

**COASTAL CLIMATE CHANGE VULNERABILITY AND ADAPTATION  
IN FUNDY NATIONAL PARK, NEW BRUNSWICK**

by Jenna Miller

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Department of Geography and Environmental Studies  
Saint Mary's University  
Halifax, Nova Scotia, Canada

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Members of the Examining Committee:

Dr. Danika van Proosdij (Supervisor)  
Department of Geography and Environmental Studies  
Saint Mary's University

Dr. Mathew Novak (Second Reader)  
Department of Geography and Environmental Studies  
Saint Mary's University

## **ABSTRACT**

### **Coastal Climate Change Vulnerability and Adaptation in Fundy National Park, New Brunswick**

by Jenna Miller

As global climate changes, coastal areas such as Fundy National Park in New Brunswick are projected to feel the effects of sea level rise and associated increase in storm surge. The purpose of this research was to determine the vulnerability of the Park's coastline to climate change impacts using field based and GIS assessments along 7km of coastline that was accessible overland. Current and future vulnerability of coastal assets were assessed under current conditions and climate change projections for 2050 and 2100 using ArcGIS 10.4 as a tool for visualization and analysis of projected sea level rise along the Park's coastline. Finally, the Atlantic Climate Adaptation Solutions Association (ACASA) Coastal Community Decision Tree Web Tool was used to assess options to adapt the coastline to identified vulnerabilities, and a specific adaptation plan was created through combined use of the web tool recommendations and local knowledge. It was found that of the assessed coastline, 47% of the backshore was stable or intact, 32% was partially stable or damaged, and 19% was unstable or failing. There was a direct correlation between the locations of some low-lying features with certain coastal assets, so these assets were deemed to be vulnerable, and adaptation options were explored for their particular locations. The coastline of Fundy National Park is a major tourist draw for the Park, so it is in the best interest of managers to create a climate change monitoring and adaptation plan to maintain the coastline for the safety and enjoyment of visitors into the future.

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## RÉSUMÉ

### **Coastal Climate Change Vulnerability and Adaptation in Fundy National Park, New Brunswick**

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En lieu du changement climatique global, les régions côtières comme le Parc national Fundy au Nouveau-Brunswick sont projetées de ressentir les effets de l'élévation du niveau de la mer et une augmentation associée de risques d'inondation par les ondes de tempête. L'objectif de cette recherche était de déterminer la vulnérabilité de la côte du Parc aux impacts du changement climatique en évaluant 7km de la côte (accessible par voie terrestre) au terrain et en usant un GIS. La vulnérabilité courante et en futur des actifs côtiers était évalué en regardant les conditions courantes et les projections futurs du changement climatique en 2050 et 2100 en utilisant ArcGIS 10.4 comme un outil de visualisation et d'analyse de l'élévation du niveau de la mer projetée le long de la côte du Parc. Au fin, l'arbre décisionnel en ligne pour les communautés côtières de l'organisation des Solutions d'adaptation aux changements climatiques pour l'Atlantique (ACASA) a été utilisé pour évaluer des options pour adapter la côte aux vulnérabilités identifiés, et un plan d'adaptation spécifique a été créé en usage combiné de l'outil en ligne et des connaissances locales. Il a été constaté que de la portion de la côte examinée, 47% de la zone arrière-plage était stable ou intacte, 32% était partiellement stable ou endommagé, et 19% était instable ou en échec. Il y avait une corrélation directe entre la position de certaines zones de faible élévation et le site de certains actifs côtiers ce qui a présumé la vulnérabilité de ces actifs et la considération d'options pour les adapter en location. La côte du Parc nacional Fundy est une attraction touristique pour le Parc alors c'est dans l'intérêt des gestionnaires de créer un plan pour surveiller et adapter la côte aux impacts du changement climatique pour la sécurité et le plaisir des visiteurs à venir.

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## **CHAPTER 1: Literature Review**

Fundy National Park protects a span of New Brunswick's Bay of Fundy coastline. Under changing climate conditions, coastlines worldwide are being impacted and assets on these coasts are increasingly vulnerable; it is important that managers and planners in coastal locations such as Fundy National Park are aware of the current and future vulnerability of local assets to these climate effects so that they can assess and implement adaptation strategies. Fundy National Park is protected both federally and internationally, as such, it is especially important that its vulnerability be assessed so that appropriate adaptive management plans can be implemented to allow its landscape to be enjoyed by its many visitors for years to come. This research will determine the current and future vulnerability of the Park's coastline and create a potential adaptation plan based on the identified vulnerabilities.

### **1.1 Rationale, Purpose and Objectives**

Climate change is not actively being considered at Fundy National Park (FNP); the term is not mentioned in the most recent Management Plan (2011). Coastal vulnerability has also never been studied in FNP. As it is protected both federally and internationally, the coastline in Fundy National Park needs to be studied if it is to be preserved for future generations. The purpose of this research is to assess the current and future vulnerability of the Park's coastline to

climate change effects and to create a plan to adapt to the identified vulnerabilities under the following objectives:

1. Characterize the geomorphic environment and assess the current stability of Fundy National Park's coastline
2. Identify Park assets at risk from coastal erosion and flooding at present and under climate change scenarios until 2100
3. Apply the ACASA coastal decision support tool to identify climate change adaptation options for vulnerable coastal sections within FNP

This thesis including ArcGIS files and a final adaptation plan will be offered to Parks Canada for their own interest. It accounts for a gap in the literature pertaining to the Park. This information should assist in creating future management plans where changing climate conditions are considered.

## **1.2 Introduction**

Fluctuating weather conditions in the global climate system are occurring at a rapid pace (IPCC, 2013; Poirier, 2016), and climate change has been deemed unequivocal by the Intergovernmental Panel on Climate Change (IPCC, 2013). Warming of the atmosphere and oceans, new precipitation patterns, melting of snow and ice, rising sea levels, and increasing concentrations of greenhouse gases in the atmosphere are all expected as a result (IPCC, 2013).

Natural oscillations of the climate system have been accelerated by human activities due to a large increase in greenhouse gases in the atmosphere. This warming is putting stress on natural systems and causing changes in their function and resiliency (IPCC, 2013).

Defined as the interface between land and water, coastlines are very dynamic and are being impacted by climate change in many different ways (Lemmen and Warren, 2016). There has been an increase in coastal flooding by gradual sea level rise inundation and rapid short-term surges that are increasing in frequency, severity, and intensity with warming of the climate system. The impacts do not stop at flooding of the coastline but also incorporate coastal erosion, which is also being amplified by climate change (IPCC, 2013; Church et al., 2013; Poirier, 2016; Charron, 2013). With close to half of the world's population living within 100 km of the coast, the coastal zone is important to monitor as it faces adverse effects from climate change. As coastal communities feel the effects of climate change, their vulnerability needs to be assessed so that they can plan to adapt.

### **1.3 Flooding**

One of the major impacts of climate change on coastlines is flooding. The intensity and severity of flooding is dependent on both its temporal and spatial scale. Over a long time scale, flooding occurs through sea level rise (SLR). The overall rise in sea level in a particular area is measured relative to the elevation of the land that it borders. These changes may be isostatic, eustatic, or steric (James et al., 2014). Isostatic changes refer to the vertical movement of landmasses, both uplift and subsidence that occurs due to tectonic shift and the continued

recovery of landmasses from the effects of glaciation. Eustatic variation refers to changes in water volume on a global or oceanic scale (Davidson-Arnott, 2010); these changes are caused by the addition of melt water from ice caps, Antarctic and Greenland ice sheets, and glaciers. Steric changes refer to the thermal expansion of upper oceanic layers (Atkinson et al., 2016).

Globally, sea levels are expected to rise by 26-98 cm by 2100 (IPCC, 2013) due to a combination of isostatic, eustatic, and steric effects. This amount could be increased by several tenths of a metre if a collapse of marine-based sectors of the Antarctic ice sheet were to occur (IPCC, 2013; James et al., 2014). More locally, large portions of the Maritimes are expected to experience a very high SLR rate due to subsidence (Savard et al., 2016) with sea levels in Albert County, NB expected to rise by a metre before 2100 (Daigle, 2014). The combined influence of SLR and isostatic adjustments is referred to as Relative Sea Level Rise (RSLR). The increase in water levels in the Bay of Fundy will cause the oscillation of the tides to slow altering the resonance within the Bay as a whole. As the resonance approaches natural seiche, the tidal range will increase (Greenberg et al., 2012; Leys, 2009; Savard et al., 2016). This will not affect mean sea level but rather be measured in relation to the elevation of the highest tides (Savard et al., 2016).

Low lying areas will be slowly inundated at the rate equivalent to RSLR. In response, coastal systems including saltmarshes will retreat landward (Atkinson et al., 2016; Savard et al., 2016). This could cause areas that are not currently vulnerable to become at risk to coastal processes and events in the future. If the natural landward migration of a coastal system is impeded by the location of an anthropogenic structure such as seawall or by high relief such as a

cliff, this is referred to as coastal squeeze. Coastal squeeze can lead to habitat loss as the coastline is inundated and eroded (Atkinson et al., 2016; Savard et al., 2016; Pontee, 2013). There is also the potential for saline intrusion into freshwater sources and damage to land that has not adapted to salt water.

Over a shorter time scale, flooding occurs through storm surge. This occurs when water levels rise above predicted astronomical tides as a result of variations in wind and atmospheric pressure (Atkinson et al., 2016). The relative height of a surge above the predicted tide level is influenced by many factors, including fetch, elevation, and orientation. Fetch, defined as the length of open water over which wind has blown (Davidson-Arnott, 2010), can impact the height of a surge by allowing wave height to increase with increasing wind speed. Therefore, a coastline with the longest fetch will be more highly impacted. Coastal elevation is also relevant as low-lying areas are more frequently and severely impacted by surge events (Davidson-Arnott, 2010; Atkinson et al., 2016; Savard et al., 2016)

The gradual increase in relative water levels due to sea level rise will also impact the severity of storm surge. Where a wave breaks is proportional to wave height and wave depth (Davidson-Arnott, 2010), and with deeper water levels, larger waves will be able to reach the shore due to the reduction of the distance from shore at which they break. Higher sea levels will also allow for greater inundation of land during a surge, with land higher in elevation being reached by waves than it would be without SLR. This will also cause an increase in erosion due to more intense waves hitting lower-lying areas and water having the potential to cause damage at higher elevations than previously possible. The frequency of large surge events is linked to a

probability scale based on how often a surge of a particular size could occur in a century. Smaller surges occur more frequently, so could occur on a 1-in-5-year frequency for example while larger surges that occur very infrequently might have a 50 or 100-year return period and are viewed as worst case scenarios (Daigle, 2012). As sea level rises, surge residuals must be added on top of these higher water levels in the prediction of return periods. This means that as water levels rise, storms with high return periods become more probable so a storm that once had a 1 in 50-year probability could be increased to a 1-in-2 year return (Atkinson et al., 2016; Bernier and Thompson, 2006). Figure 1.1 depicts the linear relationship between sea level rise and increased storm surge height.

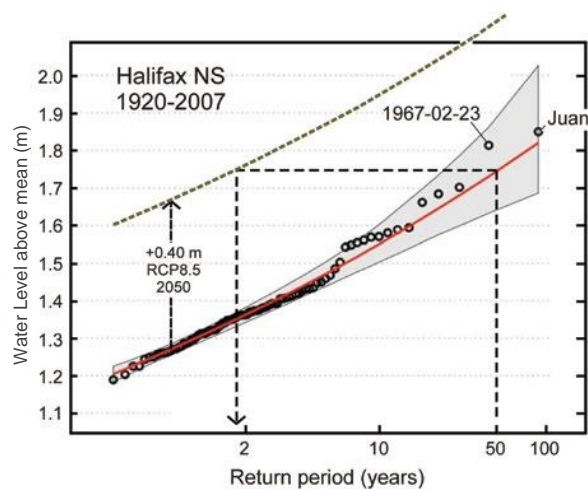


Figure 1.1. Changes in storm return period with the addition of SLR (Modified from Lemmen and Warren, 2016)



## 1.4 Erosion

Erosion is the systematic removal of material from the coastline through coastal or subaerial processes. The degree of erosion will be affected by the balance of assailing and resisting forces in a particular system. Erosion rates can also be affected by the presence of anthropogenic features. In some cases, structures can block the transport of sediment alongshore causing accretion in certain areas and erosion in others. The addition of armourstone along the base of cliffs and bluffs can protect the toe in some cases by dissipating wave energy. However, if waves are capable of overtopping the armouring (or any other structure) due to it being misplaced, on an incorrect angle, or not significant enough in height, then they can serve to amplify the erosive energy and cause scour behind and in front of the structure (Poirier, 2016; Leys and Bryce, 2016).

Coastal processes cause erosion when wave action causes a loss of sediment in a particular area. This could occur along any section of a beach profile, but has a particular effect on the backshore, which can be defined as the extent of furthest possible wave advance in a storm (Appendix A). When waves reach the backshore, they can remove material from the base or toe of cliffs and bluffs; acting as a hydrologic force. The effect of the waves on erosion is amplified when they are carrying sediment to any extent from sand to boulders due to the pounding and rolling of sediment against a cliff base; acting as a mechanical force. Toe erosion causes undercutting of the cliff or bluff which will lead to eventual slumping or collapse when a certain angle is reached and the eroded toe can no longer support the cliff face above it. It is the cause of very steep cliff or bluff profiles (Davidson-Arnott, 2010).

Subaerial processes can also cause backshore erosion, especially in the case of bluffs that are made of more loosely packed material such as glacial till as these will erode much more quickly than cliffs made of tightly packed, harder materials such as igneous rock. Subaerial processes occur directly on the coastline itself independent of coastal processes. This can include overland flow of rivers, streams, and precipitation runoff if their course brings them over the edge of a bluff; this can remove smaller amounts of sediment and cause rifts in a bluff face. Improper drainage can cause seepage into the ground and can be responsible for larger-scale failures. The erosion rate of cliffs and bluffs will also be affected by freezing and thawing during winter months and the presence or absence of vegetation (Davidson-Arnott, 2010).

Figure 1.2 demonstrates that assailing forces consist of wave energy and that resisting forces include the cliff material and its condition. When the strength of assailing forces is greater than the strength of resisting forces, erosion occurs (Davidson-Arnott, 2010).

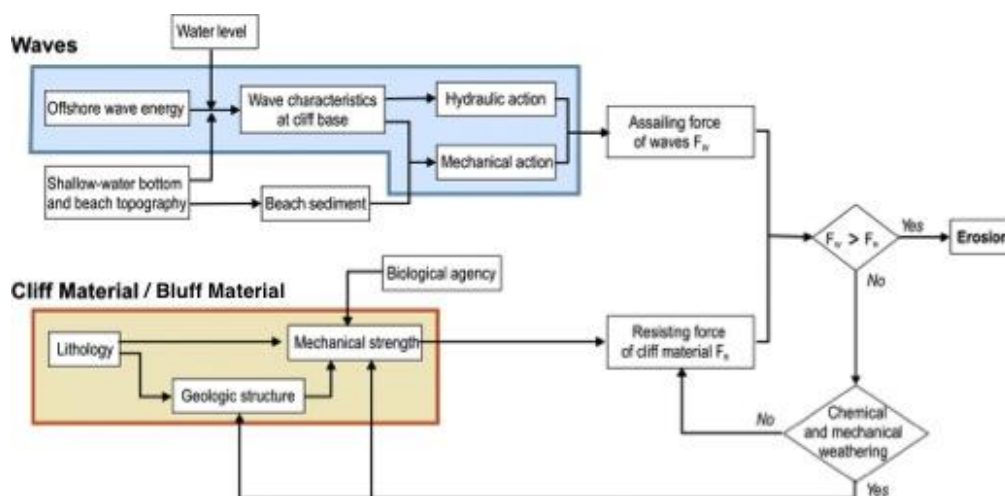


Figure 1.2. Assailing and Resisting Forces of Cliff and Bluff Erosion  
(Modified from Sunamura, 1983 in Davidson-Arnott, 2010)

## 1.5 Vulnerability Assessment

Charron (2013) defines vulnerability as “the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change. It is a function of the character, magnitude and rate of change to which a system is exposed and the sensitivity and adaptive capacity of that system.” In terms of the coast, this would encompass the degree to which communities are being adversely affected by climate change such as inundation and erosion and how able they are to adapt to these effects.

A community’s vulnerability can be assessed in terms of physical vulnerability and socio-economic vulnerability, though the two often work hand-in-hand. People can be physically vulnerable to climate change along a coast if their homes or property are or could be affected by erosion or inundation. This can have a socio-economic effect if their livelihoods are being

affected by erosion, inundation or saline intrusion of agricultural lands, damage to wharves or related coastal infrastructure in a storm event (MUN, 2012), or the loss of cultural or archaeological remains to erosion (UNESCO, 2016).

Vulnerability can be assessed with the use of LiDAR and Digital Elevation Models (DEMs) in GIS. Sea Level Rise can be mapped in a DEM by adding projected amounts onto known sea level to virtually inundate an area. The result can be overlaid on a related map to see where assets will be at risk in the future. In the field, current vulnerability can be assessed by mapping areas that are currently eroding and making assumptions as to where they could be at further risk in the future. These methods of assessment can be combined to get a better understanding of the present state of a coastline and to assess its future vulnerability (Pippard, 2012; MUN, 2012; Pietersma-Perrott and van Proosdij, 2012).

One particular form of shoreline characterization for vulnerability assessment involves classifying portions of the coastline in different zones. This approach was used by Pietersma-Perrott and van Proosdij (2012) who separated the coastal zone into 5 separate portions to reflect the vast characterization of the coastline within the hypertidal conditions of the Bay of Fundy. That particular study defined the zones as backshore, upper, middle and lower foreshore, and nearshore. The foreshore being split into three different zones allows the varied environment within large intertidal zones to be distinguished. A similar approach was taken by Tibbetts and van Proosdij (2013) in the creation of a relative coastal vulnerability index for regions with macrotidal conditions, though the nearshore zone was not included in characterization within that study due to the authors deeming its characteristics to be of limited significance when it comes

to overall vulnerability. It is specified that the, “four coastlines were chosen due to the difference in characteristics between them,” (Tibbetts and van Proosdij, 2013) meaning that as each zone has particular and potentially quite different characteristics, it adds to the quality of the assessment by distinguishing between them.

The conceptual model in Figure 1.3 was designed by Tibbetts and van Proosdij (2013) to describe both causes and consequences of vulnerability and their relationships with coastal characteristics. The outlined characteristics of vulnerability are consequentially important to deduce when undertaking a vulnerability assessment. Causes of vulnerability include tide elevation, hazards, and seaward characteristics within a coastal region while consequences of and responses to vulnerability include measuring adaptive capacity and risk factors and the undertaking of a particular response in order to adapt to identified vulnerability. Characteristics of the coastline itself that can affect its vulnerability include its exposure (e.g. higher tide height causes increased vulnerability), physical characteristics (e.g. shore width and slope), and resilience (e.g. stability). The addition or existence of protective structures can be a response to identified vulnerability, and it can affect the exposure and resilience of the coastline (both positively and negatively).

## Local Scale

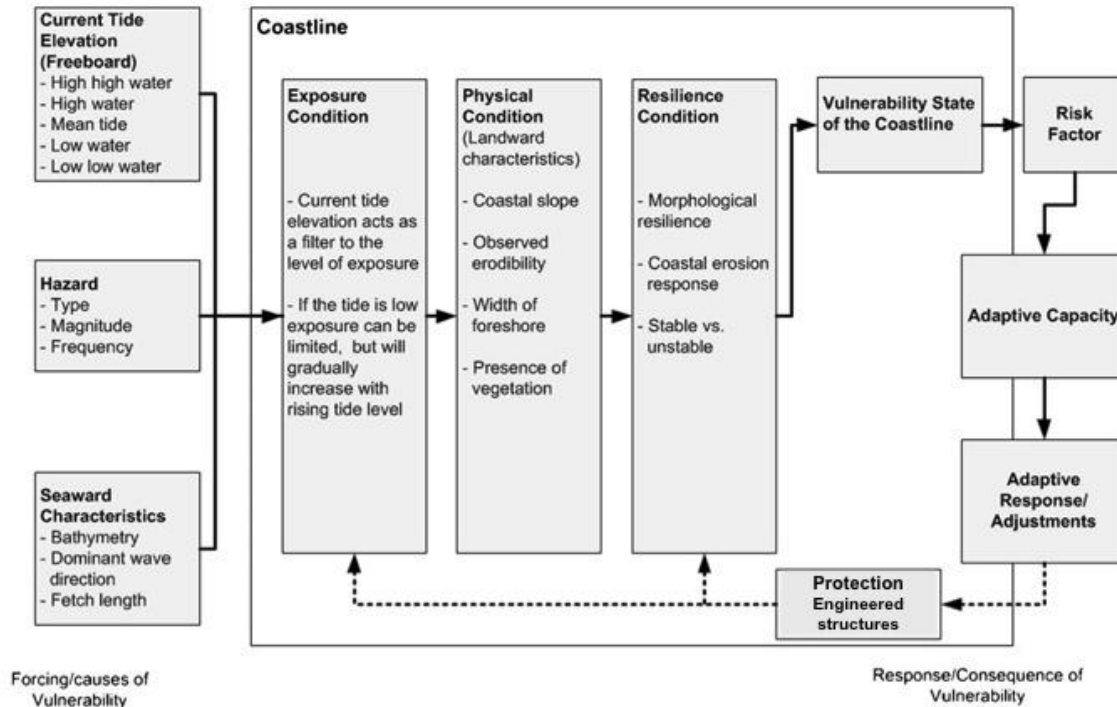


Figure 1.3. Vulnerability Assessment Conceptual Model  
(Modified from Tibbetts and van Proosdij, 2013)

## 1.6 Adaptation Planning

When an area has been deemed vulnerable to the effects of climate change, it is then important to make a comprehensive adaptation strategy to deal with the situation. Four strategies can be undertaken in the creation of an adaptation plan. These strategies are outlined by van Proosdij et al. (2016) as follows:

- Avoid – highly discouraging or stopping development in areas that are already or could become dangerous or unpredictable

- Protect – [“advance or hold the line”] helping (often engineering) the coastline to maintain its present form and use
- Accommodate – [“raise the line”] allowing land to continue to be used, but often involving changes in infrastructure and/or land use
- Retreat (relocate) – relocation of people and infrastructure away from the coastal zone by a specific margin (at minimum); can be managed and deliberate or forced abandonment

Adaptation planning is being aided by an increasing number of tools being made available to planners that can allow them to assess their future climate change vulnerability. One such vulnerability assessment tool is a sea level rise viewer designed by NOAA with overlays displaying local scenarios and marsh migration for certain locations, vulnerability, mapping confidence, and flood frequency; it is available at <https://coast.noaa.gov/slr/beta> (NOAA, 2017). Unfortunately, it only includes the USA and not Canadian coasts. Online viewers are not the only tools that can be used by planners to assess coastal vulnerability however; there are an increasing number of guidebooks being published federal, local, and non-governmental organizations. One such document is “7 Steps to Assess Climate Change Vulnerability in Your Community” that was developed by Memorial University through the Atlantic Climate Adaptation Solutions Association as a part of the Regional Adaptation Collaborative program supported by Natural Resources Canada (MUN, 2012). It was designed as a workbook to be filled out by community leaders in an effort to help them pinpoint what is vulnerable within their communities.

