COASTAL GEOMORPHOLOGY, PROCESSES AND EROSION AT THE TOURIST DESTINATION OF FERRYLAND, NEWFOUNDLAND AND LABRADOR

by

© Eric Carl Watton

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Abstract

The community of Ferryland is located on the southeastern coast of the Avalon Peninsula. The town traditionally relied on a fishing-based economy until the collapse of the fishery in the early 1990s. The present economy emphasizes sustainable development in the tourism sector with focus on archaeology, geotourism and other recreational uses. This paper discusses coastal erosion and impacts on sites and infrastructure using methods including: local knowledge, Real Time Kinematic (RTK) surveying and other survey techniques, seawater level measurement, meteorological data from a locally-installed station, custom-made drifter tube buoys, photography, HD video, and investigation using various modes of transport including inflatable boat. The major findings of the study include that the residents and stakeholders are genuinely interested in and knowledgeable of coastal erosion. The causes of coastal erosion include: large waves, surge, longshore currents, harbour oscillations, mass wasting, and location of infrastructure causing alterations of these processes. Freeze-thaw Cycles (FTC), rainfall, and gravity loosen and transport rock, till, and fill materials downslope. Large waves and currents transport the materials alongshore or into the nearshore. Harbour oscillations causing high velocity currents (> 2 m/s) are responsible for shoreline erosion and damage to property in The Pool. Historical resources such as gun batteries and ordnance pieces which date to the 1700s are being lost or threatened through coastal erosion of till and rock cliffs. Improper drainage and maintenance is responsible for erosion of roads and supporting shoulders, necessitating mitigation measures. Sediment transport and deposition during and after large wave and surge events lead to undercutting of infrastructure and increased risk of washover of existing infrastructure. Erosion is ongoing at Bois Island and Ferryland Head Isthmus through slope processes and undercutting; The Pool and the lower Colony of Avalon site through harbour oscillations and related undermining; the tombolo and the main breakwater through wave attack; and Meade's Cove including the East Coast Trail through wave attack and undercutting. The floor of the latrine in the lower Colony of Avalon site indicates that sea level was approximately 1.25m below present in the 1620s, a relative sea level rise rate of 3.2 mm/y. The recommendations include suggested mitigation to reduce impacts specific to each site.

Acknowledgements

I would like to express a sincere thank you to Dr. Norm Catto for this opportunity to study coastal erosion at such a dynamic and beautiful site, for his expert knowledge in this interdisciplinary study area, and for his exemplary guidance and supervision.

I would like to truly thank my beautiful wife Joanne Watton for her unwavering support and love. I would also like to thank my family: Mom (Eileen Watton), Brother (Clyde Watton) and Sister (Nancy Watton), Mother-in-law (Mrs. Naida Noble) and Brother-in-law (Joe Noble). I would also like to express deep gratitude to my father (Mr. Winston Watton) and my father-in-law (Mr. George Noble) who both passed away in 2013. I know you both loved, supported and believed in me to the fullest.

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Chapter 1 – Introduction and Objectives

This chapter introduces the research topic; states the purpose of research; identifies the objectives; and discusses the study area, including a historical perspective, system overview, and comments on tourism sites in the area. It concludes by describing the thesis layout.

1.1 Introduction

The coastal environment is shaped by numerous physical, biological, and chemical interactions between the atmosphere (climate and weather), terrestrial (mass movement), and marine or freshwater influences (tides, waves and currents). Short- to long-term changes in the water level and the elevation of land (relative sea level) also play an important role in determining shoreline position. Coastal geomorphology is the study of these processes and how they form or shape the coastline through erosion, deposition and accretion. The description and interpretation of coastal processes, aided by specific data collection, can reveal the actual causes of coastal processes which cause erosion or deposition.

Coastal tourist sites and related tourist activity are considered to be interrelated. The sites are subject to coastal processes which cause erosion and deposition. The description of the processes can be interpreted to provide advice on potential impacts that may eventually destroy or render the site inaccessible. The erosion of the access to the site or the actual site impacts tourism activity in the area by restricting or preventing site access.

1.2 Purpose of Research and Objectives

The purpose of the research is to investigate, describe, interpret, and present baseline data and information regarding coastal geomorphology and related coastal processes which are impacting selected coastal sites and access routes at Ferryland. This is not a comparative analysis study. This study involves original quantitative and qualitative data collection techniques and presentation for the Ferryland study area to provide further understanding into coastal processes including the nearshore, barriers, and till and fill cliffs.

This study aims to answer the following questions:

- What are the major controls on waves, surge, and currents in the study area?
- What are the major tourism sites and what type of erosion has impacted them?
- What are the modal morphology and sedimentology of selected barriers and what is the dominant wave direction and current which shape them?
- What is the major cause of erosion in The Pool?
- What are the baseline statistics on tourism activity and how are the related sites impacted or at risk of erosion?
- Based on the Colony of Avalon site, what is the estimated relative sea level change between 1620s to present?
- What are the major mitigation measures in use and what areas need mitigation measures?

1.3 Study Area and Setting

The east coast of the Island of Newfoundland is exposed to the North West Atlantic where large storms frequently impact coastal zones, including many communities and tourism destinations, such as the picturesque Town of Ferryland. Ferryland is located approximately 85 kilometres south of St. John's on the southeastern coast of the Avalon Peninsula, otherwise known as the Irish Loop of the Southern Shore (Figure 1.1). The initial settlement was founded in 1621 by Sir George Calvert. Since then, the settlement has survived various incursions such as the French in 1696 (Guiry et al., 2012; Hodgetts, 2006; Horne and Tuck, 1996). The Beothuk were also known to have frequented the settlement around 1621 (Pope, 1993). The settlement was incorporated as a municipal authority in 1971 (Municipalities Newfoundland and Labrador). In 2011, the town had a population of 465 with a municipal boundary encompassing 13.65 km^2 (Newfoundland and Labrador Statistics, 2011).

Prior to the collapse of the fishery in the early 1990s, the town thrived on a marine resource-based economy. Since then, the town has focused on sustainable development in the tourism-based economy, emphasizing natural and heritage resources such as landscapes, seascapes, Irish culture, and the Colony of Avalon archaeology site (Town of Ferryland, 2012).

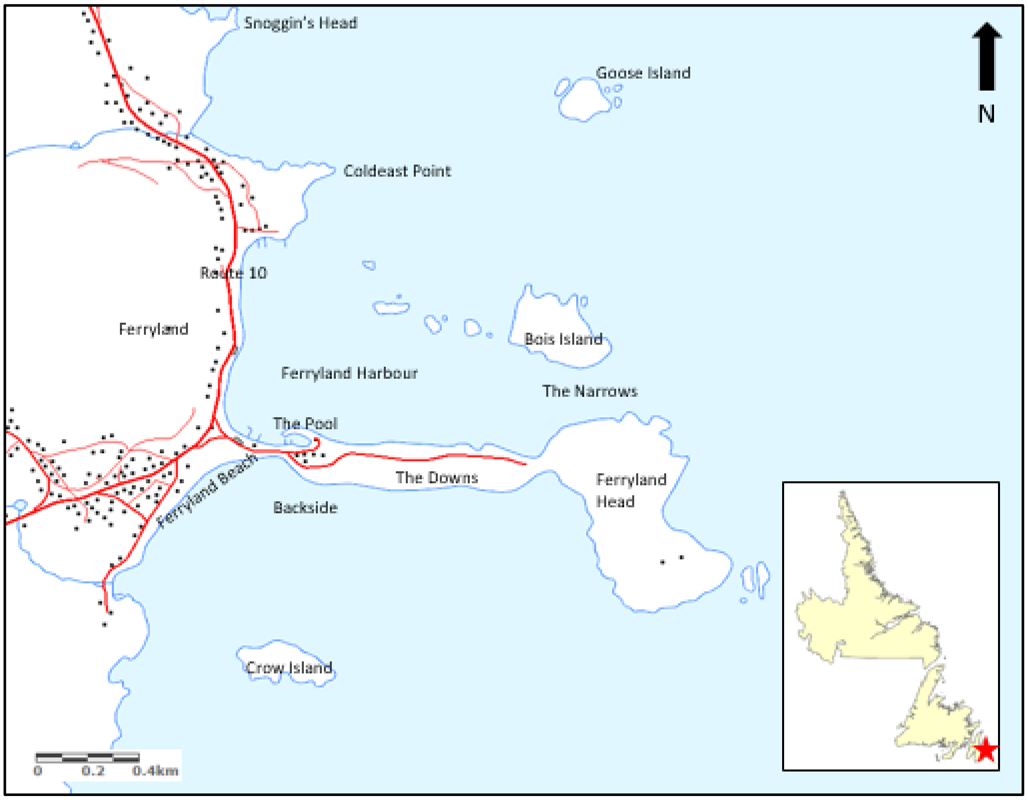


Figure 1.1. Town of Ferryland showing embayments to the north and south (Base map from ESRI ArcMap).

The main revenue generators for the Town are related to tourism; fish harvesting; small business; school (K-12); government services; and local taxes paid by residents with out-of-town employment. Tourism is the most significant in-town economic driver, with the main attractions being the Colony of Avalon, Southern Shore Folk Arts Council, and Ferryland Lighthouse Picnics. The Pool remains an important Small Craft Harbour in the category of Core Fishing, managed by the Harbour Authority of Ferryland (Fisheries and Oceans Canada, 2015). The main small businesses are Newfoundland Meat Packaging Co., small quarry operators, a grocery store, arts and crafts shops, and small convenience stores and restaurants. The main government services available are an RCMP detachment, Fisheries and Oceans field office, Canada Post Office, and a medical clinic. Much of the full time employment is out-of-town in the health care, oil and gas, commercial, industrial, government, and other fields.

This exposed coastal Town is accessible via Provincial Route 10. Route 10 runs through the town and is the only connecting roadway between the north (Northeast Avalon) and the south (Portugal Cove South). The section of Route 10 running through the community is a busy roadway. Although specific information on highway usage could not be found, occasional vehicle counts indicate that an average of approximately >800 vehicles/day (from compact cars to transport trucks) use this roadway, with significantly higher numbers on clear warm summer days due to tourist activity.

1.3.1 General Climate

Kottek et al. (2006) classify this area as a Dfc climate (snowy winters, fully humid with cool summer and cold winter) in the Köppen-Geiger climate classification system. According to Climate-Data.org (Climate-Data.org) the average annual temperature for Ferryland is 4.7 °C with an average annual rainfall of 1479mm. The prevailing winds range from gentle to hurricane force from the southwest with occasional potent storms generating hurricane force winds generally from the northeast - southeast. The nearest active weather monitoring site is at Cape Race, where Windfinder (2014) indicates that the dominant wind direction in January and February is West-Northwest, March to June is Northeast, July to September is Southwest, October is Northeast, and November and December is West, with the dominant yearly average as Northeast. Wind is subject to local topography causing funneling (South to Southwest), down-sloping (West to Northwest) and various areas of turbulence and buffeting (all directions). More detailed climate-related information is found in work by Hodgetts (2006), Catto (2006), and Wright (2004).

Prior to this study, Ferryland did not have a weather monitoring station for weather monitoring, forecasting, or climatological study. Forecasting and climatological information for areas such as Ferryland requires highly skilled meteorologists and sophisticated weather and climate modeling software. Statistical methods can be used to give a very general estimate of the climate (e.g. Government of Newfoundland and Labrador-Environment Canada, 1996). The nearest maintained weather monitoring stations to Ferryland are St. John's International Airport (YYT) and Cape Race, approximately 68 kilometres north and 42 kilometres south respectively. The St. John's Airport weather station is approximately 6 km inland from the closest shoreline at Torbay, and therefore is not suitable for measuring coastal weather conditions. Cape Race is located on the southern extent of the Avalon where weather conditions reflect more influence due to the southern exposure, including the Gulf Stream.

The community is open to oceanic weather and climate from the northeast to the southeast with moderate protection provided by a shallow sill, small nearshore islands, and Ferryland Head (tombolo). This exposure results in moderate to high impact of storm generated waves and storm surge from frequent strong low pressure systems and mid latitude cyclones of various intensities (Catto, 2006). Catto (2006) describes a storm surge that impacted the Southern Shore in 1966 causing more than $1 million (more than $5.5 million equivalent in 2014) in damages. The impacted area included Ferryland, although the most severe damage was recorded at other localities, including LaManche, Mobile, Bay Bulls, and Petty Harbour. At Mobile, approximately 23 km north of Ferryland, Catto

(2006) found that a bayhead bar was influenced by 15 hurricanes and strong winter storms, and 9 significant fall storms from 1989-2005. Many of the same storms impacted the Ferryland system. Storm surge and large waves washed out the connection to the lighthouse (tombolo) from the mainland in 2004 and 2009, with minor damage occurring in Fall 2009 (Batterson and Liverman, 2010). Other named storms (NOAA Historical Hurricane Tracks) that have also influenced the Ferryland system are: Florence in September 2006; Isaac in October 2006; Chantal in August 2007; Bill in August 2009; Igor in September 2010; Maria in September 2011; Leslie in September 2012; and Gonzalo in October 2014. Residents have recounted numerous instances of beach erosion and slope changes (mass movement), washouts on the tombolo, general sediment deposition and erosion, cliff undercutting, and damage or loss of property from, for the most part, undocumented large storms, swell and surge activity.

The last named storm prior to this study to make significant impact on the Backside System (south of the tombolo) was Hurricane Leslie that made landfall on the Burin Peninsula on September 11, 2012 as a strong extratropical storm. The southerly winds from this storm caused large waves and swell that changed the shape of the lower storm berm on Ferryland Beach, but also overwashed the breakwater, causing washout on the north side of the road surface and transportation of clasts (mostly sand, pebbles and cobbles) onto the road surface (Mayor R. Paul, Pers. Comm., June 13, 2013). The same storm uprooted large trees and stripped other trees of their foliage (Dr. P. Morry, Pers. Comm., April 4, 2013).

The weather along the coast of the eastern Avalon is variable and difficult to forecast due to variable local winds caused by numerous embayments, steep and long valleys, and numerous high elevation headlands. This is seen in the delineation of forecast regions and sub-regions issued by Environment Canada and described in the Guide to Environment Canada's Public Forecasts (Environment Canada, 2014). These regions and sub-regions are delineated loosely based on municipal boundaries but more closely depend on local factors (e.g. terrain, climate, type of land class, etc.)(Environment Canada, 2014). The coastal and inland area is divided into two main regions: the St. John's and Vicinity Forecast Region, and the Southeastern Avalon Forecast Region 0212. The St. John's and Vicinity Region is divided into two distinct Forecast Sub-Regions: St. John's and Vicinity – North of La Manche 021310 and St. John's and Vicinity – South of La Manche 021320 (Figure 1.2). Ferryland is located in Forecast Sub-Region 021320 of the St. John's and Vicinity Forecast Region and Cape Race is located in the Southeastern Avalon Forecast Region 0212, separate from the St. John's and Vicinity Forecast Region. The difference of weather conditions in these delineated areas can be easily observed during travel along the coast.

Figure 1.2. Forecast Regions and Sub-regions for the Avalon Peninsula (Environment Canada, 2013). Red star is the location of Ferryland. Prior to this study, weather and forecast could only be predicted from observations at St. John's and Cape Race.

This study included the installation of a permanent weather monitoring station to assist with water level and wave analysis. It will help reduce the challenges of both climatological research and forecasting by providing high quality weather data, and will reduce the many assumptions involved in the use of climate and forecast models locally.

1.3.2 Ecoregion

Ferryland is in the southern extent of the Southeastern Barrens Subregion of the Maritimes Barrens Ecoregion (Damman, 1983), defined by cool summers with frequent fog and moderate winters. This subregion consists of small pockets of forest separated by dominant heathlands of *Empetrum nigrum* (crowberry) and *Kalmia angustifolia* (bog laurel). *Abies balsamifera* (Balsam Fir) and *Picea nigrum* (Black Spruce) are the most common tree species with occasional *Betula spp.* (Birch) species. Heathlands dominate with exposed bedrock and heavily compacted till and erratic. Limited forest stands occur mostly in small pockets in valleys (Meades and Moores, 1994). The forested areas along the shoreline consists of tree and shrub species which experience various levels of suppression due to high wind and salt spray. This, coupled with past land-use practices (e.g. land clearing), has resulted in many open areas where various species of herbs and moss prevail.

1.3.3 Barrier to Cliff Flora and Fauna

A vegetation survey was not completed in this study, but some common species were noted. According to Catto et al. (2003), various species of vegetation establish on barrier systems depending on the substrate, stability of the system, and exposure. Barrier face (including upper storm berms) contained *Lathyrus japonicas Willd.* (Beach pea), *Iris* *setosa Pall.* (Beach-head Flag), *Cakile edentula (Bigel.) Hook* (Sea Rocket), and various other unidentified species. Transported marine organics (kelp, rockweed and other unknown species) were also noted on several segments of barrier and backshore areas. Various rooted species were noted on storm berms and on backing barrier slopes into the back barrier. These included: *Euthamia galetorum* (Golden Rod), Trifolium *pretense* (Red clover), *Centaurea nigra L.* (Black knapweed), *Vicia cracca* (Cow vetch), *Tussilago farfara* (Coltsfoot), *Cirsium spp.* (Thistle), and *Anaphalis margaritacea (L.) Clarke* (Pearly Everlasting).

Where till and rock cliffs form the back of the barrier or the upper part of the rocky shoreline, *Empetrum nigrum* (Black Crowberry), *Harrimanella hypnoides* (Moss heather), *Ledum groenlandicum* (Labrador tea), *Juniperus communis* (Common juniper), *Juniperus horizontalis* (Trailing juniper), *Taxus Canadensis* (Canada yew), *Kalmia angustifolia (Sheep laurel), Picea nigrum* (Black spruce), *Abies balsamferia* (Balsam fir), various grasses and herbs, and other vegetation make up the assemblage. Various Lichens partially cover many exposed rocks.

The area is frequented by various terrestrial, marine, and avian species. Some common terrestrial species include: *Alces alces* (Moose); *Vulpes vulpes* (Red Fox), and *Lepus americanus* (Snowshoe hare). There have been rare sightings of *Ursus americanus* (American Black Bear), *Rangifer tarandus* (Caribou) and *Canis latrans* (Eastern Coyote). Marine species include *Phoca greenlandica* (Harp Seal), *Lontra Canadensis* (Northern River Otter), and *Phocoena phocoena* (Harbour Porpoise). Common whale species include *Balaenoptera physalus* (Fin Whale); *Balaenoptera Spp.* (Minke Whale); and *Megaptera novaeangliae* (Humpback Whale) (Piatt et al., 1989). There have also been rare occurrences of *Balaena mysticetus* (Bowhead Whale) in the area (Ledwell et al., 2007). Fish harvesters have also occasionally observed *Orcinus orca* (Killer Whale) in the general area. Various shark species have been seen by fish harvesters, including *Prionace glauca* (Blue shark), Cetorhinus maximus (Basking shark), and *Isurus oxyrinchus* (Short-fin Mako Shark). Avian species include various species of the *Laridae* Family (Herring Gull, Great Black-backed Gull), *Fraercula artica* (Atlantic Puffin), *Haliaeetus leucocephalus* (Bald Eagle), *Pandion haliaetus* (Osprey), various species of *Anas spp.* (e.g. Black duck and Mallard), *Aythya spp.* (e.g. Greater Scaup), and others. Notable shorebirds include *Tringa melanoleuca* (Greater Yellowlegs), *Actitus macullaria* (Spotted Sandpiper), and *Charadrius semipalmatus* (Semipalmated Plover).

1.3.4 Topography

The topography of the area is complex with high cliffs, valleys, headlands, tombolo, islands, and other features including inlets and embayments (Figure 1.3). The upland areas are undulating (Meades and Moores, 1994) and hummocky.

Coldeast Point consists of a fairly flat area with shallow wetland pockets. The area from here following Route 10 south to the tombolo forms the base of a cliff complex of three adjoining heads known as Fox Hill, Forge Hill, and Judges Hill. The area to the south (Freshwater) slopes to the bottom of Quarry River Valley (The Valley). The tombolo joins The Downs and Ferryland Head to the mainland at the base of Judges Hill. Six main islands and numerous rocks are located in the nearshore. Quarry River flows into a small cove in Freshwater (locally known as Meade’s Cove) at the south of the study area and Freshwater River flows into Freshwater Cove north of the study area.

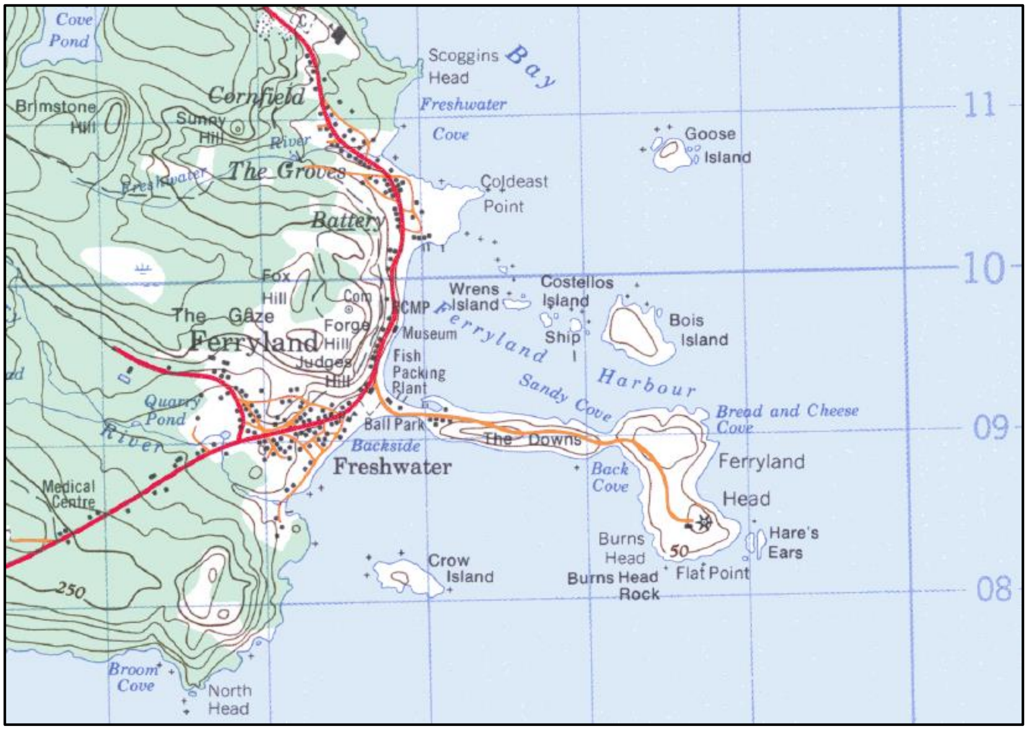


Figure 1.3. Topography of the Study Area (Department of Energy, Mines, and Resources Canada, 1984.). Grid lines are 1000 m apart.

1.3.5 Bedrock Geology

The study area consists of sedimentary bedrock units with steep bedding planes, numerous fractured and jointed surfaces, and undulating terrain consisting of steep outcrops, cliffs, and numerous geomorphic features. Figure 1.4 shows the bedrock geology and Table 1.1 provides descriptions for Groups and Formations. Formations were assessed throughout the study area for strike and dip in April 2014. Twenty measurements revealed a range of strike from 356° to 022° and dip from 58° to 74°. This positions the bedding planes nearly at 90° (shore normal) to the easterly swell and wave direction.

The bedrock consists of Late Proterozoic siliciclastic sediments of the Avalon Zone. According to King (1988), the St. John's Group and the Signal Hill Group are represented, with the oldest units to the west. The western area is underlain by the Trepassey, Fermeuse, and Renews Head Formations of the St. John's Group. To the east of the Renews Head Formation is the Signal Hill Group, represented by the Cappahayden, Gibbett Hill, and Ferryland Head Formations. More detailed stratigraphy is available in O'Brien and King (2005), and further formation details can be found on Geoscience Online (Geoscience Online).

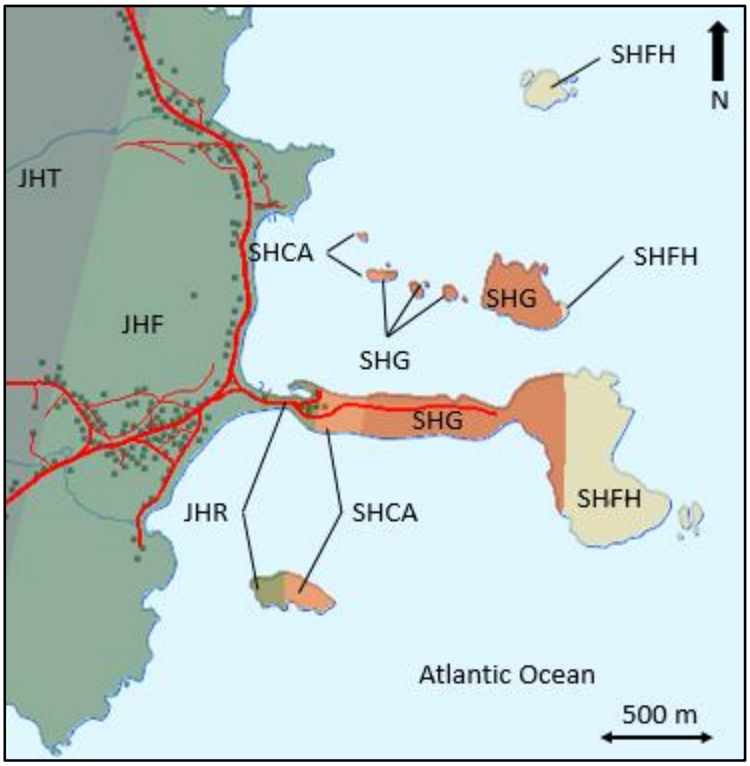


Figure 1.4. Bedrock Geology. Adapted from GeoScience Online-Geoscience Atlas. Refer to Table 1 for interpretation.

Table 1.1. Bedrock Formations of the Ferryland Study Area (Interpreted from GeoScience Online).

Label	Zone	Group	Formation	Type	Age
SHFH	Avalon	Signal Hill	Ferryland Head	Sedimentary Marine	~ 542 Ma
SHG	Avalon	Signal Hill	Gibbett Hill	Sandstone	↑
SHCA	Avalon	Signal Hill	Cappahayden	Siltstone	↑
JHR	Avalon	St. John's	Renews Head	Sedimentary Marine	↑
JHF	Avalon	St. John's	Fermeuse	Sedimentary Marine	↑
JHT	Avalon	St. John's	Trepassey	Sedimentary Marine	~ 575 Ma

The three formations of the St. John's Group represented from oldest to youngest are the: Trepassey Formation consisting of dark siliciclastic marine siltstone and argillite; Fermeuse Formation, consisting of gray to black shales and argillites with layers of sandstone; and Renews Head Formation, consisting of thin, lenticular bedded, dark-grey sandstone, argillite, and lesser shale. Argillites, shales, and siltstones are prone to fracturing and may be exposed to erosion through freeze-thaw cycles and large waves, common in this area. The Signal Hill Group to the east from oldest to youngest includes the Cappahayden Formation, consisting of thinly laminated gray siltstone and argillite; Gibbett Hill Formation, consisting of light gray sandstone with local thin beds of greenish-gray and red sandstone, argillite, tuff and conglomerate; and Ferryland Head Formation, consisting of gray sandstone and minor conglomerate (Geoscience online). In general, the units of the Signal Hill Group are more resistant to erosion than are the argillite-dominated units of the St. John's Group.

1.3.6 Quaternary Landforms and Sediments

The study area was covered by glacial ice that flowed eastward from Franks Pond Ice Centre as indicated by landforms such as rôche moutonnées, flyggbergs, and flutings (Catto and Taylor 1998), striations, and igneous clasts in diamictons throughout the area (Catto, 1998; Figure 1.5, Table 1.2). Glacial meltwater scouring and erosional features are present at the southern point of Freshwater and on the eastern edge of The Gaze. Deglaciation in this area occurred at some time prior to 9700 BP (c.f. Macpherson, 1982).

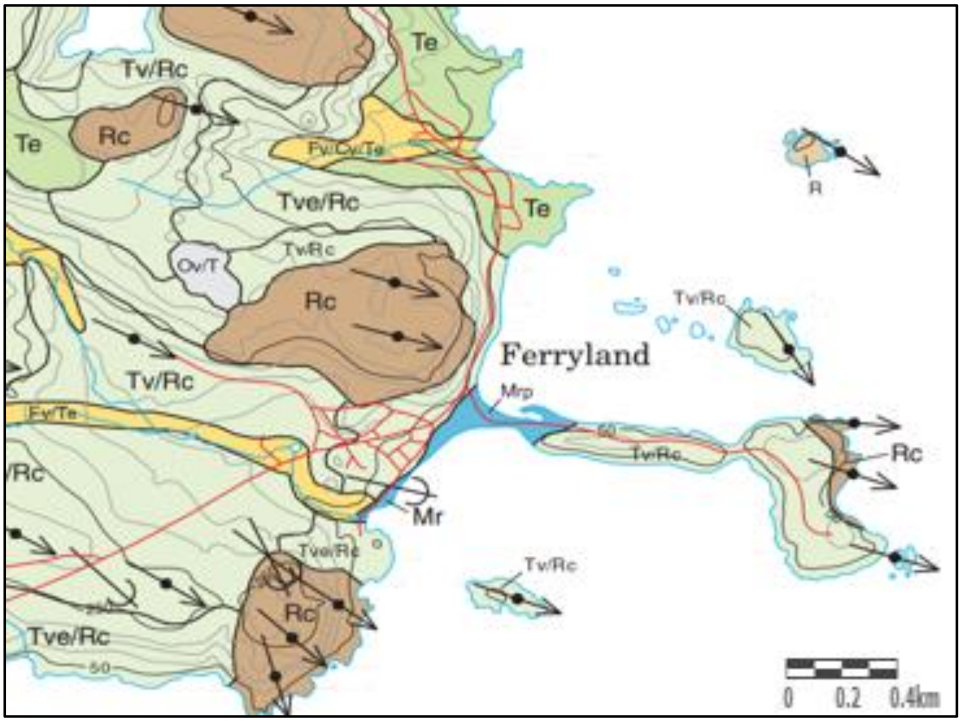


Figure 1.5. Surficial Geology and Landforms of the Ferryland Study Area (Catto and Taylor, 1998).

Table 1.2. Surficial Geology and Landforms of the Ferryland Study Area. Adapted from Catto and Taylor (1998).

Label	Description
Cv	Colluvial veneer
Fv	Fluvial veneer
Mr	Marine ridge
Mrp	Marine ridge plain
Ov	Organic veneer
Rc	Rock concealed by vegetation
R	Rock
T	Glacial
Te	Glacial eroded and dissected
Tve	Till veneer
	Rôche Moutonnée
	Striation (direction known, unknown)

Quaternary sediments are shown in Figure 1.5. Catto and Taylor (1998) describe the surficial material at Coldeast Point as eroded and dissected glacial till, along the west shoreline of Ferryland Harbour as concealed bedrock and shallow glacial veneer, the tombolo and Backside barrier as marine ridge sediments, and a narrow band of fluvial veneer is present at the stream terminus in Freshwater. The Downs and The Narrows are described as glacial veneer with the eastern exposure of Ferryland Head shown as concealed bedrock. All Quaternary deposits are thin, with maximum sediment accumulations only exceeding 3 m in valley bottoms and along some segments of coastline.

The barriers of this zone are formed from various geological formations and range in morphology partially depending on source material, wave energy, and near-shore gradient (Fairbridge, 2004). Beach-face morphodynamics of gravel barrier systems depend on the interplay of grain size, hydro-hydraulics and morphology (Buscombe and Masselink, 2006). This is related to the internal structure and stratigraphy of the barrier (Bluck, 1998). Classification and structure of barrier systems are described in detail in Carter and Orford (1984) and Jennings and Shulmeister (2002). Various controls determining type of barrier structure is discussed in Orford et al. (2002) and Forbes et al. (1995). The geomorphology and sedimentology of Ferryland Beach has previously been described by Wright (2004) and Catto (2012). Catto (2012) provides geomorphological descriptions and classifications of Ferryland Beach North (in Ferryland Harbour), Ferryland Head, Ferryland, and Ferryland South barriers.

1.3.7 Sea Level

Sea level changes occur due to many factors including changes in ocean mass, ocean volume, viscoelastic land movements and changes in terrestrial water balances (Cronin, 2012). Globally, anthropogenic activity is mostly responsible for a global sea level rise trend of 3 mm/y with local differences along specific shorelines (Abraham et al., 2013). Shaw et al. (2002) show that the sea level during the last 13 ka in Atlantic Canada has changed substantially due to glacial-isostatic adjustment (GIA) along with other factors that are not uniform across the region. Catto (2012) suggests that glacial-isostatic adjustment is one contributing factor to sea level rise along with glacial melt.

Long-term measurement of sea level requires a data set or record of long-term measurements (>40 years). Sea level change rates in the province have been measured using radiocarbon dating of tree stumps found below mean sea level (Catto, 2006), measurements of saltmarshes (Brookes et al., 1985; Daly et al., 2007) and tide gauges (Batterson and Liverman, 2010; Catto, 2012). These measurements lead to sea level change rates based on the change in a region or local area considering many factors. Catto (2006) suggested that sea level may have been as much as ~3m lower than present at Ferryland in 1621, and Batterson and Liverman (2010) suggest that along the coastlines of the Avalon Peninsula, sea-level is projected to rise approximately 100 cm by the year 2099.

Short term changes in sea level are caused by different factors than those influencing long-term changes, and result in noticeable shoreline impacts. Barometric air pressure changes (high or low pressure), wind forcing (e.g. wind speed, duration, direction, fetch, etc.), surge and storm surge (e.g. speed and direction of low pressure movement), and other factors impact the magnitude and duration of impacts. The impacts from large waves, surge and storm surge are easily seen in local geomorphology (e.g. barrier retreat and related transgression) and are remembered by many residents (e.g. causing flooding, erosion, etc.).

Generally, the sea level on the eastern coast of the Avalon Peninsula is rising at a rate of ~3 mm/y (Catto, 2006). In a more recent study along the eastern Avalon Peninsula, Catto (2012) states that the rate of sea-level rise since ca. 1960, estimated from tide gauge data at St. John's, is 3.3 mm/y. The effects of sea level rise are evident at the Colony of Avalon Archaeological Site (Catto et al., 2003). Sea level at Ferryland has not been documented with onsite in-situ instrumentation such as a tide gauge. For the first time, this study measured sea water level in Ferryland to assess any short-term factors such as tide, surge and others, and to provide a dataset for the future prediction of sea level rise.

1.3.8 Bathymetry

A description of Bathymetry is essential when assessing water level changes and erosion. Figure 1.6 shows the bathymetry in the Ferryland study area.

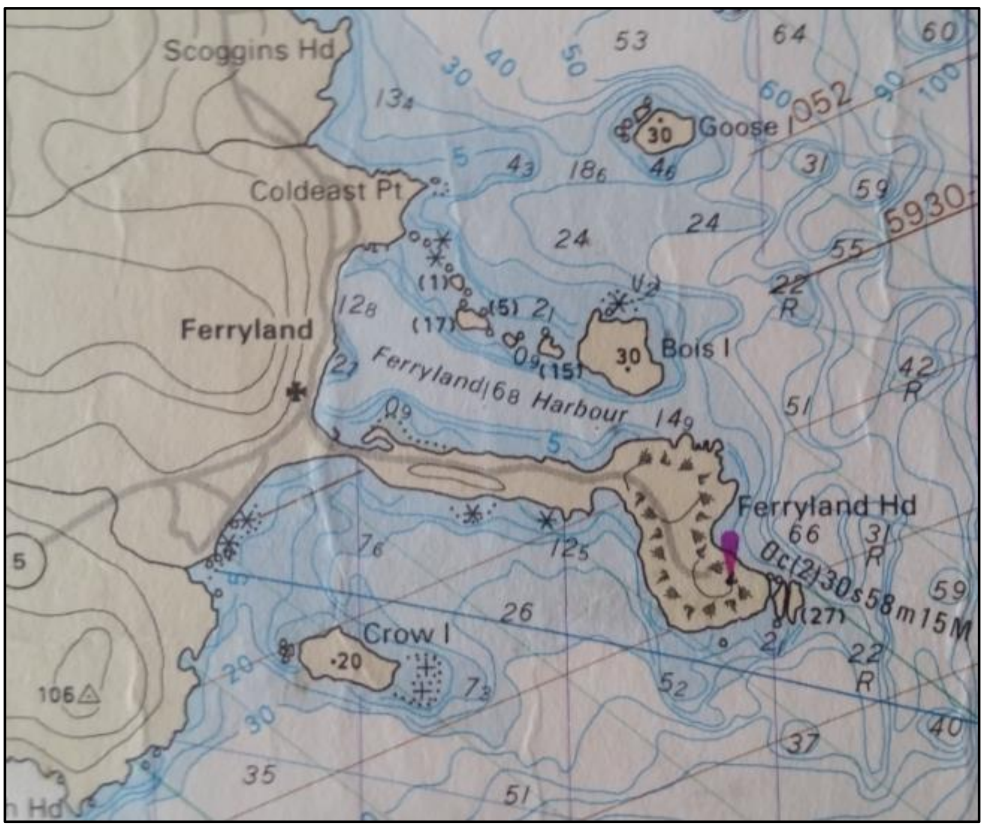


Figure 1.6. Bathymetry of the study area (Canadian Hydrographic Service-Fisheries and Oceans Canada, 1997). Ridges are in the paper chart.

The coastal areas are partially protected from oceanic conditions by a bedrock sill with scattered outcrops, islands, Ferryland Head, and numerous other shoals. North of the system is Goose Island and a small area of shoals and rocks. Coldeast Point is exposed to deep water wave approach from the east through shallowing waters between Goose Island and Bois Island that extend to the point. Here, high waves and surge are eroding a thin layer (< 2 m) of glacial diamicton from the surface of the steeply dipping Fermeuse Formation. The rock platform to the East-Northeast extends more than 100 metres off the shoreline, dropping into deeper waters towards Goose Island.

A bedrock sill extends from the southern point of Coldeast Point to Bois Island. This sill is clearly visible as jagged sedimentary units exposed at neap low tide. From west to east, there are four main islands: Wrens Island, Costellos Island, Ship Island, and Bois Island. This sill and associated islands provide moderate protection from storm-related waves and swell from the north to the east, but does not provide protection from surge events. According to local knowledge and personal experience, only two passages in this area are navigable at low to mid tide.

The open water between Bois Island and Ferryland Head is known as The Narrows and is the only deep water access to Ferryland Harbour controlling draught. Currents in this area can have high velocity during normal spring tides or storm surge interaction with the sill. No known shoals or rocks are present in this area except in proximity to the sill and islands. Deep water waves may also approach Ferryland Harbour through the Narrows.

