CSRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projection: Double_Stereographic</td>
<td>Angular Unit: Degree (0.017453292519943295)</td>
</tr>
<tr>
<td>False_Easting: 400000.000000</td>
<td>Prime Meridian: Greenwich (0.000)</td>
</tr>
<tr>
<td>False_Northing: 800000.000000</td>
<td>Datum: D_North_American_1983_CSRS</td>
</tr>
<tr>
<td>Central_Meridian: -63.000000</td>
<td>Spheroid: GRS_1980</td>
</tr>
<tr>
<td>Scale_Factor: 0.999912</td>
<td>Semimajor Axis: 6378137.00</td>
</tr>
<tr>
<td>Latitude_Of_Origin: 47.250000</td>
<td>Semiminor Axis: 6356752.31</td>
</tr>
<tr>
<td>Linear Unit: Meter (1.000000)</td>
<td>Inverse Flattening: 298.2572</td>
</tr>
</tbody>
</table>

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 2011 by Coldwater Consulting Ltd., this dataset provides a description of shore types for the entire PEI shoreline.

Documentation is provided in the accompanying report:


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

- **FSType** is 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
- **NSType** is 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
- **BSType** is 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.
- **Zo_CGVD28** is the elevation of the Canadian Geodetic Datum (CGVD28) above local 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 (2011).

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 (2011).

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 (2011).

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 (2011).

VCF is a numeric (float) value signifying the Vulnerability to Coastal Flooding as per Davies (2011). This field is computed for user-defined values of storm surge and mean sea level using the calculation algorithm "VCF.CAL".

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

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 2011 by Coldwater Consulting Ltd., this dataset identifies shore protection along the PEI shoreline.

Documentation is provided in the accompanying report:


Dataset contains 1,662 records. 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 53 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]
else
    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

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.
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