Online tools and adaptation planning documents are also increasingly being created to lay out climate change adaptation options to community coastal planners. One such tool is the ACASA Coastal Flooding and Erosion Decision Support Tool (ACASA, 2016). This could be used in conjunction with a vulnerability assessment tool such as the “7 Steps to Assess Climate Change Vulnerability in Your Community” (MUN, 2012) workbook outlined above, as it requires some previous knowledge about vulnerability in the particular area being assessed. It is designed specifically for use within Atlantic Canada and is integrated with information particular to the four provinces such as specific knowledge about coastal planning laws in each province. The tool is in the format of an on-line decision tree where specific options are given to the user and further questions about their local scenario are asked based on the answers they give. Personalized adaptation options are offered once all questions have been answered, and there are three accompanying documents that outline each potential option in detail. This tool is available at <https://atlanticadaptation.ca> (ACASA, 2016).

Generally, mandated protected areas can be used for planning and of climate change with use of strict regulation and policy (Canadian Parks Council, 2013). On an international level, UNESCO governs the protection of Biosphere Reserves through the Man and Biosphere Programme and the World Network of Biosphere Reserves. Originally created to protect portions of the world’s main ecosystems, these biosphere reserves function as global observatories for climate change adaptation. They are locations that foster research and sustainable development while contributing to landscape conservation. As the climate changes, these locations will continue to be protected and could become regional leaders for research and adaptation



management (Meggle, 2015; UNESCO, 2016; Fundy Biosphere Reserve, 2016). On a federal level, Canadian protected areas are governed by the Parks Canada Agency. In the 1970s, Parks Canada created a system plan to protect Canada's varied landscapes. This plan split the country into 39 "natural regions," each with their own land and vegetative characteristics. The hope was to eventually establish a Park within each natural region to complete the National Park System (Parks Canada, 1997).

## CHAPTER 2: Study Area

### 2.1 The Bay of Fundy

The Bay of Fundy was created in the original form of a rift valley 350 million years ago and changed forms many times in subsequent millennia until it reached its present shape at the end of the most recent ice age 13 500 years ago (Burzynski, 1985). As the ice melted, water levels began to rise. Tidal waters had been restricted in the Bay due to the position of George's Bank in the Gulf of Maine, but as the rising sea submerged it around 6000 BP, their restriction dwindled. Tides began to flow into the Bay twice daily (a diurnal cycle), bringing with them the combined amount of water of all of the world's rivers. As they entered and left the Bay, the water began to gently oscillate or seiche at a pace near to the resonance of the tides. This resonance serves to amplify the height of the tides, increasing their range. Presently, the Bay of Fundy is home to the highest tides in the world based on a maximum tidal range of over 16m (Desplanque and Mossman, 2004; Burzynski, 1985).

Geologically, the lower and central portions of the Bay's coastline are formed of more resistant igneous and metamorphic rocks. There are various types of rock such as Precambrian andecites and tuffs or Cambrian granites and diorites (Burzynski, 1985). The upper portion of the Bay is conversely composed of less resistant sedimentary rocks. These sandstones and shales include the iron-rich red Hopewell conglomerate that moulds together various gravels, sands, and

rocks. The landscape of the Bay of Fundy is geologically complex overall, being most recently carved by large glaciers that left behind gravels and till (Burzynski, 1985).

The Chignecto Bay is the northwestern basin of the Upper Bay of Fundy, flanked on one side by the province of New Brunswick (NB) and by Nova Scotia (NS) on the other (Figure 2.1). Its boundaries are defined by Cape Chignecto on the NS side and by Martin Head on the NB side. Its upper portion is split into two smaller basins separated by Cape Maringouin. The Cumberland Basin is the upper right portion and terminates at the Tantramar Marsh on the Chignecto isthmus close to the border between the two provinces. The Shepody Bay is its counterpart on the upper left, making its way up to the Petitcodiac and Memramcook Rivers and is situated completely in New Brunswick.

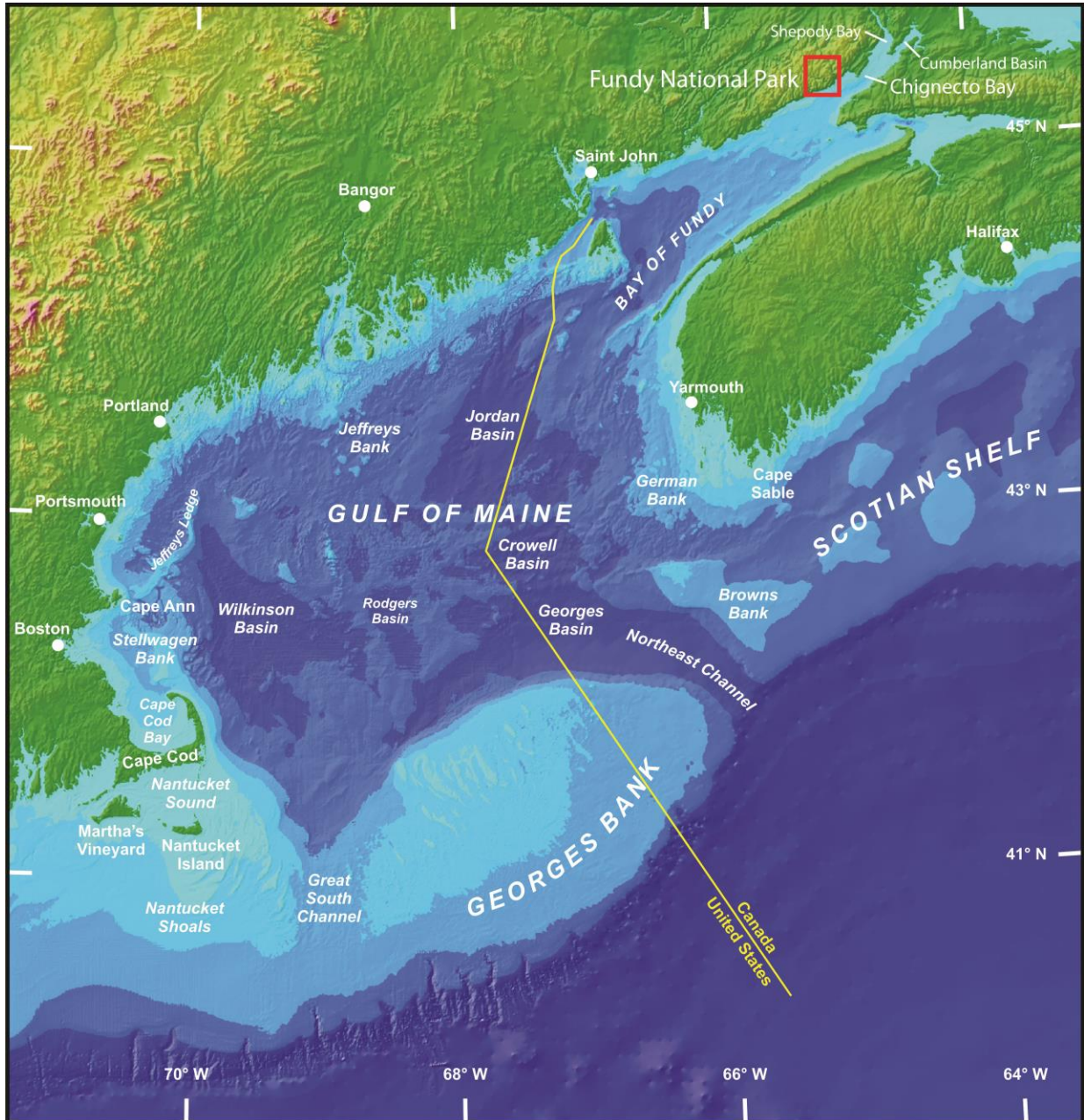


Figure 2.1. Location of Fundy National Park within the Gulf of Maine system (modified from GOMMI: base map courtesy of USGS Woods Hole Field Centre)

## 2.2 Fundy Biosphere Reserve

Officially designated by UNESCO on September 21, 2007, the Fundy Biosphere Reserve comprises an area of 442 250 hectares in New Brunswick (Fundy Biosphere Reserve, 2016). It stretches along the Bay of Fundy coastline from Saint Martins to the Tantramar marsh and inland as far as Moncton to protect the region's watershed (Fundy Biosphere Reserve, 2016).

One initiative of the Fundy Biosphere was to name 50 Amazing Places that can be found along hiking trails in the reserve. They have been deemed amazing destinations for various reasons including natural history and breathtaking scenery, and each location now has a smartphone-enabled interpretive sign where information about its significance can be accessed (Amazing Places, 2016; Fundy Biosphere Reserve, 2016).

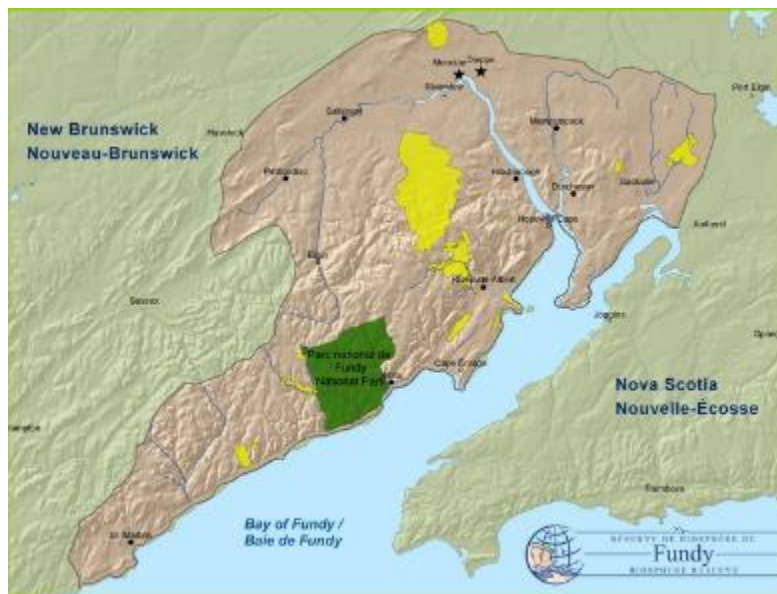


Figure 2.2. Location of Fundy National Park within the Fundy Biosphere Reserve (Fundy Biosphere Reserve, 2016)

### **2.3 Fundy National Park**

After being delayed for 22 years, New Brunswick's first National Park was established on April 20, 1948 and officially opened on July 29, 1950 (Lothian, 1976; Young, 1951). Fundy National Park (FNP) had 62 844 visitors in its first year (Young, 1951) and now welcomes over a quarter million visitors annually (Corey and Goodbrand, 2015).

FNP protects approximately 13 kilometres of coastline among its 206 km<sup>2</sup> (Parks Canada, 2010; National Geographic Society, 2011; Burzynski, 1985). Along with the Caledonia Highlands that characterize the inner portion of the Park as a part of the Maritime Acadian Highland natural region (Parks Canada, 1997), its location on the Bay of Fundy is one of the main drivers of FNP (Burzynski, 1985). The tides are one of the main tourist draws to the area, and FNP is significant as being the only National Park that protects the Bay of Fundy coastline. The coastal zone of Fundy National Park may be divided into two distinct areas.

“Half of the coast, from Point Wolfe towards the mouth of the Bay, is composed of erosion-resistant igneous and metamorphic rocks that form cliffs up to 200 m high, with much of the shore exposed to wave action, and with only a few protected beaches. In the other direction, from Point Wolfe eastward to Alma and beyond, the shore and cliffs rise up to 30 m high and are greatly affected by wave undermining. They are composed of softer sandstones, shales and glacial deposits” (Fundy National Park, 2011).

The Park does not protect the intertidal zone nor low water mark as they do not fall under federal jurisdiction (Fundy National Park, 2011).

### 2.3.1 Alma

The Village of Alma borders Fundy National Park to the southeast. This border is characterized by the location of the Upper Salmon River, a large tidal delta that has played an important role in shaping the area. At the mouth of the river, there is a large beach called the Alma Beach (in honour of the Village) of which the coastline is divided between the Park and the Village. The Upper Salmon river delta is one of the Fundy Biosphere Reserve's 50 Amazing Places due to its abnormally large size (Amazing Places, 2016).

The Park's Alma coastline is situated on the western bank of the Upper Salmon River. The Park boundary is characterized by a tidal salt marsh that sits behind a small lowland. This lowland contains a parking lot for the beach, the Molly Kool Heritage Centre (celebrating North America's first woman sea captain (CBC News, 2010), Molly Kool, who was from Alma), the highway 114 connecting the Village of Alma to the Park and beyond via bridge, a kiosk where Park Entry fees can be paid, and a small boardwalk that allows beach access. Built on a gravel terrace that was a historic outwash fan, the Alma region is characterized by Carboniferous sandstone cliffs and glacial till bluffs that, along with river flow, feed the large beach (Burzynski, 1985).

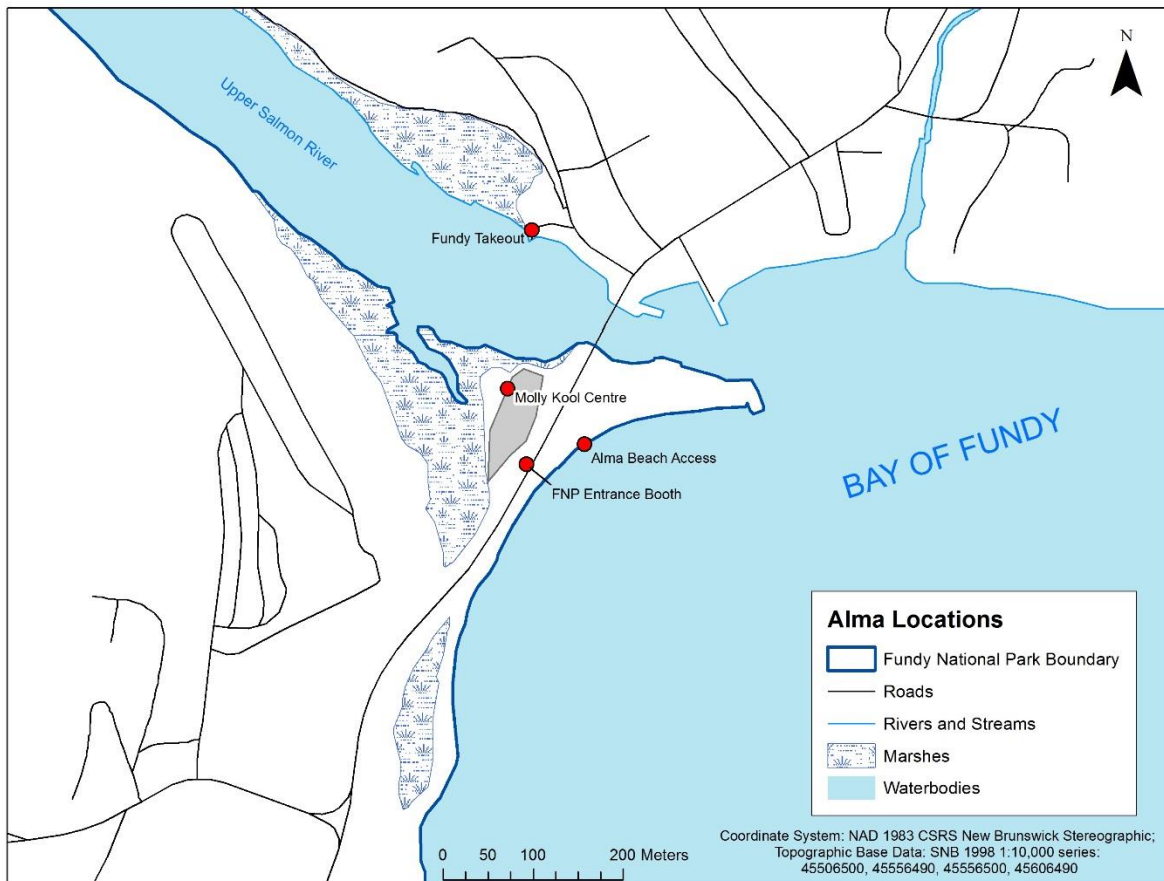


Figure 2.3. Locations within the Alma Study Area

On the far western reach of the Alma delta is section of coastline that is referred to as the Cannontown beach. This beach contains a saltwater swimming pool overlooking the Bay. The parking lot is armoured with a riprap revetment, and there are multiple beach access points. It is flanked to the west by a barachois (shingle barrier beach).

The Village of Alma was originally settled when the lumbering trade took root in the area at the base of the Upper Salmon River. A sawmill was built in this location in 1872, the



beginning of the Alma Shipbuilding and Lumber Company (Cooper and Clay, 1997). Much of the Park's forest was cut at one point due to extensive lumbering in the area, which will be revisited in Section 2.3.3. The area was also known for shipbuilding and was a shipping port home to many schooners that would transport lumber to Saint John and into the United States (Parks Canada, n.d.).

The Alma region has been hit by many storm surges over the years, including multiple events in the last 10 years. Most recently, on October 20, 2015 a surge flooded the Alma beach parking lot up to the top step of the Molly Kool Heritage Centre's deck (as can be seen in Figure 2.4), washed over a dune on the beach, and eroded and damaged the bank behind the revetment that protects the highway. This revetment has been in place for many years and is currently failing due to erosion occurring behind it. In 2010, a different surge event damaged and broke off a section of the previous staircase and exhibit in the area and it washed down the beach in the process (as can also be seen in Figure 2.4). Large rain events can also cause damage to the area when the river level rises. Two fishing boats were ripped from the wharf and run aground at low tide in November 2013 due to powerful river currents amplified by a storm (MacInnis, 2013).

Storm Surge Dec. 6, 2010



Storm Surge Oct. 29, 2015



*Figure 2.4. Recent Storm Surges  
(Photos courtesy of Parks Canada, 2010-2015)*

Perhaps the greatest storm on record to impact the region was the Saxby Gale of 1869. It produced a surge that was 1.5m higher than astronomical tides. This storm occurred in time with a high perigean spring tide at the peak of the 18 year Saros cycle during which tides reach their peak astronomical height (Desplanque and Mossman, 2004; Desplanque and Mossman, 1999).

The Groundhog Day Gale of February 2, 1976 was the greatest storm to impact the region in the 20<sup>th</sup> Century (Desplanque and Mossman, 2004). It caused incredible damage to the Bay's coastline with a surge of 1.46m (Desplanque & Mossman, 1999). Within the Park, 6-8 feet of turf was washed away around Alma beach, sandstone cliffs were undercut by 5-6 inches, several landslides occurred with trees washing over banks, and salt spray reached over a mile inland (Deichmann, 1976). Gravel cliffs were so highly eroded that armourstone was brought in to protect their bases (Burzynski, 1985). This storm has been compared to the Saxby Gale. It took place during an apogean spring tide (time of the month when the moon is furthest from the earth in its cycle) however, and it is predicted that had it occurred two weeks later during the perigean spring tide, the damage could have been worse (Burzynski, 1985; Deichmann, 1976; Desplanque and Mossman, 1999; Desplanque and Mossman, 2004; Savard et al., 2016).



*Figure 2.5. Alma in 1937  
Depicts lumber being loaded onto a scow and the old bridge location  
(Photo courtesy of Parks Canada, 1937)*

When Fundy National Park was created, land was expropriated from the Village of Alma and certain homes that had been previously located on the western bank of the Upper Salmon River were moved to the other side. The bridge linking the Village of Alma with Fundy National Park was not always in its current location and was only opened in 1967. Previously there was a covered bridge linking them a bit further upriver with remnants of both ends visible in the marsh to the right of the Molly Kool Heritage Centre and across the river next to the Fundy Take Out restaurant, the locations of which are visible in Figure 2.3.

Currently, the Village of Alma is driven economically by lobster and scallop fishing. An engineered breakwater constructed on the far tip of the Park's coastline protects the Village's

fishing wharf. It was raised and increased in size during the winter of 2016 to accommodate a multimillion dollar expansion to the wharf, which accommodates approximately 20 fishing boats. The other main economic driver of Alma is tourism due to its location on the border of the National Park. There are many small inns, bed and breakfasts, and restaurants that are kept busy during the summer months by a continuous stream of tourists.

### **2.3.2 Herring Cove**

Located more centrally along Fundy National Park's coastline, Herring Cove is a partially sheltered cove with a sandy beach. It is characterized by red sandstone from the Hopewell Conglomerate on its western boundary. Due to its partially sheltered location, it is often used by Alma's fishermen to anchor and await the high tide; for this reason, many scallop shells can be found on the beach.

Due to their rugged nature and lack of thick topsoil, the Caledonia Highlands within the Park were not extensively settled for farming activities. Herring Cove was much more sparsely settled than Alma and Point Wolfe due to the lack of a mill and large river to drive logs in the area. Instead, Herring Cove was the home to a very small fishing community and vacation homes on the clifftops. Multiple fishing weirs were operated on the beach. The area was also home to a Department of Agriculture potato research facility that operated from the early 1940s until 1974 (Lothian, 1976).

Herring Cove is the least visited of the Park's three main accessible beaches. It is the central meeting location of the Coastal East and West hiking trails, which snake along the cliffs

above it. There is a small day-use picnic area with two separate shelters, charcoal barbecues as well as a small lookout exhibit with some interpretive panels outlining the area's history and home to a usable telescope which gives a nice view of Alma's Owl's Head cliff as well as Cape Enrage and Nova Scotia further in the distance. There is a 150-step staircase that leads from the exhibit down to the beach as well as a separate staircase that leads to the beach from the Coastal West trail a few hundred metres in from its trailhead. The main staircase was built in the past 10 years to replace earlier stone stairs at the bottom of a winding trail that went down the bluff, which were not in good condition.

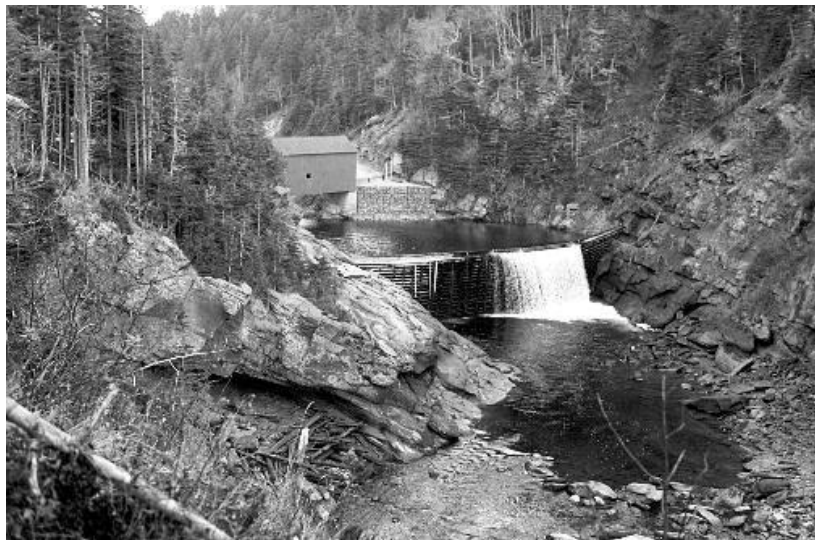
On August 29, 2015, this beach was home to a free Serena Ryder concert for 1000 people called the Quietest Concert Ever (CBC News, 2015), bringing national attention to the Herring Cove coastline. A CBC documentary was made chronicling the feat of the organizing committee of setting up a stage in the intertidal zone and tearing it down within a tidal cycle. Wooden railings and green cords were put up prior to the concert to protect delicate vegetation around the base of the main staircase, and they remain in place to date (the railings are visible in Figure 4.13). These railings, while preventing damage to the plant species, also prevent foot traffic from damaging the delicate backshore morphology in that location.