The Backside (Backside System) is located on the south side of Ferryland Head. The bathymetry is deep (~30 m) from Ferryland Head to Crow Island. This provides access for deep water waves that break close to or on the southern shoreline of The Downs. The bathymetry shoals between Crow Island and the tombolo and drops towards the west, then rises sharply to the shoreline of Ferryland Beach. The shoal is well known locally and is occasionally expressed by breaking waves on a feature known as Mad Rocks during low water.

1.3.9 Tide, Storm Surges, Wave Climate, and Currents

The tidal range at Ferryland is microtidal (Hayes, 1967) semidiurnal with a measured general range between 0.2m – 1.5m (measured in The Pool under the influence of harbour oscillations). The shallow bathymetry around the numerous islands, shoals, and Ferryland Head results in very strong localized currents during tide changes and surge conditions (F. Clowe, Personal Communication, May 12, 2014). Storm surge at all ranges of tide is accentuated in Ferryland Harbour and especially in The Pool where low tide is lower and high tide is higher than predicted.

The wave climate ranges from calm conditions to very large long period swell and wind waves which have been observed breaking over the flanks of Goose Island. The wave period was observed at generally 5 – 15 seconds with various amplitudes. Most large swell and waves are reduced in amplitude by the shallow bathymetry. However, there are instances where large amplitude waves (>4 m) have reached the coastline resulting in considerable damage (e.g. destruction of breakwater in 2009). Although wind-generated waves and swell may move in the same direction, they are mutually exclusive (e.g. NE swell resulting in breaking waves onshore during SW winds blowing offshore). Complex bathymetry and landforms also serve to reflect, refract and alter approaching swell and waves resulting in a very complex and unpredictable wave pattern in The Backside and Ferryland Harbour systems.

Local currents around the islands, tombolo and especially at The Pool are complex (J. Barnable, Dr. P. Morry, Mayor R. Paul, L. Kavanagh, Pers. Comm., Various dates 2013-14). One possible driving mechanism for the local currents is the Labrador Current (LC). The LC is divided into an inner current that flows along the southeastern Labrador Shelf and Eastern Newfoundland and another current flowing in deeper water offshore with 10% and 90% of the flow respectively (Lazier and Wright, 1993; Hetzinger et al., 2013). Measurements for these currents were taken offshore at the Flemish Pass (e.g. Greenberg and Petrie, 1998) and at Station 27 Oceanographic Monitoring Station approximately 7 km east of St. Johns (Colbourne and Fitzpatrick, 1994). The offshore component and, to a lesser extent, the inshore component shows a barotrophic variability with the North Atlantic Oscillation (NAO) (Han et al., 2010). However, it is not clear how this impacts waves, currents, and surge at Ferryland. Catto et al. (2003) provide a more detailed description of the interaction of the NAO with the coastal systems in eastern Newfoundland.

1.3.10 Anthropogenic Influences

Anthropogenic influences on the coastal system have been occurring since settlement in 1621. The early settlers likely had relatively little impact on the coastal features as compared to industrial and commercial ventures of the 19th and 20th centuries (e.g. heavy equipment, dredging, heavily fortified coastal armoring, etc.). Historical photographs retained by residents show fish flakes and stages supported by round stakes that had moderate effects on sediment transport, and certainly did not prevent barrier or shore erosion from large waves. Some examples from local accounts are: road building and multiple repairs on the tombolo, railway access, barrier quarrying, and shoreline excavations for infrastructure (e.g. fish plant, stages, etc.). Other coastal system disturbances such as armoring (e.g. breakwaters, armor stone, and retaining walls) and infills for laydown areas have had a lasting impact on sediment budgets and overall erosion of the coastline. These structures alter sediment budgets under normal tidal conditions and light sea state, and may result in significant alteration to sediment budgets under surge conditions coupled with large waves and swell, as reported by residents.

Previous events and existing conditions involving relative sea level rise and coastal erosion help predict future events. Coastal mitigation measures at community-level can cost in excess of $3 million (Liverman et al., 2003). Smaller communities such as Ferryland have limited funding for coastal assessment and mitigation, resulting in most of the work being ad hoc without needed mitigation assessment, project management, or documentation. This is obvious with shoreline fragmentation and differential erosion (e.g. at Freshwater). In an interview with Ferryland Mayor Roddy Paul on January 31, 2014, he described many occasions when the Town's staff had to repair road damage and washouts due to waves overwashing the breakwater on the tombolo. One such occurrence lasted over the three days of December 12- 14, 2013. Mayor Paul and Town staff repaired damages to the road surface with no external funding. These types of repairs are not documented, resulting in loss of information for a cost-benefit analysis. The Town of Ferryland does not have documentation on mitigation work completed in the community (Mayor R. Paul, Pers. Comm., June 12, 2014). The Department of Transportation and Works (G. Spencer, Pers. Comm., Various Dates) also have no documentation for shoulder or slope stabilization works completed on Route 10 adjacent to Ferryland Harbour. The town planner for Ferryland also had no information regarding mitigation works or erosion impacts (M. Bishop, Pers. Comm., April 7, 2015).

Coastal erosion and mitigation is evident on most sections of shoreline. Mitigation measures of various states of repair exist throughout, including retaining walls, cribbing, breakwater, sea wall, gabion, and armor stone. Residents have taken some measures to protect their properties (e.g. armoring at Coldeast Point). A sea wall/breakwater constructed in the barrier crest provides protection of private property midway along Ferryland Beach. A deteriorating seawall/breakwater provides some protection to a cluster of storage sheds near the southern extent of Ferryland Beach. Further south, a section of armor stone serves to protect a section of low elevation roadway and private property in Freshwater. Cribbing, gabions, breakwaters, and boulders serve to partially protect the roadway in lower Meade's Cove and the East Coast Trail.

1.4 Tourism Sites and Activity

Tourism is a major source of revenue for the Town of Ferryland and local business. In many areas of rural Newfoundland and Labrador, the decline of the fishery throughout the 1980s and subsequent cod moratorium in 1992 has seen a shift to tourism for economic benefits (Catto, 2002). Sullivan and Mitchell (2012) found that the heritage-scape of Ferryland is motivated by preservation and economic development through a collaboration with the civic and public sectors made possible by local support with minimal conflict.

The picturesque landscapes and seascapes, icebergs, marine wildlife, culture and heritage are key aspects of tourism development at Ferryland. The Colony of Avalon

Archaeological Site was first studied in 1992 (Tulk, 1993; Overton, 2007) and is currently a very active archaeological site. The Southern Shore Folk Arts Council hosts various events based on culture and heritage including the Annual Shamrock Festival and the Southern Shore Dinner Theatre. The Ferryland Lighthouse Picnics is located on Ferryland Head in a lighthouse that was built in 1870. This operation provides an opportunity to walk along Ferryland Head to experience the picturesque coastal features and sea life. The East Coast Trail runs through the community and offers unique vistas to enjoy the coastal features and the tourism sites. There are also various restaurants, bed and breakfasts, and other lodgings that benefit from general tourism.

Tourism attractions and sites depend on the natural beauty of the area but are also vulnerable to the impacts of storms, surge, large waves and other impacts which could be detrimental to tourism-related activities (sight-seeing, hiking, power boating, kayaking, and surfing). Observations during many site visits reveal that the tourism numbers are much lower during inclement weather conditions and storm events. However, surfers frequent the area when large waves are breaking on Coldeast Point or Ferryland Beach.

The biophysical tourism impact is overlain on a diverse and complex set of historic small-scale anthropogenic impacts such as barrier mining, mitigation (e.g. infills, retaining walls, armoring, etc.), vegetation clearance and grazing that have caused bluff failures, and many other impacts (Catto and Catto, 2012). These historic impacts are not homogeneous to an area or barrier segment, are difficult to assess, and are not explicitly investigated in this study. The impacts of erosion on tourism activity are unclear due to a lack of qualitative and quantitative research, and lack of documentation.

Tourism brings an interesting trade off of benefits and negative impacts. The benefits may include positive socioeconomic elements such as an increasing employment rate, positive community building, and increase in total revenue that may translate into upgrades in infrastructure and other enhancements. The negative impacts may include environmental degradation and sociocultural impacts such as a change in the sense-of-place or cultural conflict related to changes in a way of life and physical heritage elements.

1.5 Thesis Layout

The thesis is organized into seven chapters with this being Chapter 1 Introduction and Overview. Chapter 2 presents related research on measuring coastal processes, water level and oscillations, and tourism. Chapter 3 describes the methods used to collect baseline data, and describe and interpret coastal processes. Chapter 4 and Chapter 5 presents quantitative and qualitative results on the Ferryland Harbour System and the Backside System respectively. Chapter 6 presents baseline data on tourism activity and highlights system areas impacted or having the potential of being impacted by erosion. The conclusions and recommendations for further action are presented in Chapter 7.

Chapter 2 – Related Research

This is an interdisciplinary study of select coastal processes and coastal erosion that impact tourism-related sites and access routes. The term “tourism” will be used in its general meaning, but also to include archaeotourism and geotourism. Selected studies elsewhere have emphasized the major techniques used in this study, including surveying, tidal data, meteorological information, and photograph interpretation.

2.1 Measuring Coastal Processes

The measurement and assessment of coastal processes involves oceanography, geology, climatology, meteorology, hydrology, geomorphology, and geomatics. In addition, an array of specialized or custom-made equipment is needed to assess the various environmental parameters and anthropogenic influences. This has to be coupled with the ability to deploy, operate, analyze, and report the data.

An understanding of local weather is essential to assist in interpretation regarding storm surge (wind and barometric air pressure), wave action (wind speed and direction), slope movements and flooding (rainfall), freeze-thaw cycles (temperature), and calculating water levels (barometric pressure). Mullarney and Henderson (2013) used wind speed and direction measurements to calculate wind-generated near-surface water current shear. Morton (2002) suggests that near real-time forecasting of storm events is possible if, as a part of a greater set of monitoring, meteorological parameters are being monitored. Barometric pressure collected at weather stations in combination with tide gauge data were also used to investigate sea surge occurrences in the Gulf of Lions (Ullmann and Moron, 2007). Catto et al. (2006) also used data from a weather station to help explain water level changes in Port-aux-Basques Harbour and ferry terminal.

An understanding of water currents and basic sediment transport is necessary to assess erosion and deposition areas, the sediment budget of the system. The measurement of water currents and sediment transport is equipment and time intensive. Longshore currents have been estimated from the use of offshore wave rider buoys (Kumar et al., 2000) and directly measured using specialized devices in the surf zone (Rogers and Ravens, 2008). Shallow water (< 3m) currents can be measured using custom-made drifter buoys and an acoustic doppler current profiler (Mullarney and Henderson, 2013). Current flow depth has been measured using water level dataloggers (Rinehimer et al., 2012). Tracer tests using local clasts or specialized devices on or near barriers have also revealed longshore currents and shore-parallel swash transport induced by oblique waves (e.g. Miller et al., 2013; Bertoni et al., 2013).

Tides and instantaneous water level measurements are essential to identify the vertical extent and inundation of erosion and impacts. The measurement of tidal water level should be continuous with very limited data gaps to avoid misinterpretation or extrapolation due to insufficient data (e.g. Catto et al., 2006). Although originally designed for deployment in groundwater monitoring wells, the Onset HOBO dataloggers (Onset Computer Corporation, 2015) and similar devices (e.g. Solinst Levelogger and barologger) have been successfully used to measure water level changes in salt marshes (Hering et al., 2010; Colón-Rivera et al., 2012), estuaries (Shapiro et al., 2010), lakes (Johnson, 2012), other coastal areas (Filgueira et al., 2014), as well as wave dynamics and runup characteristics (Cariolet and Suanez, 2013). Other types of standard tide gauge systems have been used to predict surge events and conduct hind-casting along the coast of the Northwest Atlantic (Bernier et al., 2007).

Barrier assessments are necessary to establish baseline morphology and sedimentology of barriers, but also to measure erosion impacts and to monitor future impacts. The processes involved in the morphodynamics and sedimentology of barriers are complex and are usually studied as individual or small groupings of processes such as: sediment transport (Austin and Masselink, 2006); influences on clast organization (Coco and Murray, 2007), bed forms and structure (Bluck, 1998), cusp formation (Masselink et al., 2004; Pruszak et al., 2007; Dodd et al., 2008), beach ridges (Otvos, 2000); typologies and processes (Orford et al., 2002); tidal range influence (Masselink and Short, 1993; Bluck, 2011); and sea level influence (Orford et al., 2006; Catto, 2006; and many others). Barriers have been assessed for stability, as seen in work by Matias et al. (2012), who suggest that there are three main outcomes possible when wave runup meets or exceeds a barrier crest: no change due to loss of swash energy; overtopping when material is transported up the berm and deposited on top (berm building and barrier stabilization); and overwashing where the berm crest is eroded into the back slope of the berm or barrier (barrier retreat or backstepping). Changes still may occur in the swash zone due to accretion (e.g. Orford et al., 2002). Sea level rise, antecedent conditions and forcing mechanisms are the main driving factors that cause barrier retreat or backstepping via overwashing (Orford et al., 2006). The location and spacing of barrier profiles is critical in capturing volumetric changes. Theuerkauf and Rodriguez (2012) showed that the accuracy of volumetric change assessments decrease with an increase in along-beach geomorphic complexity. The size and type of wave interaction with the barrier face is also critical, as seen in a study by Cariolet and Suanez (2013) where the wave morphodynamics of runup (swash) was assessed for barrier face clast movement. The methods of assessment use the above mentioned processes to develop classification systems (Jennings and Shulmeister, 2002). Catto (2011) assembled data for 1,472 locations in Newfoundland to develop a classification for each shoreline segment including material, shoreline class, Coastal Erosion Index, Coastal Sensitivity Index, and Petroleum Vulnerability Index. This data set also includes four shoreline segments at Ferryland. The coastline of Eastern Newfoundland was also described in detail by Catto et al. (2003).

Coastal unconsolidated cliffs (bluffs) were assessed and monitored in this study. Bluffs in the mid to upper latitudes are subject to freeze-thaw related erosion, but are more prone to slope failure triggered by rainfall. Gatto (1995) describes the freezing, heaving, destabilization, erosion and redeposition of sediment particles on slopes. Once the clasts are heaved, they are more readily available for transport by gravity (due to loss of shear strength), rainfall (overland or downslope flow), and are susceptible to wind, currents and wave action. If the bluff is fronted with a barrier, the low barrier levels (elevation and width) are prone to higher recession rates, whereas higher barrier levels experience minimal recession (Lee, 2008). This can be expressed as a relationship between mass wasting (decrease in the slope of bluff) and wave attack where wasting material is removed (steepening of the bluff) with the basic threshold of barrier width presiding over barrier elevation (Shallenger Jr. et al., 2002). Spooner et al. (2013) report that a few fatalities have occurred in coastal sites in Newfoundland due to mass movements, mainly debris flows, rotational slumps, and rock falls. Increased bluff erosion due to an increase in intense rainfall events coupled with unpredictable freeze-thaw cycles may result in an increase in debris flow and rockfall. Some residents of Ferryland retell a story of a group of fish harvesters that were killed in the 1800s during a sea cave collapse at Deadman's Gulch on the north shore of Ferryland Head (Liverman et al., 2003). The current gulch is undergoing erosion via freeze-thaw cycles and rainfall. Rockfall is ongoing here as observed on several site visits.

The interrelationships between rocky cliffs, bluffs, mass wasting, and barriers can lead to erosion or progradation. Rock cliffs and rock shorelines serve to anchor barriers, supply sediment in the form of rock fragments, and support overlying or landward unconsolidated materials. Rock cliffs are susceptible to freeze-thaw cycles in most of the northern latitudes. Matsuoka and Sakai (1999) investigated rockfall from a cirque during a thaw cycle and found that maximum rockfall occurs approximately 10 days after meltout and is rarely associated with rainfall. Although the freeze-thaw cycle influences the size of the rock fragments, the joint spacing is the main control. More related to a coastal setting is a study by Lim et al. (2011) who found that there is a correlation or a slight time lag between when a micro-seismic wave from when a wave impacts a rock cliff to when loose rock blocks or fragments fall from the cliff face. Eroding rock cliffs are a sediment source to adjacent barriers.

Rock cliffs were not measured in this study due to proximity to tourism interests and complexity of measurement. However, a mention of techniques is useful for future studies. Rosser et al. (2005) used Terrestrial Laser Scanning (TLS) methods to assess the vertical cliff face in order to quantify cliff erosion. Other methods of measurement common for rock cliffs (e.g. LiDAR) are ineffective for cliff face measurement, as data acquisition from above measures only the position of the cliff edge and not undercutting or freeze-thaw cycle impacts on the face. LiDAR is more useful for measuring lower angle bluffs and slopes. Once an accurate assessment has been made on a cliff zone, then a risk assessment can be performed. Del Rio and Gracia (2009) developed a risk index based on 11 physical factors (including rainfall) and 6 socioeconomic factors, forming initial hazard and impact indexes to effectively categorize coastal cliffs. The consequences of not performing such an assessment may be significant for the identification and management of sediment supply, barrier stability and public safety.

The survey equipment for most coastal measurement has moved away from traditional emery poles, range poles and other labor- and human resource-intensive methods to Real Time Kinematic (RTK) DGPS surveying methods. Although other methods are also available (e.g. LiDAR, aerial photography, satellite imagery, etc.), RTK provides a cost-effective, efficient and very detailed (e.g. measuring by code tables) means to collect very high quality 3D data using one-person survey methods (Harley et al., 2011). RTK has been used to conduct numerous measurements including barrier measurements by walking and driving (Psuty and Silveria, 2011). Dail at al. (2000) used RTK surveying on the Waimea Bay barrier system to map and show a correlation between sand volume and wave energy flux. Lentz and Hapke (2011) used RTK and LiDAR to create high resolution topography model of the Fire Island shoreline to assess volumetric changes that may correlate with local geology. Collected RTK data were used in a geospatial mapping environment to reconstruct the paleo shoreline of a section of Virginia Beach, revealing a former location ~5 km to the east (Allen et al., 2012). RTK data in combination with geospatial software such as Geographic Information Systems (GIS) (e.g. ERSI ArcGIS Platforms) as seen in numerous studies by the United States Geological Survey (USGS)

Digital Shoreline Analysis (DSAS) (Thieler et al., 2009) and shown also in work by Brooks and Spencer (2010). While this technology is valuable, caution must be taken to ensure that the correct vertical datum is used to avoid producing misleading or erroneous results (Parker, 2003). Irvine (2012; 2013; 2014) has used RTK to establish and monitor profiles and transects on a long-term project to monitor barrier systems and slopes in Newfoundland and Labrador.

Photogrammetry and videography techniques are widely used for coastal research. Most studies incorporate photographs to show a feature or area, or compare before and after shots of impacts from a coastal event (e.g. storm surge). Ortega-Sánchez et al. (2008) utilized camera systems to record temporal barrier geomorphic changes that provided valuable insight regarding wave action, longshore transport and barrier dynamics. Video capture methods were used to study cusp formation, where it was found that cusps form under low energy accretion until infilling occurs forming a continuous berm, unless impacted by storm events leading to the formation of larger berms (Almar et al., 2008). Puleo (2009) used video cameras to help explain that the tidal level and phase are important in sediment transport and suspension within the swash zone. Smith and Bryan (2007) used a combination of barrier profiles with video cameras to develop a model to predict short-term barrier face morphology changes with wave action and water level changes.

2.2 Sea Water Level and Harbour Oscillations

Sea level changes are not uniform across a local area or region, and may occur over long and short periods of time. Long term changes occur over thousands of years at variable rates and frequency depending on many interacting factors such as, but not limited to:

changes in land water storage; meltwater distribution; vertical land motion; elastic crustal response; glacio-isostatic adjustment; and long term oceanographic changes (James et al., 2014). The long term climate change involving changes in ocean volume and land ice is the primary driver for global sea level changes (Church et al., 2013). In a study by Shaw et al. (2002), models are presented that show drastic sea level changes in Atlantic Canada since 13 ka BP. Church et al. (2013) state that the rate of global sea level rise has increased from fractions of a mm/y to almost 2 mm/y between the pre-industrial and post-industrial or early 21st century.

Various studies have been completed that involve the investigation of past sea level changes from local to regional scales. Investigations in Newfoundland include the West Coast (Bell et al., 2005), St. Georges Bay (Bell et al., 2003), Port au Choix (Bell et al., 2005), Port au Port Bay (Brookes et al., 1985), Northeastern Newfoundland (Shaw and Forbes, 1990), Avalon Peninsula (Catto, 2006; Catto et al., 2003; and others), and for the entire province (Batterson and Liverman, 2010; Daly, 2002; Daly et al., 2007; Shaw and Forbes, 1995). Investigations in the Atlantic Region are numerous including Dyke and Peltier (2000), Shaw et al. (2002), Quinlan and Beaumont (1981), Han et al. (2014); and others. All of these studies show changing sea levels at various rates. Previous research conducted by Catto et al. (2003) found that sea level at Mobile (~25 km north of Ferryland) may have been as much as ~ 3 m below current levels in the early 1600s. More recent research suggests that sea level rise is occurring at ~ 2-3 mm/y (Catto, 2006; Catto, 2011), being ~1.2 – 1.5 m below present in the early 1600s. No literature was found regarding ongoing local long-term continuous sea level monitoring sites except for federally operated tide gauge stations at St. John's, Argentia, Bonavista, St. Lawrence, and Port aux Basques (Fisheries and Oceans Canada, 2015).

Projections by James et al. (2014) suggest that areas in Eastern Canada are experiencing sea level rise with coastal inundation and periodic flooding. An accurate prediction could not be made regarding the increase or decrease in the frequency of storminess or extreme sea level occurrences on a regional level. However, subtropical cyclones tracks are moving further north (Church et al., 2013) which may have substantial impact on coastal zones such as Eastern Newfoundland. Vasseur and Catto (2008) and Masson (2014) suggest that the frequency and intensity of tropical, extratropical and other major storm events are increasing in Atlantic Canada. Masson (2014) details the impacts of Hurricane Igor on Eastern Newfoundland and stresses the importance of mid-latitude transition from a tropical cyclone (hurricane) to an extratropical system where the rainfall and wind could be more intense than the former form.

Oceanography plays an important role in decadal to yearly sea level changes as described in Papadopoulos and Tsimplis (2006), who found that although the North Atlantic Oscillation does influence the sea level in the Northwest Atlantic, the Arctic Oscillation and the position of the Gulf Stream may have a greater role. The position, strength and level of the Labrador Current (tied into the Arctic Oscillation) and how it interacts with the Gulf Stream impacts seasonal and daily currents and water levels along the Eastern Avalon. The resultant counter-clockwise direction may elevate tides above normal levels in some embayments and cause variable nearshore currents (Catto et al., 2003).

Church et al. (2013) suggest that daily tidal cycles, currents, water temperature, atmospheric pressure and weather conditions impact short term sea level. Where a tidal range exists, the highest range is termed the Spring Tide where high high tide and very low low tide are due to constructive interference between the lunar and solar bulges. The lowest range is called the Neap Tide where lower high tide and higher low tide are due to destructive interference between lunar and solar tidal bulges (Trujillo and Thurman, 2005). Currents set up by tidal cycles and interact with obstructions such as headlands, shoals, islands, and other features to produce complex features such as eddies, but also may increase tide levels locally (Ferentinos and Collins, 1980). Low atmospheric pressure and wind forcing onshore (Harper et al. 1988) may cause storm surge resulting in high to extreme water levels (Hallegatte et al., 2011) depending on tide cycle. Wave setup and setdown depend on nearshore bathymetry with setup increasing with decreasing angle of the surf zone slope (Elgar et al., 2001). Steeper steps nearshore cause plunging breakers of which the resulting pressure plays an essential role in sediment transport and profile shape (Pedrozo-Acuña et al., 2008). With respect to geomorphic changes, Orford et al. (2006) showed that storm surge in combination with sea level rise causes gravel-barrier retreat when water level is raised so that overwashing occurs. In another study on the shoreline of France, Brunel and Sabatier (2009) found that sea-level rise may have a major role to play regarding the erosion of pocket beaches while other factors such as swell and overwashing may impact other barriers systems (e.g. open beaches) to a greater extent. Catto (2006) suggests that relative sea level rise will increase the impact of wave and storm surge on barriers systems further inland.

Small embayments and fortified enclosed marine or semi marine areas can be difficult to conduct short- and long-term measurements and assessments on due to complex tides, currents, and effects of anthropogenic modifications. Heath (2003) suggests that atmospheric changes such as wind forcing, fast moving atmospheric disturbances (changes in pressure) serve to interrupt any stratification and increase flushing effects of coastal embayments. In addition to storm surge, waves and tides, there also exists water level changes due to approaching long-period waves and edge waves (Catto et al., 2003). These waves may cause localised impacts such as long-period oscillations. These are relatively common in small harbours and other semi enclosed coastal water bodies (Okihiro et al., 1993). Fagherazzi et al. (2003) found that under certain conditions the tide in small basins results in a standing wave that oscillates synchronously across the basin. Guan-Yu et al. (2004) found that wave resonance in Hua-Lien Harbour is likely caused by the entrapment of edge waves and proposed a theory to mitigate these waves and their impacts.

2.3 Tourism: Coastal Archaeotourism and Geotourism

Tourism is a broad term that is used to capture many intentional (e.g. planned) and unintentional (e.g. unplanned) travels for leisure, recreation or for a specific purpose such as to experience nature. In this study, tourism will include archaeotourism, involving visits specifically related to archaeology or archaeological heritage significance (e.g. Giraudo and Porter, 2010), and geotourism involving visits specifically related to geological and/or geomorphic significance (Rutherford et al., 2013). From the most readily accessible sites to the most remote secluded sites, archaeotourism and geotourism exist from the local to the global scale.

Archaeological sites are found at various locations, including at or near the current coastlines; some of which were coastal settlements and are now inland (e.g. Dickinson et al., 2007), and others which are now submerged under several metres of sea water (e.g. Bell and Renouf, 2003). Bailey and Flemming (2008) suggest that there may be numerous coastal landscapes that were previously exposed during lower sea levels. These areas may have provided suitable habitat for plants, animals, and humans. Many historic settlements were built out of necessity and, whether or not the sea level was changing at that time and location, the design and planning of structures were generally constructed along the waterline, possibly due to no concept of changing sea level. Bromhead and Ibsen (2006) provide a detailed record of the effects of coastal erosion and landslides on historic fortifications built out of necessity, with poorly planned locations and structural design. Taylor et al. (2011) detail cliff and barrier erosion at and near the Fortress of Louisbourg in Nova Scotia, revealing shoreline erosion that is exposing archaeologically sensitive materials. In most cases, the primary erosional mechanisms are marine attack and cliff retreat. Knowledge and mapping of archaeological sites are vital to understand human settlement history (Renouf and Bell, 2006). However, this may also lead to increased archaeotourism which, if poorly managed, may cause increased terrestrial and coastal erosion.

Geotourism sites in the coastal setting are of great interest to scientists (e.g. Reynard and Coratza, 2013), tourists, and educators due to the changing landforms related to climate change (Pelfini and Bollati, 2014). Due, in part, to this increasing interest, more geotourism sites are being identified, requiring sophisticated tools such as GIS to identify, map and assist in managing these sites (Rutherford et al., 2013). The geotourist may travel great distances to view a collapsed sea cave (Norman, 2009) or one of the many coastal features such as: sea stacks (e.g. Fox Island), arches (e.g. The Arches Provincial Park), tombolo (e.g. Ferryland), various barrier types, raised beach ridges (e.g. Trout River and Eastport), estuaries (e.g. Come by Chance), unique geology (e.g. Green Gardens at Gros Morne National Park), and many other features. The UNESCO World Heritage Site of Gros Morne National Park was established based on two criteria: unique geology and glacial-influenced surface expression including landlocked freshwater fjords (UNESCO: Gros Morne National Park, 2015) that are a result of tectonics and sea level changes. The National Geographic Society also maintains a webpage entitled Eastern Newfoundland Geotourism Mapguide (National Geographic Society, 2012) to show potential geotourists the attractions in Eastern Newfoundland.

Various studies have considered the relationships between coastal erosion and tourism such as the impacts of weather events on tourism infrastructure (Catto, 2014), coastal erosion via foot traffic (Catto, 2014), and coastal landscape response to human impact (Catto and Catto, 2012). The ongoing Coastal Archaeological Resources Risk Assessment (CARRA) Project is investigating the current and future impacts of sea level rise on select archaeological sites in the province in order to build a model to inform management and policy makers regarding the state and future of archaeological and heritage sites (Robinson et al., 2013). This follows similar work done by Westley et al. (2011) who developed a desk top model to assess archaeological site vulnerability to sea level rise on the Northern Peninsula.

Tourism sites in coastal areas are undergoing erosional impacts from coastal processes and anthropogenic activities concurrently. This makes the evaluation of these systems complex and difficult to undertake. Klein et al. (2004) show that beach tourism to clean broad beaches relies on relatively easy access. Among other coastal areas reviewed by Barbier et al. (2011), they found that many beaches have not been properly assessed for the value of ecosystem services. As an example of this, Everard et al. (2010) found that some coastal features such as sand dunes are neglected and undervalued with little appreciation for larger scale ecosystems services provided. Valuation and planning should also assess access trail design factors such as: trail type and amount of use, climate, topography, maintenance, trail base material, drainage, and others (Olive and Marion, 2009). For example, Catto (2006) found that heavy foot traffic (East Coast Trail) on the berm of a coarse gravel barrier resulted in barrier coarsening and compaction. Catto (2014) provided a description of mostly unmanaged foot traffic and consequences in sensitive coastal areas. The foot traffic is causing increased erosion mainly through the denuding of shallow soils and vegetation, exacerbating the impacts of rainfall and freeze-thaw cycles.

There are numerous examples of erosion-impacted archeological areas around the world. More than 50% of the 93 archaeological sites at Upstart Bay Australia have been destroyed by tropical cyclones between 1988 and 1992 (Bird, 1992). Two archaeological sites in the West Indies are losing up to 1 m per year due to coastal erosion and human activities such as barrier mining (Fitzpatrick et al., 2006). Hapke et al. (2010) show that where long-term studies are ongoing such as the New England and Mid-Atlantic shorelines, 65% of the 21,184 transects are eroding (some of which are adjacent to or on archaeotourism and geotourism sites). Alonso et al. (2002) found that the development of tourism and associated impacts (e.g. barrier mining and quarrying inland) has led to barrier transgression due to loss of sediment input into the barrier sediment budget. Priskin (2003) details the negative impacts (compaction, rutting, etc.) on a barrier system from four-wheel drive vehicles on a remote coastal zone in Australia. Vegetation that stabilizes barrier systems are also impacted, as seen in a study by Hesp et al. (2010) where loss of vegetation on a coastal parabolic dune related to foot traffic caused the disappearance of rare species.

Another perspective is offered by Coombs et al. (2009), who suggest that barrier width reduction due to sea level rise will not negatively impact tourism as long as climate change brings favorable conditions to outweigh the barrier width reduction. Some of the impacts of tourism can be reversed as seen with the management of trail use at Cape St. Marys that resulted in decreased erosion and reestablishment of native plants (Catto, 2014). Cornelius et al. (2008) found that increased human recreation activity control is also needed on coastal activities in and adjacent to a marine reserve in order to limit disturbance to roosting and foraging birds. One method to conduct analysis is through modelling such as conducted by Klein et al. (2004), where they related tourism economics to location to revel various statistics such as proximity to the shoreline and type of coastal zone. This identifies the type of activity and potential for erosion on different coastal landforms, some of which are more prone to human-induced erosion than others (trails incised into till cliffs generally eroded faster than rocky cliffs).

Chapter 3 – Methods

This chapter presents and describes the methods used to describe and provide baseline data to assist in the interpretation of the coastal system and impacts of erosion. No previous studies have been done in this area utilizing all of these types of description and data collection. The data on water level, weather parameters, and surveying is not included with this thesis. However, it is available upon request.

3.1 Local Knowledge and Site Visits

Local or traditional knowledge is necessary and enriches any study involving the impacts of coastal activity (Dolan and Walker, 2004). With this in mind, numerous residents, fish harvesters, tourism operators, tourists, and others were approached to discuss local conditions and challenges related to storm conditions, surge activity, related erosion, and possible mitigation measures. These discussions proved essential to describe the systems in-depth, focus the study to include a general qualitative assessment of current mitigation measures, and to develop the methods to measure parameters to meet the study objectives.

The local knowledge provided locations and descriptions of physical features including shoals, submerged rocks, previous cliff positions, local names for islands and features, and many other elements. Fish harvesters described local currents and wave climate during normal sea state, surge, and storm events. In addition, local knowledge also identified various tourism activities during different weather conditions (e.g. surfing during large wave events and diving in specific areas). This effort also increased local participation in providing information during the study, including: reporting surge events;

detecting instrument problems; operating cameras (turning off and on); searching for artifacts; and many other contributions.

On-site discussions with tourists revealed why they traveled to Ferryland and what they came to see. Many tourists came to see the Colony of Avalon and to experience Ferryland Lighthouse Picnics. Others came to enjoy events by the Southern Shore Folk Arts Council (e.g. Dinner Theatre). More were driving further south to Mistaken Point Ecological Reserve and decided to stop for a meal at the local restaurant and see the Colony of Avalon site. A smaller number came to see the geology and coastal geomorphology. One tour group of high school students were seen exploring two barriers and being given an interpretation of the tombolo. Several people were approached on the East Coast Trail and found to be enjoying the hiking and sea life (e.g. whales and harp seals).

More than 40 site visits were made to conduct field work and to speak with various stakeholders. The site visits enabled system observation, equipment deployment, surveying, photography, videography, presentations, and other work.

3.2 Photogrammetry and Videography

Still photography provides a unique time and date stamped image record of natural settings or anthropogenic influences. A Canon Rebel T4i DSLR camera and a Canon Powershot ELPH 530 HS Camera were used to capture more than 10,000 photographs of various natural and anthropogenic coastal features in this study. Viewscape management techniques were used to take repetitive photographs from the same point for comparison over time. Photographs were also used to capture and analyze barrier changes, wave approach, oscillations, vegetation cover, mass movement indicators, and many other factors and processes. Dated historical photographs can also be used to help determine the former condition and location of existing coastal features. However, in all but one case, historical photographs of Ferryland were not datable, and therefore were not used for this study.

Aerial photographs (color and B/W) were acquired in 600 dpi Tagged Image File Format (TIF or TIFF) documents from the Survey and Mapping Division of the Department of Environment and Conservation, Government of Newfoundland and Labrador. These aerial photographs were from various years and were compared to assess erosion and other geomorphological changes. Problems such as image clarity, flight line consistency, B/W to color images, and atmospheric conditions (e.g. haze and clouds) prevented detailed quantitative analysis. The aerial photographs were not suitable for comparative analysis. However, they did provide examples of wave refraction, land-use change, and other information such as battery locations.

A High Definition (HD) video camera is capable of capturing images and video of various events including tides, storms, waves, surges, impacts to coastal features, mitigation measures, and anthropogenic activities. A Canon HD R500 video camera, Canon Rebel T4i and a Canon Powershot ELPH 530 HS Camera were set up at various locations to capture normal, surge, and storm conditions, including Nor'easters and Hurricane Gonzalo. In particular, the Canon R500 was set up in the Celtic Business Development Corporation (CBDC) office. The camera was turned on at 18:00 on October 18, 2014 to record a 24-hr period encompassing the impact of Hurricane Gonzalo from the SSE. This viewpoint allowed the capture of HD video recording of wave and surge activity at the breakwater on the eastern extent of Ferryland Beach. Many other deployments were made at various points to assist in system interpretation.

A modified underwater camera was used to assess various bathymetric features. This camera was not equipped for video capture, but a small video monitor was used to view images. The camera was deployed from an inflatable boat and shoreline infrastructure (wharves) to assess: nearshore barrier slopes, sediments, organics, and morphology; rocky shoal assessments; bottom sediments; and mooring locations for dataloggers.

3.3 Water Currents and Measurement

Drifter buoys and other floating devices were used to estimate current direction and velocity in relation to wind speed and direction, and wave approach. Some buoys and floats are very sophisticated and measure multiple parameters such as wind speed and direction, air and water temperature, air quality, water currents, salinity and many more (NOAA The Global Drifter Program, No Date). Other studies have used custom designed buoys to measure currents in coastal areas (Centurioni et al., 2008; Davis, 1985; Manning et al., 2009; Ohlmann et al., 2007), and bottom temperatures (Manning and Pelletier, 2009).

Based on a review of the sources above, various other studies, local knowledge, and personal experience of coastal conditions and observation, two custom designed drifter tube buoys (DTB-1 and DTB-2) with adjustable drogue (sea anchor) were designed to specifically measure water currents to understand currents, sediment transport and erosion in select areas (Figure 3.1). The DTB's were constructed by using a 530-12 tire tube (Product # 8396574) with a 305mm aluminum pizza pan as an interior platform to provide an attachment point for the drogues. The pizza pan deck was attached to the tube with four 356mm stainless steel cable ties and underlain with DOW 37.5mm Styrofoam to provide secondary floatation and stability. The buoys were tested for buoyancy and were found to support over 25 kg. Both DTB's were outfitted with drogues (30 cm corner radar reflectors) in order to intercept water currents to measure speed and direction at the surface (DTB-1) and at adjustable depths (DTB-2). Both DTB were launched together or separately and movements compared to wind speed and direction using data from portable weather monitoring equipment or the permanently installed weather station FLEWWX-1.

Figure 3.1. Custom-made Drifter Tube Buoys. **A:** DTB-1 moving NE with surface currents in Ferryland Harbour. **B:** DTB-2 (with DTB-1 in the background) with 2 m drogue and moving S against wind waves.

The DTB's were deployed ether from shore or from an inflatable boat depending on the area and conditions during measurements. The DTB's were retrieved using water craft after a selected time period or after drift past a predetermined coastal reference point depending on weather and sea state. DTB's were monitored for general movements and timed with reference points for current direction and velocity estimates.

Various other floats were also deployed. These included tennis balls, hockey balls, ping pong balls, and modified milk creates. These smaller floating objects were deployed in nearshore areas too shallow for safe operation of the inflatable boat (<0.5 m). However, due to their small size and distance moved, they were difficult to recover resulting in the loss of many.

3.4 Surveying

3.4.1 Real Time Kinematic (RTK) Surveying

After reviewing many methods to measure barriers, erosion, deposition and the coastal processes on or near the shoreline, Real Time Kinematic DGPS (RTK) was selected due to vertical and horizontal accuracy on spot measurements (≤2 cm) and mobile accuracy (3-6cm) on moving measurements such as ATV (e.g. Lee et al., 2013). A Leica Geosystems GS14/GS15 RTK DGPS (Leica Geosystems, 2015) (Figure 3.2) system was used on July 11-14, 2014 to measure many natural and anthropogenic features including barriers, cliffs, breakwaters, roads, archaeology site features, and many others.. For ease of use and consistency with other studies in the area (e.g. Irvine, 2012, 2013), the base station was set over Provincial Horizontal Control Survey Brass Plug 019047 located on the western extent of The Downs with an Easting (x) of 314122.691 m, Northing (y) of 5209171.218 m and elevation (z) of 28.906 m (Figure 3.4). The system was set up using North American Datum (NAD) 83 for Zone 22 using MTM projection system. During the surveying, Provincial Horizontal Control Survey Concrete Pillar 83G3405 and Brass Plug 019044 were used as a tie to ensure control. Numerous accuracy checks showed an accuracy within the above values.

Figure 3.2. RTK Setup on The Downs (Point 6 in Figure 3.4).

Control points (CP) are necessary during surveys to ensure accuracy and precision but also to ensure that points and lines can be found for stakeout in monitoring surveys. 5/8 Rebar, 255 mm nails, and other points of control and significance were established and surveyed as control points for future survey work and research. Slope transects, slope monitoring points, barrier profiles and features, mitigation features, and anthropogenic features were surveyed using "occupy" (positioning over a point for >10 seconds) to ensure maximum accuracy and precision.

The RTK survey also provided elevations for sea level estimates, elevation and position for the weather station, and numerous other points for the Town of Ferryland for various future work.

3.4.2 Differential and Laser Leveling

Differential leveling is used to transfer vertical (z) elevation from a known point such as a control monument (benchmark) to a control point or other point such as an iron pin, bedrock, or other fixed surface. This technique requires two people, one operating a level on a tripod and another to operate a graduated range pole or level rod. Elevations can be transferred over distance when care is taken in equipment use and note taking (McCormac, 1995). The leveling was carried out using methodology from Kavanagh (2010). Differential leveling was completed on October 17, 2014 to transfer the elevation of the federal PCM1 2005 Chart Datum Reference Point at The Pool to the FLEWWL-1 Reference Point and an Iron Rod near the Colony of Avalon Maintenance Shed (Figure 3.4). Leveling was also conducted during grade and elevation survey for the sea level estimates and to check selected barrier profiles.

Another related method of leveling used is laser leveling where a tripod and laser level is set over a known elevation. Once leveled (most are self-leveling), one surveyor can collect spot elevations within 360° of the level using a level rod. This method was used on several occasions where the RTK equipment was not available, GPS signal was not available, or a second person was not available.

3.4.3 General Coastline Surveying

General shoreline surveying included natural features, anthropogenically constructed or altered features, grades, slopes for select study elements and other features of interest. Examples of anthropogenically altered or constructed features included armor stone, breakwater, roads, culverts, cut banks, toe-of-slope, and top-of-slope. Selected Colony of Avalon features were also surveyed. Selected road grades along erosion-prone areas were also surveyed.

3.4.4 Barrier Profiling

Barrier profiles are essential in measuring barrier morphology, clast arrangement, presence and position of organics and litter, and many other features. Most exposed high energy shore-normal barriers change in geomorphology and sedimentology depending on wave action, currents, and surge. For this study, modal conditions were desired to set up a baseline survey using barrier profiles. Multiple observations over a one year period (May 2013 to July 2014) were conducted to assess modal conditions in the area. As a baseline, 19 barrier profiles (BP) were set up and measured using RTK on Ferryland Beach, and 12 Slope-Barrier Profiles (SBP) were set up and measured on the north side (6) and the south side (6) of the Ferryland Head Isthmus. All BP and SBP were measured from a fixed point landward (rebar or nail) to the shoreline (~ low tide) during July 2014. Some of these BPs are located near those of Wright (2004) (e.g. BP 11 and 12) and previous measurements. These BPs differ from Wright (2004) in that the BPs are assigned x, y and z coordinates allowing for easy relocation in future studies. All BPs and SBPs were established by visually selecting the best fit for the barrier and other features, and where possible, utilizing anthropogenic features for reference. Each profile was assigned a number and, where possible, given an approximate shore-normal azimuth based on grid north (declination of 23.5 degrees) using a Silva Ranger Compass. Each profile was measured noting changes in ground cover (back-barrier), clast size and shape, morphological characteristics, organics, litter, and other notable features.

The criteria for repeating the survey was if wave impacts were detected on the upper storm berm (overtopping or washover) of any of the barriers. This criteria was not met from July 2014 to May 2015 so a repeat survey was not done. However, lower position barrier changes (high tide berm) did occur on numerous occasions and are described.

Major issues arise when measuring barrier profiles and transects, particularly in locating the profile lines to repeat measurements. Some researchers have used reference points (Etheridge, 2005; Etheridge and Catto, 2005; Wright, 2004) and other methods in order to mark beginning-of-line (BOL) and end-of-line (EOL) of barrier profiles. Unfortunately, some of these references have been destroyed, either by anthropogenic activities (e.g. rebuilding roads, seawalls, breakwaters, etc.) or natural processes (e.g. erosion and deposition). Through prior survey experience, considering the work of Forbes et al. (1991) and working with and assessing work done by Irvine (2012, 2013, 2013), the survey transects and profiles for this study were established using 5/8 rebar or 255mm steel nails with Mossace Red marker caps. This survey method provides data that will allow future study utilizing software such as the USGS Digital Shoreline Analysis System (DSAS) (Thieler, 2009) in the ARCGIS environment.

3.4.5 Slope Movement

A system of points were marked and established (RTK) using 255 mm steel nails with survey caps on a slope on the northern side of The Downs and both sides of Ferryland Head Isthmus. The points on the isthmus are included in the SBP profiles. The criteria for resurvey was established as: >75 mm of rainfall within a 24-h period, excessive storm surge and related wave undercutting (upper storm berm), and movement of the steel nails as detected by tape measure. None of these criteria were met and the points were not re-surveyed for monitoring in this study.

3.5 Water Level – Tides, Forcing, Surges and Waves

Numerous discussions with local fish harvesters, tourism operators, and residents indicate that tidal waters in Ferryland Harbour and The Pool vary greatly from the predicted tides for Fermeuse Harbour (Station #890), approximately 8 km south of Ferryland Harbour. One theory brought forward by residents was that under storm surge conditions and/or NE winds (forcing), a current sets up in Ferryland Harbour that elevates and pushes water into the boat basin where it builds in height to flood wharves, cribbing, stages, and sheds. Descriptions of this tidal action liken it to a standing wave or seiche. It is also thought that this wave activity is responsible for erosion and destruction of stages, wharfs and other structures in The Pool. With the support of the Harbour Authority, the Colony of Avalon Foundation and the Town of Ferryland, water level measurements were collected to determine actual water levels under varying air pressure and wind conditions and to reveal what is causing shoreline erosion in The Pool. This would not only verify the actual conditions but will also serve as data to plan any new upgrades or new construction activities in the The Pool or around the Colony Site.

Predicted tide data were downloaded from the Fisheries and Oceans Canada webpage for Fermeuse Harbour (Station #890). These data were tabulated as necessary to be compared to measured water levels in The Pool. Station #890 uses the same Chart Datum (CD) as Ferryland (R. Healey, Pers. Comm., October 17, 2014) so that daily tide predictions can be used for The Pool and surrounding areas.

This level of study required the set-up of state-of-the-art instruments to measure sea water levels from a vertical reference point such as CD in order to collect accurate and precise data. The reference point PCM1 2005 (Figure 3.4) establishes the CD reference point at The Pool and is 2.935 metres above CD (R. Healey, Pers. Comm., October 17, 2014). This point was used to provide a reference at The Pool for the tide predictions at Fermeuse #890. The CD for Ferryland is approximately 0.60 metres below the geodetic reference datum, accounting for the vertical discrepancies found during the RTK surveying which referenced the Provincial Control Monuments in the area.

The next step was to select an appropriate site to measure sea water level. The site of PCM1 was assessed and found to be unsuitable due to its proximity to the opening of The Pool, a point of occasional high surge and current activity. A rock-filled cribbed concrete-topped wharf owned by Mr. Leo Kavanagh was selected and, after permission was granted, a drill hole was established and measured with RTK. This reference point is named FLEWWL-1 (Figure 3.4). The elevation on FLEWWL-1 for CD was then established by differential leveling from PCM1 2005. FLEWWL-1 is 1.970 metres above CD. This relationship also provides a method to transfer the CD to any of the RTK points for this and future studies.

After a thorough review of the study budget, tide stations, similar studies and experience with groundwater and environmental monitoring and study, the ONSET HOBO Water Level Dataloggers (Onset Computer Corporation, 2015) was selected to measure sea water levels at The Pool. These dataloggers have been successful at measuring current flow depth (Rinehimer et al., 2012), morphodynamics of runup (Cariolet and Suanez, 2013), water level in salt marshes (Hering et al., 2010; Colón-Rivera et al., 2012), estuaries (Shapiro et al., 2010) and other coastal areas (Filgueira et al., 2014).

The saltwater level in The Pool was monitored using two Onset HOBO U20 Water Level Data Loggers set to collect readings every 5 minutes. The high frequency data collection was necessary to capture surge and other activity related to forcing, waves, and currents. The titanium model U20-001-02-Ti was deployed on a concrete block tethered to the wharf to measure water pressure (atmospheric + water head) and temperature, and the stainless steel model U20-001-04 was attached to the underside of the northern eve of the Colony of Avalon maintenance shed to monitor barometric pressure and air temperature (Figure 3.3 and 3.4). The dataloggers were retrieved every two months for cleaning, data download and analysis with the HOBOware Pro software. The HOBOware Pro software combines the water pressure and temperature with the air pressure and temperature to give a precise water level measurement (0.001 m) based on the FLEWWL-1 reference point. More than 62,000 raw data points were collected from September 13, 2014 to May 31, 2015 including air temperature, water temperature, barometric pressure, and water level from these dataloggers.

Figure 3.3. Location of Onset HOBO Dataloggers. FLEWWL-1 - drill hole in the concrete on the outer corner of the dock (just left green rope tied to the dock). **A**: Air KPa + Air °C, **B**: Air and Water KPa + Water °C.

All retrieved data were checked using four Quality Assurance and Quality Control (QA/QC) checks. The first check was to ensure secure setup so that water level data was not impacted by moving dataloggers. The second check involved collecting periodic manual water level by measuring from the FLEWWL-1 reference point (drill hole) down to the water surface at specified time and comparing to datalogger water level. The third check was field verification of datalogger functions during retrieval of data. The fourth check involved a thorough review of all data points regarding water pressure and temperature, and air pressure and temperature.

3.6 Weather Monitoring Station

Local weather patterns in this area are very complex due to variable topography in the coastal setting. Wind speed and direction, barometric pressure, temperature, humidity and rainfall play important roles in regional climate pattern, but more importantly in the many microclimates along the shoreline and islands of Ferryland. These parameters directly influence erosion, deposition of sediments, and the disintegration of bedrock by freeze-thaw cycles. Other major parameters are storm waves and surge generated offshore which impact the nearshore. Although high waves, variable currents and surge events occurred most often during storms, surge events were reported by residents to occur during relatively calm wind conditions, and large waves (e.g. rogue waves) were also described impacting the shoreline during calm periods. Impacts from surge and waves were seen at Ferryland Beach and in The Pool.

Prior to this study, the nearest weather station to the north was located at St. John's Airport, some 80 km north and 6 km inland. The nearest weather station to the south is located at Cape Race, some 40 km south. These stations are not adequate to provide specific weather data for this area (R. Snodden, Pers. Comm., June 5, 2014). During several spot checks, the weather parameters (temperature, wind speed, wind direction) differ from Ferryland to Calvert, a distance of only 2 kilometres. A weather monitoring station would help not only to categorize the local weather for the first time, but also to provide data during surge, wave, or high current events. This would enable direct weather assessment to determine if any correlation exists with the specified events. A weather station would also provide valuable data for weather observation and forecasting for the meteorological community. The online viewing of local weather would be valuable information to tourists leaving St. John's to spend a day at Ferryland (Mayor R. Paul, Pers. Comm., May 12, 2014).

A Davis Vantage Pro2 weather monitoring station (Davis Instruments Corporation, 2015) with the related WeatherLink internet link was installed to monitor and record weather conditions at the tombolo. The parameters measured include barometric pressure, temperature, rainfall, humidity, wind speed, and wind direction. These data were utilized to: assess conditions that cause coastal impacts on the barriers, cliffs and infrastructure; and help determine local currents in conjunction with the DTBs.

This station is called FLEWWX-1 and, for testing purposes, was temporarily set up on a 3-m high structure at N47.02289, W052.88496 on May 30, 2014. The console was linked to a high speed modem in the Colony of Avalon Foundation building (Figure 3.4) where it was linked to Davis Weatherlink (Davis Instruments Corporation, 2015) and activated on May 30, 2014. From this software and internet platform, the weather conditions are accessible to all stakeholders and the meteorological community at Weatherlink (Davis Instrument Corporation, 2015). FLEWWX-1 was linked with Weather

Underground (INEWFOUND78) in December of 2014 (The Weather Channel, LLC, 2015). The software accompanying this system will allow any stakeholder to download all data from the Davis console via internet connection.

On June 27, 2014, FLEWWX-1 was relocated to a utility pole established by the Town of Ferryland for long-term deployment (Figure 3.4). The utility pole is located at N47.02322, W52.88461 with a base elevation of 2.25 metres (RTK-DGPS) or 2.85 metres above CD. The rain, temperature and humidity sensors are located 3.3 m up the pole, with the wind speed and direction located above the top of the pole at approximately 11.0 m. It was necessary to elevate the anemometer and wind vane to the required height of 10 metres above grade and also place the rain-temperature-humidity sensors above natural-like ground to provide reliable measures, and high enough to deter vandalism. The finished height of this unit is 3.5 metres above grade, two metres above specification (World Meteorological Association, 2008).

Table 3.1 shows a summary of weather parameters collected from June 1, 2014 to May 31, 2015. The reed switch in the tipping bucket rain gauge was found to be improperly installed in December 2014, resulting in unreliable rainfall data from June to mid-December. Wind speed and direction data from this station was also used for the assessment of water level data and interpretation (Chapter 4). Periodic checks with handheld monitoring devices (e.g. Kestrel 3500 and Weatherhawk Skymate) confirm the accuracy of FLEWWX-1. FLEWWX-1 will be used for long-term monitoring by this author beyond this study.

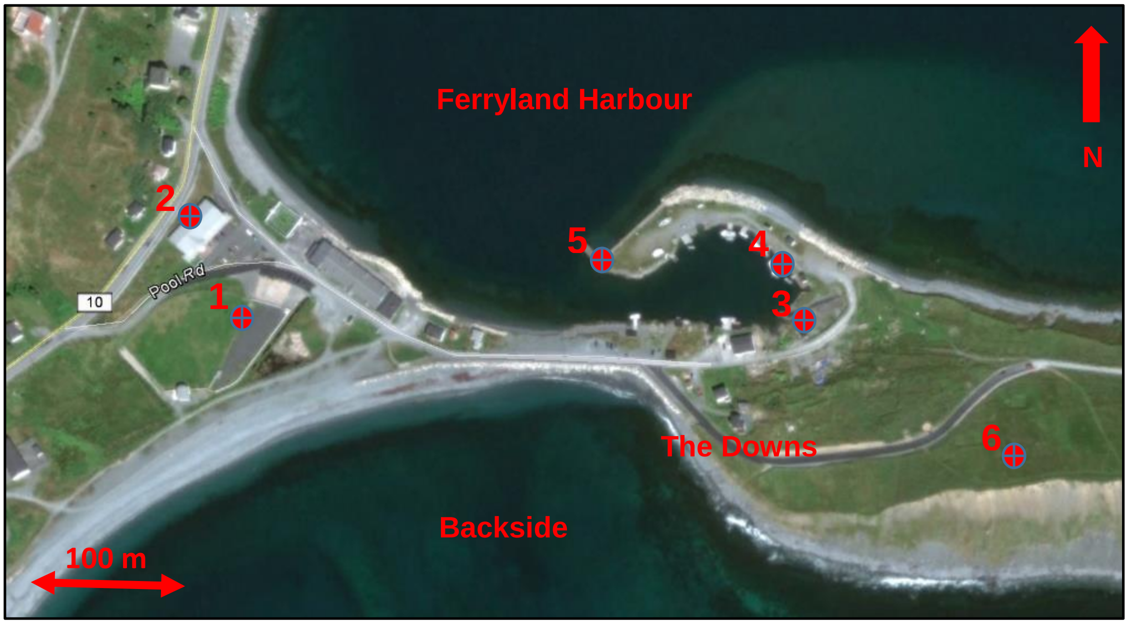


Figure 3.4. Permanent monitoring equipment locations of FLEWWX-1 **(1)**, Davis Console and internet connection for FLEWWX-1 **(2)**, air temperature and air pressure monitoring for FLEWWL-1 **(3)**, FLEWWL-1 sea water temperature and sea + air pressure monitoring **(4)**, PCM1 2005 Chart Datum (CD) reference point **(5)**, and brass plug 019047 **(6).**

Table 3.1. Monthly weather data summary for FLEWWX-1.

Parameter	Air Temperature (°C)			Wind Speed (km/h)			Bar. Pressure (Kpa)			Humidity (%)			Rainfall (mm)
Month	**Avg.**	**Max.**	**Min.**	**Avg.**	**Max.**	**Min.**	**Avg.**	**Max.**	**Min.**	**Avg.**	**Max.**	**Min.**	**Monthly**
June 2014	8.7	23.9	-1.3	10.1	56.3	0.0	1014.5	1026.6	997.6	89.5	98.0	41.0	NA
July 2014	17.4	29.1	7.0	17.5	72.4	0.0	1016.4	1026.7	1003.4	86.5	99.0	35.0	NA
August 2014	17.0	28.7	6.7	16.9	82.1	0.0	1014.5	1026.6	997.6	89.1	98.0	48.0	NA
September 2014	14.1	24.8	2.9	16.3	88.5	0.0	1016.5	1031.6	1003.5	84.7	98.0	41.0	NA
October 2014	10.7	21.5	4.2	16.7	80.5	0.0	1013.5	1031.0	975.1	87.5	98.0	55.0	NA
November 2014	5.6	18.4	-7.4	18.1	59.5	0.0	1011.7	1033.1	982.2	83.5	98.0	48.0	NA
December 2014	1.6	13.0	-9.8	17.6	57.9	0.0	1019.3	1045.8	994.1	85.8	98.0	53.0	150+
January 2015	-2.1	9.5	-14.7	16.6	74.0	0.0	1013.4	1036.0	983.7	86.2	98.0	53.0	123.2
February 2015	-2.6	6.6	-13.1	23.2	140.0	0.0	1009.8	1034.9	969.0	83.2	98.0	57.0	52.0
March 2015	-2.8	-2.6	-3.0	17.8	90.1	0.0	1007.8	1033.2	971.2	81.7	97.0	45.0	73.6
April 2015	0.5	9.7	-11.3	20.3	83.7	0.0	1011.6	1034.0	985.1	83.0	98.0	35.0	110.4
May 2016	6.2	21.5	-0.5	19.8	80.5	0.0	1016.4	1031.6	992.3	85.5	98.0	36.0	59.0
Average	**6.2**	**17.0**	**-3.4**	**17.6**	**80.5**	**0.0**	**1013.8**	**1032.6**	**987.9**	**85.5**	**98.0**	**45.6**	**83.6**

Note: Reed switch on tipping bucket was repaired in December. At least 150 mm of rainfall was recorded accurately after December 17.

3.7 Tourism

Since the decline of the fishing industry in the early 1990's, Ferryland has adapted and has become a tourism hotspot capitalizing on the picturesque coastal setting, archaeology, Ferryland Lighthouse, culture and recreation (R. Paul, Personal Communication, November 12, 2013).

Selected tourism sites in the study area were assessed based on baseline data collected, description of geomorphological processes, and interpretation. General statistics on approximate numbers of visitations per year related to tourism activity were collected. Local tourism-related businesses and the Colony of Avalon provided visitation statistics and related revenues in order to assemble an approximate value for tourism including archaeotourism and geotourism. The resulting information was used to highlight the current and potential impacts of coastal erosion, and related impacts on tourism sites.

Chapter 4 – Ferryland Harbour System

This Chapter presents results and interpretation for the research objective questions as they relate to this system, and more specifically the major cause of erosion in The Pool and an estimate amount and rate of relative sea level change between 1620s to present.

Coastal processes are impacting many sites, including those of significance for tourism-related activity. For the purposes of this paper, Ferryland Harbour includes all waters and islands inside the red outlined area shown in Figure 4.1A. The surface area is approximately 1.4 km^2 with a maximum water depth of ~17 m. Specifically, the area includes the shoreline and backing slopes and cliffs (unconsolidated and consolidated) from the southern point of Coldeast Point, southeast along the sill to Bois Island, south across The Narrows to the north shore of Ferryland Head, west along the north side of The Downs (including The Pool) to Route 10, and north to Coldeast Point. The area is impacted by terrestrial, oceanic, and anthropogenic effects. The descriptions and interpretations in this section are based on mapping and image interpretation, numerous site visits, baseline surveying, and local knowledge.

4.1 Bathymetry, Waves, Surge and Currents

The bathymetry of the harbour (Figure 4.1A) shows a fairly flat bottom that is wider at the west end and narrows in the east at The Narrows. The maximum depth is mostly consistent at approximately 13 m in the west, deepening to 17 m in the center and rising to 15 m through The Narrows. Much of the rise to shoreline is gradual shoaling except for two areas on the western extent where shoreline erosion is ongoing. Camera investigation revealed that most of the bottom in the shallow (< 3 m) nearshore is occupied by organic

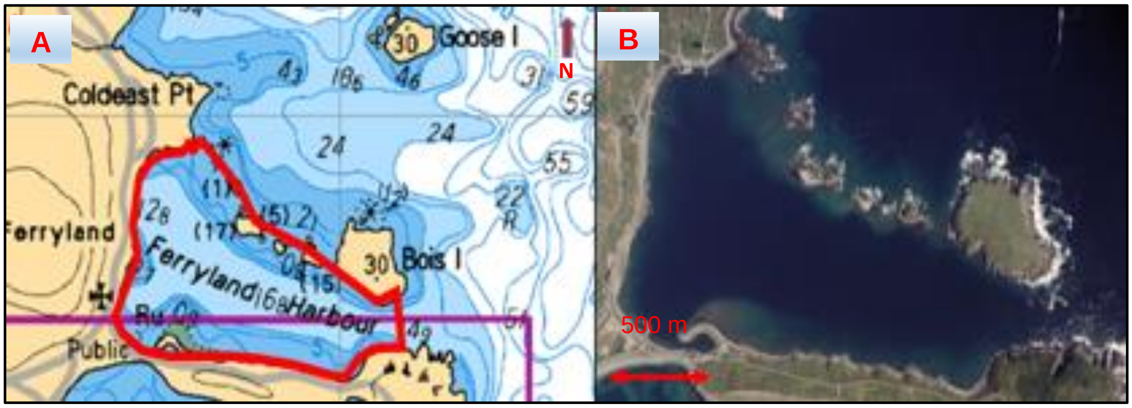


Figure 4.1. **A:** Ferryland Harbour System (Canadian Hydrographic Service-Fisheries and Oceans Canada, 1997). **B:** Deep water is dark green-blue and shallow water is lighter green-blue (Newfoundland and Labrador Government, Aerial Photograph 95044-10).

growth (e.g. kelp), except for areas of recent sediment deposition near the Pool and adjacent to the south side of the sill. The bottom in the deeper water area consists of soft mud with small scattered areas of coarser sediment.

Waves, swell, surge, and currents impact the system depending on approach direction. Wave and swell that impact this system is from NNE to E approach. Waves were observed at an estimated 4 m in height during several site visits. Information from residents and observed till erosion on the islands indicate that some waves occur >5 m. Surge occurs infrequently but plays an important role in wave approach into the harbour. Surge increases water level and, depending on tide stage, allows waves to reach higher in mitigation measures (cribbing) and the base of till and fill cliffs. This can cause material to be washed from cribbing and slope destabilization (via undercutting) respectively. The major currents are from the NE and from the E.

4.2 Coldeast Point to Bois Island including The Sill

4.2.1 Coldeast Point and the Sill

Coldeast Point (Figure 4.1) is a fairly flat inhabited area of thin till veneer and peatland overlying glacially eroded steeply dipping sedimentary bedrock. Nearer to the promontory, there is approximately 1-2 m of till on the underlying bedrock, the surface of which is approximately 1 m above msl. The actual point is the northern extent of an armored crescent-shaped cobble-boulder barrier that terminates to the south at an anthropogenically modified point now consisting of sand on eroded bedrock (Coldeast Point South). This barrier system is controlled by bathymetry, sea level rise, waves, tides, surge and anthropogenic influences (armoring and sediment nourishment). Numerous local accounts and observation reveal that large waves, surge events, and associated currents around the point (NE-SW) continue to erode the veneer, exposing more bedrock and increasing the landward width of the rock platform.

The southern extent of Coldeast Point marks the northwest point of a sill consisting of a system of exposed rocky areas, islands, and shoals. This northwest to southeast aligned sill separates the relatively shallow water of Ferryland Harbour from the deeper waters offshore to the northeast. There are six distinct areas of exposed bedrock and islands, two of which are bedrock (rock platforms) that are intermittently underwater during high high water or surge events, and four islands: Wrens Island, Costellos Island, Ship Island, and Bois Island (Figure 4.2). Field investigations reveal that they have a base of glacially eroded bedrock and are capped with till veneer (Figure 4.3).

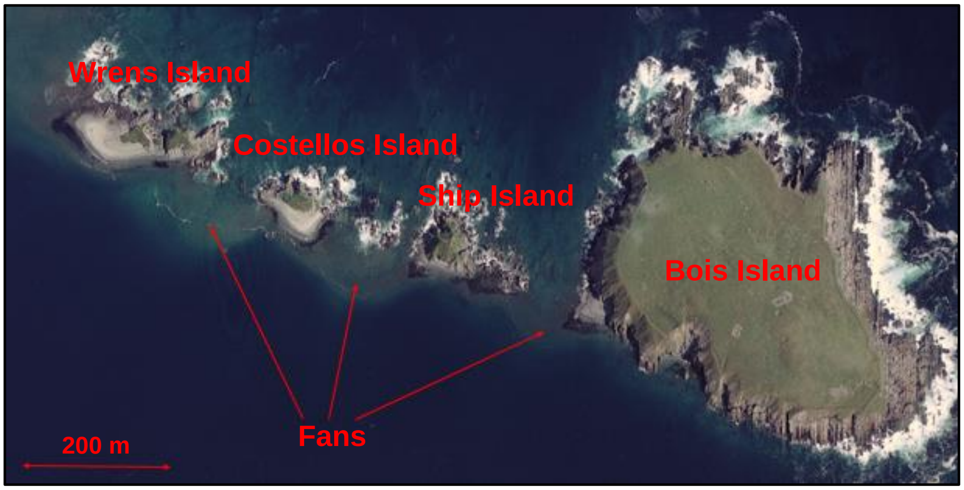


Figure 4.2. The islands and underwater fans of the sill. (Newfoundland and Labrador Government, Aerial Photograph 95044-10).

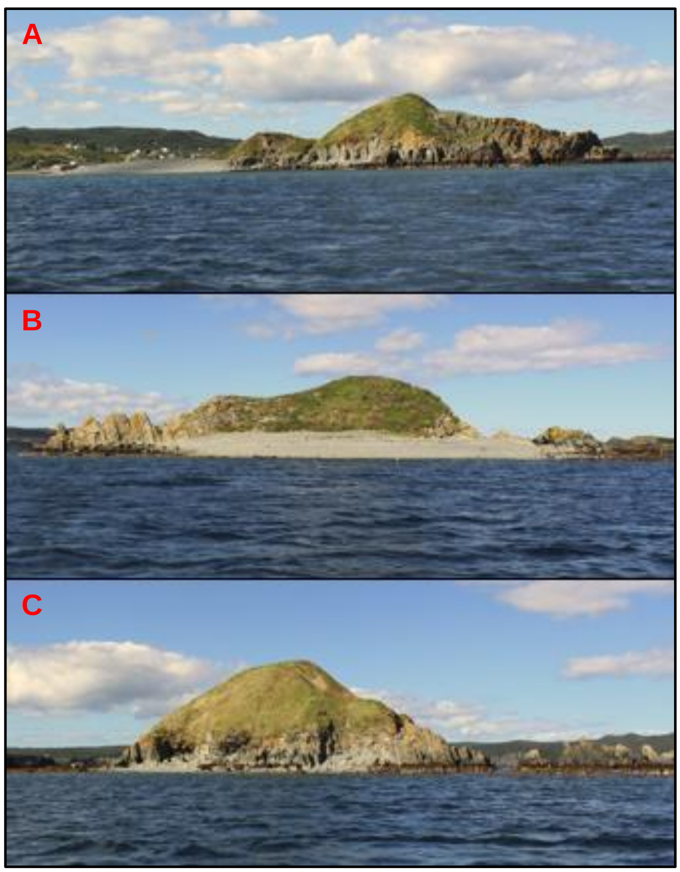


Figure 4.3. Islands on the sill. **A:** Wrens Island with associated cobble barrier. **B:** Costellos Island with associated cobble barrier. **C:** Ship Island with the remnants of a cobble barrier. Bois Island is discussed separately.

The northeastern sides of the islands consists of steep rocky cliffs that transition to eroded jagged bedrock and eroded angular blocks forming small rock platforms at msl. The seaward edge of these platforms consists of jagged and eroded rocky cliffs that drop off steeply into deeper water. Differential erosion is prevalent with numerous examples of less erosion-resistant stratigraphic beds eroded from between more erosion-resistant beds. Joints and fractures are prevalent indicating weathering and erosion caused by freeze-thaw cycles where the expansion of joints and fractures results in the release of angular blocks. The majority of this eroded material is transported towards and into the harbour by large waves and currents from a north-easterly direction.

The southern sides of Wrens Island and Costellos Island (Figure 4.2) consist mostly of multiple berm barriers of pebble, cobble and boulder clasts. Waves were observed breaking on the N-NE side and refracting around the islands to travel shore-parallel to these barriers. Examination of the till cap and eroded rock reveal that large waves break around and, at times, over these islands to further denude the till veneer cap and remove and erode blocks of sedimentary rock from the north side to the south side. During site investigations in September and October 2014, the steeply dipping sedimentary stratigraphy was denuded except for the remnants of the till cap on the N-NE side with numerous open joints and fractures susceptible to frost action. Large angular pieces of bedrock with a maximum observed size of 0.8 m wide and 0.3 m thick were observed in various positions on and around the islands, including on the barrier surface on the south side. The presence of angular blocks in-situ, around the edges of the cliffs, and on the barriers indicates transport by large waves. Evidence of wave and current transport is seen where large blocks (0.4 m x 0.3 m) have been deposited on the barriers, separated from the source rock. Underwater video also revealed some angular blocks and scattered smaller angular clasts off the beach step. Video also revealed similar angular blocks around outcrops and seaward of Costellos and Ship Islands, a result of back wash from large wave runup on the northern rock platforms of the islands.

On the harbour-side of the sill, the three islands have mostly retained till veneer on the tops and southerly facing slopes. There is evidence of till erosion by freeze-thaw cycles, rainfall, and large waves. Grasses dominate most of the slopes down to either a bedrock shore or rounded-angular cobble barriers. These barriers are shaped by waves and currents from the north-northeast which refract around the islands creating high current velocities. The barriers are also impacted by occasional wave action from the east through The Narrows.

The submerged areas between the islands are a complex arrangement of exposed and submerged bedrock, eroded bedrock blocks, and gravel accumulations. An analysis of aerial photos, Google Earth and field observation via underwater camera from an inflatable boat revealed underwater fans between Wrens Island and Costellos Island, Costellos Island and Ship Island, and Ship Island and Bois Island (Figure 4.2). These fan deposits occur on the southern edge of the sill, extending from shallow water between the islands into Ferryland Harbour. The underwater fan structure indicates clast transport and deposition by waves and currents traveling through the shallow waters between these islands. Occasional sea ice under the influence of northeast wind and surge is also partially responsible for the transport of blocks and the shape of the sloped shallow areas. Underwater video reveals that, in some places, these fans are connected to the barriers by a slope controlled by waves and currents. There are very few clasts along the northern edge of the sill. This indicates that some of this sediment may be antecedent, while much of the material is a result of eroded bedrock from the north side and, to a lesser extent, from around the islands where exposed bedrock and tills continue to be eroded and transported into Ferryland Harbour.

Multiple field observations indicate that the sill provides moderate protection for Ferryland Harbour against very large waves from the NE. This is the case especially at low low water when most of the jagged bedrock sill is exposed, blocking large waves and moderate surge. However, this effect is lessened during high high water conditions and surge when water depths exceed 2 m over the sill. The result is that large waves and currents enter into the harbour and cause erosion to most of the shoreline, especially along the Colony of Avalon Site at the harbour front and along Route 10. All local accounts and system observations indicate that these islands have eroded and continue to erode with every successive major storm event (erosion of till and bedrock blocks). Erosion rates cannot be quantified, due to the lack of large waves and surge from the N-NE during the study period, and the absence of suitable baseline or previous photogrammetric data.

4.2.2 Bois Island

Bois Island is the largest of the islands in the Ferryland Harbour System and is also the most archaeologically significant. Although not a formal Provincial Historic Site, the Island is registered in the Provincial Archaeological Site Inventory and is protected under the Historic Resources Act (M. Drake, Pers. Comm., June 4, 2015). The island contains three documented gun batteries and a fourth undocumented gun battery dating to 1746 or before. Ordnance pieces and artifacts date to the early 1700s, indicating settlement and temporary inhabitation by civilians and military personnel who defended Ferryland during the 17^{th} to 18^{th} century. Figure 4.4 shows the general location of the gun batteries.

Figure 4.4. Gun Batteries on Bois Island. North is up. (Adapted from Newfoundland and Labrador Government, Aerial Photograph 95044-10).

The rocky shoreline of the island varies in slope and elevation with aspect and exposure. The eastern shoreline consists of an eroding low angle rocky slope with bedding planes normal to dominant wave approach. The northern shoreline consists of steep rocky cliffs with sea caves, remnant eroding stacks from former arches, and eroding till cliffs due to bedding plains at oblique to shore-parallel orientation to large N-NE waves. The western and southern shorelines consist of steep rocky cliffs with an eroding till cap. A cuspate spit on the southwest shoreline marks the convergence of waves and current from the N-NE and E. Sediments in this spit are from rock fragments and material eroded from the rocky cliffs and till cliffs on the north and west side, and the south side during wave and current action from the N-NE and E respectively.

The island shows multiple signs of bedrock weathering and erosion. Till veneer erosion is prevalent on most bluffs. Freeze-thaw heave in the rocky cliffs (joints, fractures, and bedding plains) and on the till cliffs is the dominant cause of erosion, followed by transport via rainfall and gravity. Large waves and currents transport all but the largest pieces away from the base of the rocky cliffs. Residents described an event similar to a combined debris avalanche and block slide in 2012 on the western till slope approximately 30 metres above msl (Figure 4.5A). From site observation, this slope failure was caused by a combination of cliff erosion and debris slide. Figure 4.5B shows a similar example directly east of the 4-Gun Battery (Figure 4.4).

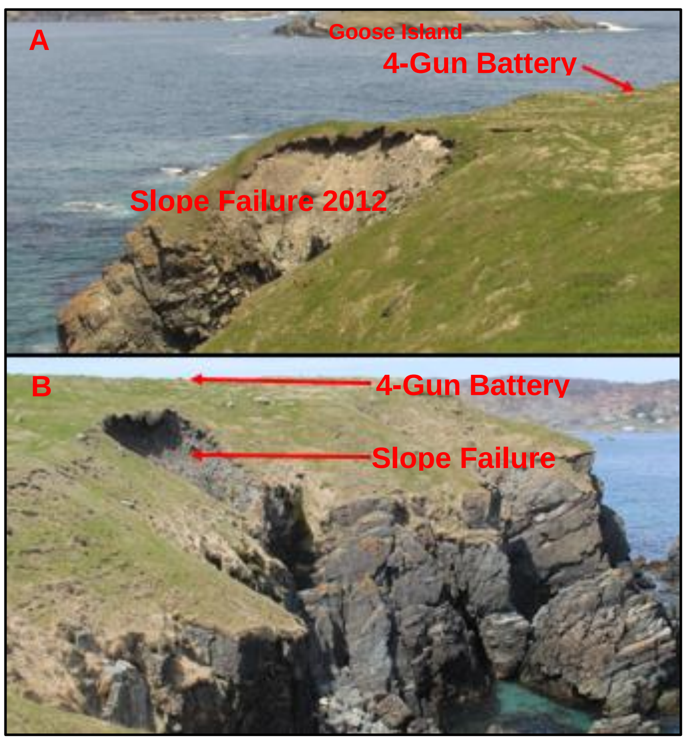


Figure 4.5. Slope Failures near 4-Gun Battery. **A:** Slope failure west of the 4-Gun Battery in 2012. **B:** Slope failure east of the 4 Gun Battery prior to 2012.

Photographs taken of the island and information from residents indicated that some of the ordnance from the batteries was at risk of being eroded. Other pieces had been displaced and have fallen to the rocky shoreline of the island. A site visit on June 5, 2015 revealed the location of four gun batteries, 17 ordnance pieces and two potential locations. Table 4.1 shows locations for the ordnance. Figure 4.4 shows the main gun batteries on the island and Figure 4.6 shows the location of each ordnance piece found during a site visit on June 5, 2015.

Table 4.1. Location information for ordnance on Bois Island and Ferryland Head North.