### **2.3.3 Point Wolfe**

The Point Wolfe Estuary is located at the mouth of the Point Wolfe River and is one of the Fundy Biosphere Reserve's 50 Amazing Places (Amazing Places, 2016). The Point Wolfe Estuary is geologically special. On one side of the River, the cliffs are made up of Precambrian

andesite and tuff while the other side is made up of significantly younger red sandstone from the Hopewell Conglomerate, and at the back of the estuary is a terminal moraine made up of glacial till deposits from the most recent ice age (Burzynski, 1985). This causes a large variation in sediments on the beach from boulders to mud.

Historically, similar to Alma, Point Wolfe was a bustling logging community with a fully functional sawmill, shipbuilding, and shipping docks, and a complete dam across the river mouth (Fundy National Park, 1984). This dam was only removed in 1985 to allow for complete fish passage (Cooper and Clay, 1997), and a small portion of it can still be seen under the red covered bridge the crosses the river's mouth.



*Figure 2.6. Point Wolfe Dam in the 1970s with the bridge in the background  
(Photo courtesy of Parks Canada, mid-1970s)*

The Point Wolfe covered bridge is a reconstruction of a prior bridge and was built in 1992. The previous covered bridge had been destroyed in 1990 in a construction accident when rock blasted from the neighbouring cliffs to reduce landslide risk fell on the bridge and destroyed it. It is the fifth bridge to stand in that location since 1853.

Point Wolfe may not have any permanent residents now, but it is home to a campground with 145 sites that bring visitors to the area. Many day-use trails begin from the beach's parking lot, including Shiphaven, which spans from the beach parking lot to the covered bridge along the top of the cliffs at the back of the estuary. It is one of the most highly used trails in the Park. with interpretive panels that talk about the forest and historical use of the area and a wonderful location to take high and low tide pictures showing the estuary empty and full with the tide. There is also a hiking trail that descends to the central western section of the beach from the parking lot; this was recently opened as a replacement of a prior trail which had suffered large amounts of erosion. Other trailheads include Coastal West, Coppermine, Goose River, Marvin Lake, and Foster Brook trails and it is the current end point of the Fundy Footpath that leads through Goose River all the way to the Fundy Trail Parkway in St Martins.

#### **2.3.4 Climate Change Projections**

Warming of the global climate system has been deemed unequivocal by the IPCC (2013), leading to increased surface and ocean temperatures over the majority of the globe as well as shifting precipitation patterns. Within Atlantic Canada, temperatures have been warming over the past century at a pace similar to or greater than the global average (Savard et al., 2016) with a



slightly larger increase in minimum temperatures than maximum temperatures (Atkinson et al., 2016). This trend of surface temperature increase is expected to continue and become more intense, and while all seasons will be highly affected, there will be the greatest increase in temperatures in the winter (Savard et al., 2016). Furthermore, annual precipitation is also projected to increase overall with the largest increase coming in the winter months and summer and autumn totals remaining fairly stable (Savard et al., 2016). This precipitation will come mostly in the form of rain with a projected decrease in snowfall (Atkinson et al., 2016). These changes in the winter months could lead to an increase in erosion due to diminishment or complete loss of an ice foot that protects the base of the erodible bluffs in Fundy National Park as Freeze-thaw patterns could also change due to the rising winter temperatures, and this could cause mass wasting and increased bluff erosion through subaerial processes.

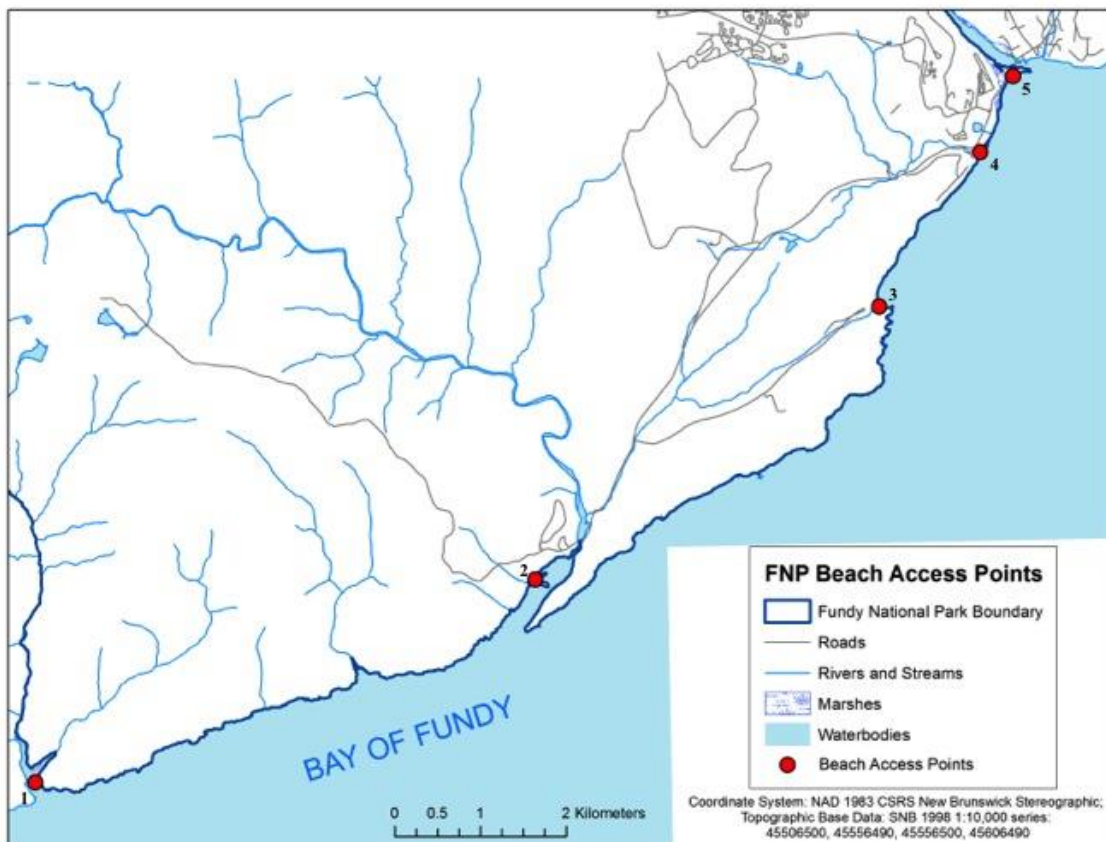
## **CHAPTER 3: Research Design and Methods**

This research combines field-based data collection with geomatics with the purpose of assessing the vulnerability of Fundy National Park's coastline. To undergo a vulnerability assessment, it is necessary to first understand the geomorphic and stability characteristics of the coastline being studied. This was achieved through the field portion of the research during the summer of 2016. The collected data were used to undergo an assessment of the stability and current vulnerability of Fundy National Park's coastline. Stability was assessed as a function of the extent of recent erosion within a segment of coastline or as a function of the state of repair of an anthropological feature or asset built on the coastline. ArcGIS 10.4 was used to assess future vulnerability to climate change through mapping of sea level rise and the identification of coastal assets in areas that are currently vulnerable. Finally, an adaptation plan was created to assess the best manner for the Park to adapt their coastline to the identified vulnerabilities.

### **3.1 Site Selection**

This research focused on portions of the coastline within Fundy National Park that were accessible by land due to the dominance of high cliffs and bluffs without access points. Visitors who come from around the world to experience Bay of Fundy tides frequent the accessible portions of the coastline. Accessibility was important for the study sections so that it was possible to walk at low tide to photograph and characterize the coast, though it had to be accessible for a

long enough period at low tide to walk an entire section. These precautions were taken so that there was no chance of being caught by the rising tide. Within the study sections (Figure 3.2), there are access points at Alma beach, Herring Cove beach, Cannontown beach, and the Point Wolfe estuary (Figure 3.1). Within Fundy National Park, there is one other estuary, Goose River, that has an access point (Figure 3.1) down the bluff, but it is located at the end of an 8km hiking trail, so it was not possible to visit it due to time constraints.



*Figure 3.1. Beach Access Points within Fundy National Park  
 (1) Goose River, (2) Point Wolfe, (3) Herring Cove, (4) Cannontown, (5) Alma*

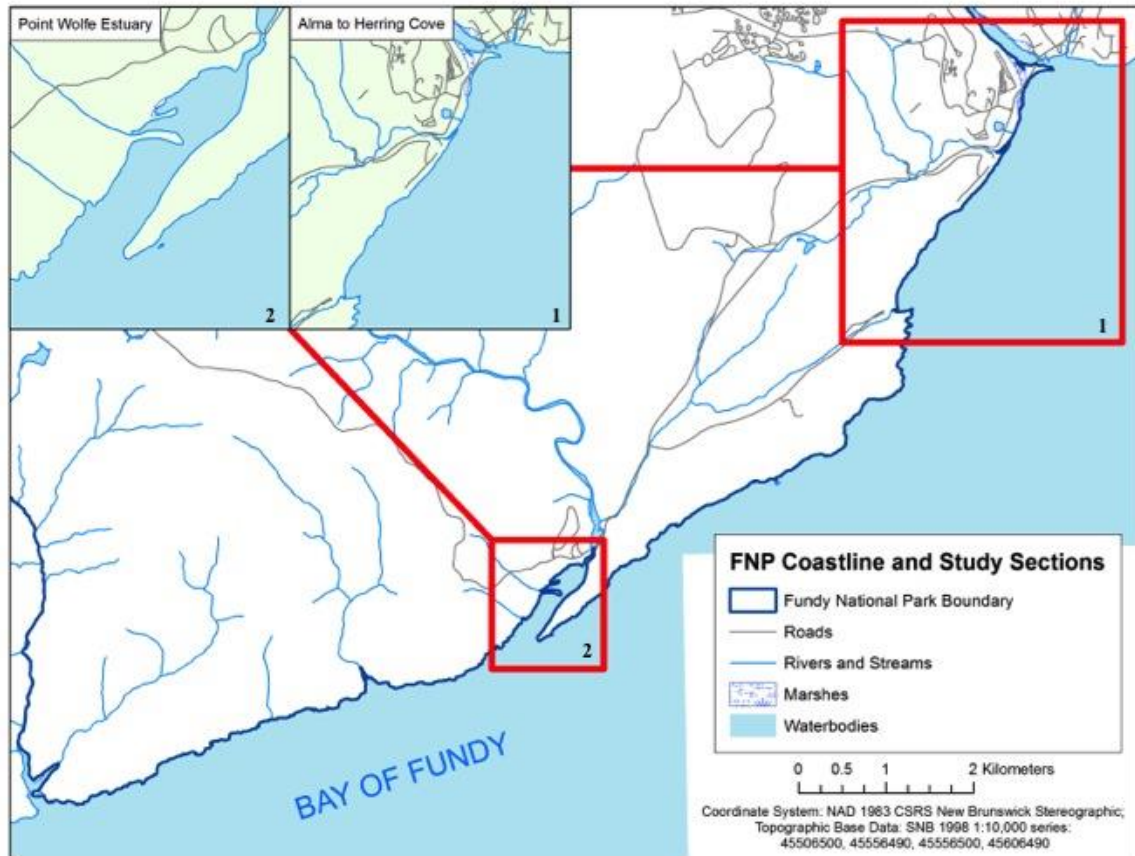


Figure 3.2. Study Area Sites and Fundy National Park Coastal Extent

### 3.2 Field Data Collection

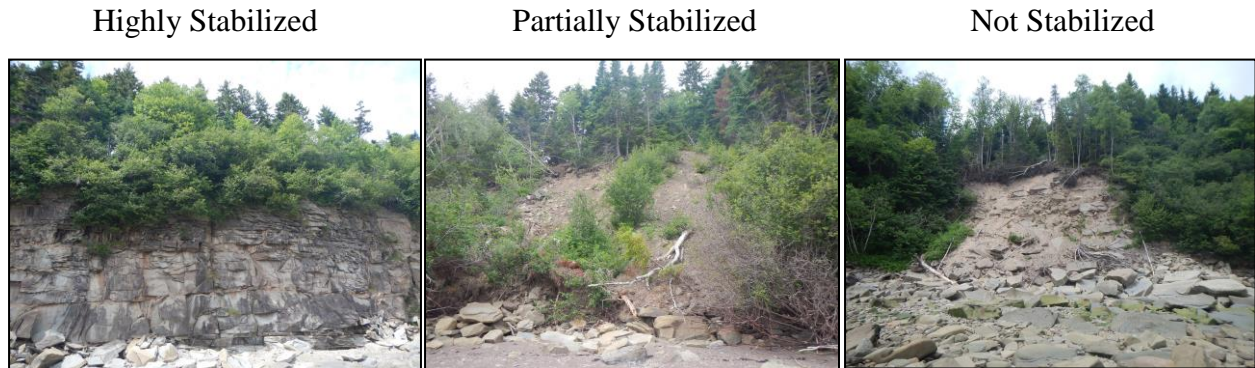
A Trimble Yuma tablet integrated with ArcGIS software was used to collect data in the field. The ArcGIS project contained background orthophotos as well as lines representative of the coastline. The coastline within the study sections was digitized in ArcGIS by delineating it from the orthophotos (taken in 1996-1997 with a scale of 1:35 000), which were retrieved from the GeoNB Data Catalogue (<http://www.snb.ca/geonb1/e/DC/catalogue-E.asp>).

Within this study, the coastline was characterized in three distinct zones: the nearshore, foreshore, and backshore. The nearshore consists of the intertidal zone or region that is periodically covered by water on every tide, the foreshore is the area that can be covered by a tide but not on every cycle (area within wrack lines), and the backshore is the furthest reach of waves during a storm event. There are more site-specific definitions that are found in the vocabulary list in Appendix A. Each zone was represented by a continuous line, which was segmented in the field. The line shapefiles were linked to a characterization attribute table that used drop down menus to assign predetermined options of characteristics of each coastline segment visited in the field. The characterization charts can be found in Figures A.1-A.3. Examples of characterizations include cliffs, bluffs, dunes, a beach, and a platform. The Yuma tablet is also GPS-integrated, so exact location in the field could be tracked relative to the coastline.

In the field, the entire coastline of the identified study sections was walked over a three-day period. As the coastline was walked, the line shapefiles (nearshore, foreshore, backshore) were broken in ArcGIS on the Yuma when there was a change in characterization. This created segmented lines for each shore zone where each segment had particular characteristics. Changes that would warrant a break in the shapefile could be anything from the overarching type of coast (e.g. bluff to anthropogenic feature), to the height or stability of a cliff, bluff, or slope, or the grain size of the intertidal zone (e.g. cobble to gravel). Further descriptions of all possible characterizations can be found in Appendix A. A break was made only when the new area was larger than 2m wide because anything smaller was not large enough to be significant, could not be properly displayed on the Yuma, and would be complicated to subsequently analyze. Upon

completion of the fieldwork, the lines representing each zone were fully broken into segments that are individually characterized.

One important component of the field characterization process was to assess the stability of the coastal segment being observed. In this study, stability could be characterized as highly stabilized, partially stabilized, or not stabilized (see Appendix A for further definitions and see Figure 3.3 for examples of each). The stability of the backshore was assessed with the use of a method termed a rapid geomorphic stability assessment, which utilizes a combination of geoindicators including slope angle and topography, and the presence of vegetation (Bush et al., 1999). The presence of vegetation can be an indication of the length of time that has elapsed since erosion occurred; if there is no vegetation present then erosion was likely recent whereas the presence of dense vegetation could demonstrate long-time stability, and if vegetation is beginning to regrow after an erosion event, the current slope could be moderately or partially stable. The angle and topography of a bluff or cliff could also be an indication of its stability; an even slope on a low angle demonstrates high stability whereas a steep or oversteep angle and the presence of large gullies and slump scars illustrates high instability, and a more moderate slope with an irregular or stepped topography potentially including minor gullies can indicate moderate stability (Bush et al., 1999). Overall knowledge of the stability of a coastline segment and whether it is actively eroding was important to the later assessment of its vulnerability.



*Figure 3.3. Examples of Coastal Stability Characterizations  
(June 2016)*

Geotagged photographs were taken with either a Nikon COOLPIX AW110 or an Olympus TG-4 for each segment that was characterized as well as other additional features. This allows them to be further observed and compared and also allows the photos to be spatially integrated into GIS by the location and direction that they were taken. For shoreline segments, the photos were taken primarily perpendicular to the shore if the area was smaller and parallel to the shore if the segment was larger (see Figure 3.4 for examples).

Shore-Perpendicular









Shore-Parallel



*Figure 3.4. Examples of Shoreline Segment Photographs  
(Images June 2016)*

Beyond the characterization of the nearshore, foreshore, and backshore, data on other coastal assets were also collected in the field including the locations of structures, access points, and streams. These features are outlined in Figure 3.5. The location of structures was noted to assess the importance of their physical locations and to determine if they are at risk.



Additional Feature	Importance of Inclusion	Photo
Drain	Can indicate an area of possible increased water flow, so there could be a higher probability of erosion	
Pump for saltwater pool	Asset located in the intertidal zone; could be damaged in a surge	
Bridges	Important assets for transportation; could be at risk in a large surge if undermined or water levels rise very high	
Remnants of historical assets (dam, wharves, bridge, mill)	Historically had a large impact on land use and morphology. Part of the remnant dam was washed away in a recent storm surge.	
Access Points (old and new)	Important assets to allow beach/coastline access; old ones closed due to erosion issues; replacements could be equally at risk	
Stream/River	Bring overland flow of water into the coastal zone. An increase in flow during a heavy rainfall event or snowmelt can increase erosion.	

*Figure 3.5. Additional Features Included  
(All images taken summer 2016)*

When there were areas that showed signs of backshore erosion but they were too small to allow the backshore characterization line to be broken, they were added to the GIS file on the Yuma as erosion point features. These were apparent as small areas of unstable backshore caused by both toe erosion and, more commonly, subaerial processes. In some cases, the erosion was likely caused during a single storm event apparent as scour behind old bulkheads and between riprap armouring. There were also a couple of areas where there was evidence of surge flooding including dune washover and a break in a shingle or sand barrier with brackish areas in behind. These flooding points were also marked as point features.

### **3.3 Vulnerability Assessment**

A vulnerability assessment was performed in ArcGIS 10.4 using the data that were collected in the field. The base data used in the ArcMap file includes NB Enhanced Topographic Basemaps and orthophotos obtained from the GeoNB website. The basemaps have a 1:10 000 scale, and the aerial imagery has 1 m resolution. The Trimble Yuma tablet that was used in the field has a positional accuracy of 3-5 m, making the data it collected suitable with the 1:10 000 scale maps.

Once all sections of the coastline were fully characterized using the integrated decision tree, summary statistics were taken from the attribute data. These summary statistics made it possible to pinpoint lengths and percentages of coastline in the study area that had particular attributes. This could include isolating unstable cliffs and bluffs to see where the coast is actively

eroding (which was determined using the rapid geomorphic stability assessment) or isolating anthropogenic features.

Sea Level Rise mapping was performed in ArcGIS 10.4 as a function of future vulnerability. This was done through use of LiDAR data provided by Fundy National Park. The LiDAR came in the form of a LAS Dataset. From the LAS dataset, a LAS Multipoint file was created in ArcGIS 10.4 using the “LAS to Multipoint” tool by separating only Ground points from all other types. The LAS Multipoint cloud was then modified into a raster dataset using the “IDW” tool in ArcGIS 10.4, creating a TIFF file with a resolution of 1m. With the IDW, it was possible to delineate different sea levels by separating the cells based on their elevation values. Depending on the chosen values, this could be used to depict how much of the coastline would be flooded at certain sea level elevations. The elevation values are measured using the Canadian Geodetic Vertical Datum of 1928 (CGVD28) against current Higher High Water Large Tide (HHWLT) of 6.5m for Alma (Daigle, 2014). HHWLT is a value representative of the average yearly highest tide over a 19-year period (Fisheries and Oceans Canada, n.d.). For the purposes of this study, mapped sea level is the combination of potential relative sea level values and potential 1-in-100-year storm surge for 2050 and 2100 scenarios. Data for this was taken from Daigle (2014). The completed IDW can be overlaid on the study area map to show where coastal assets will be at risk in the future.

*Table 3.1. Storm Surge and Sea Level Rise Data (Daigle, 2014)*

Return Period	Surge Residual	Level 2010	Level 2050	Level 2100
1-Year	0.54 ± 0.20	7.04 ± 0.70	7.36 ± 0.84	7.91 ± 1.08
2-Year	0.62 ± 0.20	7.12 ± 0.70	7.44 ± 0.84	7.99 ± 1.08
5-Year	0.73 ± 0.20	7.23 ± 0.70	7.55 ± 0.84	8.10 ± 1.08
10-Year	0.81 ± 0.20	7.31 ± 0.70	7.63 ± 0.84	8.18 ± 1.08
25-Year	0.92 ± 0.20	7.42 ± 0.70	7.74 ± 0.84	8.29 ± 1.08
50-Year	1.00 ± 0.20	7.50 ± 0.70	7.82 ± 0.84	8.37 ± 1.08
100-Year	1.08 ± 0.20	7.58 ± 0.70	7.90 ± 0.84	8.45 ± 1.08

### 3.4 Adaptation Planning

The Atlantic Coastal Community Decision Tree Web Support Tool was used to undertake adaptation planning. It can be found at <http://atlanticadaptation.ca>. This online tool was designed by the Atlantic Climate Adaptation Solutions Association (ACASA) and academic, private sector partners and is available to be used with their permission.

The coastal community decision tree tool is designed to be used in cases where assets can be negatively impacted by coastal processes either currently or in the future. Therefore, if a coastline has no anthropogenic features and is in no way being impacted or used by people, then it is unnecessary to use the decision tree to assess adaptation options as these locations can be left to allow nature to take its course and coastal processes to continue unchanged and unhindered. It is appropriate to be used in the context of Fundy National Park due to there being human use of the coastline within Park boundaries. These human features could be vulnerable to climate change impacts, and it important to assess potential options for adaptation.

The decision tree tool leads the user through a long series of questions about the state of the coastline that must be answered in order to allow it to assess the type of adaptation options that have the potential to work well for the area. Once all necessary data are entered, the tool will present different options to assess. With the data that was compiled in the field along with the completed vulnerability assessment of Fundy National Park's coastline, it was possible to run the tool and to have it assess adaptation options for different locations within the study sections. The tool's function was tested to see if the options that it presented are reasonable for the study area, and a final assessment of its outputs was completed.

## CHAPTER 4: Results

### 4.1 Shoreline Classification and Vulnerability Assessment

In June 2016, a total of 7 km of Fundy National Park's coastline was characterized using field observations supplemented with geotagged photographs, and a hand held GIS mapping device (Yuma tablet). Shore stability was assessed in the field and noted in the field observations. For the sake of this fieldwork, the coastline of Fundy National Park was divided into two sections: Alma to Herring Cove and Point Wolfe. Beyond these two sections, the Park's coastline is largely inaccessible and not visited by the public. This chapter will look at the details of these classifications and their relations as indicators of current vulnerability.