Date Collected	By	Battery	Type	Descriptor	Latitude	Longitude	Elvation (m)	Azimuth (Grid)	Exposure	~ Distance from Bluff
2015-06-05 10:57	Eric Watton	BOIS 6 Gun	Assume Demi Cannon	6.1	N47 01.584	W52 51.931	24	140	Exposed, At Risk	0 m In Eroding Bluff
2015-06-05 10:58	Eric Watton	BOIS 6 Gun	Assume Demi Cannon	6.2	N47 01.583	W52 51.934	25	154	Completely Covered	<2 m
2015-06-05 10:58	Eric Watton	BOIS 6 Gun	Assume Demi Cannon	6.3	N47 01.586	W52 51.939	24	211	Completely Covered	<2 m
2015-06-05 10:59	Eric Watton	BOIS 6 Gun	Assume Demi Cannon	6.4	N47 01.588	W52 51.942	24	246	Partially Covered	<2 m
2015-06-05 10:59	Eric Watton	BOIS 6 Gun	Assume Demi Cannon	6.5	N47 01.590	W52 51.945	25	222	Partially Covered	<2 m
2015-06-05 11:00	Eric Watton	BOIS 6 Gun	Assume Demi Cannon	6.6	N47 01.593	W52 51.950	24	~ 220	Undetermined - Assumed Covered in Last Ordnance Position	<2 m
2015-06-05 11:31	Eric Watton	BOIS 8 Gun	Assume Demi Cannon	8.1	N47 01.551	W52 51.732	15	44	Partially Covered	<3 m
2015-06-05 11:39	Eric Watton	BOIS 8 Gun	Assume Demi Cannon	8.2	N47 01.549	W52 51.733	16	86	Almost Completely Covered	<3 m
2015-06-05 11:40	Eric Watton	BOIS 8 Gun	Assume Demi Cannon	8.3	N47 01.547	W52 51.735	16	160	Partially Covered	<3 m
2015-06-05 11:40	Eric Watton	BOIS 8 Gun	Assume Demi Cannon	8.4	N47 01.545	W52 51.736	15	154	Partially Covered	<3 m
NA	Eric Watton	BOIS 8 Gun	Assume Demi Cannon	8.5	NA	NA	NA	NA	Undetected - Assume Between 8.4 & 8.6	<3 m
2015-06-05 11:45	Eric Watton	BOIS 8 Gun	Assume Demi Cannon	8.6	N47 01.541	W52 51.742	15	128	Almost Completely Covered	<3 m
2015-06-05 11:45	Eric Watton	BOIS 8 Gun	Assume Demi Cannon	8.7	N47 01.539	W52 51.743	15	118	Almost Completely Covered	<3 m
2015-06-05 11:48	Eric Watton	BOIS 8 Gun	Assume Demi Cannon	8.8	N47 01.538	W52 51.747	16	138	Almost Completely Covered	<3 m
2015-06-05 12:03	Eric Watton	BOIS 2 Gun	Assume Demi Cannon	2.1	N47 01.671	W52 51.808	11	44	Partially Covered	<2 m
2015-06-05 12:14	Eric Watton	BOIS 4 Gun	Assume Demi Cannon	4.1	N47 01.698	W52 51.935	18	NA	Exposed, At Risk	0 m In Eroding Bluff
2015-06-05 12:14	Eric Watton	BOIS 4 Gun	Assume Demi Cannon	4.2	N47 01.705	W52 51.937	1	NA	Eroded, On Rocky Shore	Eroded
2015-06-05 12:14	Eric Watton	BOIS 4 Gun	Assume Demi Cannon	4.3	N47 01.705	W52 51.937	1	NA	Eroded, On Rocky Shore	Eroded
NA	Eric Watton	BOIS 4 Gun	Assume Demi Cannon	4.4	NA	NA	NA	NA	Undetected - Assume on shoreline Not Visible or Lost	Eroded
2015-06-05 13:56	Eric Watton	FH 2Gun	NA	Batt2C	N47 01.337	W52 51.505	~ -2	NA	Local Knowledge-Eroded, In Water-No Visual	Eroded
2015-06-05 13:56	Eric Watton	FH 2Gun	NA	Batt2C	N47 01.337	W52 51.505	~ 2	NA	Local Knowledge-Eroded, On Rocks-No Visual	Eroded

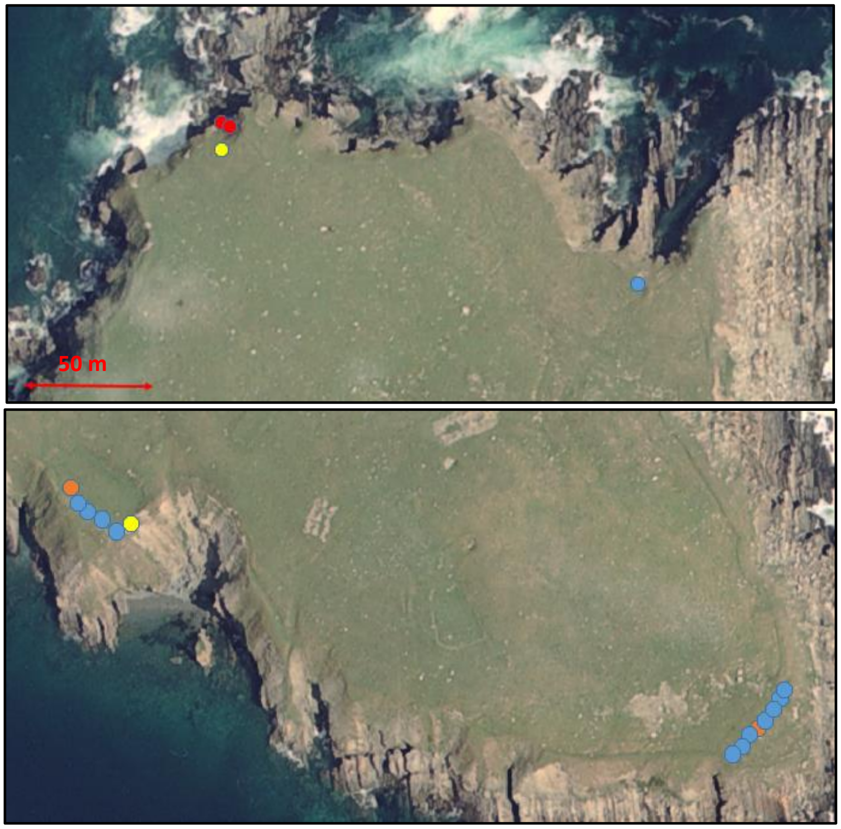


Figure 4.6. Locations of ordnance. North is at the top. Blue indicates some nearby erosion and in-situ, orange indicates possible location (visually undetected), yellow indicates at risk via erosion, and red indicates eroded and displaced (Adapted from Newfoundland and Labrador Government, Aerial Photograph 95044-10).

Erosion is impacting all batteries. The ongoing erosion at the 6-Gun Battery is shown in Figure 4.7. This ordnance piece is at risk and will likely fall soon based on the lack of supporting sediment and seaward tilt angle. A debris slide has also impacted the western edge of this battery, although no ordnance is directly at risk. Erosion is threatening the 8-Gun Battery as shown in Figure 4.8. Freeze-thaw and rainfall erodes the till cliff while occasional very large waves wash sediment from the base of the cliff.

Figure 4.7. 6-Gun Battery. Erosion of ordnance due to slope processes. June 2015. 5 of 6 ordnance pieces were located with one ordnance piece at risk of erosion and one visually undetected piece. However, movement of a compass needle and light probing indicated a possible location and a GPS position was taken. The pocket beach and area to the left is the primary area subject to erosion from freeze-thaw cycles and easterly waves. Photo taken from N 47° 1.564', W52° 51.883' looking West.

Figure 4.8. Location of ordnance at the 8-Gun Battery. The orange arrow near middle indicates the possible location of the undetected ordnance at this site located by ground thumping and compass needle movements. Inset shows eroding till cliff along the SE flank of this site – red arrow showing one of the ordnance locations. Photo taken from N 47° 1.566', 52° 51.751' looking SE.

The 2-Gun Battery is also being threatened by freeze-thaw and rainfall on the till cliff (Figure 4.9). One ordnance piece is in place, however, a small indentation (just above the existing in Figure 4.9) indicates that a second ordnance piece was also in this battery. The location of this piece is unknown. The 4-Gun Battery is almost completely eroded with one ordnance piece in-transit down the till cliff and two pieces on the rocky shoreline (Figure 4.10). The location of the fourth piece is unknown. A detailed shoreline survey was not done in this area.

Figure 4.9. 2-Gun Battery. **A**: Ordnance with erosion left. **B**: Eroding till cliff with site sign directly below **A**.

Figure 4.10. 4-Gun Battery. **A:** the only remaining ordnance. **B:** two pieces of ordnance that have been eroded from the till cliff. The fourth piece could not be located and is assumed to have been eroded and transported offshore to the west. A shoreline investigation was not completed although the piece could not be seen from a boat.

Bois Island is a historically significant site that is undergoing erosion, causing the loss of major archaeologically significant artifacts including elements of military history. Several ordnance pieces have been undercut by erosion with the remaining pieces only a few metres away from being displaced. The island is also rich in other archaeological elements, indicated by former stone foundations, a well, and several other anthropogenic features.

Approximate erosion rates can be derived from the current positions of ordnance and the design of the intact batteries. An example of this is the 4-Gun Battery, which is almost completely eroded with one piece of ordnance in transit down the till cliff. If the remaining ordnance was positioned on the back of the fore berm as seen in the other batteries, then the edge of the till cliff must have been at least 3m seaward from the present position. If the ordnance was placed here in 1746, then in 269 years, approximately 3m of till cliff has eroded. This results in an estimated erosion rate of approximately 1.1m/century.

All Gun battery sites are under attack via freeze-thaw cycles, rainfall and gravity influences on cliffs, and wave attack from the NE (2-Gun and 4-Gun Battery) and Easterly wave influences (6-Gun Battery and the 8-Gun Battery). The evidence suggests that additional ordnance pieces will fall from the cliffs in the near future. The consequences are the loss of unique artifacts, heritage and military history, and the opportunity to include this information into the province's documented heritage.

4.3 The Narrows

The Narrows is the area of water between the southern rocky shoreline of Bois Island to the northern rocky shoreline of Ferryland Head, and is the only deep water access to Ferryland Harbour. It contains a sill between the Bois Island and Ferryland Head, separating the shallow water of Ferryland Harbour from the deeper waters offshore. The sea state in this area can become very rough with the interaction of currents, waves, and surge in and out of Ferryland Harbour. Large swell and wind-generated waves approaching from NE to E-SE are of particular concern as they enter The Narrows. These waves refract around the shorelines of Bois Island and Ferryland Head but also interact with, at times, opposing surface currents. From the location, orientation and shape of the pocket beach on Bois Island (below the 6-Gun Battery), the shape, orientation and geomorphology of Sandy Cove, The Narrows are the geomorphic influence that focuses wave attack on the southern shoreline of Bois Island and the Ferryland Head Isthmus. Wave interference was observed during low to moderate sea state with very rough water. Unpredictable rogue waves (>5 m) have been observed and their occurrences are well known by local fish harvesters. The eroded material in the Narrows area is transported by currents from the east to west (into the harbour). Current activity depends on several factors, including direction of storm waves, surge, and tide stage.

4.4 The Narrows to The Pool

The section of shoreline between The Narrows and Colony site near the outer armor stone of The Pool includes Sandy Cove, The Downs, and the Colony of Avalon harbourside.

4.4.1 Ferryland Head and 'Cannon Gulch'

Ferryland Head North forms the southern shoreline of The Narrows. The segment is defined by steep rocky cliffs, inlets eroded into weak stratigraphic units, the remnants of Deadman's Gulch (a former sea cave), and rocky shoreline from the eastern extent of Ferryland Head to the eastern extent of Sandy Cove (Figure 4.11A). The reflective shoreline in combination with the southern steep rocky cliffs and shoreline of Bois Island funnel and refract oceanic waves and surge into Ferryland Harbour. The waves refract to the south at high water or during surge events into Sandy Cove, causing the undercutting of the north slope of Ferryland Head Isthmus.

According to local knowledge and site observation, a 2-Gun Battery (est. 1700s) existed on the north shore of Ferryland Head on a former till cliff that has been eroded (Figure 4.11A). According to fish harvesters and residents, the ordnance pieces have been eroded from the battery and are now separated, with one submerged in seawater and visible at low water during calm conditions, and the other perched on a rock ledge concealed from seaview by an outcrop. The ordnance pieces are larger (greater than 6 inch inside diameter – assumed Demi Cannons) than are the pieces on Bois Island. The ordnance pieces are significant due to their larger size and undocumented location. Several site visits were attempted, but the sea state and lack of landing spots in the narrow gulch prevented shore access or underwater camera deployment. The site is significant due to the possible presence of ordnance and may contain new information regarding military history.

Figure 4.11. 2-Gun Battery at Ferryland Head. North is up in **A**. **A:** Location of 2-Gun Battery (red rectangle) and eroded ordnance pieces (red dots) (Newfoundland and Labrador Government, Aerial Photograph 95044-10). **B:** approximate location of ordnance pieces (red Arrows).

4.4.2 Sandy Cove Barrier System

Sandy Cove (Figure 4.12), and the unconsolidated slope to the gravel access road, form the northern section of the Ferryland Head Isthmus. The cove contains a 200 m long barrier that is semi-sheltered from large swell and waves from the open ocean by Bois Island, the sill to the north, and the northern extent of Ferryland Head to the east. The barrier is flanked by an exposed sandstone cliff to the east and rocky shoreline to the west. Cusps form on the western half of the barrier and range from 1m H X 6m W X >20m L to smaller cusps averaging 0.5m H X 2m W X 4m L. Large waves enter through The Narrows and refract southward, causing changes in barrier morphology, sediments, and slope undercutting. Smaller waves (generally < 1 m) approach the barrier from the northwest, either from wind-generated waves across the harbour or from refracted waves through the gap between Bois Island and Ship Island. The barrier consists of angular to rounded boulders to the east and cobbles to sand-sized clasts forming approximately half the length of the barrier to the west. This clast arrangement is a result of transport of boulders by waves from the sandstone cliff to the east and the finer sediments as a result of till slope erosion (creep and undercutting) and occasional longshore current transport from the west. Figure 4.12 shows the barrier with increasing barrier elevation (A) and increasing barrier width (B) from east to west (right to left). This is evidence of the dominant wave and current direction from refracted waves entering through The Narrows. The sediment is piled higher to the west with the rocky shoreline serving as an obstruction to further westerly alongshore transport.

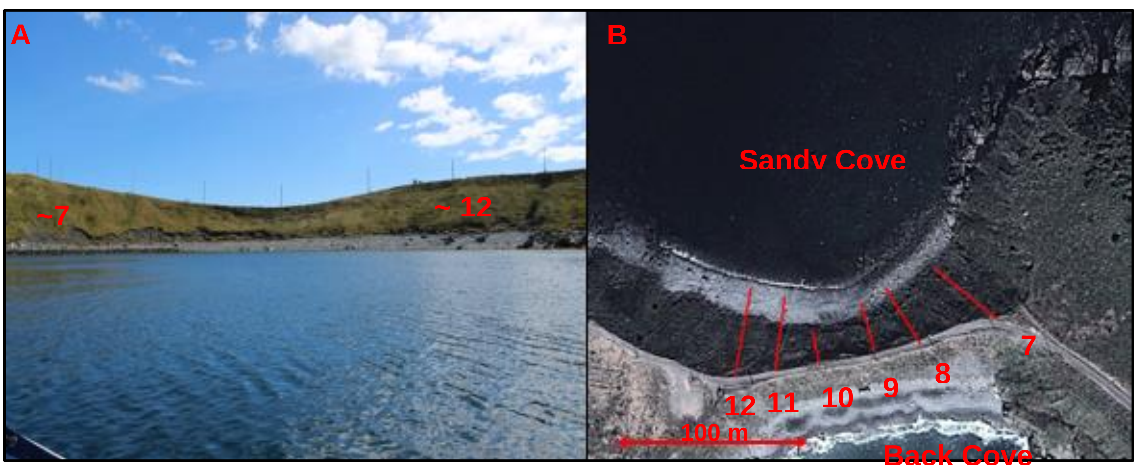


Figure 4.12. Sandy Cove. **A:** the northern aspect showing slope erosion due to water drainage, undercutting, and failing gabion/retaining wall. **B:** the planview of SBP 7-12. SBP-10 was cut off due to RTK receiver issues (Google Earth Image). Google Image is not georeferenced to MTM datum.

The wave and current transport rates is dependent on many factors including longshore current velocity and longshore wave power (Table 4.2). Longshore Current Velocity (V_1) is calculated using the following formula (McNeil, 2009):

$V_1 = 1.17\sqrt{(gh_1)}\ \sin\alpha\ \cos\alpha$ **(Equation 1)**

Where, g = gravity (9.8 m/s^2), h_1 = wave height, and α = angle of incidence (from shore normal).

Longshore Wave Power (P_1) is calculated using:

$P_1 = Eu\ \sin\alpha\ \cos\alpha$ **(Equation 2)**

where **$E = \frac{1}{2}\rho gh^2$** (Wave Energy Density)

Where, $\mu = \sqrt{(gd)}$ and p = density of salt water (1026 kg/m^3), and d = water depth (off beach step).

The dominant easterly wave approach is from refracted waves from The Narrows to the east. The depth of water off the beach step at low tide is 0.5 m, high tide 2.1 m, and high tide plus surge at >3 m. The wave heights range to an observed 2.5 m from the east and up to 1 m from the west (storm conditions exceed 2.5 m). Easterly waves approach at a maximum of 30° and northwesterly waves approach at a maximum of 30° at SBP-9. The northwesterly waves are either from wind-driven waves or from large NE waves that are refracted around the western shoreline of Bois Island (lesser wave height at impact).

Table 4.2. Sandy Cove barrier - wave energy and longshore transport rates under different water levels and wave heights.

Wave Approach	Water Level	Water Depth	Wave Height (m)	V_1 (m/s)	E (J/m^{-2})	P_1 (kW/m)
E-NE	Low Tide	0.5	1	1.5	5032.3	4506
			3	2.6	45290.7	40554.1
	High Tide	2.1	1	1.5	5032.3	9234.6
			3	2.6	45290.7	83111.2
	Surge (0.9m)	3.0	1	1.5	5032.3	11037.4
			3	2.6	45290.7	99336.8
NW	Low Tide	0.5	0.5	1.0	1258.1	1126.5
			1	1.5	5032.3	4506.0
	High Tide	2.1	0.5	1.0	1258.1	2308.7
			1	1.5	5032.3	9234.6
	Surge (0.9m)	3.0	0.5	1.0	1258.1	6821.6
			1	1.5	5032.3	11037.4

The longshore current velocity is calculated as 1.5 m/s and 2.6 m/s (E-NE) at 1 m and 3 m wave heights, and 1.0 m/s and 1.5 m/s (NW) at 0.5 m and 1 m wave heights. The longshore wave power also increases with depth of water, suggesting that larger waves move more water longshore than smaller waves. As waves increase in size, and water depth increases (surge), longshore energy increases, resulting in the longshore motion becoming relatively more significant than shore-normal energy. Large easterly approaching waves effectively cancel any refracted waves from the NW: the waves are large enough to cause a significant westerly longshore current that blocks any refracted NW waves or related currents.

Increased longshore current on the barrier face and toe-of-slope transports available materials to the west, as seen in the barrier face heights in Figure 4.13. This is also seen in the clast arrangement in profiles (Figure 4.14) where a boulder fabric on the eastern extent of the barrier (SBP8) transitions to a cobble assortment with transient berms (SBP-11 to SBP-12). The cobble location indicates dominant wave transport from east to west with higher and steeper berms after higher wave and water level events. In addition, some cobbles from this area of the barrier are transported further to the west along a short segment of rocky shoreline.

Six slope-barrier profiles (SBP) were measured during RTK surveying in July 2014 (SBP 7-12 in Figure 4.12B) and represent the geomorphology during this time only. The baseline data provided can be using for future monitoring. Each profile was oriented based on slope access and spacing to allow near shore-normal placement. Slope Nails were established at 0.00 near the edge of the gravel road, -7.00 m, and -14.00 m slope distance, and remain in-situ for future monitoring. The profiles were measured down the slope and across the barrier to the edge of water to establish baseline slope and barrier morphology, erosion features, and enable slope monitoring.

Figure 4.13 shows a comparison of barrier face width to elevation. Barrier face width is defined as the profile in the horizontal distance between the Highest Barrier Elevation landward (HBE) and the water level during the survey. The highest elevation is also measured at this point unless a berm in the profile is higher, which then it becomes the highest elevation.

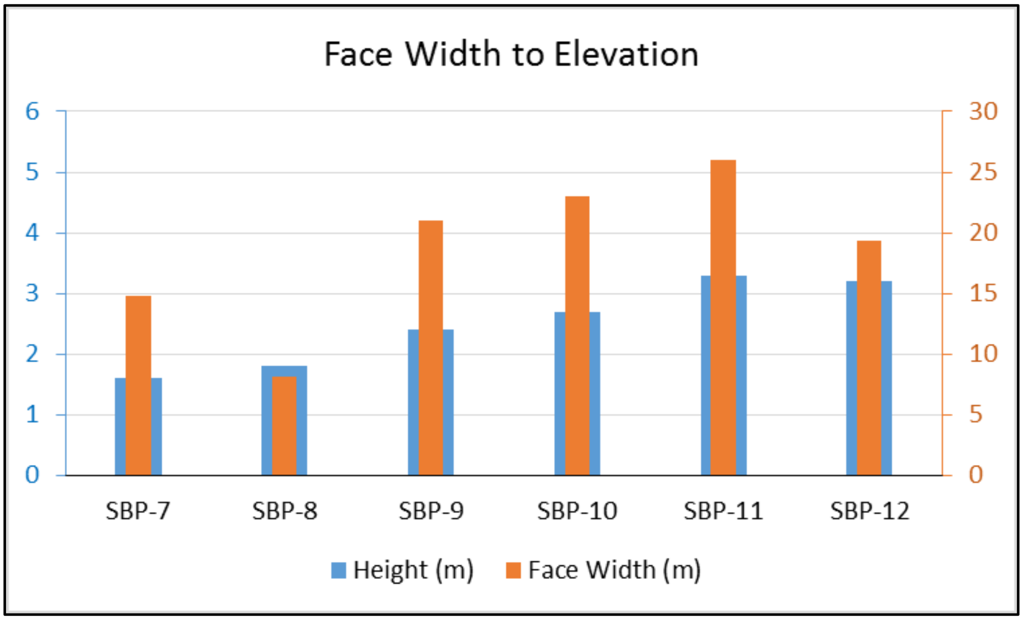


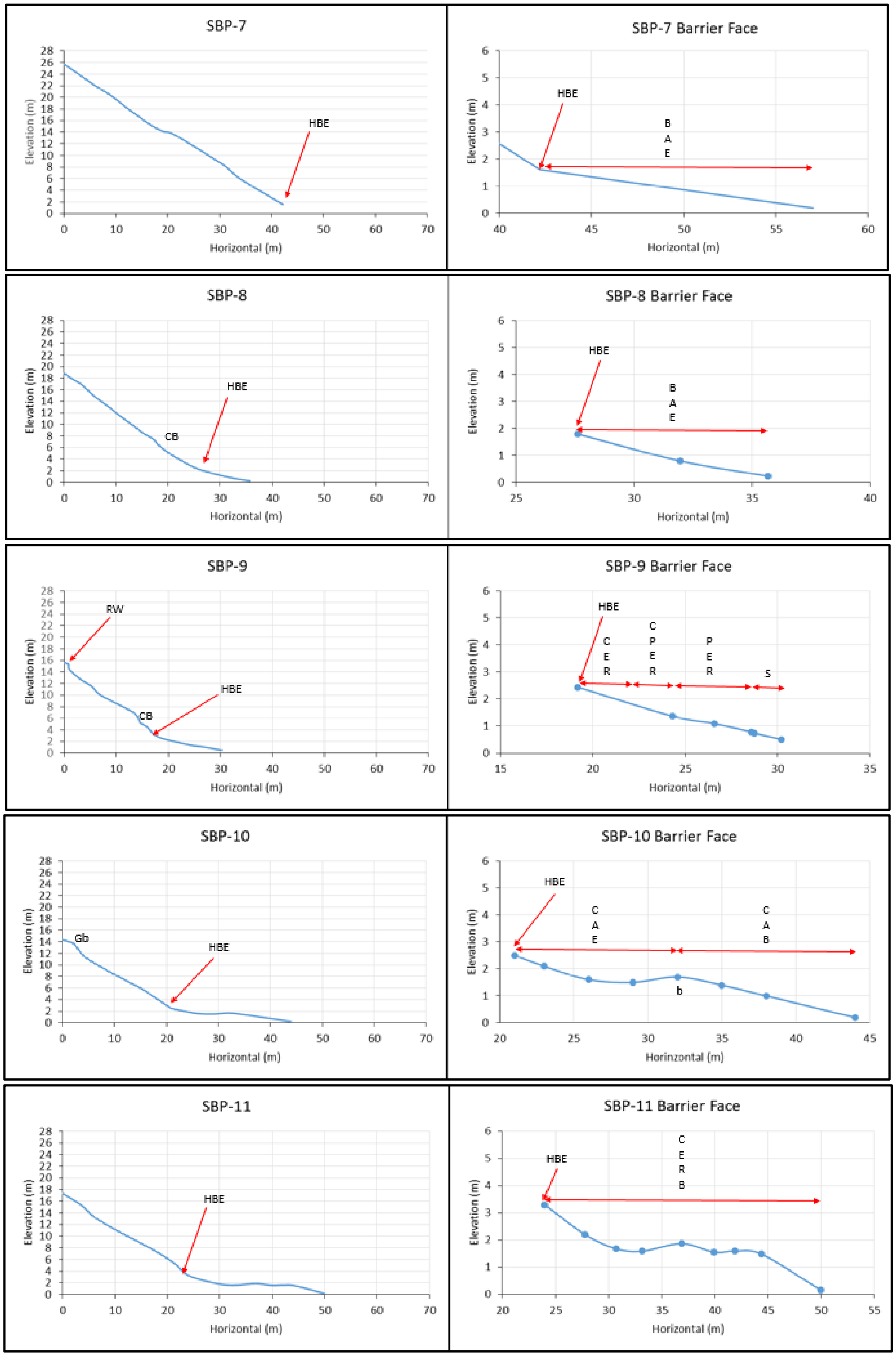
Figure 4.13. Sandy Cove barrier face width to barrier elevation comparison.

The barrier increases in elevation from SBP-7 to SBP-11 with a slight drop at SBP-12. The barrier face width also generally increases from SBP-7 to SBP-11 with a decrease at SBP-12. The lesser barrier elevation and face width at SBP-8 is due to the proximity of a transition from a boulder barrier to a sand and pebble barrier face – sand and pebbles have been deposited west of SBP-8. The lower barrier elevation and narrower face width at SBP-12 is a result of dominant E-W longshore current and sediment transport over the low rocky shore protrusion on the west end of the barrier. Sediment is trapped against the eastern edge of this protrusion. Once the trap is filled, any excess is transported over the protrusion to the west. This barrier was observed over 40 times, and the sediment pattern represents the dominant wave approach and sediment transport for this barrier. As such, the pattern indicates that waves and sediment transport during the time of this study has remained with little change in height to face width in the transects along the barrier. This indicates that waves refracting around Ferryland Head consistently approach the barrier in a similar way with every wave and surge event. Cobbles and pebbles are transported across the boulder fabric and toward the west end. Clasts here are reworked from these waves and smaller waves from the N-NE. This pattern also aligns with local accounts and observations of wave approach.

The slope barrier profiles (Figure 4.14) are described using codes (labels in the figures) contained in Table 4.3. The left part of each figure shows the barrier and back barrier features. The figure to the right shows the barrier face features beginning at the Highest Berm Elevation (HBE shown in the left figure) and running to water level. The blue line (both left and right figures) and the blue markers (right figure only) indicate the measured profile and major points respectively. The red horizontal lines and the labels (e.g. CER) in the right figures indicate sediment type. Labels directly above the profile indicate surface elements (e.g. "M" for Marine Organics) and labels below the profile indicate geomorphological features (e.g. "B" for Berm). This is baseline information and includes profile descriptions to allow for detailed future monitoring.

Table 4.3. Code and descriptions for barrier profile interpretation.

Code	Description	Code	Description
AS	Armour Stone	ATV	ATV trail
BB	Back of barrier	BW	Breakwater
BBW	Profile at beginning of breakwater	CB	Cut bank - due to undercutting
EBW	Profile at end of breakwater	FH	Fire hydrant
FW	Fresh water	HBE	High barrier elevation during survey
Gb	Gabion	GR	Gravel road
PR	Paved road	Cb	Cribbing
T	Walking trail	WL	Water level
B	Boulder	E	Equantic
C	Cobble	R	Roller
P	Pebble	B	Blade-shaped
S	Sand	D	Disc-shaped
b	Berm	A	Angular-shaped
RW	Retaining wall	Grass	Terrestrial organic
ATVc	ATV compaction	M	Marine organic


SBP-7
Elevation (m)
Horizontal (m)
HBE
SBP-7 Barrier Face
Elevation (m)
Horizontal (m)
HBE
B A E
SBP-8
Elevation (m)
Horizontal (m)
HBE
CB
SBP-8 Barrier Face
Elevation (m)
Horizontal (m)
HBE
B A E
SBP-9
Elevation (m)
Horizontal (m)
RW
HBE
CB
SBP-9 Barrier Face
Elevation (m)
Horizontal (m)
HBE
C E R
C P E R
P E R
S
SBP-10
Elevation (m)
Horizontal (m)
Gb
HBE
SBP-10 Barrier Face
Elevation (m)
Horinzontal (m)
HBE
C A E
C A B
b
SBP-11
Elevation (m)
Horizontal (m)
HBE
SBP-11 Barrier Face
Elevation (m)
Horizontal (m)
HBE
C E R B

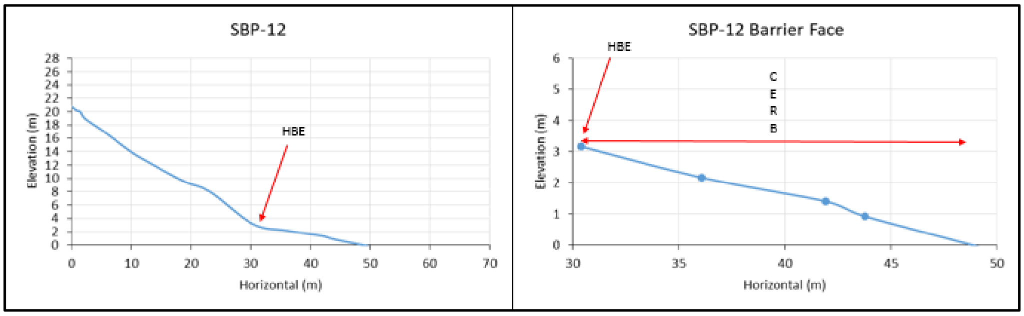


Figure 4.14. Six Slope-Barrier Profiles on the Sandy Cove System. HBE in SBP-7 is at large boulder barrier not accessible to waves. HBE is Highest Barrier Elevation during survey. SBP-10 is cut off at HBE due to RTK receiver reception.

SBP-7 consists of a grass-covered slope from 25.7 m to a sharply eroded turf edge at 8.1 m. From here to 1.5 m is an exposed till slope. From 1.5 m to water level at approximately 0.2 m consists of angular and equantic boulder fabric. This section was not surveyed due to slippery footing, but is indicated as a straight line to water level (0.3 m) at an estimated horizontal distance from HBE. The grass-covered slope shows signs of slumping. The turf edge to the HBE is exposed due to wave undercutting.

SBP-8 consists of a grass-covered slope from 18.8 m to 7.4 m where a sharp turf edge marks the beginning of an exposed till slope to 1.8 m. From HBE at 1.8 m to water level at 0.2m, angular and equantic boulders with sporadic cobbles are present throughout. The grass-covered slope shows shore-parallel openings in the sod indicating slope movement. The turf edge to HBE is exposed due to wave undercutting.

SBP-9 begins with the grass-covered road edge at 15.6 m dropping to the top of a retaining wall at 15.2 m (Figure 4.15). The bottom of the face of the retaining wall is 14.4 m, where a grass-covered slope continues to turf edge at 6.7 m. From here, the exposed till slope continues to HBE at 2.4 m where four sections of sediments cover the barrier to water level at 0.2m, with the upper edge of a cusp consisting of equantic and roller cobbles, unsorted equantic and roller cobbles and pebbles, equantic and roller pebbles, and sand to water level. The retaining wall is tipping downslope, with multiple occurrences of small slump sections towards the turf edge. The turf edge to HBE is exposed due to undercutting.

SBP-10 begins at the road edge at 14.4 m and drops to the supporting gabion at 14.0 m, of which the top surface is sloped away from the road to an elevation of 13.6 m. The compacted fill material at the bottom of the gabion (Figure 4.15) located at 12.0 m drops over a grass-covered slope to turf edge at 2.7 m. Problems with RTK equipment prevented measuring past this point, however, manual slope and run measurements (laser leveling and tape measure) reveal that the exposed till continues to 2.5 m. This is HBE, and two sections of angular and equantic cobbles followed by angular cobbles and boulders extend to water level at 0.2 m. The gabion is tipping downslope and the grass-covered slope from the gabion to the turf edge is broken in places by shore-parallel cracks which indicate slope movement. The turf edge to HBE is exposed due to undercutting.

SBP-11 begins at the road edge at 17.3 m and drops over a grass-covered slope to a turf edge at 3.29 m with a walking path crossing at an oblique angle at 12.5 m. The exposed till slope consists of angular boulders and cobbles from the turf edge to HBE at 1.5 m. From here, equantic and roller cobbles with sporadic partially buried angular boulders extend over two berms to water level at 0.2 m. The grass-covered slope show signs of rotational movement. The turf edge to HBE is exposed due to undercutting.

SBP-12 begins near the road edge at 20.2 m and drops over a grass-cover slope to 8.0 m where exposed angular boulders in till continues to HBE at 3.1 m. From here, equantic and roller cobbles with sporadic partially buried angular boulders extend over two berms to water level at 0.2 m. Slope movement signs are dominant, with soil creep on the upper slope, debris slide over the exposed section, and undercutting.

The profiles show a fabric of boulders (SBP-7 to SBP-9) and berm and cusp formation beginning between SBP-9 and SBP-10. Berms and cusps increase in elevation to west of SBP-11 where elevation decreases towards the rocky shoreline west of SBP-12. Sediment is transported from The Narrows along the shoreline, across the boulder fabric, and into the barrier area between SBP-9 and SBP-12. Large waves and current events transport some of this sediment further west into other pocket beach areas along the shoreline of The Downs. On rare occasions, waves (< 1m) from NW weather systems impact the barrier by refracting around the west side of Bois Island. During these events, sediment is reworked and berms and cusps eroded or accreted based on tide stage and duration of event. This system is dominated by shore-parallel transport from east to west with occasional perturbations from NW waves. Evidence of the small perturbations are minimal, with the occasional presence of cobbles from the west to the east only visible on the western extent of the boulder fabric (near SBP-9). Most observations show no cobbles on the western end of the boulder fabric. In addition, small cusps (<0.5 m in depth) in the lower berm of the western segment were observed on occasion with horns aligned slightly west from shore-normal. This also indicates low energy NW wave action. During large wave events (approaching through the narrows), cobbles in this area are transported to the west, leaving only the boulder fabric. Variations result from wave events and changes in the sediment budget caused by increased erosion of material from the eastern cliff or Ferryland Head Isthmus (higher barrier and increased face width), or sediment erosion caused by wave events at low low water that remove sediment from the barrier and transport it west (lower barrier height and decreased face width). This interpretation also suggests that large waves under surge conditions and reduced sediment supply from the eastern rocky shoreline will cause further undercutting of the till cliff that supports the road on the isthmus.

The steep slope from the barrier up to the gravel access road is mostly grass-covered. A section of gabion and retaining wall intended to support the north edge of the road is failing due to slope creep (Figure 4.15).

Figure 4.15. Looking east - gabion and retaining wall on north edge of road at Ferryland Head Isthmus in May 2013. **A:** looking west - gabion tipping downslope as creep continues. **B:** Retaining wall tipping downslope as creep continues.

Field observations and numerous local accounts suggest that Ferryland Head Isthmus is eroding on the north side. The gravel road surface is at risk of failure on the north side due to inadequate water drainage, compromised mitigation measures, and slope movement induced by wave undercutting. Runoff from rainfall was observed on many site visits. Surface runoff was observed flowing down and cutting channels in the east section of the road surface. In the spring of 2013, runoff eroded the side of the road surface and cut a channel down the slope onto the barrier. In 2013, this eroded section was repaired.

However, the water drainage now flows down the eastern grade to the gabion (Figure 4.16) where it flows under the gabion, down the slope, and across the barrier to the saltwater. The gabion and retaining wall supporting the northern road edge is failing, with observable change over the course of this study. The angle of the gabion wire cage and the retaining wall to plumb increased to the north from 12° in July 2013 to 16° on December 2014, indicating slope movement and probable added compaction of the road surface, especially in wet conditions when water flows from the road surface down behind these structures. Rainfall, water drainage from the road, and freeze-thaw cycles are the main factors causing slope instability, while wave and current undercutting is causing erosion at the toe-of-slope, further destabilizing the slope. Slope failure caused by the above factors and the continued use of motor vehicles on this roadway is likely to result in further movement, causing eventual road failure.

Figure 4.16. Sandy Cove Slope. **A:** shows former road runoff drainage channel (green linear vegetation) and slope failure/undercutting. **B:** shows failing gabion and residual water after rainfall drainage down the eastern road surface from Hurricane Gonzalo. **C:** shows slope drainage and debris flow with failed gabion and retaining wall above. Note: the square timber in **C** is from the failing retaining wall above.

Erosion from wave attack did not occur at the interface between the barrier and the till cliff during the study period. Evidence of this is the lack of freshly cut till cliff material at the toe-of-slope along the top of the barrier. Water flow from road drainage and some minor debris flow was noted. However, tape measure checks on the slope nails revealed no slope movement in the SBPs. A follow-up survey was not completed as no slope movement was detected and it would very likely show normal barrier face changes as described above. Longer term monitoring would be needed in order to detect changes, especially after heavy rainfall events.

4.4.3 The Downs – North Side

The north side of The Downs consists of a rocky shoreline with pocket beaches (average length ~50 m) from the western extent of Sandy Cove barrier to the Colony of Avalon site at the harbourside (Figure 4.17). Most of the toe-of-slope where the grassy slope meets the bedrock shows signs of wave and surge impact via undercutting. Differential erosion reveals the dominant east-west influence of larger waves and currents entering from The Narrows. The upper to mid slopes indicate creep movement with sporadic linear, partially grass-covered openings at normal to oblique angles to the bluff edge. Several places along the slope also show signs of rotational movement. Six monitoring slope nails and a top-of-slope/edge-of-road transect were established in a section of slope west of the gun battery to monitor slope movement, including the edge of the road (Figure 4.17). This section of road is at risk for failure due to improper water drainage, slope movement, and motor vehicle loading. Routine tape measure checks on these slope nails revealed no slope movement during the study period.

Figure 4.17. The Downs North. Differential erosion is evident from the sediment deposition to the east (right) of shore-normal outcrops. This is further evidence of dominant wave approach from the east and associated sediment transport. The slope monitoring site near the gun battery is shown. (Google Earth).

4.4.4 Colony of Avalon – Harbourside

The Colony of Avalon is adjacent to Ferryland Harbour on the western extent of The Downs (Figure 4.17 and Figure 4.18). RTK data, tape measurements, observation and local knowledge indicate that a till cliff flanking the northern edge of the Colony site is undergoing erosion measured (tape measure) at 0.10 m over 2 years (the study period), resulting from undercutting and mass movement through freeze-thaw and rainfall (Figure 4.18). Local knowledge indicates that the segment of coarse barrier shoreline has narrowed by approximately 5 m over ~ 60 years. The adjacent retaining wall and associated boardwalk on the northern edge of the Colony of Avalon site has continued to be undermined over the last 5 years. Further loss of topsoil could result in the loss of valuable artifacts, as some have been noted in the upper 0.60 m of soil and turf (Dr. B. Gaulton, Pers. Comm., October 20, 2015). Associated with this segment is the shoreline and shoal directly to the west (three red arrows in left of Figure 4.17) that has also experienced erosion (at an unknown rate). Local accounts indicate that a wide sandy walkable beach was present here approximately 60 years ago. Observation and tape measurements indicate that the outer edge of this shoal is approximately 20 m north of the existing armour stone on the north side of the spit.

Figure 4.18. Colony of Avalon – Harbourside. **A:** is Harbourside area of concern (Google Earth Image), **B:** is July 2013, and **C:** is December 2014. Disregard water level and barrier exposure. Note cliff erosion at the end of the boardwalk.

Large storm surges (>0.80 m) were not observed during the study period. However, detailed observations during a DTB-1 deployment during moderate NE winds, the location of the erosion at the end of the boardwalk, and local knowledge, reveal at least two specific conditions that result in marine erosion. One scenario occurs when high high water or surge events occur during a rising tide combined with moderate to large waves from the northeast. This results in an influx of water into the harbour, creating a west-east current from The Pool towards The Narrows (Figure 1.1). Waves, although dissipated by the sill, reach this shoreline and, combined with a moderate west-east alongshore current, result in wave attack at the face of the till slope and easterly transport of sediments. This also explains the erosion impact that is accentuated directly east of the boardwalk and lessens further east. The other condition is rarer and occurs as a result of waves approaching from the east at high high water or surge that are refracted through the Narrows to create a lower velocity alongshore current flowing east to west. This current and associated waves transport sediment from the till cliff west towards the shoal off The Pool. The current has lower velocity at this location due to the distance from The Narrows and the interference from the NE influences. The differential erosion (Figure 4.17) and the eroded face of the cliff (higher in the west than the east) indicates that the former scenario is more common. According to Aardvark Archaeology Limited (2006), a layer of organic matter, branches, and culturally-related material was discovered at ~1 – 1.5 m below water level (assume mid-tide range from pictures) during site excavation on the outer spit during a beach stabilization project in 2006. It is unclear as to the exact source of this material. However, the report suggests that the beach was once much lower and wider. This information aligns with local knowledge regarding a low-strung sandy beach in this area where people spent time at leisure activities (from numerous local sources).

4.5 The Pool and Water Level Measurements

The Pool is a shallow (< 4 m) bulb-shaped basin semi-enclosed by a fortified curved spit. The spit material consists of marine sediments, and multiple areas of artificial infills of varying thicknesses taken from nearby sources (e.g. quarry, barriers, till bluffs) (Figure 4.19).

The Pool is frequently subjected to very high and very low water levels accompanying harbour oscillations. The water movement and associated currents cause erosion of fill, damage to structures, damage to the Colony of Avalon lower site, and damage to small- to medium-sized motor vessels. Incorporating communication with local residents, business owners, Colony of Avalon Foundation researchers and staff, fish harvesters, and results from the use of various equipment and technology, the following subsections describe erosion causes and impacts.

Figure 4.19. The Pool. **Left:** is the western aspect taken from The Gaze in 2014. **Right:** is the Eastern aspect taken from The Downs.

4.5.1 Erosion

The main cause of erosion and related damage to land and property in The Pool is water currents associated with tidal action and frequent long period harbour oscillations. The current in the narrow shallow entrance to The Pool was measured using DTB-1 on several occasions. Both flood and ebb current velocities during oscillations (amplitude of >0.35 m and period 160 s) were > 2 m/s near the opening to The Pool. According to residents and fish harvesters, this represents calm water, compared with some past events where The Pool was likened to a washing machine with higher amplitudes and current velocities. Accounts of water resembling foam and visibility of the bottom at this location indicates that the oscillations exceeded >2.5 m. Residents also gave numerous examples of the small sheds (at the inside of the north armor stone) being afloat, stage floors inundated, and boats floating over docks. Using measurements from FLEWWL-1 and site grades taken with RTK, this would place the water level at > 2.8 m above CD. During the more than 40 site visits, additional pieces of the breakwater and dock structure in the Pool were noted at various locations including accompanying displaced marine organics forming a line > 2 m above CD.

Numerous observations reveals that erosion occurs on both flood and ebb of the oscillation. During flood and ebb, sediment and debris is eroded from the shore of the shallow entrance to The Pool. Where oscillations occur during low low water, sediment and debris is eroded from the bottom of the entrance to The Pool (depth < 0.5 m) by high velocity currents along the bathymetry. Sediment and fill is also eroded from the various segments of the shoreline during flood and ebb where higher velocity currents form along segments of the shoreline and in areas where water is forced between objects (e.g. wharf supports and cribbing). During these events, some of the suspended sediment is transported out of The Pool into Ferryland Harbour during ebb flow. This results in the erosion of banks and fill material supporting wharves, stages, retaining walls, and other shoreline supports. Erosion observed during several site visits is accentuated where currents flow between narrow passages such as the lower Colony of Avalon site and between cribbing and pilings. The eroded material may be transported along the shoreline, but more commonly into deeper water towards the center of The Pool. The destabilized wharves, stages, and shoreline supports eventually fail due to undermining. Residents and fish harvesters also state that many boats have been damaged from impact with wharves during oscillations, and from grounding during very low water. Numerous efforts, costing an unknown amount, have been attempted to repair the damage. However, the currents (related to oscillations) have not been addressed through any known methods or structural design.

An example of a minor harbour oscillation in The Pool occurred on November 28, 2014. Figure 4.20 shows four photographs that detail a small segment of this oscillation event.

Figure 4.20. A, B, and C show one period of an oscillation (~0.5 m) at The Pool on November 24, 2014 (there were more than 5 periods during this event). Photographs were taken at 12:51 (A), 12:53 (B), and 12:55 (C, D) respectively. C shows sediment laden water and floating debris at the end of the period. D, taken at the same time as C (secondary remote camera) shows flooding of the Lower Colony site. Water level in A, C, and D is approximately 2 m above the quays. The red arrows indicate the position of FLEWWL-1.

During this event, fine sediment was transported in the current. Larger sand- to cobble-sized fill materials were observed tumbling into the deeper water. Debris (round sticks in the water in 4.20A and D) from damaged shoreline supports was also moved and, in one case, a piece of a piling from a damaged seawall made impact with a smaller motor vessel on the opposite side of The Pool. Local knowledge indicate that past water level has risen above the floor of the white shed on many occasions (left in Figure 4.20A and C).

4.5.2 Water Level Measurement

The Onset HOBO dataloggers produced water level data via HOBOPro Software from the initial deployment on September 17, 2014 to the last readout for this study on April 30, 2015. Numerous tide anomalies and oscillations were noted. Surge as a result of Hurricane Gonzalo was also detected. From CD, the average water level was 0.79 m with a maximum water level at 2.07 m on November 22, 2014 (0.09 m above FLEWWL-1 reference point shown by red arrows in Figure 4.20) and the minimum water level at - 0.31 m below CD on January 22, 2015. The maximum barometric pressure recorded by HOBO U20-001-04 (#10508350) was 104.750 kPa on December 3, 2014 and the minimum pressure was 96.924 kPa on February 13, 2015. Barometric pressure in an open dynamic system such as coastal environments is only one factor in determining water level. Waves, runoff (high rainfall), wind forcing, local current and other factors also influence water level.

An example of surge and oscillations occurred as a result of Hurricane Gonzalo which grazed the southeast Avalon Peninsula in early to mid-morning of October 19, 2014. The tide was at neap, with measured average range of 0.6 m. The storm caused elevated water level due to low atmospheric pressure and surge during its passage. Figure 4.21 shows a comparison between water level, predicted water level and barometric pressure and Figure 4.22 shows the wind direction and speed as measured by FLEWWX-1.

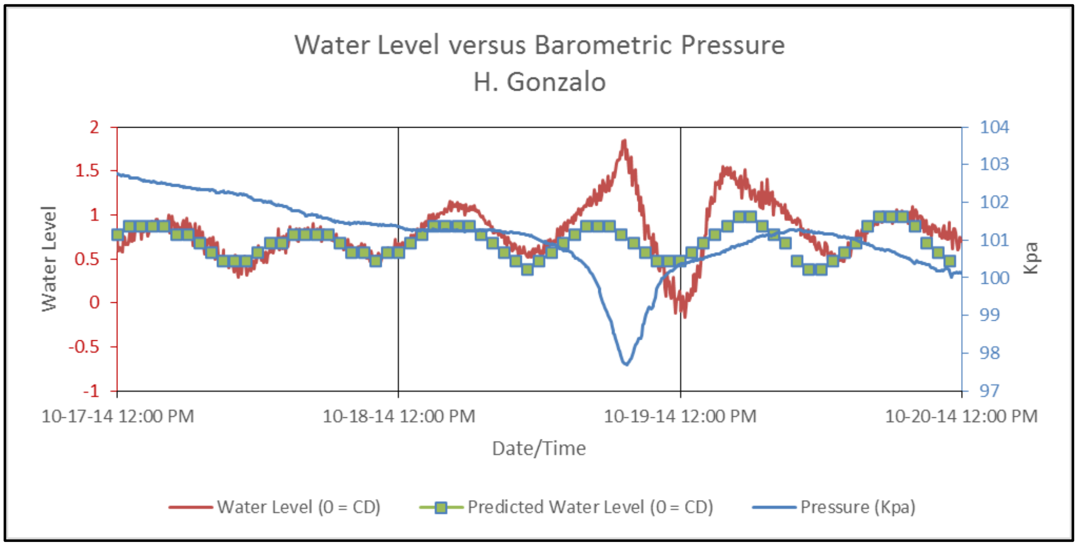


Figure 4.21. Water level changes during the passage of Hurricane Gonzalo.

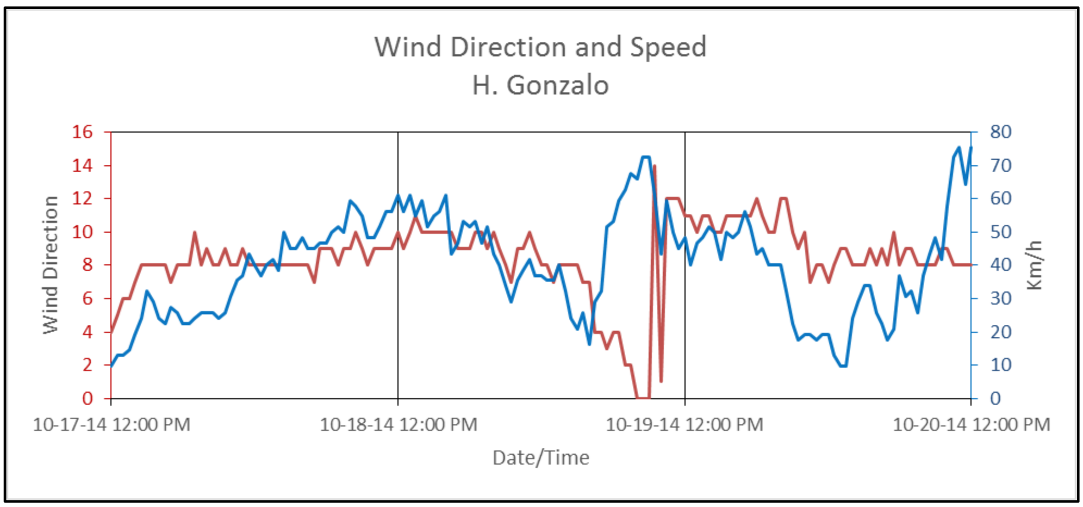


Figure 4.22. Wind speed and direction before, during and after Hurricane Gonzalo. Wind direction interpretation: N = 0, NNE = 1, NE = 2, ENE = 3, E = 4, ESE = 5, SE = 6, SSE = 7, S = 8, SSW = 9, SW = 10, WSW = 11, W = 12, WNW = 13, NW = 14, NNW = 15.

Figure 4.21 shows many oscillations in The Pool as shown by very sharp rises and falls in water levels over short time periods. Barometric pressure dropped gradually and then sharply during the overnight into the early morning of October 19th. The evening of the 18th shows a rise in tide (predicted and measured) slightly prior to the normal wave cycle. The seawater at this point was under the influence of surge being pushed ahead of the approaching Hurricane Gonzalo. Normal high tide was exceeded to an elevation of 1.856 m above CD at 07:15 AM. Oscillations occurred with amplitudes > 0.25 m and periods up to 130 seconds. The water then sharply dropped to low low tide before rising again, followed by two distinct oscillation events during the fall back to low tide and a return to normal tide cycle.

The wind speed increased just after midnight on the 19th, and shifted from southerly to northerly. According to residents, northerly to northeast winds result in high water levels in the harbour, but especially in The Pool.

A site visit on October 21 revealed varying amounts of shoreline erosion with an estimated 0.10 m of fill removed in the highest impacted area. This occurred adjacent to and under an older wharf (still in use). The observed erosion also included the removal of some shoreline fill near the supports for several wharves, including the wharf with FLEWWL-1. This fill was likely transported towards the bottom of The Pool (towards the center) as no obvious shoreline deposition areas were seen.

Accentuated water levels occur occasionally for no obvious meteorological reason. Figure 4.23 shows the highest recorded water level during a relatively calm period on November 22, 2014 at 7:40 AM. Figure 4.24 shows the corresponding wind paramters.

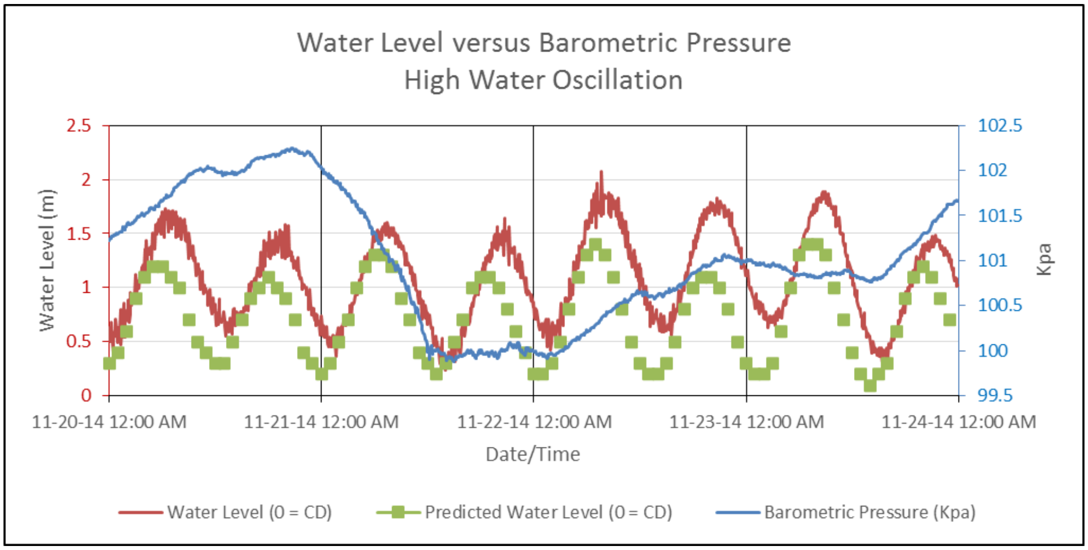


Figure 4.23. Highest recorded water level in datalogger deployment history (September 13, 2014 to May 31, 2015).

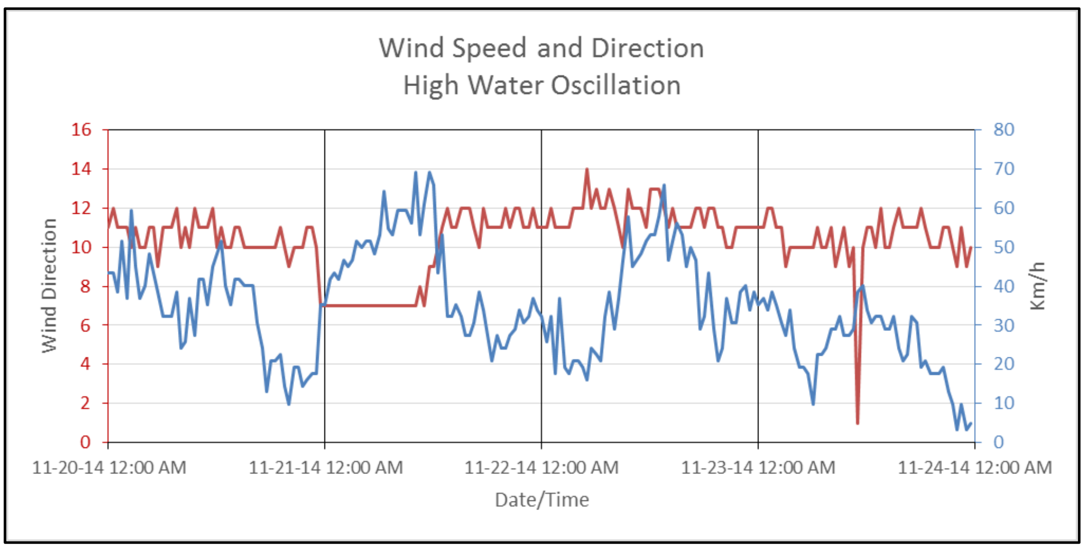


Figure 4.24. Wind speed and direction prior to, during, and after the highest recorded water level.

Figure 4.23 shows a number of features including higher than normal high tides and higher than normal low tides, numerous oscillations, a sharp drop in barometric pressure, and a long period oscillation with an amplitude of up to 0.8 m. The accentuated high high water seems to coincide with the low pressure over the area. However, the wind speed was fairly light and from the southwesterly direction, blowing offshore (Figure 4.24). The cause of this anomaly remains unclear. Most high and low tides are accompanied by oscillations of various amplitudes and periods.

The example and observation provided for Figure 4.21 and 4.22 indicate that surge and oscillations cause erosion on the shoreline of The Pool. Figure 4.23 and Figure 4.24 show numerous oscillations that may also contribute to erosion at the shoreline. There is a wealth of local knowledge regarding similar events.

The lowest measured water level occurred on January 22, 2015 (Figure 4.25).

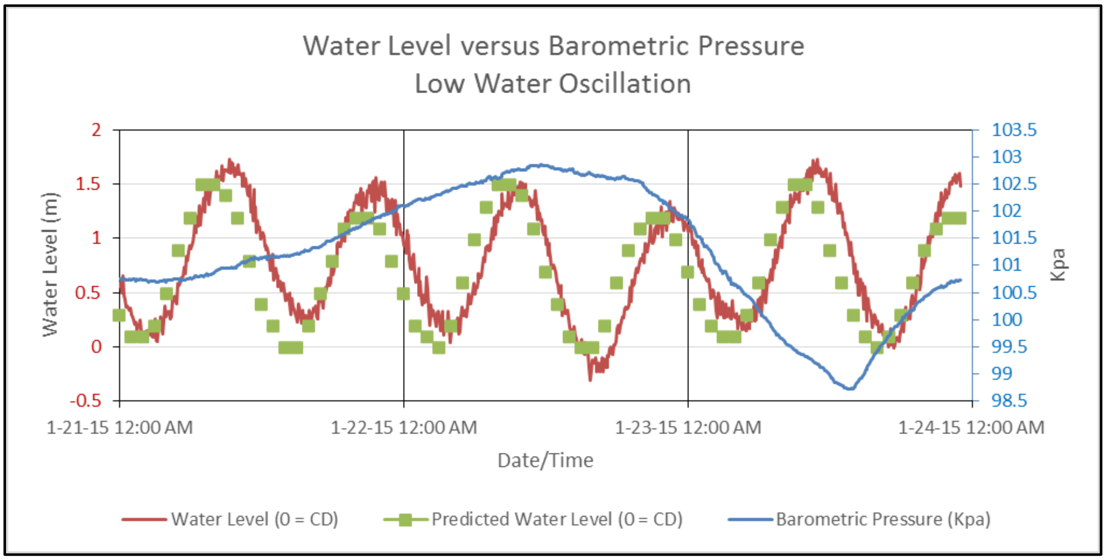


Figure 4.25. Low low water example showing oscillations.

The graph in Figure 4.25 shows an oscillation that provided the lowest water level of -0.31 m. The wind direction and speed during this event was not conducive to producing low low water levels that would be expected under very high pressure with prolonged southwesterly-westerly wind (Figure 4.26). The data highlight several points regarding meteorology and water level changes. Not all water level changes are related to meteorological events. Water level can be influenced by local and regional current changes (Labrador Current), lunar and solar cycles, and surge related to ocean floor processes. Not all low-pressure systems result in storm surge that causes impact to HHW mark and above. An example occurs when a low-pressure system is weak or when a strong low-pressure system occurs during neap.

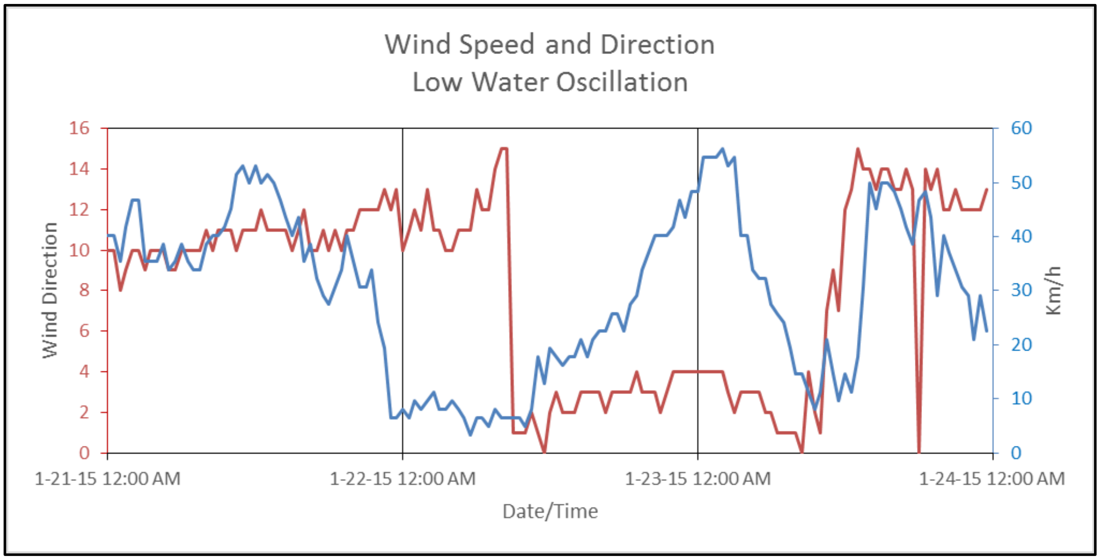


Figure 4.26. Wind speed and direction prior to, during, and after the lowest recorded water level that occurred during an oscillation at low tide under light northeasterly winds. The cause of this oscillation remains unclear.

Surge and oscillations occur at The Pool and the data and observation provided suggest that these events contribute to erosion in the tidal zone (and beyond) along the shoreline of The Pool. This is significant due to the frequent oscillations that erode small amounts of material with each event. This type of erosion is difficult to detect in the short-term and requires a long-term monitoring plan. From April 2013 to May 2015, the shoreline has eroded more than 0.20 m around some of the wharf supports, while no change was seen around other areas. An investigation into current movements in The Pool is needed to assess how currents impact the shoreline in different areas.

4.5.3 Colony of Avalon – The Lower Site and Sea Level

The Pool also includes many parts of the Colony of Avalon Site. Since some of the site is in-situ and more of the site is reconstructed to represent the time of use, some of these features can be used to estimate sea level at the time of use. One method of estimating sea level during the historic use of an in-situ structure is by using functional archaeology. This determines the use, function or purpose of an artifact or structure during the time of use (Auriemma and Solinas, 2009), and then measures the difference in a sea level reference point at present (or any other selected time). An example of this is a study conducted in northern Adriatic Sea where archaeologists determined the elevations of former fish ponds and compared to present sea level to estimate sea level changes (Pirazzoli and Tomasin, 2013).

During the RTK work in July 2014, many features were surveyed including points in the Colony of Avalon site. Wooden barrels or quays were used as a part of dock structure between 1621 and 1624. (Dr. B. Gaulton, Pers. Comm., June 28, 2014). There are two visible in-situ quays on the south side of The Pool (Figure 4.27) that are underwater except during low low water. The quays have been eroded at least ~ 0.15 m below the operational height that existed during use (Dr. B. Gaulton, Pers. Comm., October 20, 2014). The elevations of the upper edges of the quays were measured using RTK (MTM Datum) as -0.25 m (add 0.60 m for CD). That indicates that the quay surface was at ~ -0.10 m. The quays were also leveled to FLEWWL-1, which revealed the same measurement. In order for a dock to function, these quays must have been at least 1.0 – 1.5 m above high high water in the 17th century to provide docking for medium to larger sized boats with a freeboard >1 m. Using the same datum, that would place the HHW mark during the time of use at -1.10 m to -1.60 m. Present day HHW (without surge) measures ~1.50 m above the quays (predicted and measured) at an elevation of 1.35 m. Therefore, the difference in HHW level from 1621 to present (394 years) is 2.45 m to 2.95 m. This would suggest a sea level rise rate of 6.2 mm/y to 7.5 mm/y.

Figure 4.27. Quays at the lower site. May 2, 2015.

Measurements were also taken on the structure known as the store room floor and a latrine (Figure 4.28) that was used in the same time period as the quays. This area is flooded during high high water. The elevation of the storeroom floor is 1.0 m. However, the actual floor of flagstone is ~0.10 m below this surface at 0.90 m. The top layer was installed by archaeologists to protect the actual flagstone floor from erosion (Dr. B. Gaulton, Pers. Comm., October 20, 2014). This indicates that the storeroom floor was ~ 1.0 m above the operational surface of the quays to keep dry goods from becoming wet. During the oscillation event on November 22, 2014, the entire area was inundated in >0.5 m of water causing some stone movements and additional bank erosion around the site. Local knowledge suggests that surge can rise much higher. The latrine is located just west of the store room floor (Figure 4.28). When in use during 1621 to 1624, this pit would have been flushed during high high water. The base of the latrine was measured by RTK and showed an elevation of -0.10 m (MTM Datum), approximately the same elevation as the operational surface of the quays. This indicates that high high water during the period of use was no higher than this level at maximum. Today, the latrine floor is occasionally submerged in over 2 m of water. However, if flushed by HHW, then the water level must have been at or slightly above this level. This would place HHW at ~0.00 m to allow ~0.10 m of water for flushing the latrine. This indicates that the difference in sea level from the 1621-1624 to present is approximately 1.25 m. This indicates a sea level rise of 3.2 mm/y.

The calculated rates for sea level rise from the latrine and the quay surface thus differ, and the HHW for the latrine flushing is 0.10 m higher than the estimated highest operational surface of the quay. If the quays were in use at the same time as the latrine, then either the top of the quays have been eroded more than estimated here, or the latrine has been reconstructed higher than the original position. However, as the storeroom floor and the latrine are believed to be in their original position, the evidence indicates a sea level rise of 1.25 m or 3.2 mm/y from 1621-24 to present.

Figure 4.28. Storeroom floor and latrine

The eroded surface of the quays do not represent the functional height during use, nor does it provide a good reference height for sea level estimation as the quay could have been much higher than 1 m above water level. However, the current height of the latrine is at the functional height during the time of use. Therefore, the estimate of the quay height is much less precise than the latrine. The sea level rise estimate from 1621 to present of 1.25 m (3.2 mm/y) at the latrine is more precise.

4.6 Tombolo North to Coldeast Point

Except for outcrops and a few short segments of barrier, this section of shoreline consists of fill materials related to the support of Route 10, a coarse pebble-cobble barrier, and fishing-related structures including a former fish plant and wharf. Mitigation measures include a retaining wall, sea walls, and various slope stability efforts.

4.6.1 Route 10

A 0.7 km section of Route 10 runs adjacent to the west shoreline of Ferryland Harbour. Although some of this shoreline consists of rocky shore and cliff, there are two segments that are under marine attack (waves, surge, and currents) and active mass wasting. The southern segment consists of a fill slope that supports the east side of Route 10. This slope is undergoing continuous debris topple and flow caused by rainfall and freeze thaw cycles, and accentuated by wave and surge undercutting. The last attempt to stabilize two particular sections of this slope occurred during July 2014 (Figure 4.29). Since then, some localised areas of fill and boulders have moved slightly downslope. No wave or surge undercutting was detected since the July 2014 repair. However, it is expected to occur during future wave and surge events due to a lack of armoring at the toe-of-slope. Surge and wave activity would have to impact the toe-of slope for an extended time at or above the HHW mark. Sediment material along this level of the shoreline is mostly fill (varying sizes) and debris that has fallen down during slope stabilization above. Failure is not imminent. However, heavy rainfall with slope runoff combined with large waves may cause washouts and road failure in restricted areas (areas of slope with existing signs of slope failure and weak shoulder areas).

Figure 4.29. Slope stabilization on the fill slopes supporting Route 10, July, 2014.

The northern segment of concern consists of a barrier backed by a cribbing structure approximately 70 m in length that supports the seaward shoulder of Route 10 (Figure 4.30). The initial fill that was placed in this cribbing was smaller in diameter than the openings between the cribbing. This resulted in the erosion of this material between the cribbing timbers from surge and wave activity, and flow from rainfall and road drainage. High high water and surge events coupled with waves inundate the lower cribbing and transport the small fill material outside, causing the upper slope to move down into the cribbing. Each occurrence causes further erosion of slope material in the cribbing resulting in further slope movement. The consequence is erosion of the fill slope that supports the east side of Route 10.

Figure 4.30. Cribbing installed along Route 10. **A**: White truck is traveling south on Route 10. **B**: Empty sections of cribbing and broken timbers. Surge, waves and currents erode undersized fill from inside the cribbing, causing further slope movement and destabilizing the road shoulder.

4.6.2 The Fish Plant Area and Wharf

This area is defined by heavily impacted barriers and shoreline obstructions. The main structures are a former fishing wharf (top of concrete pad ~0.30 m above normal HHW) and the remnants of a cribbing-reinforced infill that supports a former fish plant. The eastern segment of the barrier is subject to large waves, surge, and high velocity currents that flow under northeast forcing conditions from Coldeast Point across the sill and into Ferryland Harbour. The former fishing wharf is occasionally under water during high high water and wave conditions, as is the retaining wall and fill around the former fish plant (Figure 4.31). Recent efforts to mitigate erosion at Coldeast Point involved placing a line of large boulders from the Coldeast Point south to approximately 20 m onto the sill. Although this activity has trapped some sediment to mitigate erosion at this point, it is unclear as to how the sediment budget will be impacted for the barrier segments towards and including the barrier on the northern section of concern of Route 10.

Figure 4.31. Water Level at the former fish plant and wharf. The predicted tide is 1.3 m. Actual is ~ 1.8 m. Wind NE at 45 km/h. Nearshore wave height ~ 0.5 m. Waves breaking and washing over wharf and waves breaking outside and on the sill (line of white water in background).

4.7 Summary

The Ferryland Harbour System is exposed to large waves, surge, and high velocity variable currents. The complex topography and bathymetry funnels, refracts and reflects wave energy and currents causing erosion in varying segments of the shoreline. The resulting erosion is impacting tourism-related sites and access routes with the most significant areas of concern being: Bois Island, Ferryland Head Isthmus, the Colony of

Avalon Dig Site, The Pool, tombolo, and Route 10. The major causes of erosion are summarized in Table 4.4 and include marine attack (waves, surge, currents and sea level rise), slope processes (consolidated and unconsolidated types) and anthropogenic influences. Sea level rise is estimated at 1.25 m or 3.2 mm/y from 1621 to present.

Table 4.4 Significant areas of concern with cause and type of erosion.

Site or Access	Cause of Erosion	Erosion Type	Known or Estimated Rate	Consequence
Bois Island	freeze-thaw, surge with wave attack, rainfall, currents	debris slide, rock topple, cave collapse	variable by site. est. at 0.01 m/y (1.1 m/century)	loss of heritage and military history
Ferryland Head Isthmus	freeze-thaw, rainfall, surge with wave attack	rotational slide, creep, debris slide, undercutting	baseline data collected	loss of access to lighthouse and Ferryland Lighthouse Picnics
The Colony of Avalon (Harbourside)	freeze-thaw, rainfall, surge with wave attack	debris slide, debris flow	estimated 0.05 m/y	continued loss of important artifacts
The Colony of Avalon (Lower Site)	currents (tide and oscillations)	undercutting	baseline data collected	continued loss of important artifacts and threatens access to The Pool
The Pool	currents, anthropogenic (infilling)	undercutting, undermining	variable along the shoreline, up to 0.20 m/y	hazard to users, loss of artifacts, and further erosion at the Colony of Avalon
Route 10	freeze-thaw, surge with wave attack, rainfall	debric slide, debris topple, and undercutting	variable along the shoreline, rate unknown	hazard to users, potential loss of access to all sites south

Chapter 5 – The Backside System

This chapter presents baseline data, describes coastal processes, and provides interpretation of the Backside System. This system consists of the area including the southern cliffs and barriers of Ferryland Head south, The Downs, Ferryland Beach (and Freshwater); Meade's Point and Cove; Crow Island and associated shoals; and surrounding shallow waters (Figure 5.1). Exposed outcrops and erosion-denuded bedrock form rocky coastal cliffs and rocky shorelines. Two distinct pocket beaches, Back Cove and Meade's Cove, and Ferryland Beach, a long crescent-shaped barrier confined at either end by rocky shorelines, make up the barrier subsystems.

5.1 Bathymetry, Waves, Surge and Currents

Figure 5.1 shows the general bathymetry and shoreline topographic features including locally known features of the system.

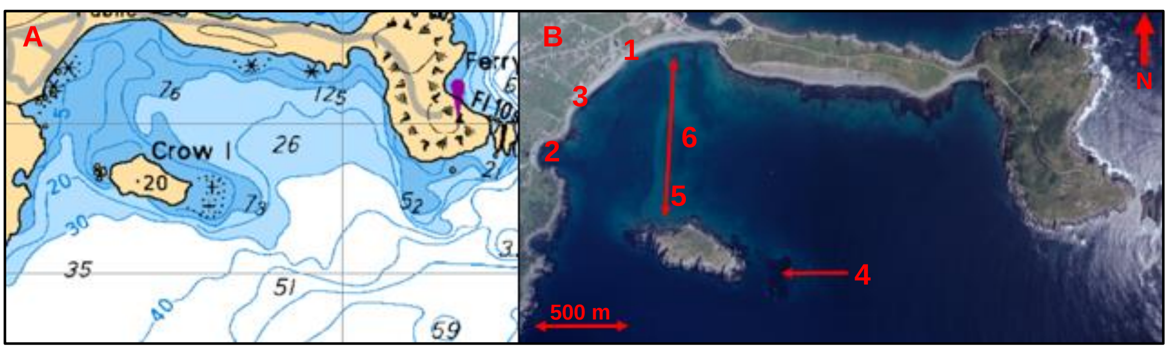


Figure 5.1. The Backside system. **A:** is Bathymetry (Canadian Hydrographic Service-Fisheries and Oceans Canada). **B:** locally known features: Ferryland Beach (1), Meade's Cove (2), The Valley (3), Crow Rock (4), Mad Rocks Sill (5), Mad Rocks (6), and others (Newfoundland and Labrador Government, Aerial Photograph 95044-10).

The key features controlling wave and current activity are Crow Island and associated shoals, the morphology of the tombolo to Ferryland Head South, the deep water access from the S-SE, and the nearshore shallow water between Crow Island and Meade's

Cove. Crow Island refracts and reflects approaching waves, creating wave interference in the embayment. Deep water waves that have been transformed to nearshore waves enter through the southeastern deep water and break near or onshore. The 20 m – 10 m shoaling bathymetry between Crow Island and Meade's Cove allows these waves to travel through this area and break on the shoreline.

Mad Rocks (local name) lie on a sill (Mad Rocks Sill) between Crow Island and the breakwater at the tombolo (Figure 5.1B). This shoal, at a minimum depth of 3 m, is evident on the aerial photos and hydrographic chart, and is described by fish harvesters (F. Clowe, Pers. Comm., March 12, 2014). Mad Rocks consists of angular boulders resting on a bedrock platform. It is likely a former barrier system, with an elevation of 2 - 3 m below present sea level. The available sea level history (Catto, 2012; and observations discussed in Chapter 4) suggests that the barrier represented a marine beach.

A boat survey using a Garmin fishfinder (dual-scan sonar) revealed a relatively linear shoal from the northwest extent of Crow Island to Ferryland Beach (light colored bathymetry in Figure 5.1B). This shoal flattens and rises to the low tide berm at the south edge of the breakwater (approximately at BP-5 in Figure 5.9). The western edge of the sill aligns with the bedding plane orientation of bedrock in the area indicating a bedrock base. An underwater camera investigation revealed a relatively steep negative grade west from the sill towards Ferryland Beach and a gradual negative grade to the east towards Ferryland Head. The sill is critical in wave dynamics and Ferryland Beach morphodynamics. During low tide and large wave approach from ESE, residents have described waves >4 m breaking on this shoal. Subsequent to breakage, much reduced waves gently swashed into the barrier at or below the low tide berm. On several occasions during spring tide, waves were observed traveling over the shoal and breaking on the high tide berm and further up the barrier face.

5.1.1 Crow Island and Crow Rock

Crow Island consists of till veneer (>2 m in some places) overlying glacially eroded sedimentary bedrock. Freeze-thaw cycles (e.g. presence of blocks and pieces on the rocky shoreline), rainfall, and mass wasting are the main factors influencing erosion around the island with wave transport of material into the nearshore. The rocky shoreline on the north (relatively sheltered) transitions to higher rocky cliff faces >5 m above low low water on the southern shore. The south side has numerous eroded sections of strata resulting in deep (vertically and horizontally) eroded inlets. The till cliff on the eastern edge of the island and the till cap are eroded by wave action. A large rock platform known as Crow Rock is adjacent to and east of Crow Island. This platform is approximately 1 m below surface at low low water and is responsible for wave reflection and refraction, as seen in Figure 5.2. A smaller rocky shoal to the west (Meade's Cove side) breaks and refracts waves from the S-SE, resulting in moderate wave energy towards Meade's Cove. The island and the sill provide partial protection to Ferryland Beach from large ESE waves. Site visits and observations during wave events show that the island provides wave interference inside the embayment which reduces wave heights prior to shore impact along the mid-section of Ferryland Beach.