As an indicator of future vulnerability, potential Sea Level Rise mapping has been completed for the two characterized segments using projections outlined by Daigle (2014). The lowest interval displayed reaches the HHWLT value of 6.5m at CGVD28. The remaining intervals of 7.58m, 7.9m, and 8.45m represent current (2010), 2050, and 2100 1-in-100 year storms. With these water heights inputted into digital elevation maps created using LiDAR data, flooding hazard can be visualized as is displayed in Figures 4.3 and 4.7.

### 4.1.1 Alma to Herring Cove

The first section of coast that was studied encompasses 4.35 km that stretches from Herring Cove to the Park boundary at Alma (Figure 3.2). It makes up about 1/5 of the Park's total coastline. This section was walked in the field and characterized on June 27-28, 2016.

Overall, the backshore of the coastline from Alma to Herring Cove has a highest proportion of bluff with that making up 37% of its total length. This is followed by anthropogenic features (18%), cliffs (15%), and organogenic slope (12.5%). The remaining backshore characterizations are illustrated in Figure 4.1. Half of the backshore is partially stabilized or damaged<sup>1</sup>, 26% is not stabilized or failing, 20% is highly stabilized or intact, and the final 4% is representative of a waterbody.

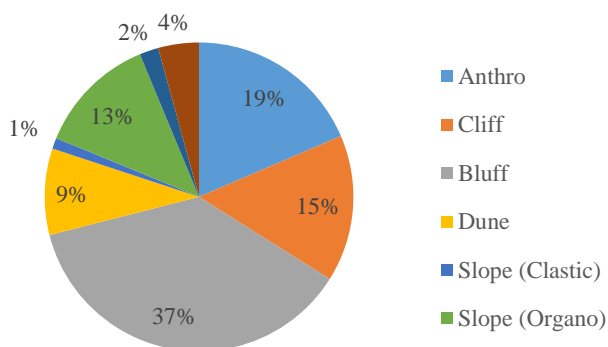
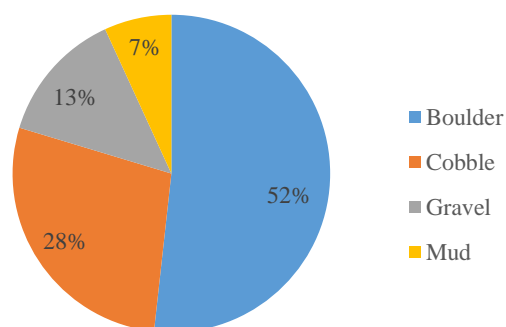


Figure 4.1. Prevalence of Backshore Characterizations - Alma to Herring Cove

<sup>1</sup> Please note that for the majority of backshore characterizations such as bluff or dunes, stability is expressed as highly, partially, or not stable whereas in the case of anthropogenic features, it is characterized as intact, damaged, or failing.

From Alma to Herring Cove, there is no foreshore along 58% of the coastline. Of the remainder, beaches are the dominant landform (82%) with organogenic wetlands occupying 18% of the coastline. The beach primarily consists of cobbles (41.7%), sand (31.7%), and boulders (26.6%). The nearshore between Alma and Herring Cove is predominantly (97%) coastal flat with a small section (3%) of platform. The flat can be separated largely into boulders (52%) and cobble (28%) (Figure 4.2).



*Figure 4.2. Nearshore Beach Characterizations - Alma to Herring Cove*

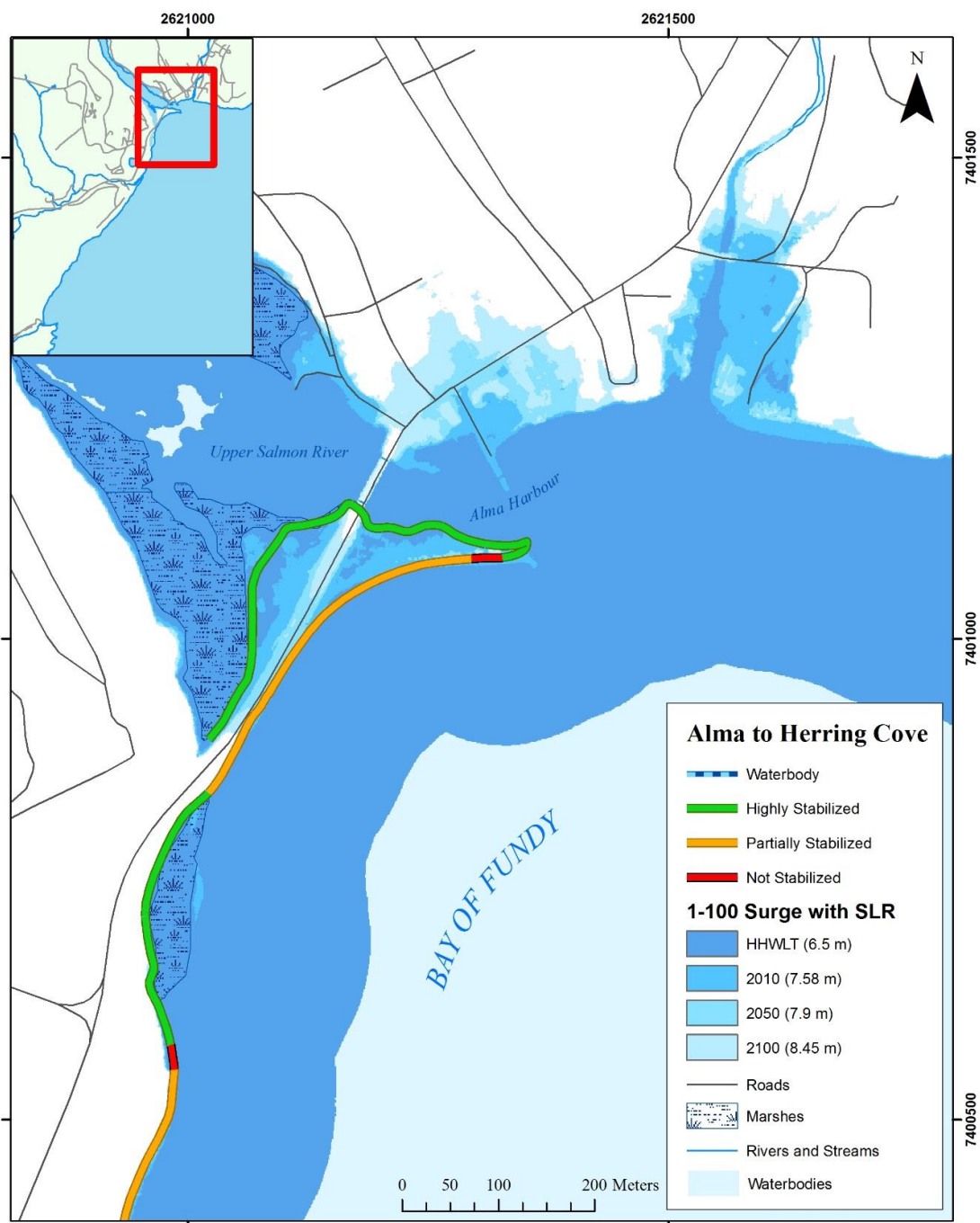


Within the Alma to Herring Cove segment, the main areas that will be affected by flooding are low-lying areas at Alma Beach and Cannontown Beach. These low-lying areas are also the locations of assets and infrastructure such as parking lots; therefore, this vulnerability has implications for their current and future use. The remaining coastline will not be affected by sea level rise or storm surge flooding due to the higher elevation of the bluff and cliffs.

The first portion of the Alma to Herring Cove segment spans from the Village of Alma along the Park's coastline to an area of backshore marsh (Figure 4.3). The first unstable and a portion of the first partially unstable section consists of impeded sand dunes. These dunes border a failing riprap revetment that is pounded by waves during high wind events that coincide with high tide. Erosion is evident landward of the revetment, undermining the structure, and with each new minor storm event, rocks are pushed further along the beach and have now surrounded the beach access point as of January 2, 2017 (Figure 4.4 and Figure 4.5). The other portion of highly unstable backshore is a 20 m section of steep organogenic slope that has suffered a large amount of recent erosion (Figure 4.6), which threatens a lookout overlooking the Bay that is frequented by tourists. Beyond that section of unstable bluff, the base of the bluff is somewhat protected with failing revetment that is in front of an old, rusted and broken metal bulkhead (Figure 4.6) that spans into the second portion of the coastline in Figure 4.7.

The subsection of coastline represented in Figure 4.3 demonstrates not only erosion hazards as described in the previous paragraph, but also displays flooding hazards. Large portions of the lower part of the Village of Alma will flood as time progresses. Unfortunately, much of this portion of the Village contains motels and businesses that cater to tourists that visit the Park.

Within the Park, it is very important to note that portions of the main highway link connecting the Park to Alma are flooded at both 2050 and 2100 levels. Presently, water is able to reach the highway during large wave and surge events (Figure 4.5). The dunes along the upper portion of the Alma beach are completely flooded at the 2100 level as well as the Alma Beach parking lot that also houses the Molly Kool Heritage Centre. Also important to note is that the location of the Park entrance booth on the highway is flooded once the 2050 level is reached. Overall, there are many important assets at risk due to sea level rise and storm surge flooding hazards in this region.



Coordinate System: NAD 1983 CSRS New Brunswick Stereographic; Topographic Base Data: SNB 1998 1:10,000 series: 45506500, 45556490, 45556500, 45606490; Stability data collected June 27-29, 2016; Sea Level Rise Intervals from Daigle (2014); LiDAR from Leading Edge Geomatics, flights June 16 - October 30, 2016, Horizontal Accuracy: 0.30m, Vertical Accuracy: 0.145752m at 95%.

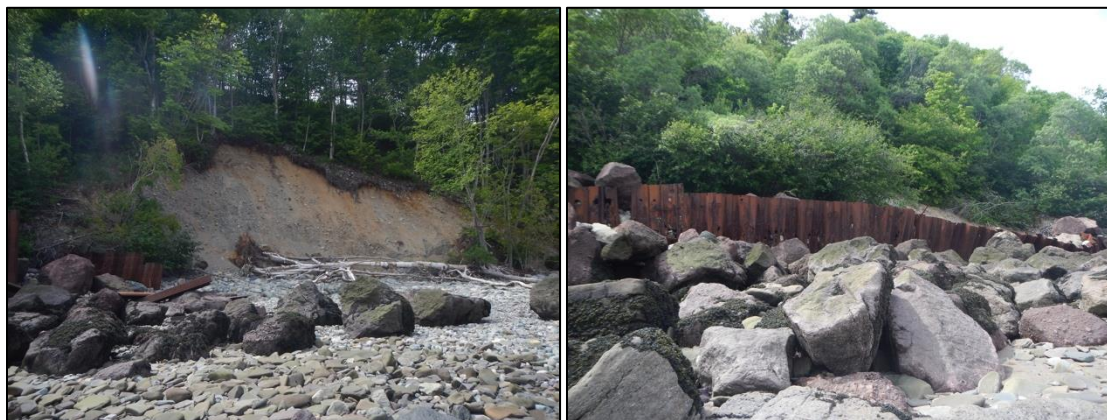
Figure 4.3. Flooding and Stability in the first portion of the Alma to Herring Cove segment



*Figure 4.4. Alma Beach access stairs on June 27, 2016 and extent of boulders from the damaged revetment at the time*



*Figure 4.5. Gale-force winds on December 30, 2016 caused large waves that further damaged the Alma Beach revetment. Boulders from the revetment have been pushed beyond the beach access stairs (Jan. 2017). (centre photo courtesy of Robin Stuart, 2016)*



*Figure 4.6. Unstable slope and riprap revetment placed in front of a rusted bulkhead (June 2016)*

The second portion of the Alma to Herring Cove segment (Figure 4.7) spans from the aforementioned backshore marsh to an unstable section of coast located below the old Devil's Half Acre road that is in the process of being removed. There used to be a coastal trail that had to be moved back from the cliffs multiple times due to erosion and was later closed completely due to the difficult upkeep. The upper portion of this coastline contains the aforementioned failing revetment placed in front of a rusted bulkhead (Figure 4.6). The small red portion of coastline within the orange consists of a location where riprap is not predominant in front of the damaged bulkhead. The portion of backshore in this section that corresponds to a waterbody is consistent with a barachois located behind a shingle barrier (Figure 4.8). Beyond the barachois is an intact riprap revetment (Figure 4.9) that borders the parking lot for Cannontown beach access and the Park's saltwater swimming pool. This parking lot would completely flood from a present-day 1-in-100-year storm.

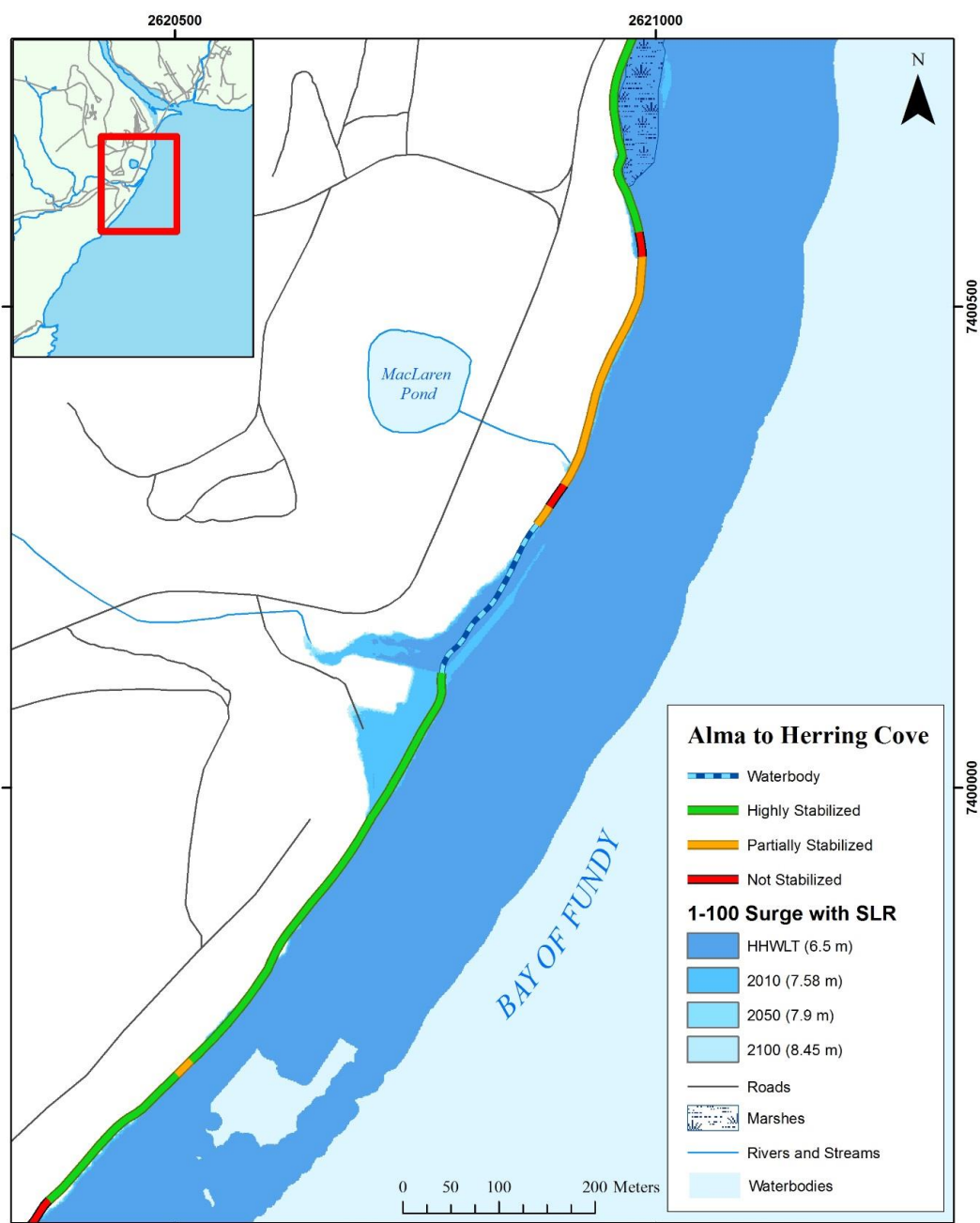


Figure 4.7. Flooding and Stability in the second portion of the Alma to Herring Cove segment



*Figure 4.8. Barachois behind a shingle barrier  
(June 2016)*



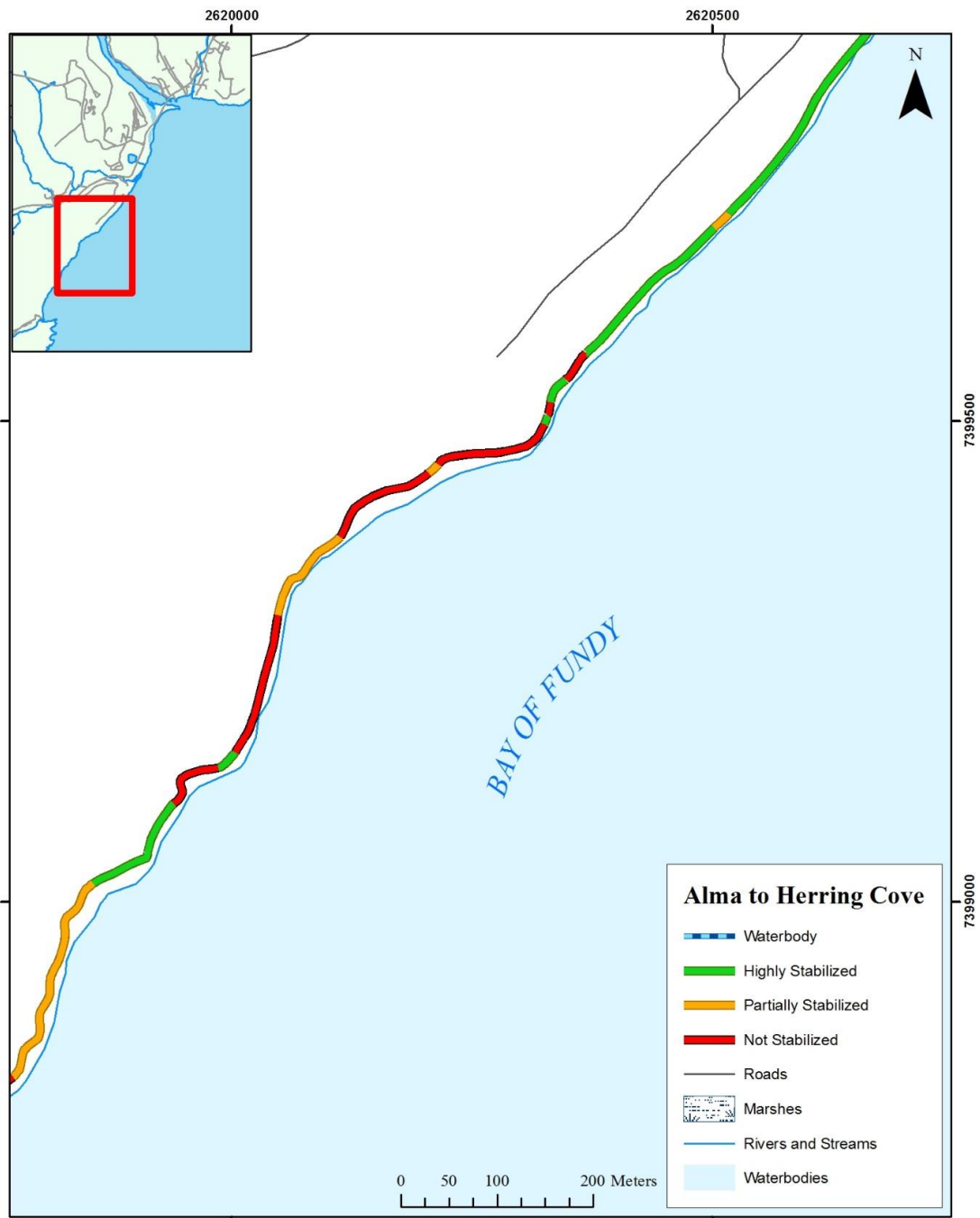
*Figure 4.9. Intact riprap revetment at Cannontown Beach  
(L: June 2016, R: August 2016)*

The third subsection of the coastline between Alma and Herring Cove (Figure 4.11) consists solely of high cliff and bluff, and there are no access points. The majority of the backshore within this portion is unstable or partially unstable with large amounts of recent and less recent erosion evident by the growth of vegetation within the eroded portions. Those that have vegetation re-growing along eroded portions have been deemed partially unstable (Figure 4.10). Beyond the far reach of the now-closed Devil's Half Acre hiking trail, there are no assets along this portion of the coastline, so its instability is not a negative attribute. A small percentage of the coast in this portion is what is referred to as unconsolidated over solid (Figure 4.10), which consists of a bluff on top of a bedrock base. The majority of these are unstable overall with large amounts of eroded material in front of the solid base.





*Figure 4.10. Bluff types within the third portion of coast from Herring Cove to Alma.  
Top left: unconsolidated over solid  
Top right: not stabilized  
Bottom left: partially stabilized  
(Images taken June 2016)*



Coordinate System: NAD 1983 CSRS New Brunswick Stereographic; Topographic Base Data: SNB 1998 1:10,000 series: 45506500, 45556490, 45556500, 45606490; Stability data collected June 27-29, 2016; Sea Level Rise Intervals from Daigle (2014); LiDAR from Leading Edge Geomatics, flights June 16 - October 30, 2016, Horizontal Accuracy: 0.30m, Vertical Accuracy: 0.145752m at 95%.