5.1.2 System Wave and Current Dynamics

The Backside System is more exposed than the Ferryland Harbour System making it more susceptible to wave impacts. The direction and velocity of waves and currents do not always coincide with wind speed and direction as measured at the FLEWWX-1. Various types of waves such as gravity and wind-generated waves approach the system from the Northwest Atlantic. Crow Island, numerous shoals and rocks, bathymetry, and the shape of this embayment control wave and current dynamics. Swell and wind-generated waves are influenced by the bathymetry and surface obstacles such as Crow Island. The rocky shoreline and surrounding shoals are the major surface influence in refracting and reflecting wave energy, causing localized longshore currents depending on wave direction (Figure 5.2).

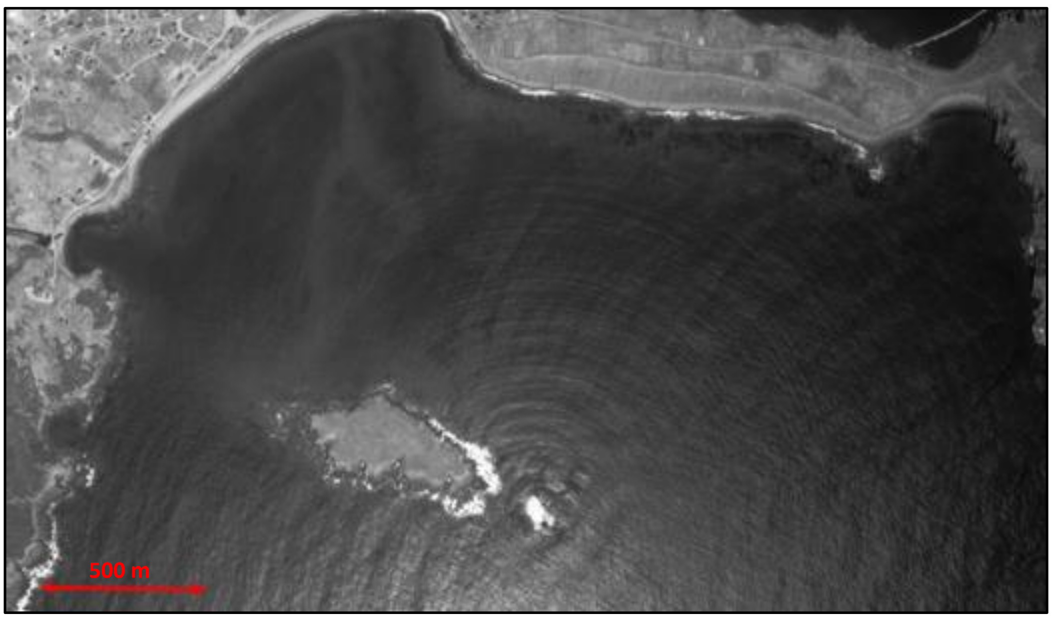


Figure 5.2. Aerial Photograph showing wave refraction and reflection resulting interference and calm conditions on Ferryland Beach (Newfoundland and Labrador Government, Aerial Photograph 87044-029).

Waves that encounter obstacles, such as reflective coastlines, refract or reflect, which may cause localized currents. The angle of the slope rise to the shoreline influences the type of wave interaction. One of the major types of wave interaction with reflective coastlines are breaking waves, which may be surging, plunging, or spilling if the beach slope is abrupt (e.g. vertical), steep, or gradual respectively (e.g. Dean and Dalrymple, 1991). The angle of the wave approach to the shoreline combined with the slope rise will help determine current direction if no other overriding factors exist (e.g. existing longshore current from another direction). The refraction of the wave at oblique angles can cause alongshore currents to develop.

An example of this refraction is shown in Figure 5.3. Waves approaching from the SE refract around Crow Island resulting in two wave approach directions into Ferryland Beach.

Figure 5.3. Still image of HD video showing two wave directions during the aftermath of Hurricane Gonzalo (October 19, 2014). **B:** is direction of SE swell from H. Gonzalo and **A:** is direction of SW refracted wave traveling south to north along Ferryland Beach. Wind NE at 72 km/h.

To investigate waves and currents in the Backside System, DTB-1 and DTB-2 were deployed on two separate occasions to qualitatively assess surface currents. In the first deployment on July 3, 2014, swell (H=~0.5 m, λ=~30 m, T= ~15 s where H is wave height) from the SSE (wind SW at ~20 km/h) refracted around the west shoal of Crow Island and resulted in a surface current at least 2 m in depth (reflector of DTB-2 set for 2 m depth) flowing south to north at ~ 0.03 m/s between Crow Island and Ferryland Beach. Waves were also refracted around the east side of Crow Island and Crow Rock, causing interference with occasional rogue waves at Mad Rocks Sill. The south to north current was dominant, although the current seemed to dissipate before the area of water directly off the tombolo breakwater. This is a result of the sill that limits current movement from the SSW except at high high water or during surge conditions. In another deployment on July 17, 2014, during swell (H=~0.5 m, λ=~30 m, T= ~17 s) from the east (wind S at ~28 km/h), the DTBs moved from a point between the Backside Cove and Crow Island towards Ferryland Beach. Tide was ~1.2 m above CD (high tide) as scaled from a bedrock reference point near Meade's Point. DTB-1 moved away from the westerly track of DTB-2 further to the north as a result of the southerly wind. During the same time, breakers were observed approaching and refracting around the west of The Downs boulder barrier into the tombolo breakwater. A number of methods to determine flow were deployed including tennis balls, ping pong balls, and modified milk crates at varying site visits. During this site visit four floating tennis balls revealed a nearshore surface current moving south along Ferryland beach towards Freshwater (NE to SW) at ~ 0.02 m/s. Later this day, during calm conditions, currents seem to subside with no preferred direction. These two examples show that the direction of approaching waves (wind independent) result in two different current directions along Ferryland Beach. This observation suggests that larger waves (>3 m) under surge conditions over high tide (less shoaling before shore impact) coupled with the same direction wind-generated waves would result in stronger longshore currents. The higher velocity currents would be capable of transporting more barrier sediment alongshore (e.g. fabrics and other clast sorting) and material from till and fill cliffs to and along the beach face. These two examples align with local knowledge that describe wave impact and currents in this area. The DTBs were not deployed in sea states where wave and current conditions were large enough (H= >0.5 m) to cause safety concerns (e.g. boat launch, equipment deployment/retrieval, etc.).

On the northern section of Ferryland Beach, numerous observations of wave and current activity indicate that the dominant longshore current is SW from the southern rocky shoreline of The Downs and is enhanced by the refracting waves around the western extent into the eastern extent of Ferryland Beach. As an example, the E-SE wave approach will be used to create longshore current velocity rates and longshore wave power during low water, high water and surge conditions at the point where Mad Rocks Sill shoals into Ferryland Beach (around BP-5). This calculation (Equation 1 and 2 on page 78) is based on zero longshore current flow from the refracting waves. The water depth at low water, high water, and a hypothetical, but realistic to the system, surge level is 0.5m, 2.1m, and 3.0m (0.9 m surge on high water) respectively from 0.0 m Chart Datum (CD). Incident wave angle is 25 degrees under dominant E-SE wave approach. The formulae presented in Section 4.4.2 will be used to provide these numbers with the results of these calculations presented in Table 5.1.

Table 5.1. Wave energy and longshore transport rates under different water levels and wave heights.

Water Level	Water Depth$_{Sill}$	Wave Height (m)	V_1 (m/s)	E (J/m^{-2})	P_1 (kW/m)
Low Tide	0.5	1	1.3	5027.4	3910.4
		3	2.2	45246.6	35193.4
High Tide	2.1	1	1.3	5027.4	7998.5
		3	2.2	45246.6	71986.9
Surge (0.9m)	3.0	1	1.3	5027.4	9598.2
		3	2.2	45246.6	86384.3

The longshore current velocity is calculated revealing 1.3 m/s and 2.2 m/s flow rates (NE to SW) at 1m and 3m wave heights respectively showing that higher refracting waves produce higher velocity longshore currents. The wave energy density also shows that higher waves produce higher density. The longshore wave power is also higher with wave height, but the water level increases also provide higher wave power at and on the barrier face. This corresponds to the system description and observation above. Similarly to the Sandy Cove example discussed in Chapter 4, it is expected that wave induced shore-parallel energy (current and transport) will increase in proportion to any shore-normal energy, resulting in increased sediment transport. This is also apparent from the flat profiles of BP-1 to BP-4 that transition into berms near BP-5 and further south (all BP shown in Figure 5.9).

Intermittently, a small cuspate spit forms on Ferryland Beach where the Mad Rocks Sill shoals into the barrier near BP-5 (Figure 5.9). At its observed maximum, the spit is ~ 6 m in width, ~ 1 m above low water, and extends ~ 1-3 m seaward. The spit does not always occur in the same place (sometimes forming further SW towards BP-6) and size varies from no spit to the dimensions above (possibly larger). This spit indicates that, under currently unknown circumstances, currents moving northward along Ferryland Beach and westward along The Downs intersect along the barrier at the tombolo to form this feature. This suggests that the sill may act as a divider causing development of distinctive cells – one cell on the west side between the sill and Ferryland Beach and one cell on the east of the sill. One scenario that partially explains the intermittent nature of the spit is seen from the observation of the currents in the Back Side System. Waves approaching from the E-SE during high high water or surge conditions cause a E-W (SW current) longshore current that transports coarse sand, pebbles and cobbles from the area between BP-1 and BP-4 to the SW where shoaling occurs near BP-5. The shoaling slows the longshore current and sediment transport causing deposition. During this time, a NE current from the SW may be strong enough to either provide enough flow to redirect the SW current off the barrier, or add additional sediment at the same position to add to the spit accretion. The spit was observed on two separate occasions without temporal photography or video. The shape and size of the spit depends on the size of the waves, available sediment, water depth, and strength of the longshore current. The spit is obliterated when the SW current overpowers the NE current resulting in the transport of sediment further along the barrier towards the SW and into deeper nearshore water west of Mad Rocks Sill.

5.2 Ferryland Head South to The Downs

5.2.1 Back Cove

Back Cove (Figure 1.3) is a small shallow embayment on the south side of the Ferryland Head Isthmus (Figure 5.4). It contains a high energy shore-normal reflective barrier pocket beach system open to the south. The 130 m long barrier is flanked on the east by the rocky cliffs of Ferryland Head, on the north by an eroding unconsolidated cliff supporting a gravel access road, and on the west by a rocky shoreline at the base of The Downs. Berm and cusp accretion and erosion are frequent in this system. Cusps are shore-normal and, during calmer periods, average 0.5m H X 3m W X 5m L with much larger cusps forming during storm events. The cove and barrier is frequently impacted by storm surge and large waves (breakers observed >5 m high). The observation of breaking waves reveals that the bathymetry shoals to approximately 3 m depth at ~200 m south of the barrier. This correlates to the adjacent eroding rock cliff on the eastern flank of the cove.

Longshore current is minimal with most of the sediment reworked on the barrier or from the barrier into the nearshore during large wave events.

Rock cliffs and till slopes provide sediment to the Back Cove barrier. The rock cliffs to the east provide some sediment material to the barrier through rockfall in the form of eroded pieces and blocks. Freeze-thaw is the main mechanism for weathering, while rainfall and wind erode the pieces into the shallow nearshore and surf zone. Wave energy

Figure 5.4. Back Cove barrier and till cliff. **A:** taken in September 2013. Barrier showing slope erosion due to debris flow, creep, undercutting. Sediment has been built up into berms after summer accretion. **B:** planview of SBP 1-6 (Google Earth). Google Image not georeferenced to MTM datum. Note the position of the large angular boulder on A and B.

transports angular-subangular pieces into the barrier system where they are reworked from angular to rounded pebbles-boulders. The till cliff provides sediments (silt to boulders) through mass wasting processes and undercutting. Freeze-thaw cycles heave and loosen the till cliff face, and rainfall, wind and gravity erodes and transports it downslope.

Several igneous cobbles were observed at various locations on the barrier. These are not from the parent bedrock and have eroded from the till material or from fill material intended to stabilize the road above. Further investigation in June 2015 revealed that igneous cobbles are present in the till material near SBP-6 (Figure 5.4B) and in the fill materials that support the road.

The section of till and fill material making the slope from the barrier to the gravel road is undergoing erosion and mass wasting. The western and eastern extents of the till slope are undergoing continuous creep, debris flow, and sliding with the eastern slope showing more frequent movement. The finer components of till and terrestrial organics are washed away from the barrier while the coarser sand to boulders are retained and reworked in the barrier system. Debris flow and earth flow on the eastern extent is noticeable after most rainfall events. Road drainage is not noticeable along this slope, in contrast to the Sandy Cove side. The middle section of the till and fill (above the boulders) slope adjoining the road edge to the back barrier is fairly stable, with few signs of creep and no signs of debris flow. However, there are signs of infrequent undercutting that occurs mostly during late fall to early spring storms, when much of the barrier sediment is in nearshore berms (no to little barrier face berms), allowing large waves to runup to the toe-of-slope.

Six slope-barrier profiles (SBP) were measured during RTK surveying in July 2014 (Figure 5.4B). Each profile was oriented based on slope access and spacing to allow shore-normal placement. Slope nails were established at 0.00 (near the edge of the gravel road), -7.00m, and -14.00m slope distance. The profiles were measured down the slope and across the barrier to the edge of water. Figure 5.5 shows a barrier face to barrier elevation comparison.

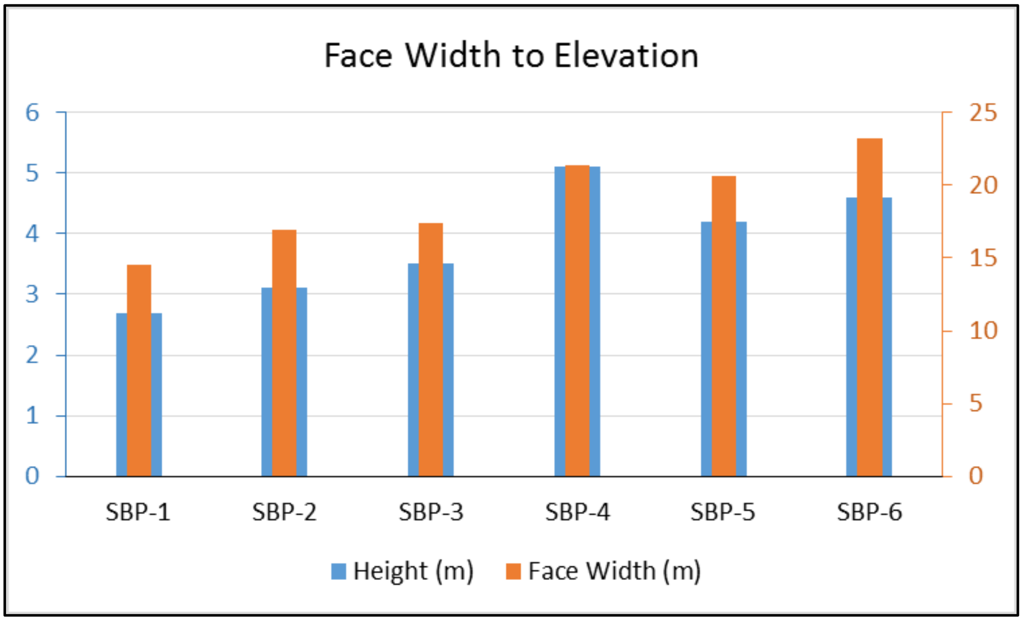


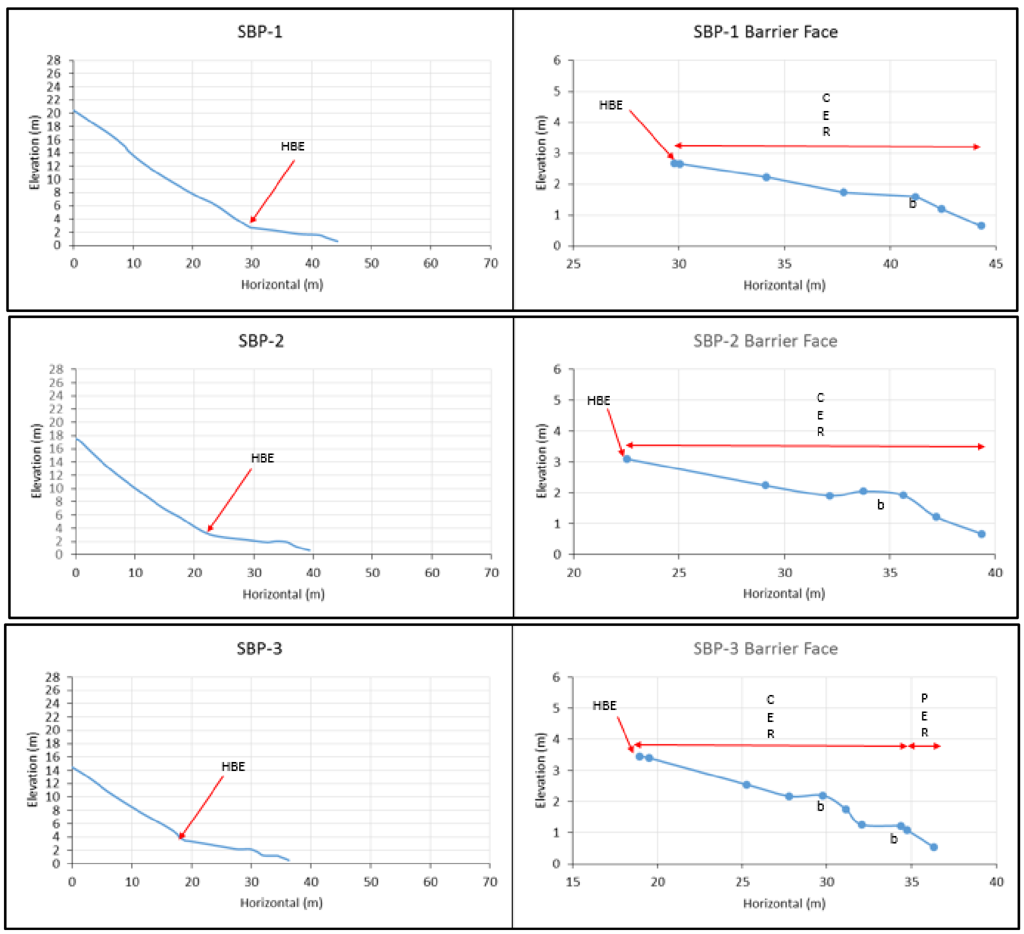
Figure 5.5. Back Cove barrier face width to barrier elevation comparison.

The barrier face increases in width from HBE to water level from SBP-1 to SBP-6. The barrier face is narrow at SBP-1 due to the transitioning to rocky shoreline directly to the west. The elevation increases from SBP-1 to SBP-4 with a slight drop to SBP-5 and rise to SBP-6. There is more sediment (mostly cobbles) in the segment from SBP-4 to SBP-6 due to a major source of new sediment to the system from the rocky cliff east of SBP-6 and the large angular boulder (Figure 5.4) that is in the storm berm between SBP-3 and SBP-4. The large boulder serves to trap sediment in the storm berm at Highest Barrier Elevation (HBE) between SBP-4 and SBP-6 until it is eroded by surge and large waves.

The observed wave approach, symmetrical cusps, and confinement (rock cliff to the east and rocky shoreline to the west) show that this is a shore normal system with minimal shore-parallel sediment transport. The height and face width of the barrier suggests that sediment is built higher in the east than the west. More than 40 site visits reveal that sediment is reworked, and the barrier profile is concave following large wave events.

However, the comparison in Figure 5.5 represents the modal configuration of the barrier and profiles following substantial periods of relative calm.

The following profiles were measured during the RTK survey in July 2014. The figures represent the shapes of the profiles, and the text descriptions and discussion that follow provide further interpretation. Table 4.1 provides the codes and interpretation for the profiles. As with the profiles in Chapter 4, these profiles were not resurveyed for the same reasons.



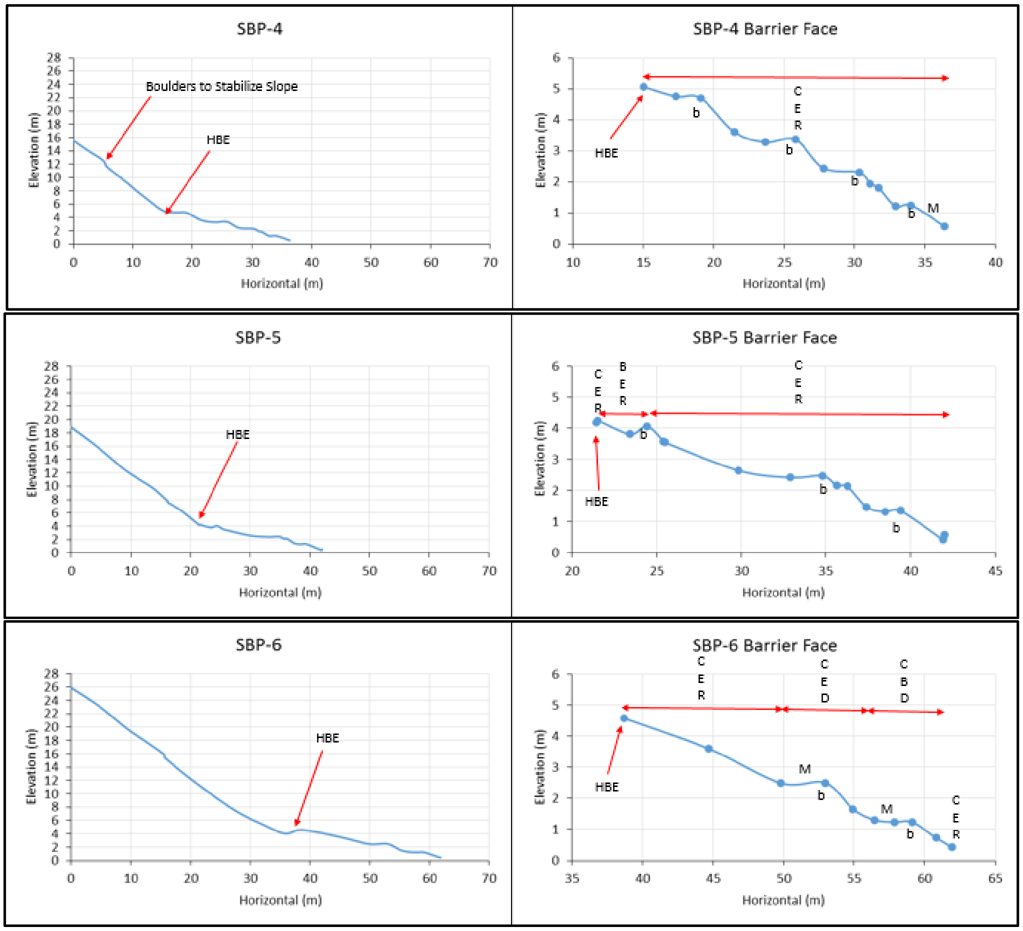


Figure 5.6. Slope-Barrier Profiles at Back Cove. Six profiles collected on July 13, 2014. 0.0 is ~low low water. Red arrow is the landward edge of the barrier or base of slope. The boulder line in SBP-4 is the slope stabilization effort to stabilize the road edge. **HBE** refers to Highest Barrier Elevation during survey.

The six slope barrier profiles reveal that all slope sections are undergoing mass wasting, but differences exist among the eastern and western extents and the middle section. All SBP are undergoing undercutting by shore-normal waves during high high water or large wave events. The following descriptions are measured vertically from 0.00 MTM. Actual water level could not be measured using the RTK pole in all profiles due to the steep unstable beach step.

SBP-1 shows a grass-covered slope from an elevation of 20.5 m to 10.2 m where it transitions into exposed till undergoing slip, creep, and debris fall to HBE at 2.6 m. The barrier from HBE consists of one berm of equantic and roller cobbles at 2.6 m to the water level at 0.6 m. Signs of mass wasting are prevalent on the slope. The cobble beach exposed in this profile transitions into rocky shoreline approximately 15 m west.

SBP-2 shows a grass-covered slope from an elevation of 17.5 m to 7.1 m where it transitions into exposed till undergoing slip and debris fall to HBE at 3 m. The barrier from HBE SBP-2 consists of one berm of equantic and roller cobbles from 3.0 m to the water level at 0.6 m. Debris slide, topple and debris flow are prevalent in the lower slope with obvious undercutting.

SBP-3 shows a grass-covered slope from 14.5 m to 4.8 m with large boulders placed between 10.8 and 7.3 m to stabilize the upper slope. The slope from 4.8 m to 3.4 is exposed till to HBE, respectively. The barrier from HBE consists of two berms of equantic and roller cobbles from 3.4 m to 1.2 m where a transition to equantic and roller pebbles occurs to the water level at 0.541 m. Undercutting is evident in the lower slope.

SBP-4 shows a grass-covered slope from 15.5 m to 7.4 m with large boulders placed between 12.3 m and 11.0 m to stabilize the upper slope. The segment from 7.4 m to 4.7 m consists of exposed till to HBE, respectively. The barrier from HBE consists of four berms of equantic and roller cobbles from 4.7 m to 0.6 m including marine organics (kelp). Undercutting is evident in the lower slope.

SBP-5 shows a grass-covered slope from an elevation of 18.8 m to 9.7 m where it transitions into exposed till undergoing slip, creep, debris fall and flow, with undercutting to HBE at 4.2 m. The barrier from HBE consists of four berms of equantic and roller cobbles at 4.2 m transitioning into a short berm of boulders from 3.8 m to 3.5 m, transitioning back to equantic and roller cobbles 3.5 m to 0.4 m.

SBP-6 shows mostly exposed till from 25.9 m to HBE at 4.0 m. Earth flow, slide, debris fall, and mud flow are prevalent. At 4.0 m, earth and mud flow is commonly observed after rainfall or between periods of upper berm reworking. The barrier consists of three berms of equantic and roller cobbles from 4.5 m to 2.4 m. It transitions to unsorted equantic and disc cobbles with organics from 2.5 m to 1.3 m, and then to blade and disc cobbles near water level at < 0.6 m where a narrow section of equantic and roller cobbles are present.

The profiles show multiple berms, and the highest angle barrier face is located in SBP-4 directly east of the large boulder in the top of the storm berm (Figure 5.7A). All SBPs show the high tide berm at ~2 m. This indicates barrier accretion at and near the large boulder, but also indicates minor sediment transport from the accumulated sediments trapped in the eastern segment to the western segment towards the rocky shoreline. It also suggests that the large boulder helps maintain the barrier face width in the eastern segment and therefore helps prevent substantial undercutting at elevation 5m to 6 m between SBP-5 to SBP-6 that would further undermine the till cliff under attack between SBP-5 and SBP-6. The pattern generally consists of one or two berms from SBP-1 to SBP3 and three or more from SBP-4 to SBP-6. The number changes with every large wave event. The high tide berm is almost always present, except during major barrier erosion during large storms (e.g. Hurricane Gonzalo in 2014), when the convex profile evolves to concave.

The multiple berms and convex profiles described during this survey formed under accretionary conditions during summer when surge and large waves are rarer than during

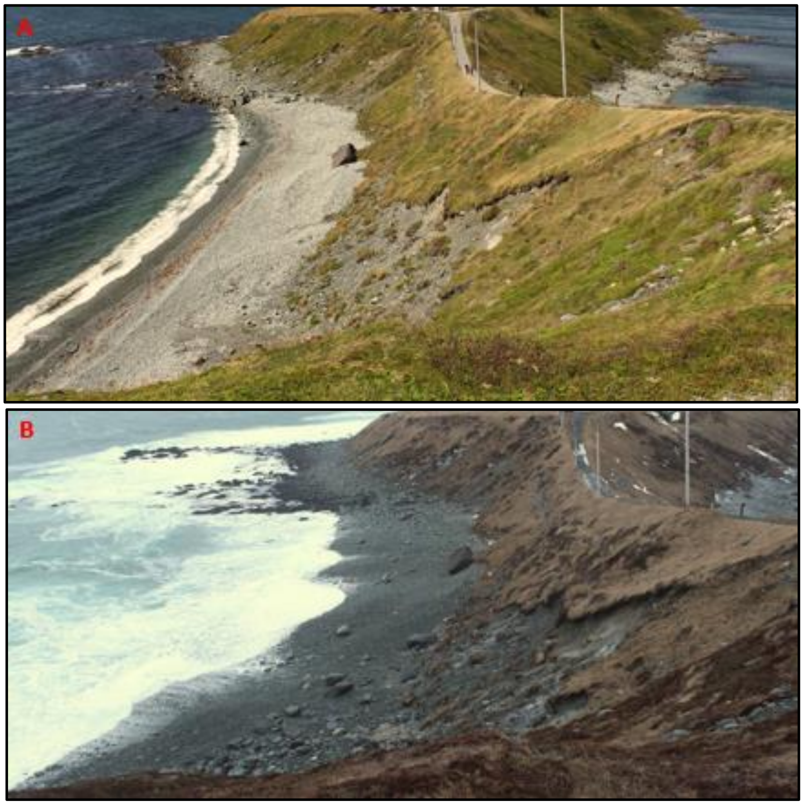


Figure 5.7. Back Cove Barrier looking west. **A:** August 2014 and **B:** January 2015. The multiple berms and convex profiles (**A**) have been eroded by higher water levels and large waves resulting in large shallow cusps and concave profiles (**B**). Also note the debris flow triggered by a recent rainfall in the bottom left of **A**. **B** shows more loose surface material above upslope of the same point than **A.**

late fall to early spring. Berm building and convex barrier profiles are related to calmer conditions, whereas the erosion of berms and concave profile development are related to larger wave events. Except for infrequent late summer storms and hurricanes, the calmer period normally occurs during summer to early fall, and higher frequency of storms and large waves occur during Fall to Spring.

Erosion from wave attack did not occur at the interface between the barrier and the till cliff during the study period. Evidence of this is the lack of freshly cut till cliff material at the toe-of-slope along the top of the barrier. A follow-up survey was not completed as it would very likely show normal barrier face changes as described above. These changes are not considered to be significant on the integrity of the till cliff and the gravel road.

Erosion of the barrier by wave attack at high tide or surge during a convex profile may result in undercutting of the till cliff. In this scenario, the till cliff is undermined and further destabilized. If this occurs during a heavy rainfall or during thaw conditions, then slope movement may occur which would likely further steepen the till cliff and possibly further destabilize the gravel road on the isthmus.

5.2.2 The Downs – South

Other than antecedent marine sediments, reworked till material that is a product of erosion, and fill material (e.g. armour stone) reworked into the barrier, the south till slope of the Downs is the major natural terrestrial sediment supply for Ferryland Beach.

Sediment is displaced from this till slope by freeze-thaw cycles, rainfall, and gravity, where it is moved downslope by flow, slip and fall processes to the rocky shoreline. During high high water, surge and large waves from the southeast, the sediment is moved along the shoreline from east to west. After the waves refract and break around the western rocky shoreline on the western extent, the fines settle out in the shallow water or on the eastern extent of Ferryland Beach (near "B" in Figure 5.8B). Descriptions of slope movements from residents indicate mud flow, topples, debris avalanche and other types of mass movement. During multiple site visits, debris slide, topple, and flow was observed on this slope during rainfall events, and twice during thaw conditions in the Spring 2014. They also have described brown sediment-laden water in the Backside during heavy rainfall events during wave action from the SE. This suggests erosion of sediment from the toe-of-slope of The Downs by high high water, large waves and transport by an E-W longshore current.

Figure 5.8. Eroding till slope on the south side of The Downs. **A:** the view from The Lookout. **B:** The dominant sediment transport is from east (right) to west (left) towards the breakwater (near the letter B in **B)** (Google Earth).

5.3 Ferryland Beach

This reflective high energy shore-normal (with rare shore-parallel activity) barrier forms the southwestern part of the tombolo and extends approximately 1 km SW to the rocky shoreline of Meade's Point (Figure 5.9). The NE extent is a transition from a gentle sloping boulder barrier on the western extent of The Downs to a steeper coarse sand segment seaward of the eastern extent of the breakwater (east of BP1 to BP-4, Figure 5.9). To the SW, the barrier consists mostly of sedimentary cobbles with transient berms of cobbles and pebbles in the intertidal zone. Large angular boulders from previous mitigation measures and smoothed equantic boulders from local parent bedrock are almost completely buried in the intertidal and surf zones in the eastern section (BP-1 to BP-7) and in the SW (BP-16 and BP-17). Most of these are not visible during berm accretion during calm periods. The barrier is anchored in place on a marine ridge (BP-1 to BP-9) and on glacially eroded bedrock, till and fill materials from BP 10 to BP-19. Minor backstepping via overwashing (small overwash fans) is occurring between BP-7 and BP-14, with artificial mitigation holding the barrier between BP-1 to BP-7 and BP-15 to BP-19. Residents indicate that the beach extended seaward up to 30 m approximately 60 years ago (e.g. A. Harvey, Pers. Comm. December 15, 2013). At that time, the intertidal zone berms were lower than present day, but of similar composition with more sand in the intertidal zone.

The barrier is impacted by large E-SE waves (>3 m) and shows features such as cusps and multiple berms where there is no mitigation in or at the intermediate berms (between the high water berm and storm berm) and the storm berm. Cusps average between 0.5-1m H X 3m W X 8m L for small cusps to more than 1.0-1.5m H X >10m W X >40m L for the larger cusps in the intermediate and storm berms. Marine organics are common on and landward (transported by wind) of the barrier, although rarely observed between BP-10 and BP12, and BP-13 and BP-15. Berms consists mostly of unsorted equantic and roller cobbles with lesser amounts of blades and discs. Pebbles are common in the intertidal zone.

Recent storms that have impacted the sediment structure and morphology include Post-tropical Storm Leslie during September 2012 and during the offshore passage of Hurricane Gonzalo during October 19, 2014 that resulted in large waves and surge which reworked the high tide and lower intermediate berms. Observations made on Monday

October 22, 2014 revealed that the coarse sand at the eastern extent of the breakwater (between BP-1 and BP-3) was replaced by coarser pebbles and cobbles. Cusps formed from BP-4 south to the outfall (between BP-14 and 15 in Figure 5.8). HD video taken from 18:00 Saturday October 20 to 18:00 Sunday October 21 revealed waves >3 m breaking along Ferryland Beach.

Anthropogenic influences are prevalent from NE to SW. From local knowledge and interpretation, the breakwater and armor stone limit natural berm building through accretion during calm periods and accentuate erosion during high wave events; especially during high water and surge conditions with longshore currents. This suggests that the accentuated erosion is due to a lack of sediments. The outfall in the intertidal-surf zone at The Valley acts as a groyne during longshore transport of cobbles and pebbles which destabilizes the armour stone that anchors the outfall pipe. Residents have observed the pipe displaced and above water. According to residents, Meade's Point is undergoing erosion (estimated 10 m lateral retreat over 50 years) due to freeze-thaw, rainfall, and wave undercutting, resulting in the widening of the rock platform and loss of private property atop a till cliff (T. Meade, Pers. Comm. March 8, 2014).

5.3.1 Ferryland Beach Profiles

Beach Profiles (BP) were measured using RTK during July 11-12, 2014. Each BP (Figure 5.9 and Figure 5.10) was measured from point 0.00 m seaward to the low low water level except for BP-2 to BP-4 that begin at water level at The Pool and end at water level at The Backside. Most measurements are given in elevation in relation to 0.00m MTM except where horizontal distance is specified. Table 5.1 contains the code descriptions for symbols used in the BP profiles that follow. All points including nails and rebar can be resurveyed for monitoring purposes using a RTK survey system.

For the purposes of this study, the barrier is divided into four segments that consider exposure, width of beach, reflective properties, depth of nearshore water, and other factors as described. Specifically, Figure 5.8 shows the four segments as BP-1 to BP-3, BP-4 to BP-9, BP-10 to BP-15, and BP-16 to BP-19. Anthropogenic influences will be discussed in the next section.

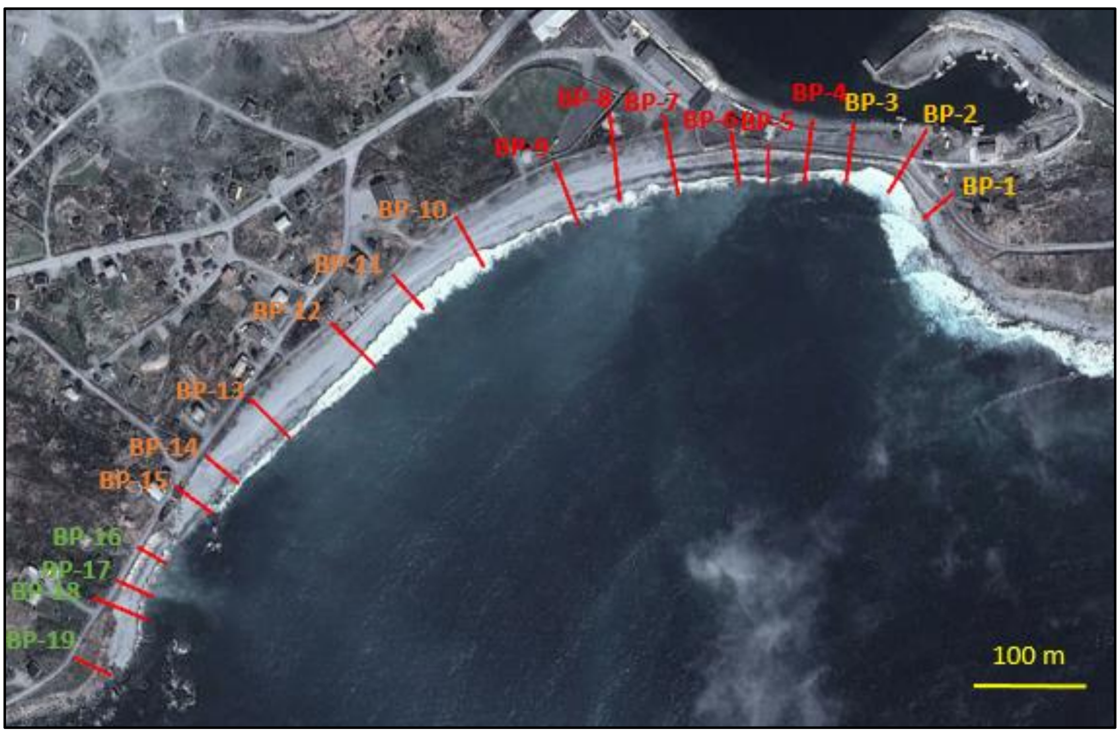


Figure 5.9. Ferryland Beach showing the tombolo, breakwater (BP-1 – BP-7), refracting waves, road to the lighthouse, and 19 Barrier Profiles (Google Earth Image). The four segments are shown in yellow, red, orange, and green. Approximate scale in lower right corner.

Figure 5.10 shows the face of the barrier (from low tide up to either the storm berm or the lowest point of mitigation) to elevation comparison of all profiles along the barrier. It emphasizes the influence of exposure, mitigation, and nearshore bathymetry.

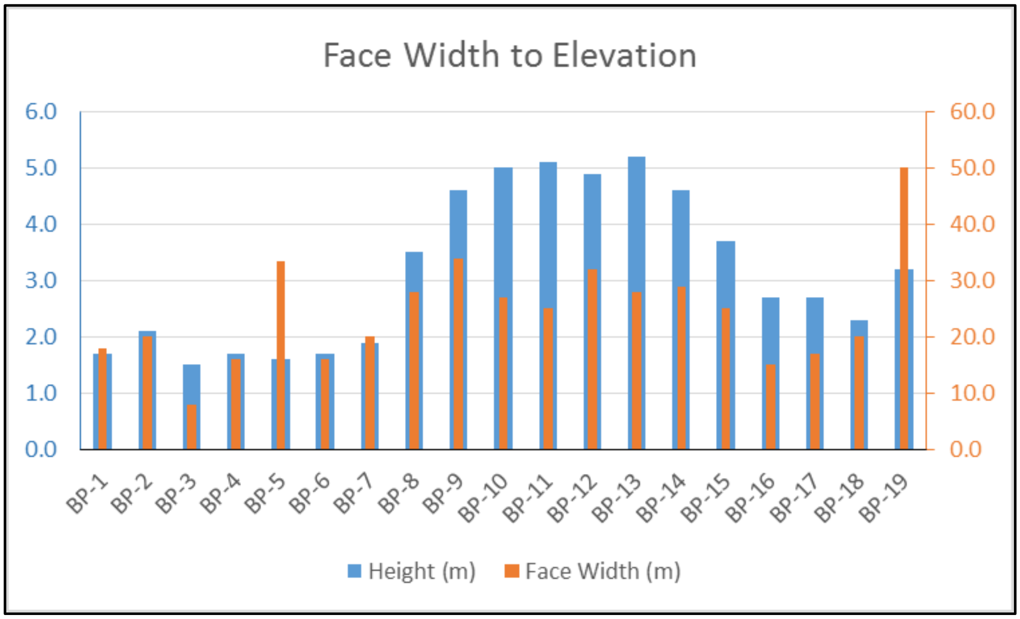


Figure 5.10. Barrier face width to elevation comparison.

BP-1 to BP-7 show a relatively narrow barrier face width and low barrier elevation due to the presence of a breakwater and armour stone. The exception is BP-5 which shows a wider barrier face due the turn in the breakwater and the sediment accretion as a result of influence from Mad Rocks Sill, longshore transport that shoals into the barrier between BP-4 and BP-6. BP-8 to BP-15 show a higher barrier elevation relative to barrier face width. This is due to the direct E-SE exposure to large waves and the deeper nearshore water between Mad Rocks Sill and the barrier. BP-16 and BP-17 show a lower elevation and narrow barrier face due to the armouring along the roadway and deeper nearshore water. BP-18 to BP19 show decreased barrier elevation and face width with the exception of the face width of BP-19, including a bedrock platform. The shore-normal nature of this system transitions to shore-oblique or shore-parallel between BP-1 and BP-7 during large wave events from the ESE, which create a dominant E-W current from The Downs into this area. Shore-normal conditions prevail between BP-8 and BP-19 except during extreme wave approach from the south, when shore-oblique conditions result from large southerly approaching waves between Crow Island and Freshwater. This results in a SW to NE current that transports sediment NE along the barrier towards the tombolo. BP-1 to BP-5 are influenced by shoaling nearshore water, transitioning to progressively deeper water off BP-7 to near BP-13. From here, the nearshore water off the beach step is relatively shallow to BP-19, with a restricted deeper section between BP-16 and BP-17. BP-8 to BP-15 show the highest height and face width pattern. This suggests large wave approach from the ESE during higher tides so that waves travel over the sill and break on the barrier face, resulting in the building of a high storm berm. These profiles represent the conditions in July 2014.

The segment BP-1 to BP-3 (Figure 5.8 and 5.9) is specifically differentiated from the other profiles due to the influence of refracting waves from SE, shoaling water from the SE, and the influence of Mad Rocks Sill to the SW.

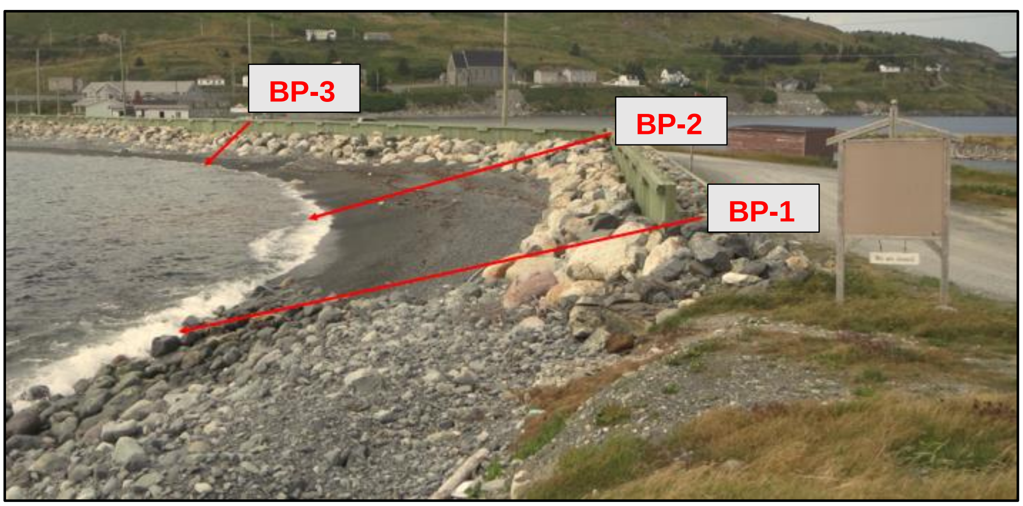


Figure 5.11. BP-1 to BP-3. Post survey completion – arrows for location and direction only. BP extend further to the right and follow actual elevation. Note coarse sand, armour stone, breakwater, cribbing and road.

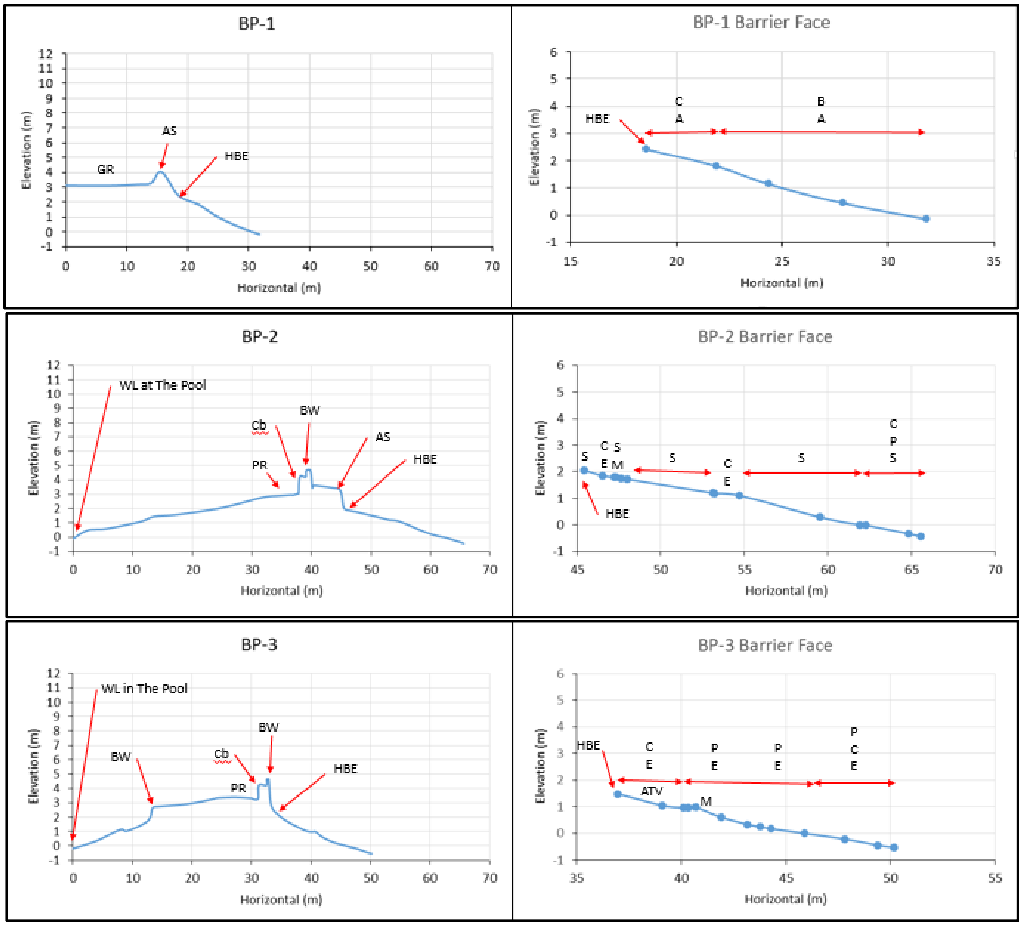


Figure 5.12. BP-1 to BP-3 Profiles.

BP-1 begins on a 255 mm nail near a utility pole between the gravel road and the Breen residence. From HBE, there are two sediment types; angular and equantic cobbles and angular and equantic boulders to water level at -0.3 m. The profile is straight with accumulated cobbles in the upper third of the profile that have been transported from the toe-of-slope of The Downs during high water and waves events.

BP-2 begins at the water level on the southern side of The Pool. The profile crosses various anthropogenic features to HBE at 2m. From here, there are seven sediment types to the water level at – 0.4 m; sand, equantic cobbles, sand with marine organics, sand, equantic cobbles, sand and cobbles with pebbles and sand at the water level. The shore-parallel line of cobbles at mid-profile is the top of a small berm that was created during near shore parallel sediment transport from the SW.

BP-3 begins at -0.2 m at the water level in The Pool. No armour stone was visible seaward of the breakwater during this survey. From HBE, there are three sediment types; equantic cobbles, equantic pebbles and a mixture (50/50) of equantic cobbles and pebbles at water level at -0.3 m.

The segment BP-1 to BP-3 is minimally exposed to the S-SE, contains the lowest barrier elevation, lowest angle barrier face, and has significant mitigation influence. Wave approach and sediment transport is dominantly at an oblique angle (essentially shore-parallel) from the SE with rare occurrences from the SW. Large waves (>3 m) impact this section. The dominant wave impact occurs as waves refract around the western boulder barrier of The Downs, but are mostly restricted to this segment due to the influence of Mad Rocks Sill running from Crow Island to the barrier at BP-4 to BP-6. Berms or cusps have not been observed in this section. Sediment here is predominantly coarse sand and pebbles with occasional replacement with larger pebbles and cobbles. This replacement is due to sediment (angular cobble) longshore transport driven by refracted waves from the western boulder-cobble barrier of The Downs, and rarely from SW to NE traveling waves further south (BP-5 to BP-7), as indicated by the occasional presence of well-rounded equantic cobbles that are not present on the western barrier of The Downs. The abrupt transition between the western boulder-cobble barrier of The Downs to coarse sand (Figure 5.11 near BP-1) marks the area where wave action is refractive, accentuating the longshore current which transports sediment rapidly across the boulder barrier (western shoreline of The Downs) into the sand-cobble barrier at BP-1 to BP-3. The accumulation of coarse sand is also a result of deposition as the currents from the east slow due to the sharp left curvature of the barrier between BP-1 and BP-3 and the shoaling effect of Mad Rocks Sill, indicated by the wide barrier face at BP-5.

The segment from BP-4 to BP-9 (Figure 5.13A) is delineated to emphasize the change in sedimentology and morphology near BP-4, barrier width changes, berm evolution, and exposure. Dominant wave approach and sediment transport transitions from shore-parallel to shore-normal from BP-4 to BP-6, with shore-normal dominating from BP-6 to BP-9. BP-9 also marks the last profile in the northern section of Ferryland Beach regarding the extent of the westerly current influence from wave refraction around The Downs during surge and large wave conditions. This segment has more of an east-southeastern exposure to wave approach than the previous segment. At high high water or storm surge, Mad Rocks Sill is ≥4 m underwater allowing larger waves to travel over the sill and break near or on the beach face. The segment is also exposed to occasional wave action from the south that causes longshore transport of clasts towards BP-4 as described above.

The bathymetry off the beach step of the section between BP-4 to BP-9 consists of the transition of Mad Rocks Sill into deeper water further south. Figure 5.14 shows a small accretionary spit that develops during minor to moderate wave action into BP-1 to BP-3. This spit is eroded during moderate to high wave action due to stronger westerly longshore currents that transport sediments further SW. A spit also occurs further SW near BP-5 and BP-6. The bathymetric drop off the beach step between BP-8 to BP-9 is steeper than BP-4 to BP-7 and is evident in the unstable beach step that is usually at the critical angle of repose. The profiles for this segment are contained in Figure 5.15.

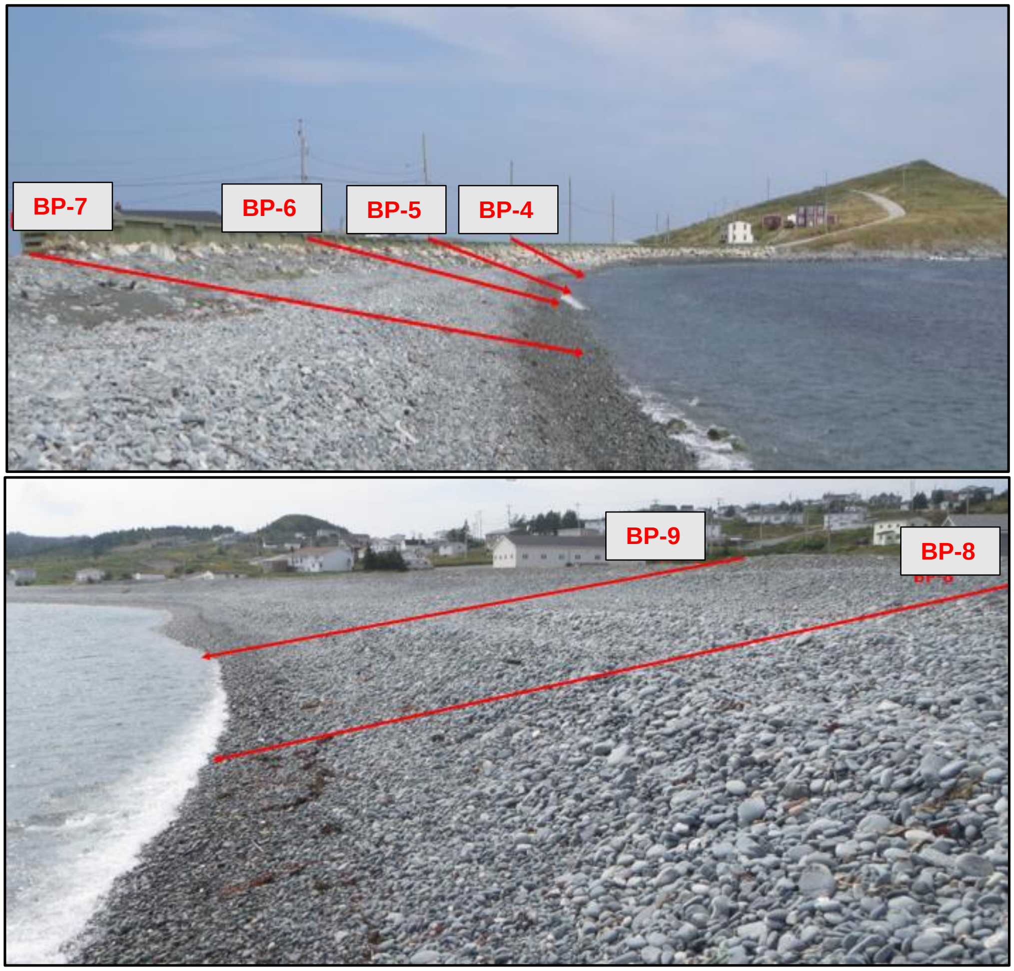


Figure 5.13. Approximate locations of BP-4 to BP-9. The dark coloration nearshore of BP-4 and BP-5 show the marine organics of the shoal related to Mad Rocks Sill. The cuspate feature in the intertidal zone south of BP-9 indicates the division of the northern and southern sections of nearshore currents and geomorphic factors. BP-10 is directly south of this cuspate point (below).

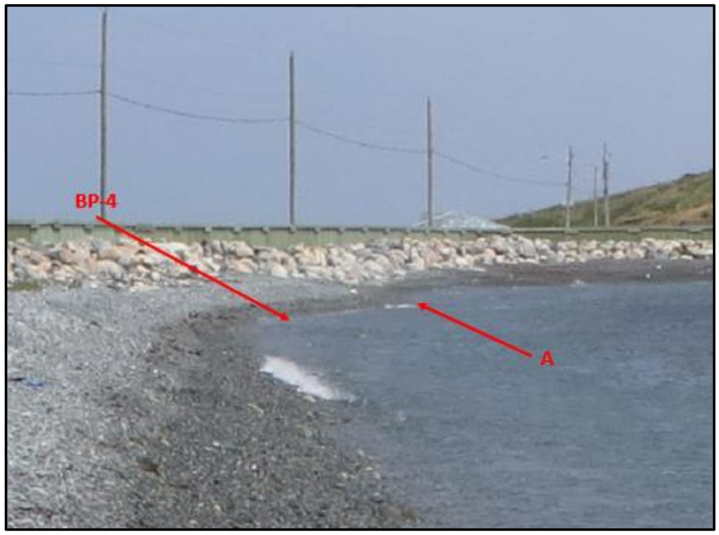
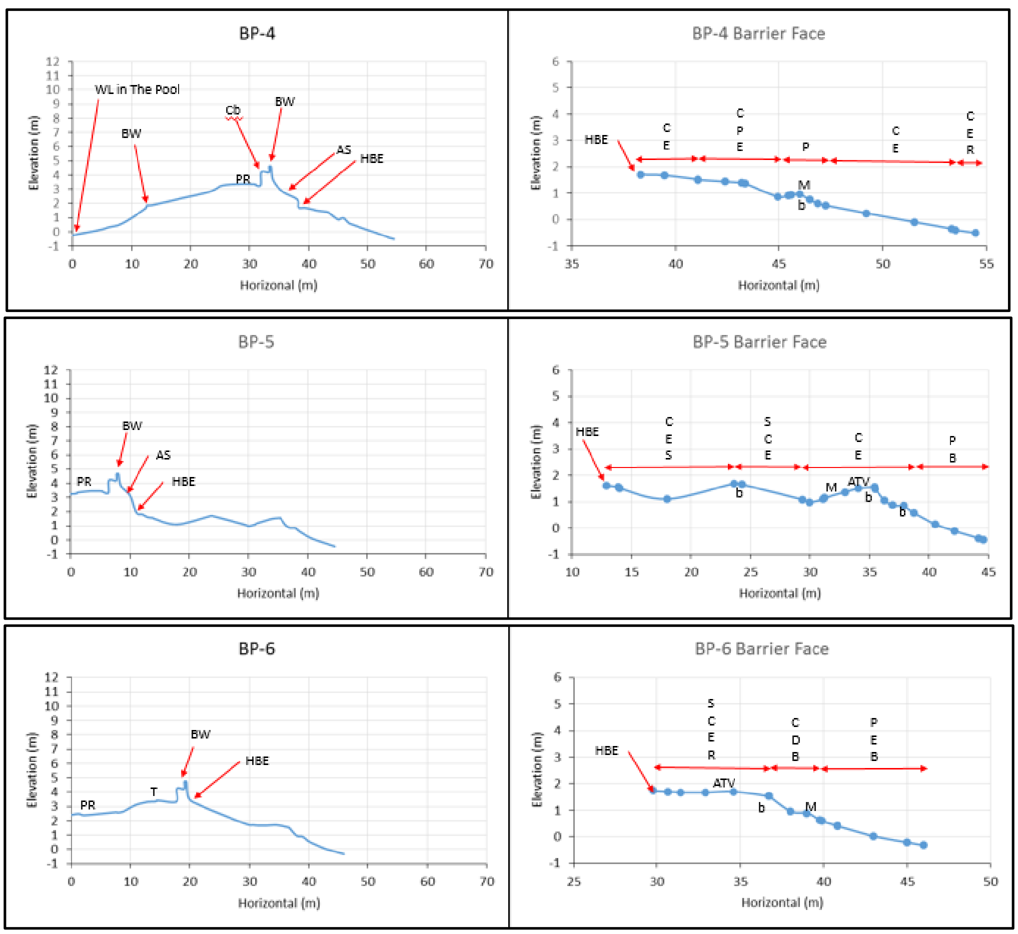


Figure 5.14. Transient cuspate spit (**A**) that marks the average westward edge of cobbles that transition to coarse sand further west towards The Downs.



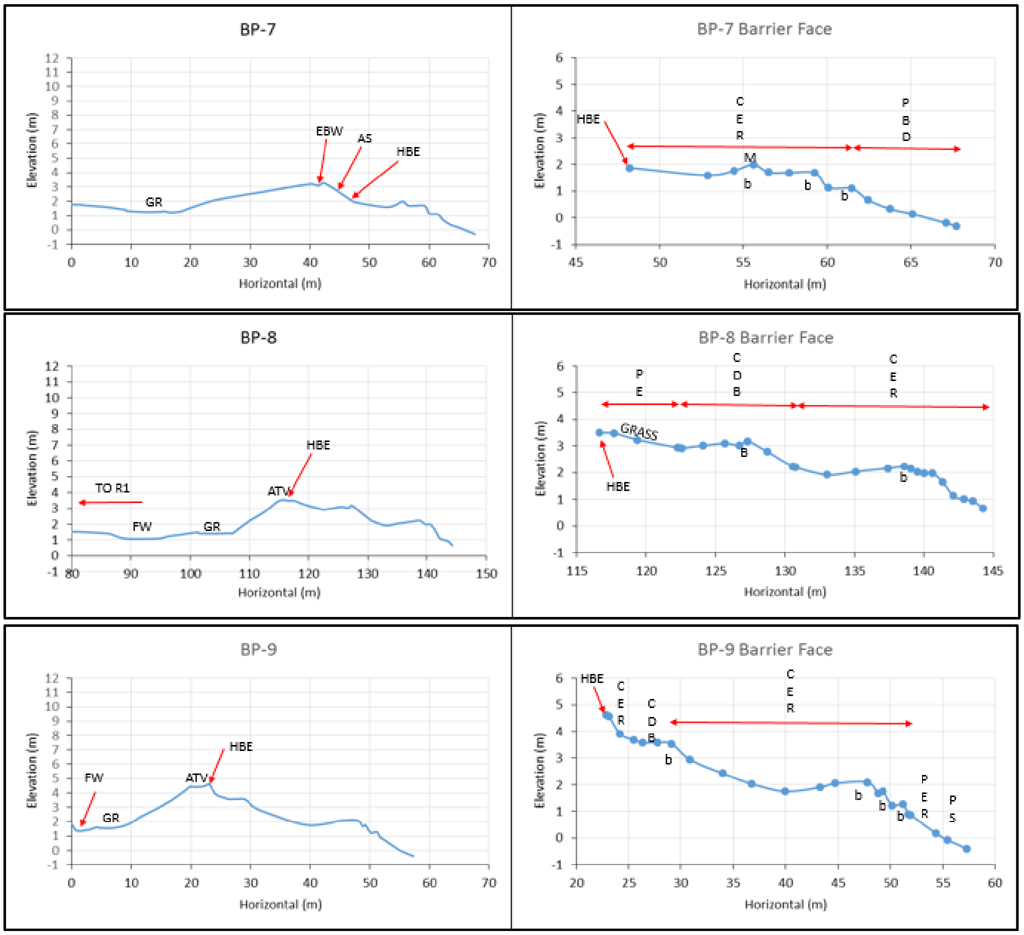


Figure 5.15. BP-4 to BP-9 Profiles.

BP-4 begins at -0.3 m at the water level in The Pool. From here it rises over sand and cobbles to the base of a dilapidated breakwater at 1.65 m. The top of the breakwater is at 1.9 m. From the breakwater to the paved road surface at 3.2 m consists of compacted fill exhibiting drainage cuts from overtopping of the main breakwater. The right figure begins at HBE and consists of five sediment types: equantic cobbles, cobbles and equantic pebbles, a berm of pebbles covered with marine organics, equantic cobbles, and equantic and roller cobbles to water level at -0.5 m. BP-4 is near the transition point from the coarse sand of BP-1 to BP-3 to the remainder of Ferryland Beach.

BP-5 begins on a 255 mm nail at 3.2 m near the eastern end of the fence on the roadside of the Herb Williams property fence. From here, it crosses the road at 3.4 m and then extends over compacted fill material to the cribbing. There are four sediment types and two berms seaward of HBE, shown in the right figure. Equantic cobbles and sand transition into sand and equantic cobbles to form the first berm. Equantic cobbles form the second berm followed by mixed shaped pebbles with partially buried equantic and angular boulders (< 0.5 m diameter) and angular armour stone (> 0.5 m diameter) on the berm face to the water level at -0.4 m. Boulders and armour stone are partially buried along the water line and are visible into the nearshore.

BP-6 begins on a 255 mm nail at 2.4 m near the western end of the fence on the roadside of the Herb Williams property. The ground cover is grass and compacted fill at 2.4 m to the edge of the paved road at 2.4 m. From HBE, there are three sections of sediments to water level; sand with scattered equantic and roller cobbles, disc-shaped cobbles with partially buried boulders and armour stone, and equantic pebbles with partially buried boulders and armour stone to and beyond the water level.

BP-7 begins on a 255 mm nail at 1.8 m. From here, the line crosses compacted fill material above fresh water between 1.7 m and 1.3 m, below freshwater level for a distance with a low point of 1.2 m including an ATV trail. The line rises above 1.3 m to the base of the cribbing at 3.2 m with sand between 2.0 m to 2.4 m and cobbles between 2.5 m and the cribbing. This line does not run up over the retaining wall and seawall, but along the southern edge of the cribbing and breakwater. From HBE, there are two sections of sediments and three berms; equantic and roller cobbles make up the first section and the three berms with disc-shaped pebbles with partially buried boulders and armour stone forming the second section to and beyond water level at -0.2 m.

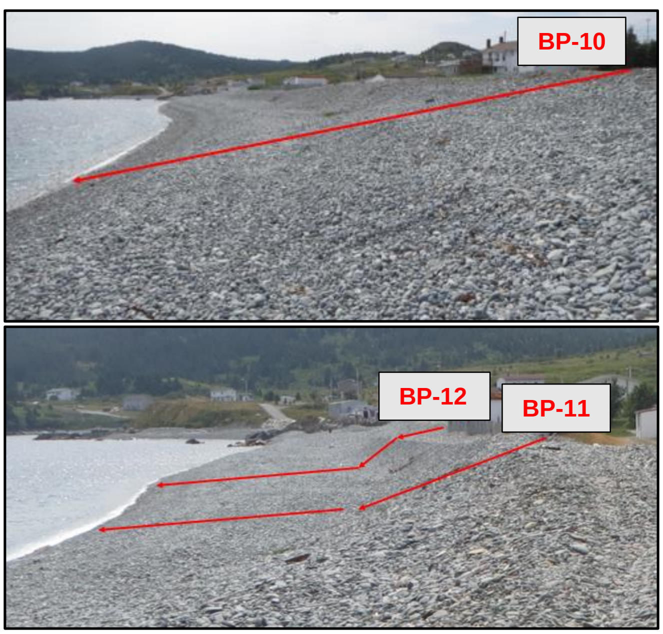
BP-8 begins on a 5/8 rebar with a red morasse marker cap labeled R1 near the easterly fence of the Folk Arts Field (directly north of the beginning of BP-8 and BP-9 in Figure 5.8) at 1.7 m. From here it runs a distance of ~107 m to a cobble mixed clast shape and size at 1.4m with the lowest point submerged in freshwater at ~1.0m elevation. This section is included to establish a baseline over the former lagoon, now infilled. The back barrier slope rises from here over equantic and roller cobbles to a maximum elevation of 3.5m where the storm berm has been flattened and compacted (up to ~0.75 m of the storm berm has been flattened and spread) by ATV traffic. The ATV trail is ~1.5 m wide. From HBE, there are three sediment types and two berms; equantic pebbles with a grass-covered patch, predominantly disc-shaped cobbles with partially buried boulders and one piece of armour stone, and equantic and roller cobbles forming the last berm to water level at -0.2 m.

BP-9 begins on a 5/8 rebar with a red morasse marker cap labeled R2 near the easterly corner of the outdoor theatre of the Folk Arts Field at 1.8 m. From here it crosses a grass-covered ditch with minimum elevation of 1.3 m and a gravel trail at 1.6 m to the cobbles of mixed shapes at the base of the back barrier slope at 2.9 m. The back of the storm berm consists of equantic cobbles. The top of the storm berm has been flattened similar to BP-8 and consists of mixed shapes of cobbles. From HBE, there are five sediment types and three berms; equantic and roller cobbles transition to disc-shaped and blade cobbles with sporadic boulders (naturally sourced), equantic and roller cobbles make up the third section into the intertidal where equantic and roller pebbles occur below the high tide berms and pebbles and sand dominate the water level area at -0.2 m.

Cusp formation occurs on a nearly daily basis in the intertidal zone, with larger cusps >30 m long occurring on the storm berm face during large wave events (>3 m). Wave approach is dominantly shore-normal from refracted and funneled E-SE waves with rare occurrences from the south. Large waves (>4 m) impact this section during surge conditions.

The segment BP-4 to BP-9 shows the increasing exposure to the SE, cusp formation, berms, sediment sorting, marine organics and barrier morphology past the end of the breakwater. Exposure to the SE shows berm building, cusps (average dimensions 1m H X 8m W X 20m L) and a defined high tide berm. Berm accretion and erosion is frequent with quiet calm periods and large wave conditions respectively. BP-4 to BP-5 marks the change in the width of the barrier, sediment structure, depth of the nearshore, and the alongshore transport. The width of the barrier face changes from 20.5 m at BP-4 (from breakwater to water level) to BP-5, BP-6, and BP-7 at 36 m, 26 m, and 26 m, respectively. At the time of survey, the width of BP-5 represents the accumulation of barrier sediment at the northern extent of Mad Rocks Sill. The coarse sand on the barrier face between BP-1 and BP-3 transitions sharply to pebble and cobble berms showing cusps at or near BP-4. The segment from BP-4 to BP-9 consists mostly of cobbles with pebbles and partially buried boulders in the intertidal zone. The shallow area of the surf zone and nearshore bathymetry of Mad Rocks Sill deepens to the SW along the nearshore (BP-7 to BP-9) and shallows to shoal nearshore at near BP-12. The beach step in this area drops sharply into deep water, especially between BP-8 to BP-9. Wave action and alongshore transport occurs predominantly from the easterly direction (The Downs), although occasionally strong SW to NE current occurs when waves enter through the west of Crow Island. Overwash fans are present, although residents indicate that overwash events are infrequent. Residents state that the barrier in this segment has moved further landward (rate unknown), has a steeper barrier face, and has lost the broad sandy intertidal zone that was present approximately 100 years ago.

BP-10 to BP-15 (Figure 5.16) are delineated into a segment based on easterly exposure and influence of Crow Island, shore-normal activity, nearshore bathymetry, berm formation, and barrier impacts due to anthropogenic activities. The segment consists mostly of cobbles with an accentuated storm berm between BP-11 and BP-12, major anthropogenic influences in the southern section, and multiple berms. Cusp formation is similar to the previous segment. However, the cusps are at times slightly oblique to the SE.



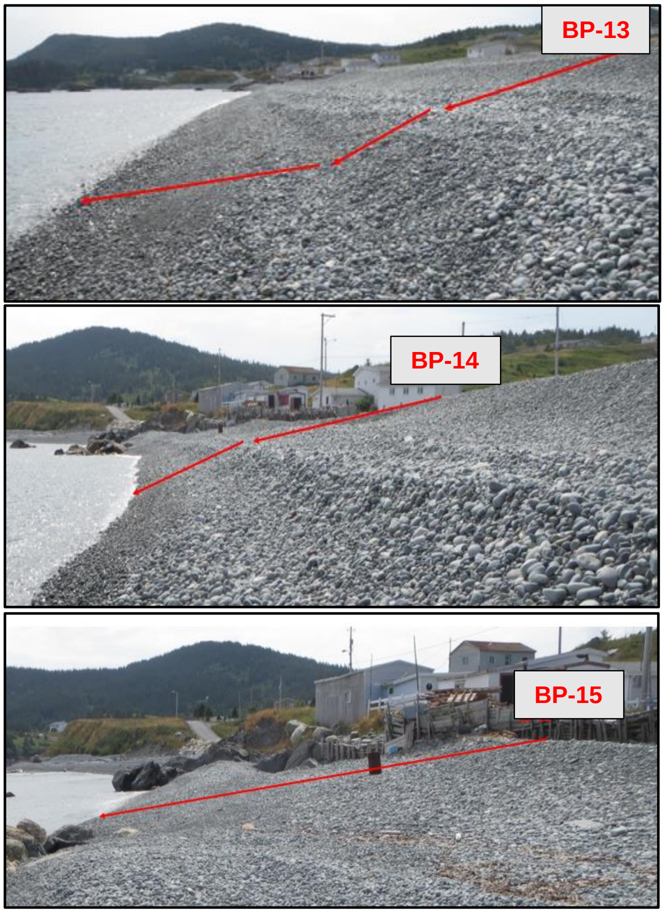
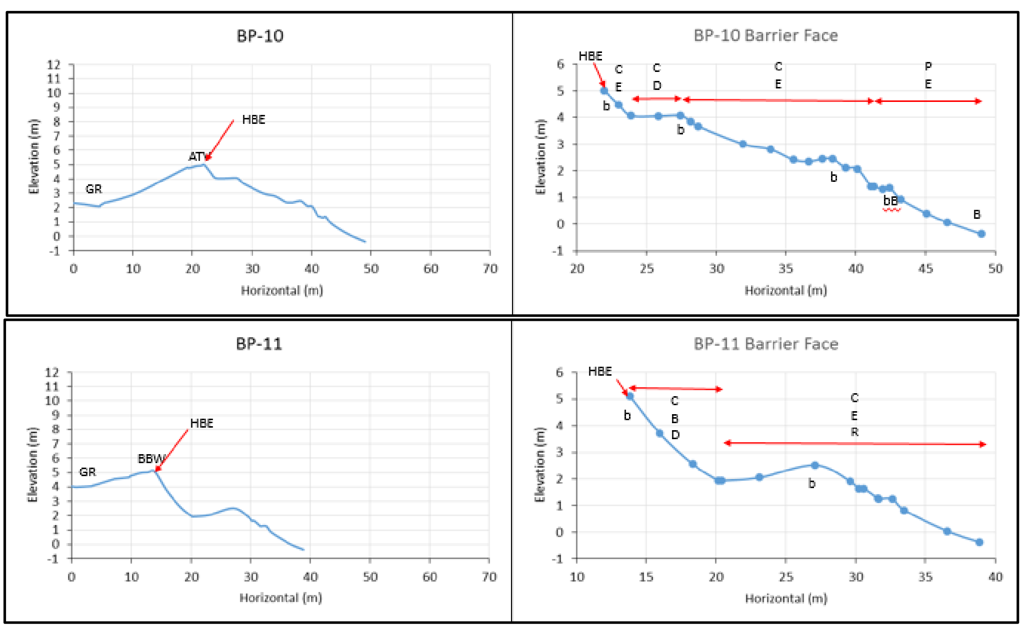


Figure 5.16. Approximate locations of BP-10 to 15.



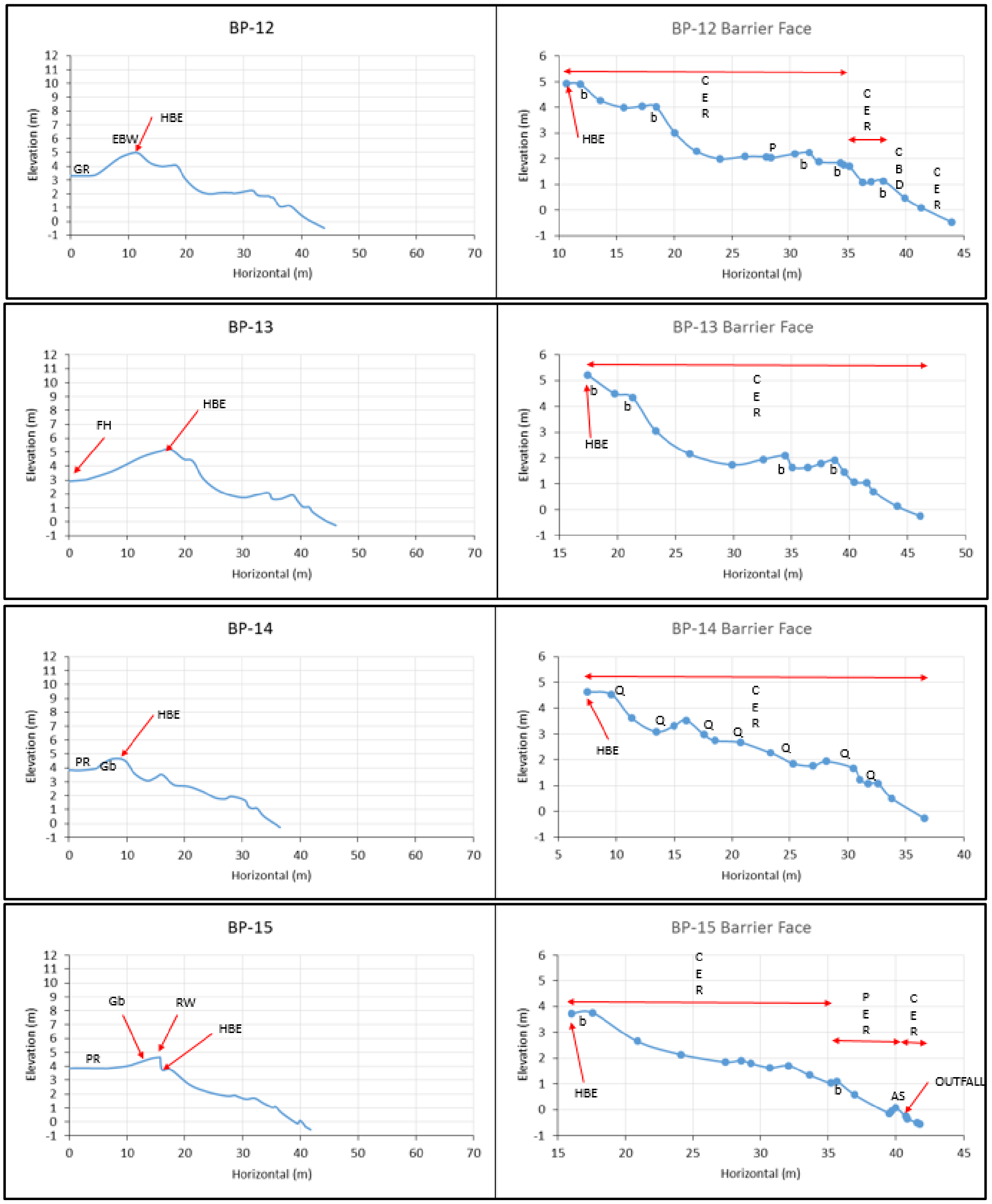


Figure 5.17. BP-10 to BP-15 Profiles.