Figure 4.11. Stability in the third portion of the Alma to Herring Cove segment

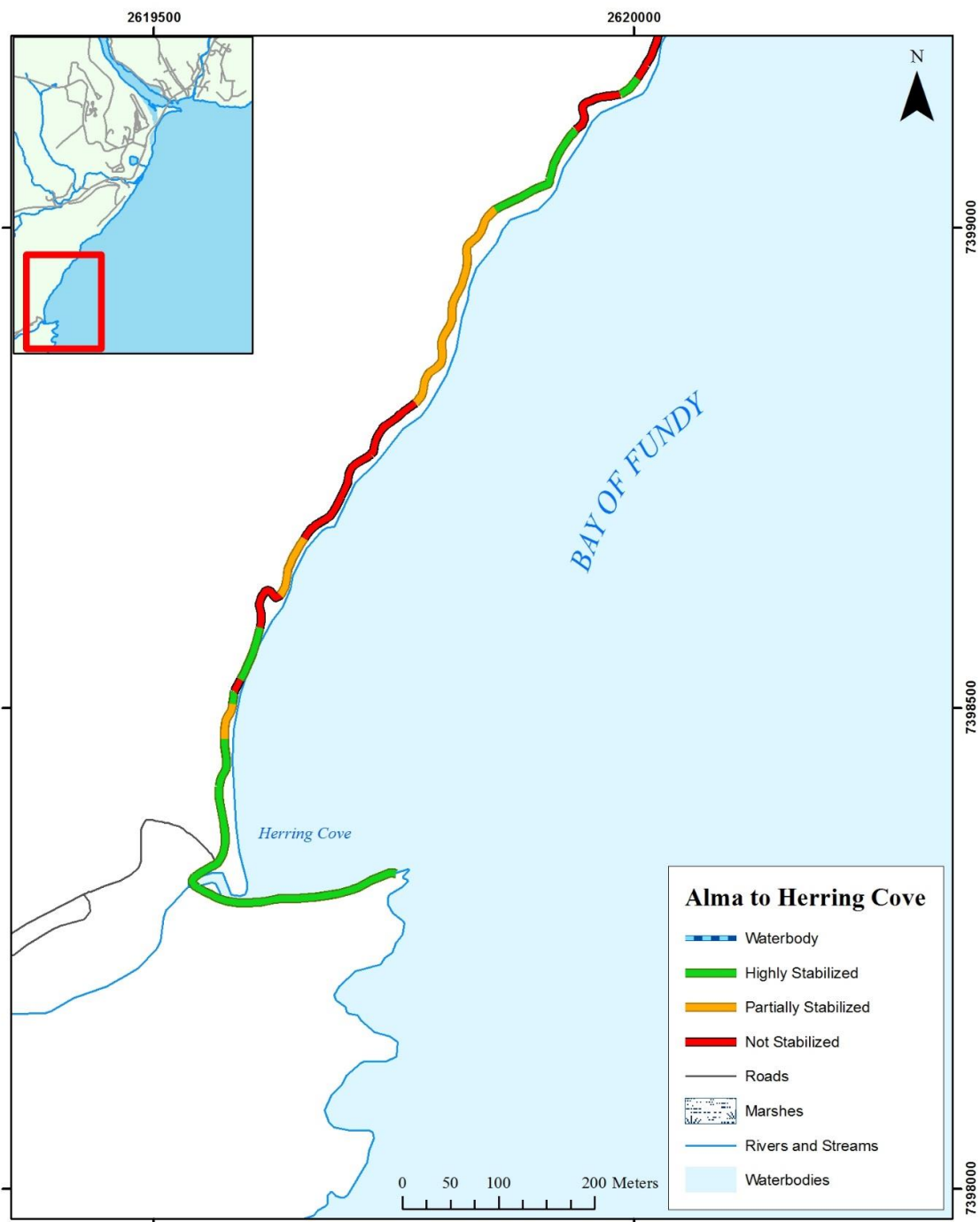
The final portion of the Alma to Herring Cove segment (Figure 4.14) spans from the middle of the long portion that consists mostly of unstable and partially stable bluff to the end of the segment at the edge of Herring Cove beach. There are two sets of beach access stairs that allow visitors to descent onto Herring Cove Beach (Figure 4.13), and these are both located along the final highly stabilized portion of coastline. At the large pointed bend in the final stable segment, the type of backshore shifts to a red sandstone cliff (Figure 4.12) from organogenic slope. This portion of the coast is not affected by flooding due to the height of the cliffs, bluff, and slopes.



*Figure 4.12. Red sandstone cliffs at Herring Cove  
(June 2016)*



*Figure 4.13. Access  
stairs at Herring Cove  
Left: main access stairs  
Right: access to Coastal  
West trail  
(June 2016)*



Coordinate System: NAD 1983 CSRS New Brunswick Stereographic; Topographic Base Data: SNB 1998 1:10,000 series: 45506500, 45556490, 45556500, 45606490; Stability data collected June 27-29, 2016; Sea Level Rise Intervals from Daigle (2014); LiDAR from Leading Edge Geomatics, flights June 16 - October 30, 2016, Horizontal Accuracy: 0.30m, Vertical Accuracy: 0.145752m at 95%.

Figure 4.14. Stability in the fourth portion of the Alma to Herring Cove segment

### 4.1.2 Point Wolfe

The coastline of the Point Wolfe section is approximately 2.7km long, thus around 2/3 of the length of the Alma to Herring Cove section. This segment was walked and characterized on June 29, 2016. It consists of a large tidal estuary at the mouth of the Point Wolfe River.

The backshore in the Point Wolfe Estuary is dominated by high cliffs, which make up 56% of its length, while a 20% portion of its length consists of outcrop (Figure 4.15 and Figure 4.18). The vast majority of the backshore is highly stabilized at 91%, and the remaining unstable (6.5%) and partially stable (2.5%) sections are found only within the bluff and organogenic slope sections at the back left and central portions of the estuary as can be seen in Figures 4.16 and 4.17. The single section of organogenic wetland is highly stabilized. As was discussed in Chapter 2, the cliffs on the western and eastern sides of the estuary are from different geologic time periods with those on the west being from the Pre-Cambrian era (specifically the Middle Neoproterozoic) and those on the eastern portion being part of the Hopewell Conglomerate (Figure 4.18), like the red sandstone cliffs at Herring Cove (Figure 4.12). It is important to note that there is a short, highly-used hiking trail at the top of the eroding bluff. This trail, named Shiphaven, has many lookoffs overlooking the estuary that are very close to the top edge of the unstable bluff. This bluff is eroding due to subaerial processes, so it could pose a danger to visitors. There are multiple signs along the length of the trail warning visitors of dangerous cliffs and to remain on the trail for their safety (Figure 4.20).

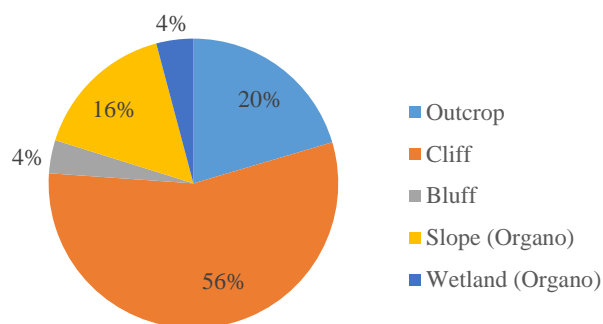
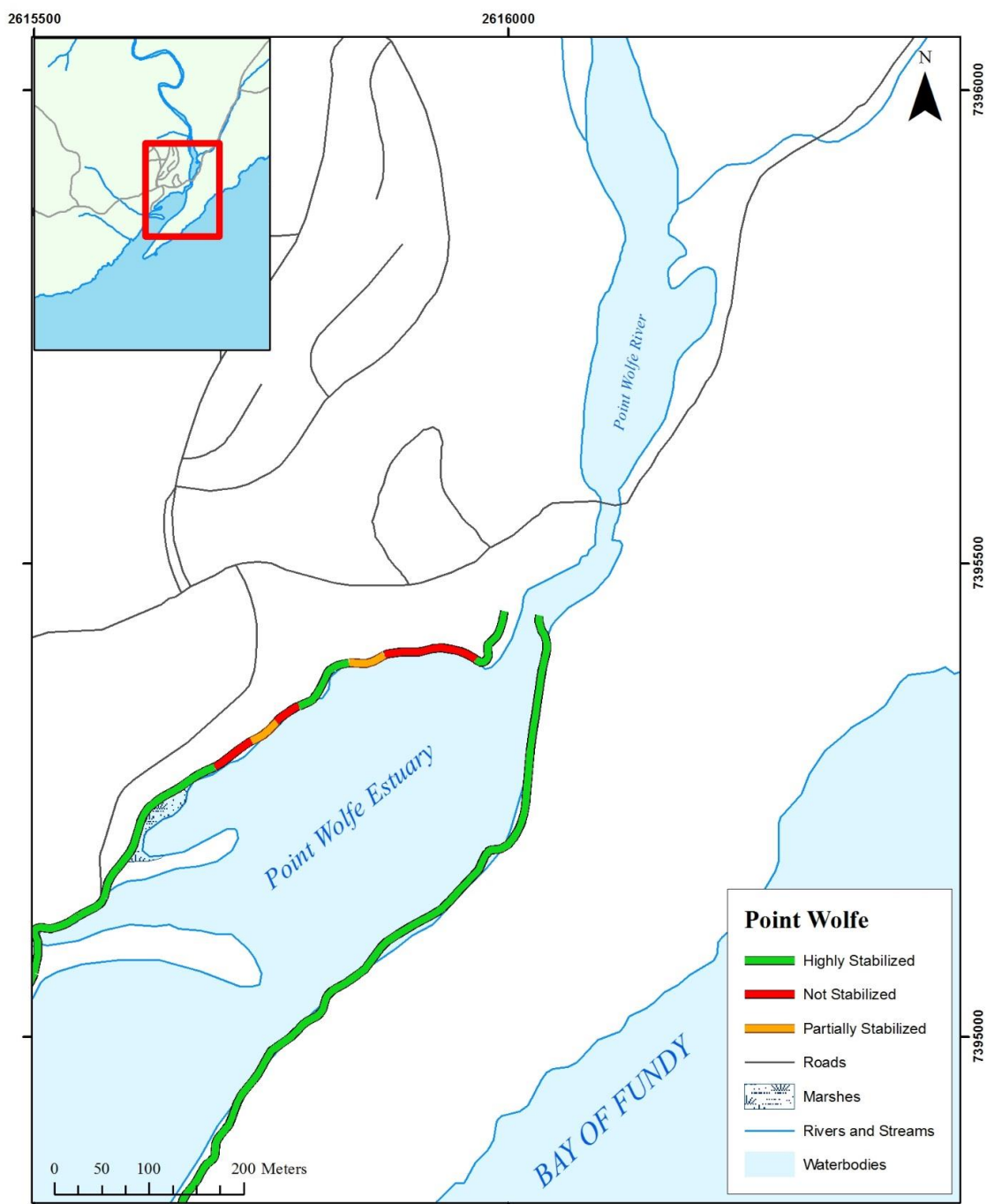


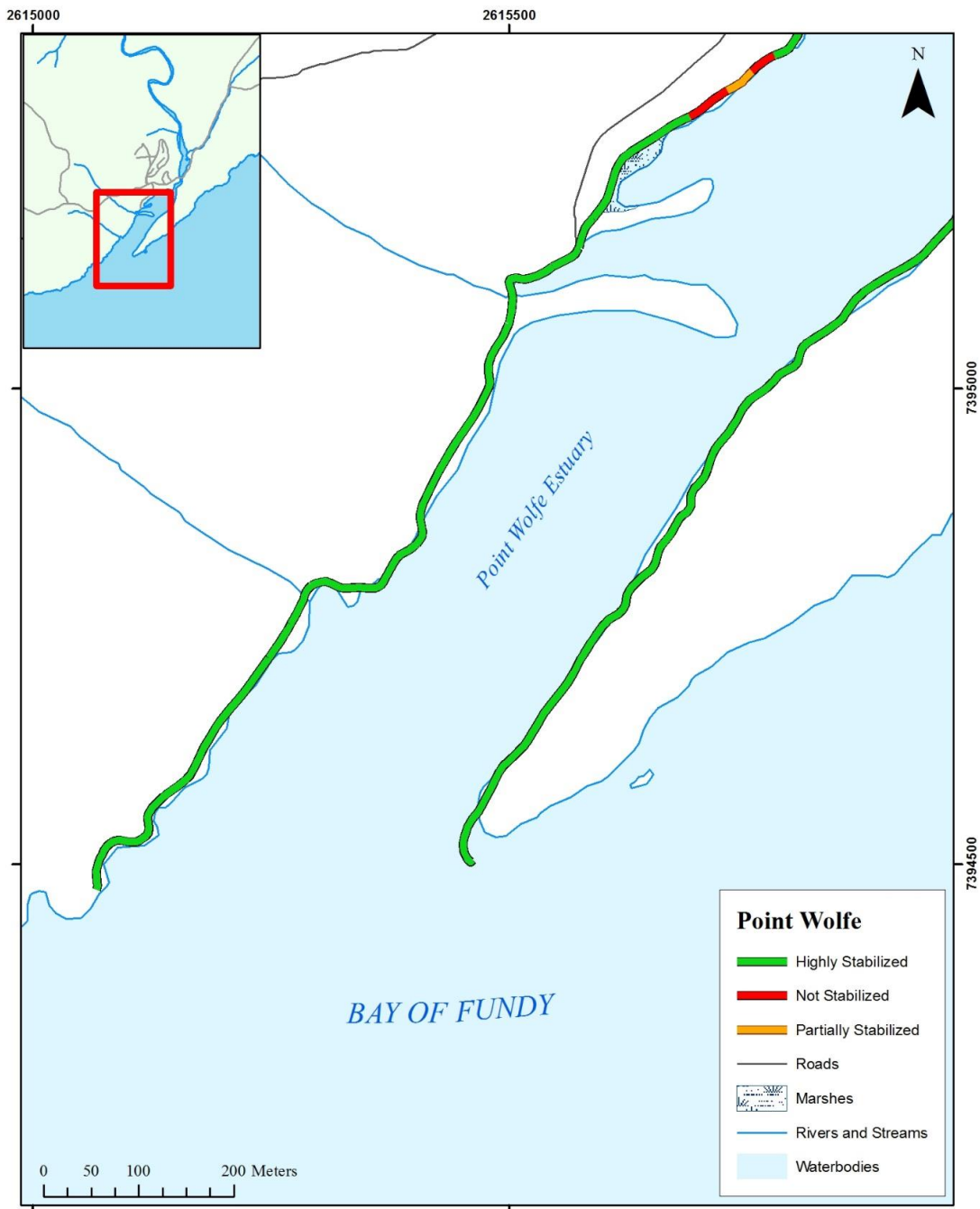
Figure 4.15. Prevalence of Backshore Characterizations - Point Wolfe

Within the Point Wolfe Estuary, there is no foreshore along 78% of the segment. The remainder is characterized as beach with sediments split between sand (59%), cobble (26%), and boulder (15%). The nearshore in the estuary consists of flats (81%) and platform (19%). The flats are a great mixture of sediment types with large patches throughout the estuary. These patches are made up of boulder (43%), cobble (24%), gravel (17%), and sand (16%). These nearshore characterizations are what are nearest to the cliffs, representing the patches immediately at their feet. This does not account for larger portions of the intertidal zone within the estuary where there are large patches of mud and less boulders. Examples from the nearshore are visible in Figure 4.19.



Coordinate System: NAD 1983 CSRS New Brunswick Stereographic; Topographic Base Data: SNB 1998 1:10,000 series: 45506500, 45556490, 45556500, 45606490; Stability data collected June 27-29, 2016; Sea Level Rise Intervals from Daigle (2014); LiDAR from Leading Edge Geomatics, flights June 16 - October 30, 2016, Horizontal Accuracy: 0.30m, Vertical Accuracy: 0.145752m at 95%.

Figure 4.16. Stability within the upper portion of the Point Wolfe Estuary



Coordinate System: NAD 1983 CSRS New Brunswick Stereographic; Topographic Base Data: SNB 1998 1:10,000 series: 45506500, 45556490, 45556500, 45606490; Stability data collected June 27-29, 2016; Sea Level Rise Intervals from Daigle (2014); LiDAR from Leading Edge Geomatics, flights June 16 - October 30, 2016, Horizontal Accuracy: 0.30m, Vertical Accuracy: 0.145752m at 95%.

Figure 4.17. Stability within the lower portion of the Point Wolfe Estuary





*Figure 4.18. Backshore types in the Point Wolfe Estuary*

*Top Left: outcrop*

*Top Centre: cliff on the western portion (Pre-cambrian)*

*Top Right: cliff on the eastern portion (Hopewell conglomerate – red sandstone)*

*Bottom Left: unstable bluff*

*Bottom Centre: organogenic slope (partially stabilized)*

*Bottom Right: organogenic wetland (behind sand beach foreshore and sand flat nearshore)*

*(All photos taken June 2016)*



*Figure 4.19. Point Wolfe Nearshore types*

*Left: platform*

*Right: patches of cobble, gravel, sand and mud*

*(Photos taken June 2016)*



*Figure 4.20. Signs warning visitors of dangerous cliffs below at various points along the Shiphaven trail overlooking the Point Wolfe estuary. There are trees falling to the bottom of the bluff just behind the fence in the photo on the right.  
(Photos taken August 2016)*

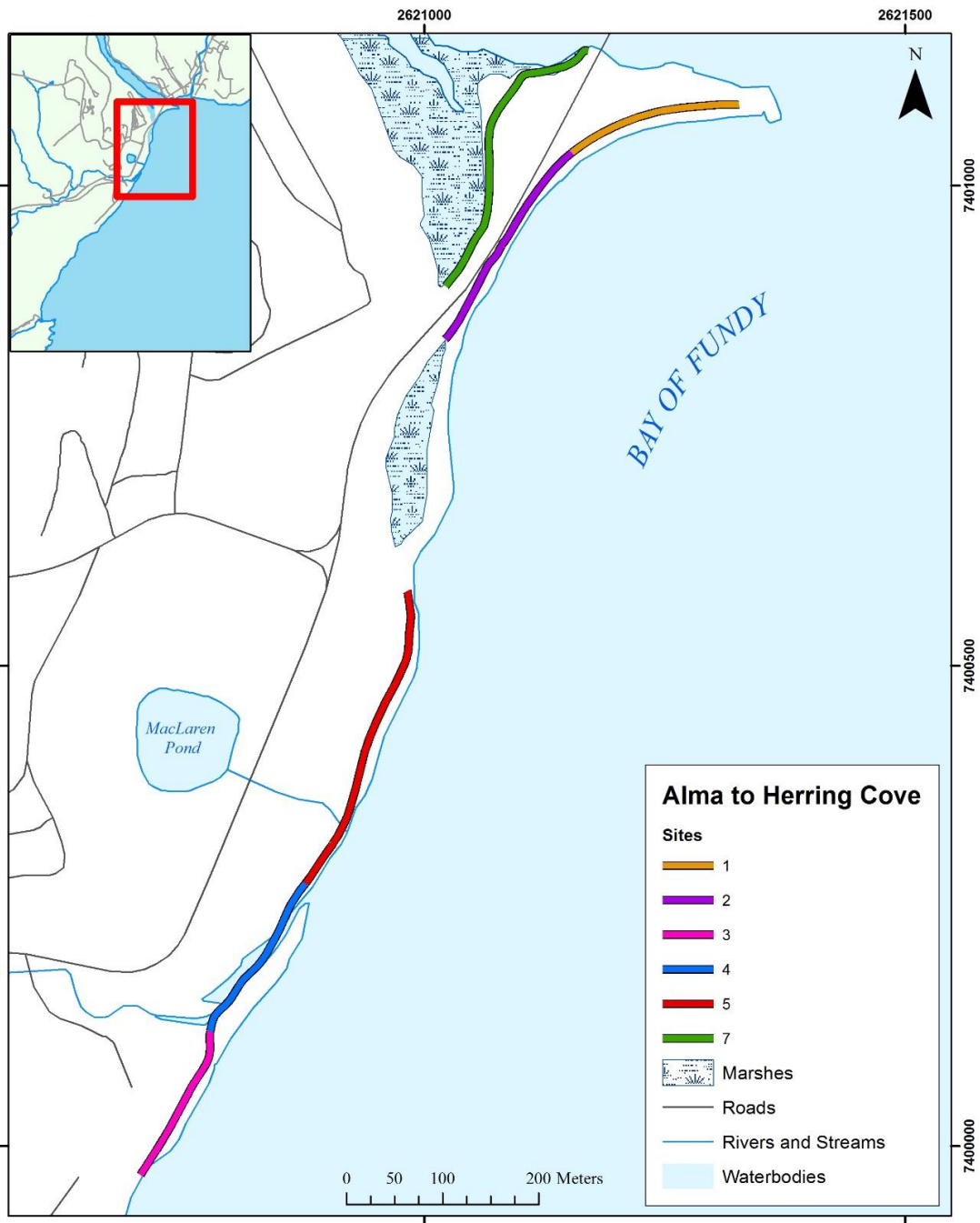
## 4.2 Adaptation Options

When looking at the options that the Park can pursue to adapt to climate change along the coast, it was first important to identify areas along the coast where assets were at risk so adaptation is necessary. For the portions of the coastline where assets are not at risk, it is not as important that potential adaptation options be explored as the instability of the coastline is not leading to vulnerability. In fact, erosion of these sections is feeding sediment into the littoral cell to replenish beaches, marshes, and tidal flats in the coastal area.

To analyze potential adaptation options, the Atlantic Climate Adaptation Solutions Association (ACASA)'s Coastal Community Adaptation Online Toolkit Decision Tree Tool (<https://atlanticadaptation.ca>) was utilized. With coastal characterization information that was obtained in the field, different areas along the coastline were identified as sites with separate attributes that should be analyzed separately. Seven sites were identified based on their characterizations and proximity to assets and infrastructure. These sites are as follows:

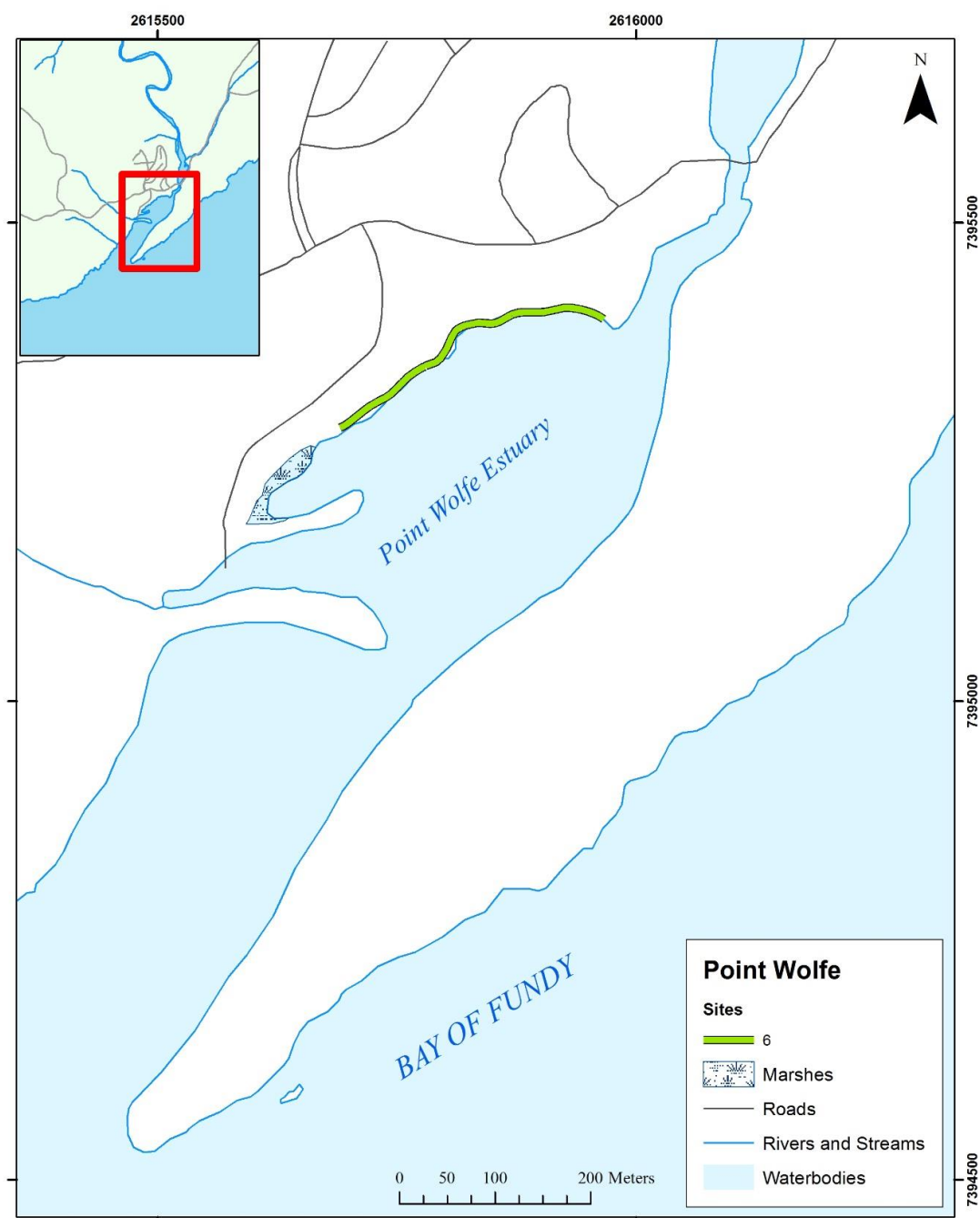
- 1) Sand dunes along the backshore of Alma Beach
- 2) Alma beach rip-rap revetment
- 3) Cannontown Beach / Swimming pool parking lot revetment
- 4) Barachois adjacent to the Cannontown Beach / Swimming Pool parking lot
- 5) Revetment in front of damaged bulkhead along the base of the Headquarters Bluff
- 6) Eroding Bluff and Slope at Point Wolfe with Shiphaven hiking trail on top
- 7) Upper Salmon River saltmarsh behind the Alma Beach parking lot

Sites 1-5 and 7 are visible in Figure 4.21, and Site 6 is visible in Figure 4.22.



Coordinate System: NAD 1983 CSRS New Brunswick Stereographic; Topographic Base Data: SNB 1998 1:10,000 series: 45506500, 45556490, 45556500, 45606490; Stability data collected June 27-29, 2016.

Figure 4.21. Sites within the Alma to Herring Cove Segment



Coordinate System: NAD 1983 CSRS New Brunswick Stereographic; Topographic Base Data: SNB 1998 1:10,000 series: 45506500, 45556490, 45556500, 45606490; Stability data collected June 27-29, 2016.

Figure 4.22. Site within the Point Wolfe Segment

When it comes to adapting to both flooding and erosion issues, the Land Use Planning (LUP) Options most recommended by the web tool for all Sites (Figures 4.21-4.22) would include land use conversion and redevelopment, a regional/rural (non-statutory) plan or land use policy, a watershed management plan, land swap, and strategic land acquisition (land bank). Also very effective overall would be a green shoreline rating system and/or an emergency preparedness/management plan. The most appropriate engineering options for erosion issues include the relocation of infrastructure, and where built structures already exist, their maintenance, repair or replacement. All options that the web tool outlined are displayed in Tables 4.1-4.4. These options can be further explored in Appendix C where Figures C.1-C.4 outline application, functionality, compatibility, and cost of engineering options, and the full results of the decision tree tool are also available.

Certain other options have been deemed as most suitable for flooding issues but not as suitable for erosion issues. Five out of the seven identified Sites (1-4, 7) have suffered flooding issues while all are affected by erosion. LUP options that are also considered useful for flooding include managed retreat/abandonment and abandonment. Engineering options for flooding include stormwater management, a drainage ditch, a rain garden or constructed wetland, or a dyke. There are not options that have been identified as being most useful for erosion issues beyond those that function for both flooding and erosion.

Land use conversion and redevelopment involves changing land use within coastal regions and removing unsuitable uses and structures when necessary. This could, for example, involve returning a built environment back into a natural ecosystem or into land for recreational use. It can be used in conjunction with land acquisition and land swap (Manuel et al., 2016).

Land acquisition involves the acquiring of land for public purposes, and along the coast this can facilitate adaptation by increased public safety, prevention of (further) structural damage or the preservation and/or restoration of habitat (Manuel et al., 2016). Land swap involves the exchange of land between levels of government or between government and private landowners. This could involve the exchange of coastal land for something inland to allow for coastal adaptation and to diminish the vulnerability of landowners (Manuel et al., 2016). These three LUP options are all suitable for all Sites that were explored with the decision tree tool as planning options for both flooding and erosion issues.

A regional plan (non-statutory) or land use policy involves the cooperation of various municipalities for planning efforts spanning a region (Manuel et al., 2016). The creation or maintenance of such a plan was considered as one of the best LUP measures for all Sites within FNP when it comes to flooding and erosion issues. In the case of the Park, this could involve joint planning efforts with Alma and potentially other surrounding rural areas even as far away as St. Martins due to the Fundy Footpath spanning the length of the coastline from the Fundy Trail Parkway all the way to FNP.

Watershed management plans involve managing development on land within a particular watershed to prevent pollution, protect habitat and deal with stormwater runoff. This involves a regional effort, so multiple communities may need to cooperate and work together to create and implement a plan such as this (Manuel et al., 2016). A watershed management plan was identified as being an important LUP tool for all Sites within FNP for the management of both flooding and erosion issues. Such a plan for the region could be coordinated through the Fundy Biosphere Reserve, which already gives a level of protection to the Upper Bay of Fundy's

watersheds within New Brunswick, including those within Fundy National Park (Fundy Biosphere Reserve, 2007).

A green shoreline rating system or coastal development rating system involves promoting the sustainable use of coastal regions by allowing the function of natural processes, maintaining the function of habitats, minimizing pollution, and reducing human impacts on coastlines. This system dissuades the use of hard-engineering structures in coastal developments and rates coastal properties based on how “green” they are by looking at and rewarding environmentally-friendly design criteria (Manuel et al., 2016). This was deemed to be suitable for flooding and erosion issues at Sites 1, 2, 4, and 7 while it would only be somewhat suitable for Sites 3, 5, and 6.

An emergency preparedness and/or management plan involves the identification of areas at risk along the coast during an emergency or disaster as well as effectively communicating that information to local citizens. This could involve evacuation plans and coordinating the response to emergencies. Overall, the aim is to reduce the damage that disasters can cause and plan out steps for a post-disaster response (Manuel et al., 2016). This has been identified as being most suitable for flooding and erosion issues at Sites 2, 3, and 7 while only somewhat suitable for Sites 1, 4, 5, and 6.

Managed retreat or managed abandonment is a LUP tool that involves moving people and infrastructure back from the coast, possibly through land use conversion or redevelopment. It is the best option for public safety when protection measures are no longer viable or will be too expensive over time with increasing risk (Manuel et al., 2016). Abandonment is a form of coastal retreat that can occur with or without planning when a storm or an area prone to storm impacts is left to the sea. Use of the land may or may not be rendered obsolete. It is really a worst-case



option for affected land (Manuel et al., 2016). Managed retreat and abandonment were identified by the decision tree tool as being among the best LUP options for FNP when it comes to flood planning at all Sites, however there are some reservations about using them as best-practice planning measures for erosion.

The relocation of infrastructure can go hand in hand with managed retreat and involves removing infrastructure from vulnerable coastal areas and instead bringing it further inland so it does not inhibit nor is inhibited by coastal processes or events. It could also involve abandoning coastal infrastructure altogether to no longer be used or perhaps building replacements inland (Leys and Bryce, 2016). Relocation has been identified by the tool as being the most suitable engineering option overall for erosion as the only option that would be good for all Sites, and it is a good choice for all Sites for flooding issues as well. Realistically, relocating infrastructure away from the coastal zone is the only way to ensure it is completely protected from coastal processes. The relocation of important infrastructure while not overall impossible, could be very difficult due to the nature of the infrastructure use (such as beach access stairs and the saltwater swimming pool filled using water from the Bay) and due to the nature of the landscape and its planning (location of the highway). A specific example is that of the Molly Kool Heritage Centre (Figures 2.3 and 2.4), which was only relocated and reconstructed in the Alma Beach Parking Lot in 2010 (CBC News, 2010); it is not imperative that it be located on the coast, so it could have been better placed from the beginning due to its vulnerability.

The maintenance, repair or replacement of existing structures can be undertaken in many ways depending on the state of the structure (intact, damaged, failing) or whether or not the structure is causing damage (Leys and Bryce, 2016). This has been deemed as effective when

facing both erosion and flooding for all Sites that have protective structures already, whether these structures are natural (Sites 1, 4) or built (Sites 2, 3, 5). Sites 6 and 7 do not have protective structures. The various structures are in different states of repair already, so more work would be necessary for those that are currently damaged, failing or impeded.

Stormwater management generally involves the reduction of runoff by promoting the infiltration of water in developed areas (Leys and Bryce, 2016). A drainage ditch or slough is a type of stormwater management that involves the construction of trenches (potentially connected by culverts) that allow for the drainage of floodwaters into a larger waterbody such as the Bay or a lagoon. They facilitate the recovery of land from flooding events by stopping water from settling inland (Leys and Bryce, 2016). A rain garden or constructed wetland is another type of stormwater management. Rain gardens are small planted areas often located in urban or built areas that act like sponges to absorb water during rainfall events when the surrounding impermeable surfaces are unable. Constructed wetlands are often larger than rain gardens and can be found in low-lying regions in the landscape. They are able to filter pollutants from stormwater runoff and absorb large amounts of water (Leys and Bryce, 2016). These three engineering measures are all considered to be good options for the all of Sites that are experiencing flooding by the decision tree tool, however they would be better suited for freshwater flooding and heavy precipitation so might not be the best option for these particular areas that are affected by saltwater storm surge.

Dykes are linear, earthen structures that run along the coastline at a particular height above sea level with the function of preventing the flooding of low-lying coastal land. They are generally constructed with gradual slopes on the side bordering the water to deter wave energy,

and are armoured with stone in many cases to reduce erosion. They generally require an aboiteau (one-way flood valve) to allow the land to drain while preventing the entrance of seawater (Leys and Bryce, 2016). The construction of dykes was deemed a good option by the decision tree tool at all Sites affected by flooding, however the tool had some concerns with the construction of an aboiteau at all of the Sites. These concerns come due to the loss of intertidal habitat that is caused with their construction.

Beyond these options that were deemed by the web tool to be more generally suitable for all or most Sites, there are a few options outlined in Tables 4.1-4.4 that would be good options for one of the seven Sites. These include a wetland policy (Site 4 flooding and erosion), dry or wet floodproofing buildings (Site 7 flooding), raising infrastructure (Site 7 flooding), floating buildings (Site 7 flooding), a living shoreline or wetland (Site 7 flooding and erosion), dune building (Site 1 flooding and erosion), and plant stabilization (Site 7 erosion). The locations of the Sites are displayed in Figure 4.21.

A wetland policy aims to control development within a wetland area, and this can include tidal salt marshes. Policies are not laws in and of themselves, but they can be implemented through formation of legal regulations and by-laws (Manuel et al., 2016). This was deemed to be suitable for both flooding and erosion within Site 4, where there is a small amount of wetland behind a shingle barrier. Interestingly, it was deemed as something that would not currently be appropriate for the wetland located at Site 7 due to the fact that there is already a built environment along the shore of that marsh. That development is not actually within the wetland itself but rather on higher ground behind its backshore, so a wetland policy should still be put into place in that location to prevent development from occurring within the marsh itself.

Dry floodproofing involves the construction of floodwalls around a property to prevent floodwaters or a storm surge from reaching structures. This could also include the application of waterproof coatings to the lower outside portion of buildings to stop water from penetrating the structures (Leys and Bryce, 2016). Wet floodproofing allows the entrance of floodwaters into lower level of non-residential buildings such as parking structures though requires cleanup after a flooding event (Leys and Bryce, 2016). Raising infrastructure is a type of wet floodproofing where all critical use areas of a structure are moved above flood levels. This can be achieved by putting a building on stilts or by raising the height of the land where a new structure will be constructed (Leys and Bryce, 2016). Another manner in which to accommodate buildings to flooding hazards are to build them with the ability to float. This often involves giving a concrete foundation a buoyant core, and then building on top of that. Buildings with fixed foundations can also be made amphibious by giving them the ability to rise during extreme flooding events (Leys and Bryce, 2016). These options were limited to Site 7 due to that being the only location that is protected and therefore has low wave energy. These options are only useful to combat flooding issues and not the erosion that is also an issue at the Site.

Dune building or dune restoration helps the natural catchment of sand dunes with the construction of fences that allow dune mobility but can hold sediment to reduce flooding and erosion during storm events (Leys and Bryce, 2016). The building or restoration of dunes in Site 1 along the sandy region at the top of Alma beach could be effective in lessening the effects of erosion and flooding. There is evidence of dunes in this region, but they are impeded and have not taken on much shape. If larger dunes are able to form, they will stabilize the shoreline and block flooding from reaching the highway behind them along that particular segment of

shoreline. Site 1 is the only one with significant enough sand supply that is able to dry and be moved by aeolian processes to form dunes.

A living shoreline or wetland can stabilize a shoreline. The restoration of coastal marshes can increase the resilience of a coastline to climate change impacts as long as there is unrestricted higher ground behind them as marshes are able to retreat and remain intact and balanced when faced with sea level rise. The (re)introduction of appropriate vegetation into the ecosystem will provide short-term protection from erosion and flooding until the species become established (Leys and Bryce, 2016). This option was identified as best for Site 7, which is already a coastal salt marsh. The maintenance and an increase in size and health would be beneficial to this particular marsh as it faces increased flooding from both the adjoining Upper Salmon River and the Bay. The other Sites would not be as appropriate for a living shoreline or wetland due to their high wave energy environments.

Plant stabilization can be a very-cost effective manner to stabilize shorelines that are made up of loose sediment or to capture blowing sediment in dune building. As plants take root, they will hold sediment in place and can reduce erosion. Care must be taken to use plants that will not negatively impact native species or the local ecosystem (Leys and Bryce, 2016). This could be effective only in the marsh at Site 7 due to its protection and low wave energy. All of the other Sites are in areas with high wave energy, and that would negatively impact the plant species and not allow them to take root.

Table 4.1. Land Use Planning Measures for Flooding from the ACASA Decision Tree tool  
(MS = Most Suitable; SS = Somewhat Suitable)

	Site 1	Site 2	Site 3	Site 4	Site 7	Compilation
Green shoreline rating System	MS	MS	SS	MS	MS	MS 4/5 SS 1/5
Land use conversion & redevelopment	MS	MS	MS	MS	MS	MS 5/5
Managed retreat / abandonment	MS	MS	MS	MS	MS	MS 5/5
Emergency preparedness/management plan	SS	MS	MS	SS	MS	MS 3/5 SS 2/5
Regional/rural plan (non-statutory), land use policy	MS	MS	MS	MS	MS	MS 5/5
Watershed management plan	MS	MS	MS	MS	MS	MS 5/5
Land swap	MS	MS	MS	MS	MS	MS 5/5
Abandonment	MS	MS	MS	MS	MS	MS 5/5
Strategic land acquisition (land bank)	MS	MS	MS	MS	MS	MS 5/5
Integrated community sustainability plan	SS	SS	SS	SS	SS	SS 5/5
Climate change action/adaptation plan	SS	SS	SS	SS	SS	SS 5/5
Secondary community plan or area plan	SS	SS	SS	SS	SS	SS 5/5
Foreshore lease	SS			SS	SS	SS 3/5
Shoreline/coastal management plan	SS	SS	SS	SS	SS	SS 5/5
Transfer of development credits	SS	SS	SS	SS	SS	SS 5/5
Conservation subdivision design	SS	SS	SS	SS	SS	SS 5/5
Site monitoring	SS	SS	SS	SS	SS	SS 5/5
Stormwater management plan		SS	SS	SS	SS	SS 4/5
Land trust	SS			SS		SS 2/5
Conservation easements	SS			SS		SS 2/5
Wetland policy	SS			MS		MS 1/5 SS 1/5
Options that are not appropriate at this time	Rolling easements (L24), Waiver (L20), Tax or development incentive (L12), Subdivision by-law or regulation (L15), Development agreements (L19), Variances (L21), Urban design standards (L29), Setbacks (L14), Statutory community plan (L10), Land use by-law and zoning (L13), Development standards (L18), Wetland regulation (L9)					

Table 4.2. Engineering Measures for Flooding from the ACASA Decision Tree tool  
(SC = Some Concerns)

	Site 1	Site 2	Site 3	Site 4	Site 7	Compilation
Drainage ditch	Good	Good	Good	Good	Good	Good 5/5
Stormwater management	Good	Good	Good	Good	Good	Good 5/5
Dry floodproofing building	SC	SC	SC	SC	Good	Good 1/5 SC 4/5
Wet floodproofing building	SC	SC	SC	SC	Good	Good 1/5 SC 4/5
Raised infrastructure	SC	SC	SC	SC	Good	Good 1/5 SC 4/5
Floating building					Good	Good 1/5
Rain garden / constructed wetland	Good	Good	Good	Good	Good	Good 5/5
Relocate infrastructure	Good	Good	Good	Good	Good	Good 5/5
Living shoreline / wetland	SC			SC	Good	Good 1/5 SC 2/5
Dyke	Good	Good	Good	Good	Good	Good 5/5
Detainment pond	SC	SC	SC	SC	SC	SC 5/5
Tide barrier / aboiteau	SC	SC	SC	SC	SC	SC 5/5
Dune building	Good				SC	Good 1/5 SC 1/5
Artificial dune / buried revetment	SC			SC	SC	SC 3/5
Seawall	SC	SC	SC	SC	SC	SC 5/5
Maintenance, repair or replacement of existing structure	Good	Good	Good	Good		Good 4/5
Options to avoid	Plant stabilization (E11), Nearshore breakwaters (E6), Beach nourishment (E10), Perched beach / sill (E9), Artificial reefs (E8), Rip-rap armouring (E3), Shore-perpendicular breakwater (E5), Scour protection (E1), Engineered revetment (E2), Dredging (E18), Retaining wall (E7), Groynes (E4), Bluff drain (E19)					

Table 4.3. Land Use Planning Options for Erosion from the ACASA Decision Tree tool  
(MS = Most Suitable; SS = Somewhat Suitable)

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Compilation
Green shoreline rating System	MS	MS	SS	MS	SS	SS	MS	MS 4/7 SS 3/7
Land use conversion & redevelopment	MS	MS	MS	MS	MS	MS	MS	MS 7/7
Managed retreat / abandonment		SS	SS	SS	SS	SS	SS	SS 6/7
Emergency preparedness/ management plan	SS	MS	MS	SS	SS	SS	MS	MS 3/7 SS 4/7
Regional/rural plan (non-statutory), land use policy	MS	MS	MS	MS	MS	MS	MS	MS 7/7
Watershed mgmt plan	MS	MS	MS	MS	MS	MS	MS	MS 7/7
Land swap	MS	MS	MS	MS	MS	MS	MS	MS 7/7
Abandonment	SS	SS	SS	SS	SS	SS	SS	SS 7/7
Strategic land acquisition (land bank)	MS	MS	MS	MS	MS	MS	MS	MS 7/7
Integrated community sustainability plan	SS	SS	SS	SS	SS	SS	SS	SS 7/7
Climate change action/adaptation plan	SS	SS	SS	SS	SS	SS	SS	SS 7/7
Secondary community plan or area plan	SS	SS	SS	SS	SS	SS	SS	SS 7/7
Foreshore lease	SS			SS		SS	SS	SS 4/7
Shoreline/coastal management plan	SS	SS	SS	SS	SS	SS	SS	SS 7/7
Transfer of development credits	SS	SS	SS	SS	SS	SS	SS	SS 7/7
Conservation subdivision design	SS	SS	SS	SS	SS	SS	SS	SS 7/7
Site monitoring	SS	SS	SS	SS	SS	SS	SS	SS 7/7
Stormwater mgmt plan	SS	SS	SS	SS	SS	SS	SS	SS 7/7
Wetland policy	SS			MS				MS 1/7 SS 1/7
Land trust	SS			SS	SS	SS		SS 4/7
Conservation easements	SS			SS	SS	SS		SS 4/7
Options that are not appropriate at this time	Rolling easements (L24), Waiver (L20), Tax or development incentive (L12), Subdivision by-law or regulation (L15), Development agreements (L19), Variances (L21), Urban design standards (L29), Setbacks (L14), Statutory community plan (L10), Land use by-law and zoning (L13), Development standards (L18), Wetland regulation (L9), Setbacks (L14)							



Table 4.4. Engineering Measures for Erosion from the ACASA Decision Tree tool  
(SC = Some Concerns)

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Compilation
Relocate infrastructure	Good	Good	Good	Good	Good	Good	Good	Good 7/7
Living shoreline / wetland	SC			SC			Good	Good 1/7 SC 2/7
Dune building	Good						SC	Good 1/7 SC 1/7
Artificial dune / buried revetment	SC						SC	SC 2/7
Seawall	SC		SC			SC		SC 3/7
Plant stabilization	SC	SC	SC	SC	SC		Good	Good 1/7 SC 5/7
Beach nourishment	SC	SC	SC	SC	SC		SC	SC 6/7
Perched beach (sill)	SC			SC			SC	SC 3/7
Artificial reefs	SC	SC	SC	SC	SC		SC	SC 6/7
Scour protection							SC	SC 1/7
Rip-rap armouring	SC	SC	SC		SC		SC	SC 5/7
Nearshore breakwaters	SC	SC	SC	SC	SC		SC	SC 6/7
Maintenance, repair or replacement of existing infrastructure	Good	Good	Good	Good	Good			Good 5/7
Shore perpendicular breakwater			SC		SC			SC 2/7
Options to avoid	Stormwater management (E22), Rain garden/constructed wetland (E21), Dyke (E16), Detainment pond (E20), Dry floodproofing building (E24), Wet floodproofing building (E25), Raised infrastructure (E26), Engineered revetment (E2), Tide barrier/aboteau (E23), Drainage ditch (E17), Floating building (E27), Retaining wall (E7), Groyne (E4), Dredging (E18), Bluff drain (E19)							

## **CHAPTER 5: Discussion and Conclusion**

The goal of this thesis was to assess the vulnerability of Fundy National Park's coastal environment to climate change impacts and then to subsequently determine the most suitable options to adapt to the identified vulnerability. This was achieved first through characterization of the geomorphic environment and current coastal stability, which was undertaken in the form of a hazard assessment. Seven kilometres of accessible Park coastline were characterized through visual assessment in the field in June 2016. This was followed by identification of assets at risk to climate change impacts, both currently and through future climate change scenarios up to 2100. ArcGIS 10.4 was used to visualize and analyze the intersection of flooded areas with these assets. Finally, potential climate change adaptation options were assessed using the ACASA Coastal Community Adaptation Online Toolkit Decision Tree Tool for Sites identified to have vulnerable assets along the coast. All data pertaining to the characterization, vulnerability, and adaptation assessments will be made available to Fundy National Park directly. The remainder of this discussion is laid out in the manner of an appraisal of the main objectives of the research project as well as the creation of a list of final recommendations and opportunities for Fundy National Park pertaining to the findings.

### **5.1 Characterization of the Geomorphic Environment and Stability Assessment**

The characteristics of the coastal study sections within Fundy National Park are similar in many ways to surrounding regions in the Upper Bay of Fundy and the Maritimes. Rock from the

Carboniferous period is predominant along much of the characterized coastline including the Hopewell conglomerate that can be found at both Herring Cove and Point Wolfe, which is named for its prevalence in Hopewell Cape, NB that is home to the Hopewell Rocks (Burzynski, 1985). Much of the remainder of the Alma-Herring Cove study section has a base of carboniferous sandstone and shale that is topped in many areas by glacial till deposits, and there is a glacial moraine at the back of the Point Wolfe estuary as well. Carboniferous sandstone and shale can also be found elsewhere in the Upper Bay at Cape Enrage and the Joggins fossil cliffs (Burzynski, 1985) as well as the shale of Horton Bluff (Wilson et al., 2017), and much of the remainder of the Upper Bay is formed of sandstone from other geological time periods (e.g. Triassic in much of the Minas Basin) (Wilson et al., 2017). Beyond the Bay, much of the Maritime Gulf of St Lawrence/Northumberland Strait coast of Prince Edward Island (PEI), NB, and NS is also formed of weak, poorly cemented sandstones and shales (Davisdon-Arnott and Ollerhead, 2011). As much of the region shares a glacial history, there are many glacial till deposits throughout the Maritimes, especially within the Bay of Fundy and around the Gulf coast (Davisdon-Arnott and Ollerhead, 2011). These regions where coasts are predominantly composed of sandstones, shale, and glacial deposits are weak and suffer from high erosion rates as they can be eroded by both coastal and subaerial processes.

Similar to the highly erodible coastlines found within much of the study sections, the most stable Pre-Cambrian metamorphic rock found on one side of the Point Wolfe estuary is not unique to the area. These rocks are moderately resistant to coastal erosion and fall into a category of geologies with similar resistance across the region that includes thin limestone, well-cemented

sandstone, and other metamorphic rocks. These can be found along much of the Atlantic coast of NS as well as elsewhere in the Bay of Fundy (Davisdon-Arnott and Ollerhead, 2011).

In the Park, there are also a couple of relatively small coastal salt marshes, which are located behind the Alma beach parking lot and within the Point Wolfe estuary. The barachois located behind the shingle barrier at Cannontown beach is also a form of coastal marsh. While marshes are in existence in FNP, their areal extent is limited in comparison to much of the Upper Bay where marshes are much more predominant (Davisdon-Arnott and Ollerhead, 2011; Wilson et al., 2017). This is due to the exposure of much of the coastline in FNP, as marshes require low wave energy and shelter to be able to thrive (Davisdon-Arnott and Ollerhead, 2011).

Overall, similarities in coastal geomorphology in the region exist due to the shared geological and glacial history of the Maritimes. Within FNP, the portion of the coastline that is toward the upper reaches of the Bay (Point Wolfe to Alma) is less stable and more highly erodible than the lower portion (Goose River to Point Wolfe), which is a pattern that can be observed around much of the Bay pertaining to coastal erodibility. Predominantly shared geomorphology causes much of the region to share similar natural responses to coastal hazards and climate change impacts, and patterns of erosion and flooding exist around the Upper Bay of Fundy and around the Gulf of St Lawrence coast in the Maritime provinces. As time progresses and climate changes, underlying geomorphology is not going to change, so these coastlines will not stop being erodible or vulnerable to flooding.

## 5.2 Assessment of Current and Future Vulnerability of Coastal Assets

The most vulnerable areas that were identified in FNP are mostly low-lying areas that are currently susceptible to erosion and flooding issues and will be increasingly vulnerable as sea level rises. Low-lying areas that will be inundated by sea level rise in the future consist of the Alma beach parking lot containing the Molly Kool Heritage Centre, the Highway 114 behind Alma beach, the Park entrance booth, and the shared parking lot of the swimming pool and Cannontown beach. The riprap revetment protecting the highway along the top of Alma beach is failing, becoming undermined as it suffers from erosion. Four drains placed at intervals along the revetment are also at risk and being damaged; one of them was washed out of its location and down the beach from large, damaging waves on December 30, 2016.



*Figure 5.1. Resting place of a pipe washed out of the Alma beach revetment in a storm on December 30, 2016 (Jan. 2, 2017)*

There is similar coastal vulnerability within low-lying areas around the Bay of Fundy and across much of the Maritimes. This can be attributed to similar high rates of sea level rise across much of the region due to land subsidence (Davisdon-Arnott and Ollerhead, 2011), and tidal amplification across the Bay of Fundy (Greenberg et al., 2012; Leys, 2009; Savard et al., 2016). Coastal lowlands around the Bay of Fundy are increasingly vulnerable to coastal flooding due to high prevalence of coastal assets, particularly in dykelands that consist of reclaimed land that sits below sea level (Davisdon-Arnott and Ollerhead, 2011; van Proosdij et al., 2016; Savard et al., 2016). These dykelands are increasingly vulnerable due to the hard-built nature of dykes; they are unable to adapt to sea level rise and the flooding impacts it brings without the intervention of humans, and they can block the landward retreat of the coastal salt marshes that are often in front of them (Davisdon-Arnott and Ollerhead, 2011; Savard et al., 2016). There are also other areas in the region with many assets built along highly erodible cliffs and bluffs such as along the exposed Gulf of Lawrence shore (PEI, NB, and NS) as well as within the Upper Bay of Fundy (Davisdon-Arnott & Ollerhead, 2011).

### **5.3 Identification of Climate Change Adaptation Options**

The low-lying areas around Alma and Cannontown are vulnerable to both flooding and erosion issues, so adaptation planning must take this into consideration. Most important and useful would be the creation of a management plan including policy limiting future development within the vulnerable low-lying areas, as any new construction would also be vulnerable and is unnecessary to the area's function.

Within the Alma region, the riprap revetment that protects the highway needs maintenance as it is currently causing damage to the ground that it is supposed to be protecting. New rock should be added to replace that which has been swept down the beach and the holes that have formed (exposing the geotextile below), and care should be taken to rebuild at a maximum angle of 35-40° to allow for maximum wave dissipation and to extend the life of the structure (Leys and Bryce, 2016). Though engineering the revetment is more costly than simply dumping more riprap (one cost bracket higher in Figure C.4), proper construction would allow the structure to last much longer without being damaged or causing damage. Dune restoration can be performed at the top of the Alma beach to prevent erosion to the roadbed behind and to prevent flooding of the highway as well, and this falls within the same cost bracket as engineering a revetment (Figure C.4). This would be especially useful in the flat vegetated area that was covered by the former breakwater structure, and in the spot closer to the access stairs where a breach occurred October 29, 2015 (and during subsequent storm events). However, this might not function as well as it could due to the location of the revetment blocking the longshore transport of sediment to the dunes. The Alma beach parking lot and a small portion of the Highway 114 already suffer from flooding during storm events coinciding with high tide, and while this is not a huge issue now (as the water will recede with the tide), it will become more frequent and flooding could occur even on regular high tides with increased sea level as well as tidal expansion. When future maintenance is done to these paved surfaces, the possibility of raising them should be explored. Raising the infrastructure at a time when major maintenance is required (i.e. complete resurfacing) could help to reduce the maintenance costs overall, though

raising infrastructure is within the same price bracket as engineering a revetment (Figure C.4).

The Park entrance booth would need to be raised along with the highway.

The Molly Kool Heritage Centre should be relocated outside of the low-lying coastal area, as its location on the coastline is not imperative to its use. This is a form of managed retreat or relocation (Manuel et al., 2016) and is the best option for the future safety of the reconstructed building, but it could be quite expensive (really the most expensive adaptation option as demonstrated in Figure C.4) for the small non-profit that is in charge of the Centre's maintenance. If the Centre is not relocated, it will need to be further elevated in the future. As the building is already raised off the ground, this would involve increasing the height of the stilts and framing it sits on. Raising the building above future extreme water levels is a type of wet floodproofing, and this would come in at anywhere from a tenth to half the cost of relocation (Figure C.4) (Leys and Bryce, 2016).

At Cannontown beach, the stairs leading down to the beach from the parking lot through the revetment have been damaged beyond repair and are a safety hazard to visitors in their current state. They should be removed and replaced with a designated path descending to the beach by way of the shingle barrier (which is already an alternative route used by Fresh Air Adventures for their kayak tours as well as many visitors). The riprap revetment is in good shape, but an addition should be made where the stairs are removed because that would create a hole in the revetment and allow it to be eroded more easily. It should be assessed and maintained in the future. As with the Alma Beach parking lot, since this needs to likely remain where it is, heightening and levelling the surface should be explored when it needs future repair and resurfacing to alleviate flooding from surge and higher future tides.



At Point Wolfe, the Shiphaven trail is at risk to coastal erosion. Signs already warn against this, but it should be monitored closely due to the high rate of retreat. The fence at the red chair lookoff should be moved back from the edge and extended in length for visitor safety. In the future, as happened in the past with the Devil's Half Acre trail (prior to it closing), it could be necessary to reroute the trail further inland for visitor safety should the trail and boardwalk infrastructure become compromised.

Overall, limiting future development in the vulnerable areas is incredibly important, but many of the developed coastal areas are critical to the function of the Park. While relocation appears to be one of the best options overall, this is not necessarily true for many of the existing coastal assets found within the Sites. For example, the Highway 114 can realistically not be relocated. There is another route connecting Alma to the Park but it is an unpaved road in a major state of disrepair that runs from the opposite upper corner of the Park along its northern and eastern boundaries (Shepody and Forty-Five Roads) beyond Alma. Using that route could turn a trip that would normally be only a few seconds into an hour-long drive, and is therefore not at all realistic in the function of the Park. At least the highway currently sits high enough for frequent flooding on high tide to be a long-term issue rather than currently pressing.

The Alma beach parking lot is in a bit of a similar position where there is not really anywhere that it can be relocated and its complete loss would be detrimental to the Park; it would not be as impossible to overcome as the loss of the highway however. It sits at a lower elevation than the highway, so it will face frequent flooding issues much earlier. Luckily, as a parking lot it will be able to withstand flooding without physical detriment, though flooding at high tide could

become an issue for managing visitor safety because the tides are not going to stop rising twice daily.

Like the Alma beach parking lot, the Cannontown beach / swimming pool parking lot is also low-lying to a degree where it will face frequent flooding earlier than the highway. The swimming pool is currently being newly reconstructed, so there are definitely no plans to move its use out of the coastal zone, and this would not be realistic as the pool is actually filled by pumping water from the Bay. There is nowhere else that this parking lot could be relocated and still function, so it will also have to be maintained, but again this is a long-term issue rather than something that is currently pressing.

The ACASA coastal decision support tool functioned fairly well overall. The majority of the options that it presented as “good” or “most suitable” seem to fit with FNP’s coastal zone. There were a few exceptions however, including a few flooding options that would function much better for freshwater flooding from heavy rainfall than for saltwater storm surge (i.e. rain garden or constructed wetland). This tool could certainly be useful to coastal planners in the Atlantic Provinces as it employs information and knowledge specific to the area being explored. It would be best employed in conjunction with a vulnerability assessment though, as it is necessary to be aware of vulnerable coastal areas and what types of impacts (erosion and/or flooding) are occurring locally. It should be recognized by users of the tool that though it gives many options, the tool does not necessarily have enough background information to make completely informed decisions, so its outputs should not be taken as unquestionable.

Though the decision tree tool was useful overall, there were limitations in the use of the tool beyond the necessity of site-specific background knowledge. In this research, the designation

of FNP as federally owned and managed land was not a choice in the decision tool, so it had to be treated as an unincorporated Local Service District. This would have affected some of the land use planning choices that were given as options as some are not necessarily suited for planning on federal land. Another limitation in the tool was the ability to communicate the importance of some coastal assets that were located within the selected Sites. For example though retreat is generally always a good option, as the tool suggests, it is not always possible depending on the infrastructure (i.e. Highway 114).

Fundy National Park is vulnerable to climate change effects along only a small portion of the coastline due to the fact that the vast majority of the Park's coast is either generally inaccessible to the public (portions that were not characterized in this study) or free of assets that are cause for vulnerability. However, of the characterized sections of the coastline, there were locations that contained very important assets that will be at risk in the future, including the Highway 114 that is the Park's link with Alma and beyond. As portions of the coastline containing infrastructure have been identified as vulnerable, it is important that Fundy National Park take these future impacts into account when undergoing future planning as both the coastline generally and climate change impacts to Park ecosystems have not been accounted for in Park management plans as of yet.

As a federal agency, Parks Canada is beginning to recognize, assess, and take climate change effects into account in future planning. They recognize the usefulness of National Parks as climate observatories (Canadian Parks Council, 2013) in their roles as representatives of specific Canadian Natural Areas (Parks Canada, 1997). This practice has trickled down in regions that are currently highly vulnerable, and climate monitoring and adaptation strategies have

already been implemented in some locations. It is now important that Parks Canada expand their climate assessment initiative and require it to be undertaken on a more site-specific basis such as at the National Park level.

#### **5.4 Conclusion**

Fundy National Park is currently being negatively impacted by climate change with large portions of the coastline formed of erodible material and low-lying areas home to key infrastructure. However, Park management has not taken climate change impacts into account when undergoing future planning up to this point. This is especially true along the Park's coastline, as Park scientists are not actively monitoring it. Therefore, the vulnerability of Fundy National Park's coastline is not recognized by Parks Canada. Paradoxically, the Park's coast is an important tourist draw and therefore important to the Park's revenue, so its maintenance is incredibly important.

#### **5.5 Key Recommendations and Opportunities for Fundy National Park**

- Climate change impacts need to be discussed and accounted for in future management plans.
- Climate change impacts should be further studied in FNP's local and unique context.
- Future development should be limited in vulnerable areas (create new policies)
- The coastline should be monitored into the future to observe changes and the impact of climate change effects. FNP has the opportunity to become a climate change observatory.

- There is also the opportunity to become climate change educators with the creation of relevant visitor programming and interpretive panels.
- Coastal adaptation should be undertaken as outlined in the third section of this discussion.

The coastline of Fundy National Park holds a special place in the heart of visitors from around the world and is a major tourist draw for the Park. Therefore, it is in the best interest of Parks Canada to create a climate change monitoring and adaptation plan to maintain the coastline for the safety and enjoyment of visitors into the future.

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# APPENDIX A: Coastal characterization charts and definitions

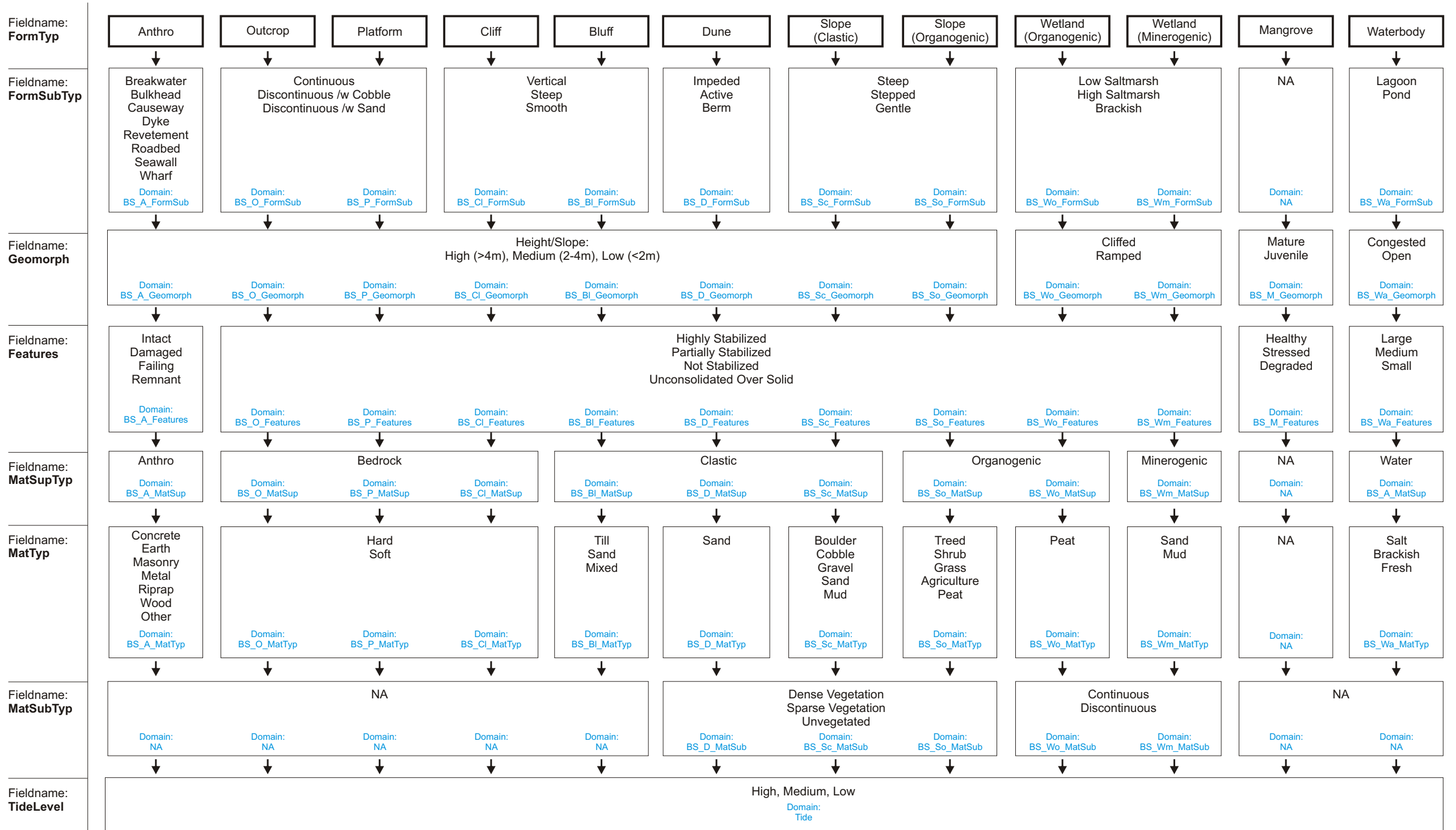


Figure A.1. Backshore Characterization Decision Tree

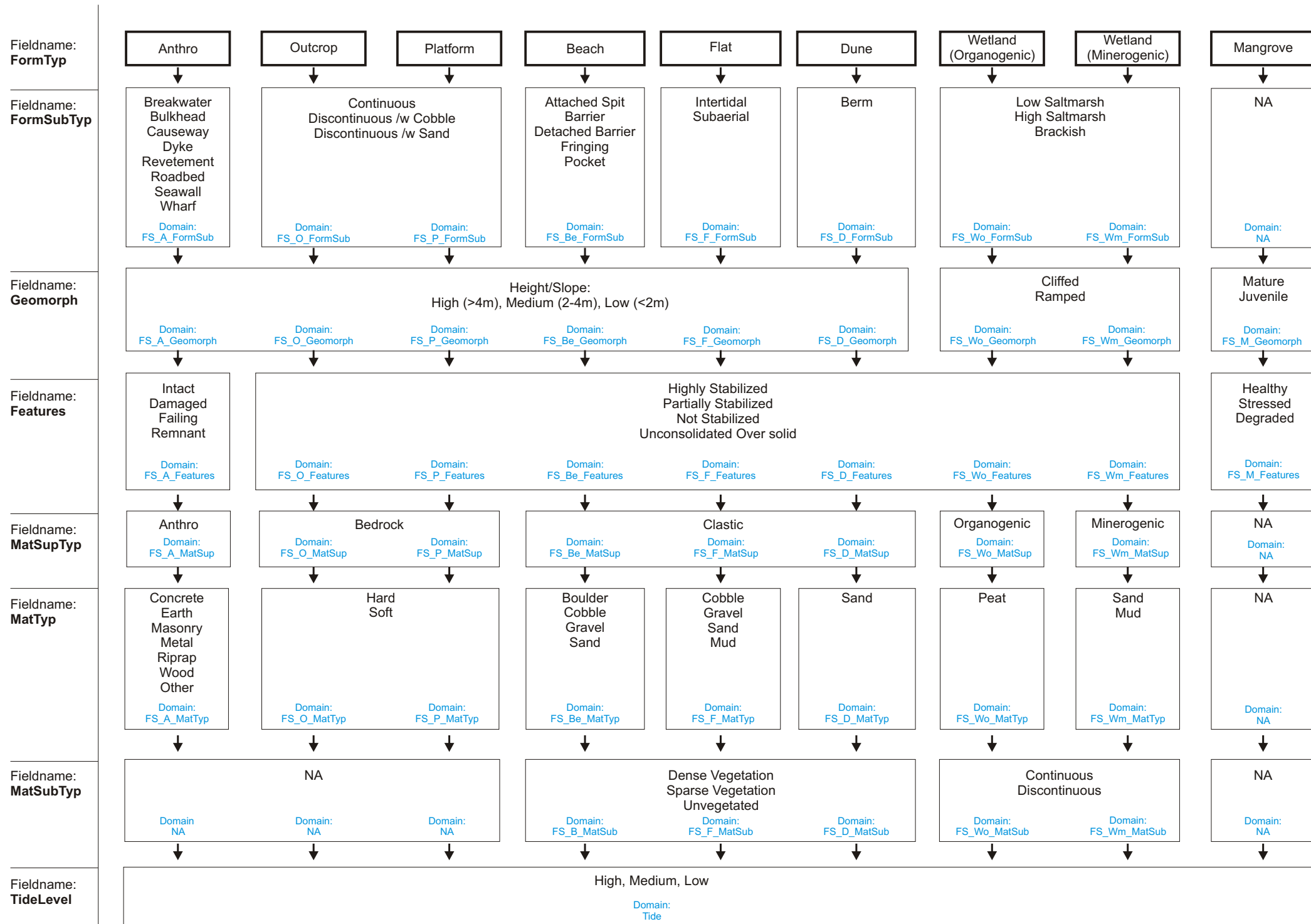


Figure A.2. Foreshore Characterization Decision Tree

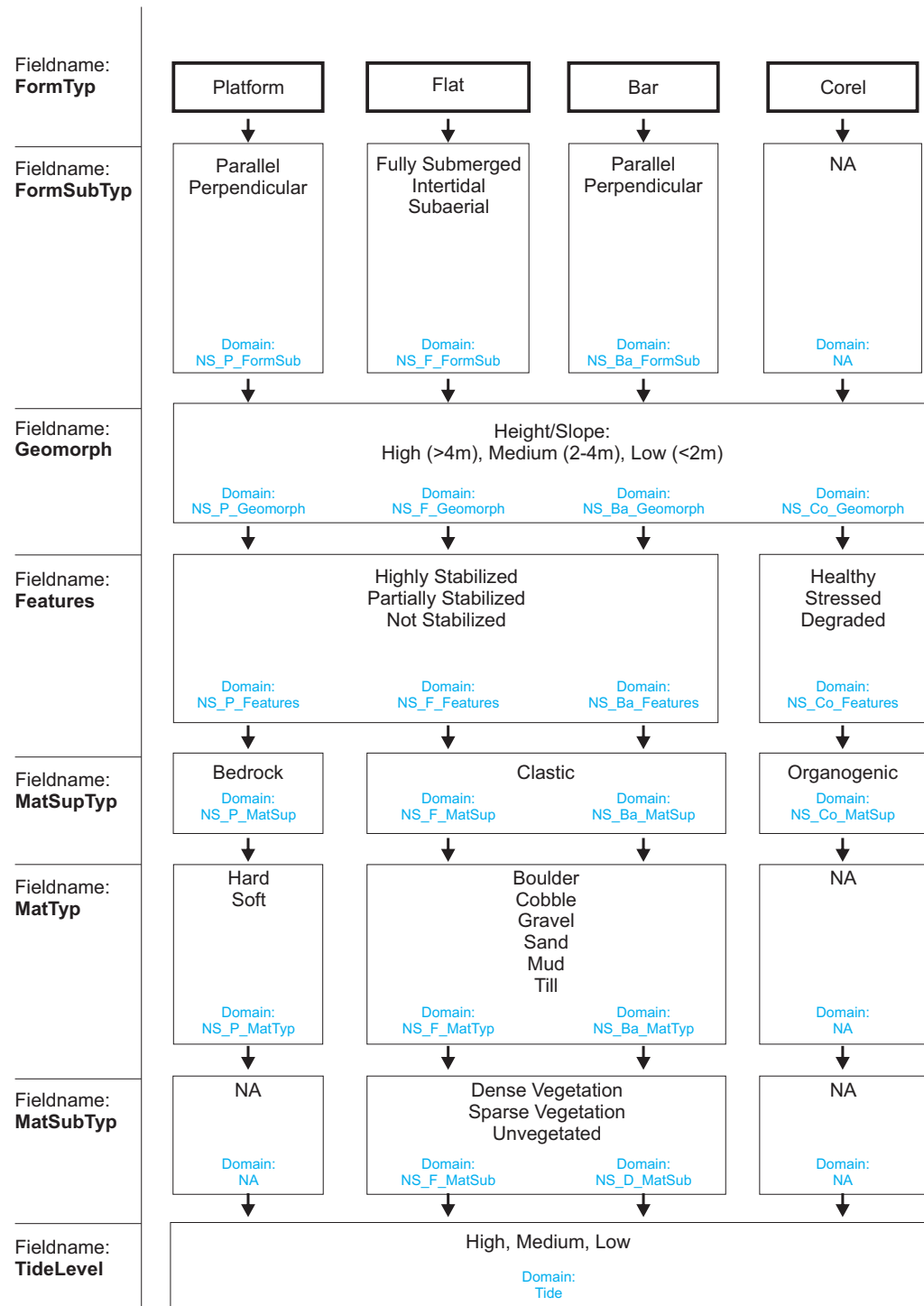


Figure A.3. Nearshore Characterization Decision Tree

## Simplified Shoreline Characterization Definitions (Courtesy of Samantha Page)

**Backshore** – extent of farthest possible wave advance in a storm

**Foreshore** – immediately in front of the backshore (area over which a storm wave would travel)

**Nearshore** – what is in front of the foreshore (in the water)

### BACKSHORE

#### FormType

*Anthro* – anything man-made

*Outcrop* – cliff that is less than 40deg

*Platform* – bedrock platform (like stepping onto a stage-small cliff)

*Cliff* – rockface steeper than 40deg (always bedrock)

*Bluff* – lower angle and very little bedrock, unconsolidated cliff with a few bits of bedrock (boulders)

*Dune* – a large mound of sand

*Slope* – unconsolidated material, shallower bluff, equivalent to platform, but unconsolidated

*Clastic* – non living

*Organogenic* – living ie: lawn, sod

*Wetland* – vegetation and wet

*Organogenic* – living, root mats with plants

*Minerogenic* – plants, some roots, mostly sand

#### Water

#### FormSubType

*Breakwater* – hardened structure at angle to the shore that stops waves energy before it reaches the shore and protects the shoreline

*Bulkhead* – retaining wall, generally made out of wood or steel

*Causeway* – specifically for road, with body water behind

*Dyke* – earthen/concrete structure to prevent flooding. Land behind dyke is almost always lower

*Revetment* – sloped structure along shore to prevent erosion

*Road* – road

*Seawall* – vertical structure that goes down to bed and breaks wave energy. Generally made of Concrete

*Wharf* – water passing underneath with mooring of boats

\*\*note: for a Gabion basket and living shoreline/soft structure, if rise>run = seawall and if rise<run = revetment\*\*

*Continuous* – all bedrock

*Discontinuous* – bedrock mixed with cobble or sand in a finger like pattern

*Vertical (cliff, bluff)* – Can't climb without rope

*Steep (cliff, bluff)* – need hands to scramble up slope

*Smooth (cliff, bluff)* – Polished surface (could be vertical or steep)

*Impeded* – stuck, stable

**Transgressive** – moving, active

**Steep (slope)** – need hands to walk up

**Gentle (slope)** – can walk up

**Stepped (slope)** – like stairs

**Low Saltmarsh** – dominated by spartina alterniflora

**High Saltmarsh** – dominated by spartina patens

**Lagoon** – historically open at some point, more often open than not, behind a barrier

**Pond** – pool of water, more often closed than not

## Geomorph

**Height:** High (>4m) – equivalent to 13ft and is greater than height of normal room

Medium (2-4m) – equivalent to 6.3 -13ft

Low (<2m) – equivalent to 6.3ft

**Slope:** High (>4m) – need hands to climb up it

Medium (2-4m) – can walk up it without using hands

Low (<2m) – very shallow gradient

**Cliffed** – straight

**Ramped** - sloped

**Congested** – full of submerged vegetation, no swimming

**Open** - swimming

## Features

**Intact** – perfect condition

**Damaged** – performing function, but looks like it could use some repair

**Failing** – needs to be replaced, but if repaired, could till go back to function

**Remnant** – abandoned, not performing function

**Highly Stabilized (outcrop, cliff, bluff, plat, wetland)** – no erosion, no talus, no recent debris

**Partially Stabilized (outcrop, cliff, bluff, plat, wet)** – some rock fall

**Not Stabilized (outcrop, cliff, bluff, plat, wet)** – actively eroding, slumping

**Unconsolidated over Solid (outcrop, cliff, bluff, plat, wet)** – bedrock base, but unconsolidated over base

**Highly Stabilized (dune)** – no sand, trees

**Partially Stabilized (dune)** – some undercutting, movements

**Not Stabilized (dune)** – blowout, no vegetation

**Large** – bay = day trip = field

**Medium** – do a tour = building

**Small** – useless to put in a canoe = big room

## MatSupType

*Anthro*

*Bedrock*

*Clastic*

*Organogenic*

*Minerogenic*

*Water*

**MatType (dominant material type)**

*Concrete* – Solid

*Masonry* – blocks cemented together

*Riprap* – boulders or others

*Metal*

*Wood*

*Other* – *Living, Gabion Basket*

*Hard* – granite

*Soft* – sedimentary (limestone)

*Till* – sticky, kind of muddy, wet, smaller grain size

*Sand* – granules

*Mixed* – mix of sand and till or others

*Boulder* – can't pick up

*Cobble* - pick up with two hands

*Gravel* – much smaller

*Sand* – granules

*Mud* – very fine, stuck together

*Treed* – well established forest

*Shrub* – bushes, with a few trees

*Grass* – primarily grass

*Agriculture* – farmland

*Peat* – spongy, root mats

**MatSubType**

*Dense Vegetation* – 75-100%

*Sparse Vegetation* – 25-75%

*Unvegetated* – 0-25%

**Tide Level**

*Is there a high tide line above you? Exposed shells and other organisms?*

**FORESHORE**

**MatSubTyp**

*Beach* – deposit of sediment

*Flat* – platform that is clastic

**Geomorph**

*Attached Spit* – large spit attached to land

*Barrier* – attached at two ends

*Detached Barrier* – detached at both ends



*Fringing* – relatively uniform, long distance

*Berm* – bumpy beach

*Pocket Beach* – crescent shaped

*Intertidal* – exposed at tide

*Subaerial* – mostly exposed

## **NEARSHORE**

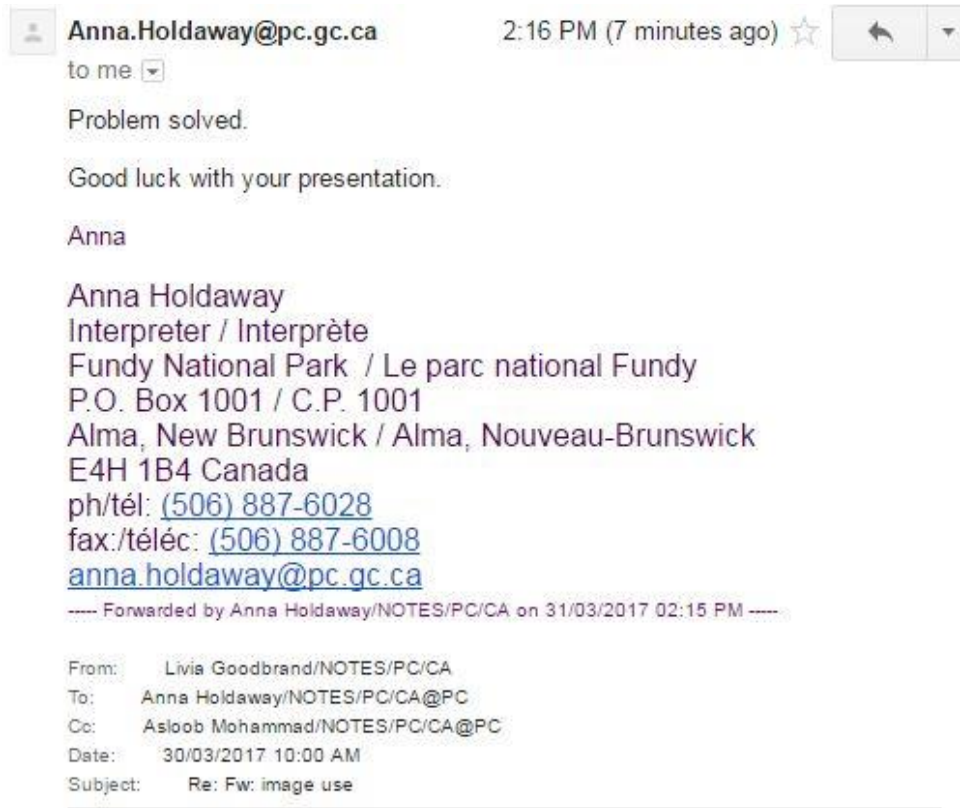
### **FormTyp**

*Bar* – if any bar within 10m of shore, classify as a bar (breaking waves)

## APPENDIX B: Permissions

\*Unless otherwise stated, all photos used were taken by the author and the author was the cartographer of all maps.

All four photographs in Figure 2.4 as well as the historical photographs in Figure 2.5 and Figure 2.6 are property of Parks Canada used with permission.



I don't really see an issue here.  
 I would simply ask her to credit the photos to Parks Canada.  
 "Credit: Parks Canada, YEAR"

The centre photograph in Figure 4.5 is used with permission from Robin Stuart.

Robin Stuart

9:21AM

Hi Robin! I have one of your pictures in my thesis and wanted to be sure that it was still alright with you that I use one?



It's this one just to let you know.

Definitely!

Good luck!!

Thank you!!

**APPENDIX C: ACASA Decision Tree Tool Resources and Results**

			PREVAILING COASTAL TYPE & APPLICATION							
Coastal region			Estuary	Salt marsh	Coastal sandy system	Cobble beach	Cliff/bluff	Rock shore	Built	Existing dykelands
Atlantic seaboard - NS, NL										
Bay of Fundy - NS, NB										
Gulf of St Lawrence and Northumberland Strait - NS, PEI										
<b>TOOLS</b>	<b>Erosion Mitigation</b>	P	Scour protection							
		P	Engineered revetment							
		P	Rip-rap armouring							
		P	Groynes (groins)							
		P	Shore perpendicular breakwater							
		P	Nearshore breakwaters							
		P	Retaining wall							
		P, A	Artificial reefs							
		P, A	Perched beach (sill)							
		P, A	Beach nourishment							
	P, A	Plant stabilization								
	<b>Erosion &amp; Flood Mitig.</b>	P	Seawall							
		P	Buried revetment							
		P, A	Living shoreline/wetland							
		P, A	Dune building							
	<b>Flood Mitigation</b>	P	Dyke							
		A	Dredging							
		A	Bluff drain							
		A	Stormwater management (also includes drainage ditch, detention pond, and rain garden)							
		P	Tide barrier/aboteau							
P		Dry flood proofing building								
A		Wet flood proofing building								
A		Raised infrastructure								
A	Floating building									
<b>Retreat</b>		Relocate infrastructure								

P - Protect  
A - Accommodate  
R - Retreat

Note: Planning tools should be considered at the same time as engineering tools, if not first.

Figure C.1. Engineering Tools and Typical Application by Coastal Type  
 (Table 3.1 in Leys and Bryce, 2016)

		Typ. position in coastal profile (Nearshore / Foreshore / Backshore)	Protection		Potential Impacts			Potential Long-Term Sustainability		
			Protection of coast above high tide	Beach/ tidal zone preservation	Lee side erosion	Aesthetics	Swimming safety	Preservation of coastal dynamics and morphology	Preservation of habitat/ biodiversity	
ADAPTIVE RESPONSES AND TOOLS	Erosion Mitigation	P	Scour protection	F	✓	X	X	-	X	-
		P	Engineered revetment	F, B	✓	X	X	-	X	-
		P	Rip-rap armouring	F, B	✓	X	X	-	X	-
		P	Groynes	N	✓	✓	X	X	X	-
		P	Shore perpendicular breakwater	N	✓	✓	-	X	X	-
	Erosion & Flood Mitig.	P	Nearshore breakwaters	N	✓	✓	X	X	X	-
		P	Retaining wall	B	✓	-	-	X	-	X
		P, A	Artificial reefs	N	✓	✓	-	✓	X	✓
		P, A	Perched beach (sill)	N	-	✓	✓	✓	X	-
		P, A	Beach nourishment	B	✓	✓	✓	✓	-	X
Flood Mitigation	Flood Mitig.	P, A	Plant stabilization	B	✓	✓	-	✓	-	✓
		P	Seawall	B	✓	X	X	-	X	-
		P	Buried revetment	B	✓	✓	✓	-	X	-
		P, A	Living shoreline/wetland	F, B	-	✓	-	✓	-	✓
		P, A	Dune building	B	✓	✓	-	✓	-	X
	Flood Mitigation	P	Dyke	F	-	-	-	X	-	X
		A	Dredging	F	-	X	X	-	X	X
		A	Bluff drain	B	-	-	-	-	-	-
		A	Stormwater management	B	-	-	-	-	-	-
		P	Tide barrier/aboteau	F	✓	-	-	-	-	X
Retreat	P	Dry flood proofing building	B	-	-	-	-	-	-	-
	A	Wet flood proofing building	B	-	-	-	-	-	-	-
	A	Raised infrastructure	B	-	-	-	-	-	-	-
	A	Floating building	N, F	-	-	-	-	-	-	-
	A	Relocate infrastructure	B	-	-	-	-	-	✓	✓
		✓	Good protection	High recreation value	Enhances sustainability					
		-	Neutral	Neutral	Neutral					
		X	Causes erosion	Negative impact	Unstable					
		<b>Legend</b>								

Figure C.2. Functional Characteristics of Engineering Tools (Table 3.2 in Leys and Bryce, 2016)

**Please note that the matrix is not reversible. Read horizontally by tool:** "if you choose this particular tool, then consider using the green ones in conjunction and avoid the red ones".  
 For example: groins require filling during construction with beach nourishment or wetlands, but beach nourishment does not require groins.

		ENGINEERING TOOLS																								
		Erosion Mitigation								Erosion & Flood Mitigation			Flood Mitigation				Retreat									
		Scour protection	Engineered revetment	Rip-rap armouring	Groynes (groins)	Shore perpendicular breakwater	Nearshore breakwaters	Retaining wall	Artificial reefs	Perched beach (sill)	Beach nourishment	Plant stabilization	Seawall	Buried revetment	Living shoreline/wetland	Dune building	Dyke	Dredging	Bluff drain	Stormwater management	Tide barrier/aboiteau	Dry flood proofing building	Wet flood proofing building	Raised infrastructure	Floating building	Relocate infrastructure
Erosion Mitigation	Scour protection																									
	Engineered revetment																									
	Rip-rap armouring																									
	Groynes (groins)																									
	Shore perpendicular breakwater																									
	Nearshore breakwaters																									
	Retaining wall																									
	Artificial reefs																									
	Perched beach (sill)																									
	Beach nourishment																									
	Plant stabilization																									
	Seawall																									
	Buried revetment																									
	Living shoreline/wetland																									
	Dune building																									
Dyke																										
Dredging																										
Bluff drain																										
Stormwater management																										
Tide barrier/aboiteau																										
Dry flood proofing building																										
Wet flood proofing building																										
Raised infrastructure																										
Floating building																										
Retreat																										

Legend  
  Generally not compatible (use one or the other)  
  Generally compatible (may use both)  
  Generally best used together

Figure C.3. General Compatibility of Engineering Tools  
 (Table 3.4 in Leys and Bryce, 2016)

		Typical cost range in Atlantic Canada				Typical maintenance interval					
		Unit	< 1,000	1,000 to 5,000	5,000 to 10,000	> 10,000	Short < 5 yrs	Variable	Long 20 yrs +		
Erosion Mitigation	P	Scour protection	\$/m road or shoreline	Local rock, typical work (e.g. road repairs)	Distant rock source and/or larger project			x			
	P	Rip-rap armouring									
	P	Engineered revetment	\$/m shoreline		Local rock	Distant rock source			x		
	P	Groynes	\$/m shoreline			Local rock	Distant rock source		x		
	P	Shore perpendicular breakwater	\$/m structure				x		x		
	P	Nearshore breakwater	\$/m shoreline			Local rock	Distant rock source		x		
	P	Retaining wall	\$/m shoreline		Mechanically stabilized panels	Concrete		x			
	P, A	Artificial reefs	\$/m shoreline		1-2 m high rock berm			x			
	P, A	Perched beach (sill)	\$/m shoreline			with 1-2 m high rock berm		x			
	P, A	Beach nourishment	\$/m shoreline		Local sand source	Offshore sand source		x			
	P, A	Plant stabilization	\$/m shoreline	x				x			
	Erosion & Flood Mitig.	P	Seawall	\$/m shoreline		Up to 2 m high	2 - 4 m high	> 4 m high			x
P		Buried revetment	\$/m shoreline		Local rock	Distant rock source			Sand cover	Rock core	
P, A		Living shoreline/wetland	\$/m shoreline	20-40 /m2						x	
P, A		Dune building	\$/m shoreline		x				x		
Flood Mitigation	P	Dyke	\$/m shoreline	Up to 2 m high	2 to 5 m high	5 to 8 m high	> 8 m high			x	
	A	Bluff drain		x					x		
	A	Stormwater management									
		Drainage ditch	\$/m ditch	x							x
		Storage (detainment pond)	\$/m3	x							x
		Rain garden	\$/m2	20-40 /m2							x
	P	Tide barrier/aboiteau	\$100 k to \$ 400 k / m2 hydraulic cross-section					x			x
	P	Dry flood proofing building	\$/m for waterfront lot width		x				x		
A	Wet flood proofing building	20 to 30 m					x				
A	Raised infrastructure	\$/m (road, or waterfront lot width 20 to 30 m)		x				x			
A	Floating building	\$/m for waterfront lot			Lot width 20 to 30 m	Lot width <20 m				x	
Retreat	Relocate infrastructure	\$/m shoreline		Road \$/m		Waterfront lot up to 30 m \$/m				x	
Land acquisition \$ not included in any of the options											

P - Protect  
 A - Accommodate  
 R - Retreat

Figure C.4. Range of Typical Construction Costs for Engineering Options (Table 3.7 Leys and Bryce, 2016)

The remainder of Appendix C consists of an accompanying PDF document that includes all decision trees that were the result of use of the ACASA Coastal Community Adaptation Online Toolkit Decision Tree Tool for Sites 1-7 discussed in Chapter 4.2. The following page includes a single page of an output as an example (page 1 of the engineering options for Erosion in Site 2). Please contact Dr. Danika van Proosdij at [dvanproo@smu.ca](mailto:dvanproo@smu.ca) to electronically access the remaining 107 pages of this Appendix.



### 3 Erosion options - Engineering measures

Options:

E1-E11 Erosion Tools

E12-E15, E28 - E29 Flooding and Erosion Tools

E16-E27 Flooding Tools

Table 2: Erosion options - Engineering measures

Option	Output Rank	Description	Cost	Environmental Impacts	Habitat/biodiversity impacts	New steps: Information typically required	Degree of Regulatory Requirements			
							Municipal	Provincial	Federal	Cumulative
<b>E29 - Maintenance, repair or replacement of existing structure</b>	Good	Some structures require maintenance over time. If there is a structure already present at your site which is causing or experiencing damage, there is the possibility of repairing or replacing it.	VARIABLE			civil engineer	Variable	Variable (NB)	Variable	Variable
<b>E28 - Relocate infrastructure*</b>	Good	The decision to relocate or abandon a coastal road, building or other type of infrastructure must be based on a complex cost-benefit analysis that includes socio-economic aspects. The value of services provided must be accounted for.	HIGH	Removal of infrastructure may cause temporary disturbance to habitat	Enhances sustainability	topography, erosion rate, flood mapping, water level	High	High (NB)	Medium	High
<b>E11 - Plant stabilization*</b>	Some concerns	Planting certain vegetation to stabilize coastline is a cost effective option in relatively protected shorelines.	LOW	Using the wrong type of vegetation may be ineffective or choke out existing native vegetation; experts should be consulted.	Enhances sustainability	topography, erosion rate, water level, wave height, biologist	Low	Low (NB)	Low	Low
<b>E6 - Nearshore breakwaters</b>	Some concerns	Nearshore breakwaters are designed to provide shelter from waves to reduce erosion of the shoreline and can be designed to increase sediment build-up in desired locations.	HIGH	Downdrift erosion if not pre-filled with enough imported sand; - Rip currents potentially hazardous to swimmers	Neutral	bathymetry, erosion rate, water level, wave height, extreme current, sediment transport, coastal expertise	Low	Low (NB)	High	High
<b>E8 - Artificial reefs*</b>	Some concerns	Artificial reefs attempt to mimic natural forms and use naturally occurring material and help restore natural reef systems.	LOW	Seabed footprint	Enhances sustainability	bathymetry, wave height, extreme current, coastal expertise, biologist	Low	Low (NB)	Medium	Medium
<b>E10 - Beach nourishment*</b>	Some concerns	Beach Nourishment adds sediment to the coastal system by depositing along the shoreline. It acts as a storm buffer. It involves periodic renourishment because it does not reduce background erosion rate.	MEDIUM	Does not reduce background erosion rate.	Neutral	topography, bathymetry, erosion rate, water level, wave height, sediment transport, coastal expertise	Low	Medium (NB)	Medium	Medium
<b>E3 - Rip-rap armouring</b>	Some concerns	Rip-rap refers to loose rock or other material piled on the shoreline to limit erosion, typically end-dumped from a truck.	MEDIUM	May cut off sediment supply and cause erosion downdrift. May induce scour at the base.	Neutral	topography, bathymetry, erosion rate, water level, wave height, extreme current, sediment transport, civil engineer	Low	Medium (NB)	Medium	Medium
<b>E17 - Drainage ditch</b>	Avoid	Drainage ditches are made up of a network of open trenches often connected by culverts. They will provide routes for water to drain from an area. ; The following answer(s) invalidated this option:2b. Coastal erosion	LOW	Increasing drainage upstream in the watershed may increase flooding risks downstream.	Neutral	topography, flood mapping, water level, extreme current, water resources expertise	Low	Low (NB)	Low	Low