BP-10 begins on a 5/8 rebar with a red morasse marker cap labeled R3 near the easterly corner of the outdoor theatre of the Folk Arts Field at 2.3 m. From here it crosses a distance of 5.5 m including a grass-covered compacted area and gravel trail to the toe of the back barrier slope at 2.4 m. The back slope consists of equantic cobbles with < 10% discs. The storm berm is at 5 m where the top has been flattened by a 2.5 m wide ATV trail (similar to BP-8 and BP-9). From HBE, there are four sediment types and multiple berms; equantic cobbles form the short face of the storm berm, transitioning into disc-shaped cobbles in a short horizontal section, a section of equantic cobbles, and a section of equantic pebbles into the intertidal zone to water level at -0.4 m.

BP-11 begins on a 255mm nail in compacted gravel at 4.0 m. The back slope of the storm berm consists of equantic cobbles with < 10% blades. HBE is located at the northern end of a round-post breakwater established in the storm berm. There are two sections of sediments with three berms; blade and disc cobbles make up the face of the storm berm transitioning into equantic and roller cobbles to the water level at - 0.4 m. A small berm is located at the high tide mark.

BP-12 begins on a 255 mm nail in compacted gravel at 3.3 m. The back slope of the storm berm consists of equantic cobbles with <15% blades. HBE is located at the southern edge of the same breakwater as described in BP-11 above. There are four sections of sediments and five berms; the face of the storm berm consists of equantic and roller cobbles transitioning into blade and disc-shaped cobbles just above high tide mark with the intertidal zone to the water level at - 0.4 m consisting of equantic and roller cobbles.

BP-13 begins on a 255 mm nail installed at 2.9 m in the grass-covered compacted gravel adjacent to and directly north of the only fire hydrant in this area. The back slope consists of equantic cobbles with < 15% discs. From HBE, equantic and roller cobbles dominant to water level at - 0.4 m with five berms.

BP-14 begins on a 255 mm nail installed in the asphalt at 3.9 m. HBE is located on the seaward edge of a gabion covered with equantic cobbles. From HBE to water level at - 0.4 m, the profile consists of equantic and roller cobbles. The cobbles in this profile are regularly moved via heavy equipment in order to clear a culvert which drains surface water from The Valley. The cobbles are returned into the storm berm with every successive storm, especially with wave approach from the SE.

BP-15 begins on a 255 mm nail installed in the grass at 3.8 m on the Williams' property. A combination retaining wall and gabion forms the upper portion of the storm berm. From HBE, there are three sediment types and three berms; equantic and roller cobbles form the first section that transitions into equantic and roller pebbles and cobbles around the armour stone that reinforces the outfall.

The segment BP-10 to BP-15 is exposed to the E-SE, contains the highest barrier elevations, steepest berm face, deepest nearshore water, and the most variable anthropogenic influences. The segment is exposed to dominant E-SE wave approach with influence from Mad Rocks Sill (shoaling waves at low low water) and funneling and refracting influences from the tombolo and Crow Island. Cusps are mostly shore-normal with occasional oblique angles from southerly approaching waves. The average dimensions of the cusps are 0.5 m-1.0 m H X 6 m W X 10 m L. Much larger cusps (>1 m H X >10 m W X >20 m L) are formed on concave barrier faces during successive large wave events. Longshore currents are determined by the approaching waves, tide and surge, with large E-SE waves resulting in a NE-SW flow and large S waves resulting in SW-NE flow.

The breakwater in the storm berm between BP-11 and BP-12 has resulted in accentuated overtopping and steepening of the storm berm (≥ angle of repose for equantic and disc-shaped cobbles). The berm here measures >5.2 m above 0.0 MTM. The water directly off the beach step increases sharply in depth due to the deep water between the

Mad Rocks Sill and the barrier, and currents that occasionally travel alongshore during wave events. The southern segment between BP-13 and Bp-15 is heavily impacted by an outfall fortified by armour stone (intertidal surf zone), excavating around the culvert draining water from The Valley, gabion, retaining wall, and cribbing that supports private property. The armour stone in the intertidal blocks or alters alongshore currents and wave energy which often results in erosion of the barrier in the downstream area of the armour stone. The excavation removes cobbles from the storm berm which is transported north along the barrier. This loss of material is minimal, but residents have noticed less barrier face width here from years ago (exact amount not known). The remedial mitigation measures (BP-15 – BP16) do provide some protection to private property. However, they also provide a flat near-vertical shore-parallel surface for oblique angle waves to remove cobbles from the barrier via longshore transport northward.

The last segment of Ferryland Beach consists of BP-16 to BP19 (Figure 5.18) and is delineated based on the SE exposure, shore-normal activity, narrow width of the barrier, bedrock control, till cliff (Meade's Point) and road armouring.

BP-16 begins on a 255 mm nail in the grass near a wire mesh fence at 5.2 m. From HBE, there are two sediment types to water level at - 0.5 m; equantic and roller cobbles, and equantic and roller pebbles. Partially buried boulders and armour stone are at or near 0.0 m. One transient berm is present at the high tide mark. This berm is eroded and accreted with large wave events and calm periods respectively. The pebbles are transported into the beach step and seaward during large wave events and transported back into the intertidal zone during calmer periods. Longshore transport is limited by an outcrop directly north of this profile.

BP-17 begins on a 255 mm nail in the grass near a wire mesh fence at 4.1 m. From HBE, there are three sediment types and one berm; equantic and roller cobbles transition into equantic and roller pebbles with equantic and roller cobbles partially burying boulders and armour stone in the lower intertidal zone. Water level is at - 0.5 m. Marine organics dominate the upper intertidal and the barrier face. The berm is more developed seaward from HBE than at BP-16 due to the influence of the rock platform to the south.

Figure 5.18. Approximate locations of BP-16 to BP19 and sediment changes. Top: BP-16 to BP-19 on August 3, 2014; bottom on January 25, 2015. Note that >0.5 m thickness of barrier cobbles have been removed. The bottom photo shows boulders from parent material and displaced armour stone. The top photo convex profile (calmer conditions) and the bottom profile is slightly concave (large waves normally associated with fall and winter storms).

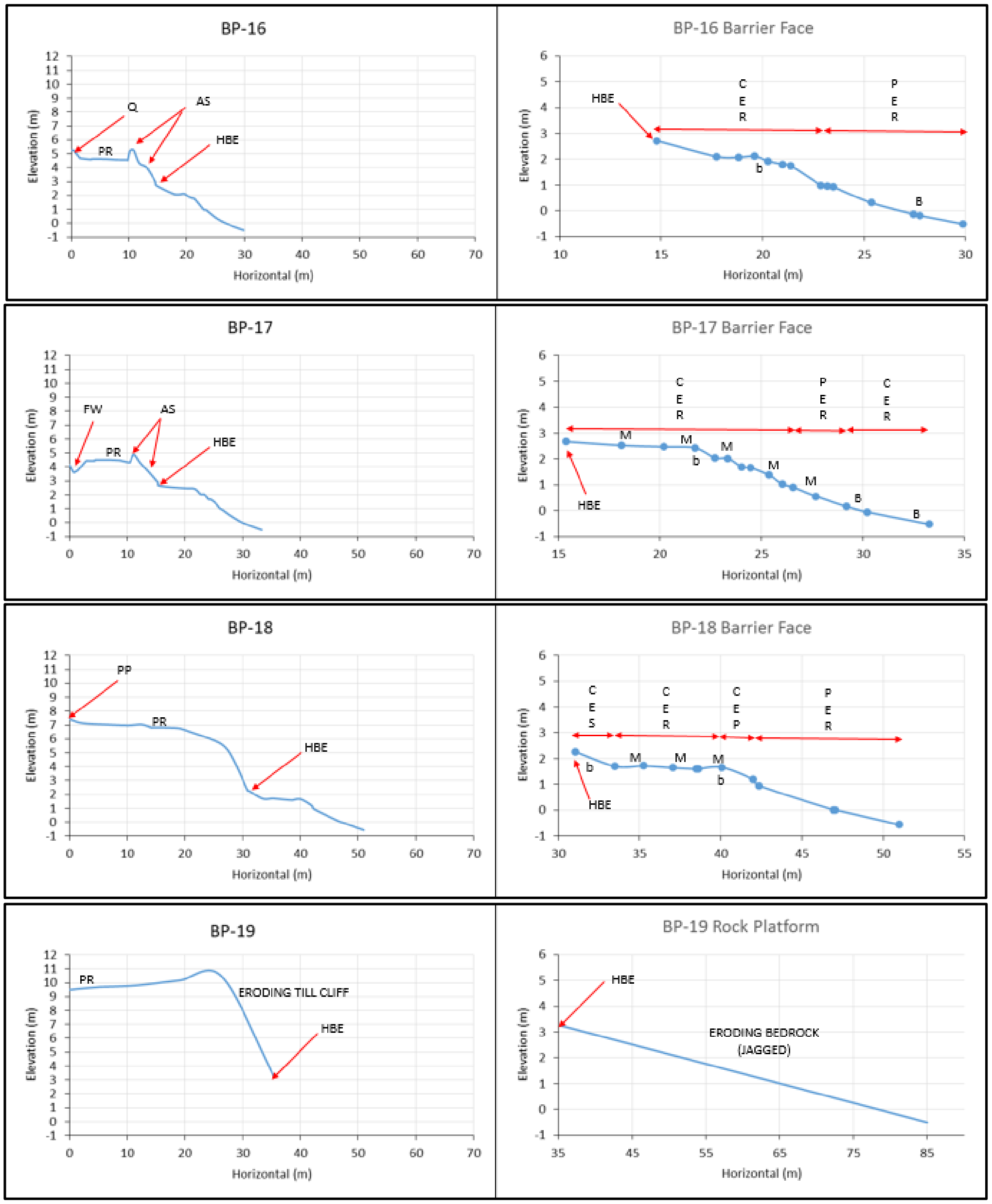


Figure 5.19. BP-16 to BP-19 Profiles. BP-19 left is could not be surveyed due to unsafe surfaces of the bedrock shore face. It is included to show the near even slope from HBE to the water line. Slope and distance were calculated with a suunto inclinometer and horizontal measurement scaled from in-field photographic interpretation.

BP-18 begins on a 255 mm nail at 7.4 m, due east of a power pole. From here the line crosses ~14.3 m of mixed grasses and alder to the landward edge of the asphalt road surface at 6.8 m. The seaward edge of road is just below 6.8 m. From here, the line follows the north side of a wire fence to the top of an eroding till cliff at 5.1 m. HBE is at the bottom of the cliff at 2.2 m. The barrier face shows four distinct sediments; equantic cobbles in sand upslope of equantic and roller cobbles, followed by equantic cobbles in pebbles, and equantic and roller pebbles in the intertidal zone. Marine organic debris is present from the HBE to the back of the tidal berm. Water level is at - 0.5 m.

BP-19 begins on a 255 mm nail at 9.5 m east of a power pole and just west of the asphalt road surface. From here, it crosses the road and grass-covered area to the top of a till cliff at 10.4 m. The cliff drops sharply to the bottom of slope at 3.2 m. RTK measurements were not taken seaward beyond this point due to the slippery surface of the exposed rock platform. The till cliff from BP-18 to BP-19 is undergoing mass wasting. The seaward edge of the platform is ~50 m from HBE.

This segment is defined by nearshore bathymetry, exposure, and barrier backing features. Nearshore bathymetry is shallow and rocky north of BP-16, and at BP-18, and exposed at BP-19, with a steep drop off the beach step between BP-16 and BP-17. Armour stone replaces the storm berm between BP-16 and BP-17 with a till cliff backing the barrier at BP-18 and BP-19. The section is exposed to wave action from the E, refracted waves around Crow Island, and oblique waves from the south. The rock platform (BP-19) serves to break and refract large waves from the S. However, the resulting northerly current transports sediments south to north, including eroded till from the cliff at BP-18 and, to a lesser extent, BP-19. Easterly waves and the resulting current combined with the armouring, till cliff, and rock platform, is responsible for the increase in barrier face width from BP-16 to BP-18. Cusp formation is common with average dimensions of 0.5 m-1.0 m H X 5 m W X 8 m L. Southerly approaching oblique waves do not form cusps as the angle is shallow and is observed only as cross-shore wash. Easterly approaching waves (between The Downs and Crow Island) are responsible for shore-normal symmetrical cusps. There is usually one berm at the average high water mark. This berm is eroded and accreted with large waves and calmer periods respectively.

5.3.2 Selected Barrier Features and Dynamics

The barrier is subject to large waves (>3 m) that reach all sections of the barrier face depending on wave height, tide stage, surge, and other factors such as forcing and topographical/bathymetric obstructions. This results in overtopping and overwashing during setup conditions. The northern extent is a reinforced breakwater which was built in 2010 (Figure 5.20) to replace a series of breakwaters destroyed in 1989, 1995, 2001, and 2009. It extends 250 m west from the edge of The Downs (BP-1 to BP-7 in Figure 5.8).

The design of the 2010 breakwater included footing the wall to 2 m depth into the barrier (Mayor Roddy Paul, Pers. Comm., March 8, 2014), armouring the seaward side with armour stone (0.5 m - >1 m diameter) and further supporting the seawall landward with continuous cribbing. The intent was that the armour stone would break the waves and dissipate energy prior to wave impact on the breakwater. The breakwater is designed to restrict water flow over the road and tombolo, and the cribbing is to provide extra support to the breakwater and provide a solid shoulder for the roadway. The road surface here has also been elevated by ~1 m to increase strength behind the breakwater and protect the public water supply line buried beneath. This water line was also raised from a deeper depth, where the previous line was occasionally immersed in salt water and would freeze (Mayor Roddy Paul, Pers. Comm., December 15, 2014). The Town of Ferryland estimated the final cost of the armour stone, breakwater, supporting cribbing and the new road at well over $600,000.00.

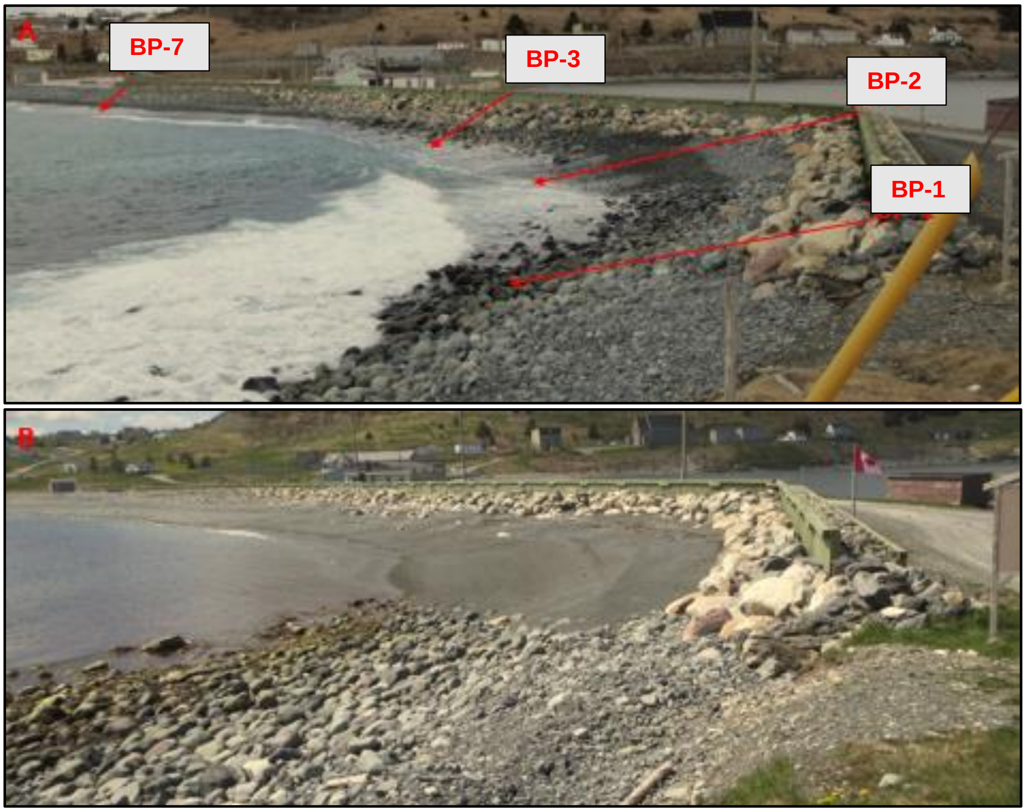


Figure 5.20. The structure of the breakwater on the south side of the tombolo. **A:** shows sediment type and elevation in April 2013 during falling tide from low high water, and **B:** shows sediment type and elevation in June of 2014 during low water. The upper section of pebbles and cobbles have been replaced with coarse sand. High high water level covers the lower armour stone in front of the breakwater at BP-2.

The water level occasionally rises to the elevation of the road surface. From RTK grade points taken as a part of the BP-2 to BP-6 profiles and other road grades, the average elevation of the top supporting horizontal timbers is 4.6 m above 0.00 MTM. The piled armour stone is ~1.5 m high and ~2-5 m wide. The paved road rises from < 2.0 m near The Pool to 2.9 m at BP-2, 3.3 m at BP-3 to BP-6, and drops to < 2.0 m to the inner tombolo.

Residents commented that saltwater occasionally comes up to the road surface to the right of the reddish-brown stage in Figure 5.20.

Multiple observations and information from residents and the Town reveal that the breakwater is holding, although there have not been any storms of the magnitude and setup of the 2009 storm event. However, there is information to suggest that future damage or failure will occur. High high water (not surge conditions) was observed covering the lower armour stone in November 2013 (Figure 5.21). From this point, there is approximately 2 m of armour stone and breakwater above water during this calm condition. The water depth over nearshore shoals was observed at ≥2 m and the low tide berm was ~1.6 m below water. This suggests that large waves during this condition would likely displace the armour stone. Impact marks on the seaward side of the breakwater from armour stone moved by large waves were observed from previous events. Many of the originally placed armour stones have been displaced seaward and are now partially or fully buried in sediment in the intertidal zone. During erosion and accretion cycles, and larger wave events, sediment accumulates seaward of the armour stone creating a swash ramp (Figure 5.20A) that provides for swash flow up to and over the breakwater. This results in sediment deposition on the paved road surface and fill erosion on the north edge and gravel surface down to The Pool. The Town is considering future maintenance to reposition armour stone that has been moved due to wave events and to address excessive sediment accretion (e.g. swash ramp) (Mayor R. Paul, Pers. Comm., Numerous Dates).

In October 2014, refracted breaking waves up to 3 m high (around the west shoreline of The Downs) were observed by HD video during the offshore passage of the short-lived (<8 hours) moderately strength (minimum pressure of 97 kPa and maximum wind speed of 76 km/h) post-tropical remnant of Hurricane Gonzalo in October of 2014. The largest of these waves approached from the southeast over a 3 hour period during falling tide at neap cycle. Most of the waves were breaking seaward of the low tide berm with significant runup into the armour stone and breakwater. Several larger waves >3 m did break above the low tide berm resulting in overtopping of the breakwater (Figure 5.22). Coarse sand from the barrier was deposited on the cribbing and on the road surface directly to the north. Overwash also caused minor erosion on the north edge of the paved road.

Figure 5.21. Water level at BP-2 breakwater. BP-2 (first turn in the breakwater) elevations reveal that the water level at this time is ~2.3 m above MTM datum; the inner paved road to the right is < 2 m above MTM datum. The water is higher on this side versus the upper right in Ferryland Harbour due to localized surge in the Backside.

A storm of similar magnitude to Hurricane Gabrielle in 2001 at surge conditions (< 1m below top of breakwater) would have very likely resulted in waves breaking very close, on, or over the breakwater. The resulting overtopping and overwashing would likely transport barrier material and armor stone over the breakwater and wash out the roadway

Figure 5.22 Wave breaking and overtopping the breakwater at falling tide during the passage of H. Gonzalo. Barrier sediment was deposited on the roadway with some erosion to north road edge was observed shortly after this moment.

and fill material, displacing sediment north into Ferryland Harbour. A long duration storm could cause the breakwater to fail, resulting in partial to complete washover or tombolo breach.

The barrier increases in width from the breakwater-armour stone to the beach step towards the southern end of the breakwater (from BP-4 to BP-7 in Figure 5.8). Swash infrequently contacts the face of the breakwater due to breaking waves on the beach step that reduce the swash energy (Figure 5.21). Noticeable accretion occurs via high tide berm building in this area during calm conditions. These berms consist mostly of pebbles that are eroded into cusps with full berm and cusp erosion occurring during every observed large wave event during rising or high tide. Cusps in the intertidal zone are shallow and short (<0.5 m H X <4 m W X <10 m L) with normal to slightly southerly oriented horns.

From the end of the breakwater south to BP-11, the barrier is mostly open with an ATV-impacted prominent storm berm ranging in elevation from >3.0 m - >5.5 m above low low water. From the lowest point on the back barrier to the low water mark, the width of the barrier is ~60 m, 40 m, 55 m, and 40 m at BP-7, BP-8, BP-9, and BP-10 respectively. The storm berm has been flattened by heavy ATV traffic with an estimated vertical loss of

0.75 m of berm elevation since the last main storm that eroded the system in 2009. Large waves and surge that may cause overtopping and barrier building at the original height of the berm will now likely result in overwashing with potential for additional barrier backstepping and localised flooding. This could possibly occur after the barrier face berms have been eroded by storm waves to create a flat or concave barrier face. An additional storm prior to the accretion of new berms with waves of 4 m could cause runup which could result in overtopping and overwashing.

The storm berm between BP-11 and BP-12 contains a vertical round-stake breakwater that has been overtopped with equantic cobbles on the north end indicating larger wave action to the north than south. Separate measurements reveal that overtopping and overwashing has occurred at ~5 m above low low water. Elevations directly behind the top of the seawall on BP-11 reveal a difference in elevation of nearly a metre, from flush seaward to -0.9 m landward of the seawall. This difference lessens to the south until the elevation is approximately equal at BP-12. In this case, the seawall is stabilizing the storm berm. The steep face of the storm berm occurs only in this segment and is related to the seawall in the storm berm that traps cobbles (accentuated overtopping and prevents overwashing creating a steep berm face).

To the SW, the barrier consists mostly of cobbles to Meade's Point, but is heavily influenced by anthropogenic activities (e.g. barrier excavating at the culvert and maintenance on the outfall), especially from BP-14 to BP-18. Meade's Point consists of a till veneer overlying glacially eroded bedrock. BP-19 has a maximum elevation of ~10.5 m above 0.00 MTM. The toe-of-slope transitions abruptly into large boulders and rock platform that extends ~50 m seaward into semi-submerged rocky shoals. Residents indicate that their parents stated that the point was ~30 m seaward from the present location around 100 years ago. Even though the till slope is currently grass-covered, there is evidence of creep and undercutting along the entire slope (sod cracks and displaced fence posts). RTK points were taken at the toe-of-slope from BP-18 to BP-19 for future assessment.

5.3.3 Anthropogenic Activities and Mitigation Measures

Between BP-14 and BP-15 (Figure 5.8), a culvert under the roadway drains surface runoff from The Valley. The seaward end of the culvert is located in the storm berm. This area is frequently excavated to allow water flow onto the barrier. This excavation also exposes the culvert and the shoulder of the roadway to wave erosion. A gabion was placed along the upper shoulder of the roadway to reduce wave overwashing. The gabion has an opening approximately half way to allow overwashing to drain back onto the barrier and drainage from the road surface (rainfall and snow melt). Residents have stated that barrier material is often thrown from the barrier onto and landward of the road. Flooding events are also a problem in this area when waves exceeding 3 m height overwash the roadway and flood homes and properties. Such an event occurred in January 1997 where the home of the Williams' was flooded by overwashing that flooded the first floor (J. Williams, Pers. Comm., April 13, 2014).

The area also contains the raw sewer outfall for many homes in The Valley. The sewer outfall is armored with large fragments (most >1 m diameter) of blasted bedrock (Figure 5.23). At low low water, most of this armored outfall except for the pipe is above water. Residents state that the large rocks have been undercut by storms, resulting in the pipe being suspended above high water. This armored area also interferes with longshore transport of sediment via currents as a result of refracting waves on the barrier face. Differential erosion causes erosion of clasts from the south end when waves approach from the E-NE and on the north end when waves approach from the S-SE. This erosion further destabilizes the large fragments that anchor and protect the pipe.

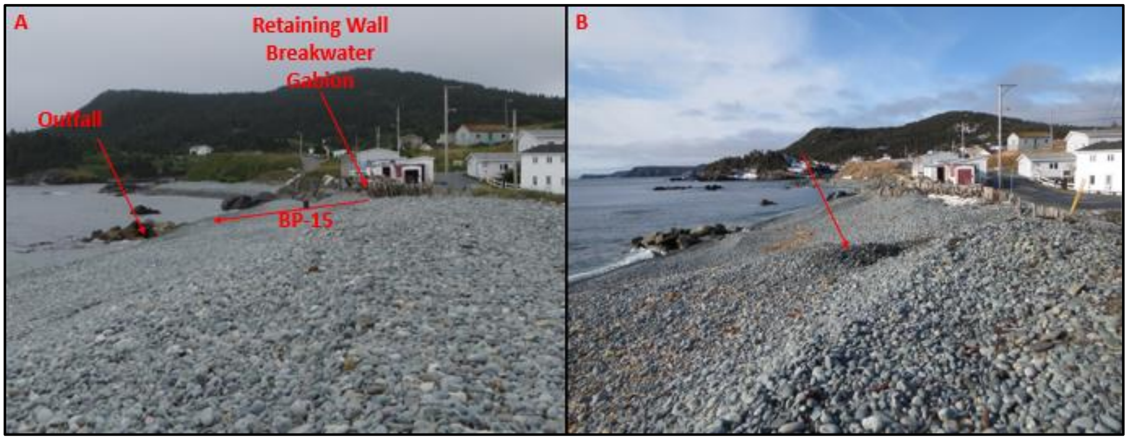


Figure 5.23. Storm berm changes at Freshwater – The Valley. **A:** shows southern Freshwater extent during August 2013. **B:** shows same during April 2014. The ridge of cobbles indicated by the red arrow in the middle of **B** is remnants of an excavated pile of cobbles to clear drainage for the culvert. Storm berm is moved landwards toward road from **A** to **B**.

BP-15 (Figure 5.23A) intersects a patchwork of retaining wall and cribbing protecting private property from erosion. These structures provide support to several storage sheds and are often impacted by large waves.

A bedrock outcrop (Figure 5.23 seaward and south of the storage sheds) partially separates this area from the SW segment of Ferryland Beach indicated by BP-16 to BP-19. This low-lying area (BP16 to BP-17) was heavily impacted many times including during Hurricane Igor in September 2010 when the runup from waves overwashed the road and caused washouts and damage to private property on the upper side of the road (A. Harvey, Pers. Comm., December 13, 2013). Amour stone now forms the storm berm of the barrier and provides support for the road. Barrier material is occasionally overwashed onto and landward of the road, although at present the armor stone is holding. The elevation of the road surface is 4.5 m above 0.00 MTM.

5.4 Meade's Cove

Meade's Cove is a small embayment with a mouth opening of ~155 m, a maximum width of ~170 m, and a depth (not water depth) of ~150 m (Figure 5.24). The northern extent is flanked by the till cliff of Meade's Point and the southern extent is a bedrock outcrop. This bedrock outcrop shows scouring as a result of glacial melt water. Quarry Brook flows into the head of the cove through a small barrier via a culvert.

Figure 5. 24. Meade's Cove. **A:** is the view from the road looking southwest. **B:** is the view from the lower cove looking north.

5.4.1 Meade's Cove Barrier and Quarry River

The barrier is a 160 m-long highly reflective shore-normal crescent-shaped pocket beach. Shore-normal cusps frequently form measuring up to 1.5 m H X 15 m W X 8 m L. Icefoot development is common during winter months, with frozen cusp horns measured up to 1.5 m high. The barrier undergoes accretion via berm building (convex beach face) during calmer sea state (usually during summer) and erosion showing a concave beach face after large storms (during fall and winter storms). Wave approach is controlled by the narrow rocky shore entrance to the cove and deep water that rises abruptly to the barrier.

Fluvial sediments, till from Meade's Point, antecedent marine sediments, and imported materials for erosion mitigation (boulders, sand, gravel, blasted rock) make up the sediments in the system. Cobbles of mixed shapes make up the upper berm(s) while pebbles and occasional coarse sand are present in the intertidal zone. Variable discharge from Quarry River via spring runoff and high discharge during heavy rainfall adds varying amounts of fluvial sediment to the system that temporarily changes the intertidal zone by increasing sand and silt (mud) to pebble and cobble ratio. Waves with daily tidal cycles (~range 1.4 m) frequently rework the barrier forming berms, cusps and rerouting the river outlet (outlet also reworked during high discharge).

The storm berm is backed by dilapidated cribbing and an old seawall on the south side of the culvert. The section of barrier on the north side of the culvert is backed by gabions, eroding fill and rocky shoreline. The barrier is <3 m in elevation and is known to be impacted by large waves (> 3 m) occasionally at high tide or surge conditions resulting in overtopping and overwashing. This results in the deposition of barrier material on the road and into the lagoon. Residents give accounts of barrier breaches, road repair and replacement.

Quarry River flows from Merrymeeting Pond, 3 km inland. The river forms a small lagoon in a shallow depression behind the barrier. During high high water and surge, the tide floods into this area through the culvert. Tidal surge was observed through the culvert, causing some minor erosion on the shore of the lagoon. Sediment is supplied to the barrier during high fluvial discharge events. Discharge was observed on several site visits, which carried high suspended and bedload through the culvert into the cove, causing high turbidity and brown coloration in the nearshore. Approaching waves transported much of this sediment onto the barrier, and it was reworked into the sediment structure. However, during one site visit under S-SE wave approach, the sediment was transported north around Meade’s Point towards Ferryland Beach.

5.4.2 East Coast Trail

The Sounding Hills section of the East Coast Trail southward from Meade’s Cove is located on the edge of an unstable till cliff undergoing erosion. Since 2013 material, including large boulders, have been observed eroded from the cliff falling to the barrier below. Freeze-thaw cycles heave and loosen the till while rainfall and wave undercutting transports the sediment onto the barrier where it is reworked or transported into deeper water. This is undermining the first 50m of the Sounding Hills Trail and is a hazard to trail users.

5.5 Summary

The Backside System is impacted by waves, surge, and currents from the ocean, and slope processes and anthropogenic activities from the land. The complex bathymetry, shoreline position, influence of Crow Island on waves and currents (funnels, refracts, and reflects wave energy and currents) impact various segments of the shoreline. The resulting impact is most significant at: Back Cove, the tombolo, Ferryland Beach, and Meade's Cove. The major causes of erosion are summarized in Table 5.2 and include marine attack (waves, surge, currents and sea level rise), slope processes (consolidated and unconsolidated types) and anthropogenic influences. Known and estimated rates vary by site.

Table 5.2 Significant areas of concern with cause and type of erosion.

Site or Access	Cause of Erosion	Erosion Type	Known or Estimated Rate	Consequence
Ferryland Head Isthmus (South)	freeze-thaw, surge with wave attack, rainfall	rotational slide, debris slide, debris flow, mud flow, undercutting	baseline data collected	loss of access to lighthouse and Ferryland Lighthouse Picnics
Tombolo	surge, wave attack	barrier erosion, breakwater failure	baseline data Collected	loss of access to the Colony of Avalon, homes, The Pool, lighthouse, and Ferryland
Ferryland Beach	surge, forcing, wave attack, SLR	backstepping, erosion of foreshore	estimated 10 m in 50 years and backstepping	flooding of heritage and recreation area
Freshwater	large waves, surge, longshore current	sediment transport	baseline data collected	destruction of roadway, private property, outfall
Meade's Cove	large waves, surge	undercutting, overwash	occuring, unknown	loss of access to homes and East Coast Trail access
East Coast Trailhead	freeze-thaw, surge with wave attack, rainfall	debric slide, debris topple, and undercutting	occurring, unknown	hazard to users

Chapter 6 – General Tourism Activity and Erosion Impacts on Tourism-related Sites

This chapter presents baseline statistics on tourism activity and discusses how the related sites are impacted or are at risk of erosion. The significance and consequences of coastal erosion on sites are also discussed.

6.1 Tourism Activity

Ferryland depends on the tourism industry for socioeconomic stability, as the fishing industry and population declines. Tourists visit the area for numerous reasons such as to purely enjoy the picturesque setting without any particular knowledge of history or natural sciences, or to utilize coastal processes and features for sport (general tourism). They also visit to observe historic human settlements and effects (archaeotourism) and to observe geological or geomorphological features (geotourism). Ferryland offers all of these attractions with striking seascapes, icebergs, marine life, Ferryland Lighthouse, Colony of Avalon, military history, topography, exposed bedrock stratigraphy, islands, and much more. The main attractions and sites associated with most tourism activity are the Colony of Avalon, Ferryland Lighthouse Picnics, Southern Shore Folk Arts Council, the East Coast Trail, and increasingly, the erosional features associated with sea level rise, large waves, surge, and currents.

Precise visitation numbers for non-residents and residents were not available through official reports. The 2011 Exit Survey Profile of Non-residents visiting the Avalon Region reports statistics from May to October 2011 (Government of Newfoundland and Labrador, 2011). An estimated 55,876 non-residents visited an archaeological site. Approximately 12.5% or 6,985 persons reported visiting an archaeological site on the

Southern Shore. An estimated 29,845 non-residents reported doing a geological tour or visited a fossil site. Approximately 10.8% or 3,223 persons reported this activity for the Southern Shore. The survey does not parse out actual site visitations, so it is not possible to interpret from these numbers the actual person visits to Ferryland or to other specific sites. However, since Ferryland has at least four main attractions to offer, and is relatively close to St. John's, it can be suggested that the many of these visitations involve one or more of these attractions. In the Resident Travel Survey Summary Report (Government of Newfoundland and Labrador, 2012), 87% of respondents indicated that they enjoy and prefer visiting local historic sites during vacation. These numbers, in combination with proximity to St. John's CMA, are encouraging for current and future tourism and heritage development in Ferryland.

The actual numbers of tourist visitations to Ferryland are much higher than those reported in the exit survey. The reported numbers for Ferryland Lighthouse Picnics show that an annual average of 6,500 persons (resident and non-resident) visit the lighthouse for a catered picnic (J. Curran, Pers. Comm., March 17, 2014). However, many people visit the lighthouse without purchasing food, suggesting that the total number of visitors could be double (13,000 persons). The Colony of Avalon reported an average five-year annual visitation (registered) of 19, 328 persons (resident and non-resident) (P. Broughton, Pers. Comm., January 15, 2015). The actual number of visitors is also thought to be much higher as many people visit off-season or choose to walk through the site in-season without registering (including the author). The Folk Arts Council reported that approximately 9,000 persons attended their summer events in 2014. The actual attendance is thought to be higher as many people attend without registering, especially at outdoor venues.

A general assessment was made regarding tourism-related employment and related revenue. These statistics were not readily available for all businesses and non-profit organizations. Many of the local tourism-related businesses and the Colony of Avalon Foundation were contacted and asked for general statistics. To respect confidentiality, the raw data will not be reported. Various numbers were reported for annual averages over single to multiple years, so 2014 will be taken as representative of the last five years (2010-14). Employment numbers reveal over 100 full- and part-time positions. There were over 150 people serving as volunteers. The greatest numbers of jobs are related to the Colony of Avalon, followed by the Southern Shore Folk Arts Council, and Ferryland Lighthouse Picnics. Overall, there are over $2 million in annual revenues from tourism-related activities, excluding all efforts to raise money and donations. This includes raw data and estimates of site fees, dining, lodging, groceries, entertainment, and other factors. This is a conservative estimate and the number is very likely higher. Through reported numbers and field observations, at least 90,000 people visited the area for tourism-related activities annually. As an example, during a site visit on a sunny warm day in July 2014, over 600 people were counted from the tombolo to the lighthouse. There were over 60 motor vehicles parked near the eastern extent of The Downs (west of the Ferryland Head Isthmus). Residents and tourism operators agree that the number of visitors to the area in-season is at least two-fold the reported statistics, as many do not register or pay to see sites.

Other attractions south of Ferryland are attracting more tourists who travel through Ferryland via Route 10. One such site is the Mistaken Point Ecological Reserve at Portugal Cove South. This site is garnering more interest from geotourists and others due to very rare fossils in an even rarer viewable location (Thompson, 2014). The site possesses some of the earliest known evidence of multicellular life in the world. It was submitted for registration as an UNESCO World Heritage Site by Parks Canada Agency in 2004 (UNESCO, 2015; Parks Canada, 2015) and is now in the process of a nomination bid for UNESCO designation (Government of Newfoundland and Labrador, March 15, 2015). A decision is expected on the designation of this site as an UNESCO World Heritage Site in 2016 (T. Power, Pers. Comm., June 12, 2015). Thompson (2014) reports that the annual statistics for a Mistaken Point Guided Tour increased from 303 persons in 2007 to 846 persons in 2011. Updated statistics were obtained from the Mistaken Point Ecological Reserve (J. Cappleman, Pers. Comm., June 15, 2015) and from the Edge of Avalon (J. Coombs, Pers. Comm., June 15, 2015). The updated statistics are in Table 6.1. Site visits to this area for bird watching suggest that many more persons visit the site than are recorded in these numbers (in-season and out-of-season).

Table 6.1. Visitation statistics for Mistaken Point Site, Edge of Avalon Interpretation Centre, and the Myrick Wireless Interpretation Centre.

Place	2006	2007	2008	2009	2010	2011	2012	2013	2014
Mistaken Point Guided Tour (Fossils)	NA	303	500	789	776	846	1,847	1,140	718*
Edge of Avalon Interpretation Centre (General Area)	3,600	5,935	5,762	5,457	5,594	6,254	8,190	5,300	5,398
Myrick Wireless Interetation Centre (Lighthouse)	1,970	1,513	1,158	1,182	1,332	1,338	2,379	1,515	1,071

*Part of the season was lost due to road closure.

This suggests that if the reserve is designated as an UNESCO World Heritage Site, then more tourists will visit to view the fossils and lighthouse-interpretation centre. Route 10 is the shortest route from the Northeast Avalon urban area and St. John’s International Airport to this site. Ferryland residents are already seeing additional tourists driving or being bussed through Ferryland, which is resulting in additional stops, generating more tourism-related activity and revenue.

6.2 Coastal Erosion - Significance and Consequences

Erosion is ongoing throughout the area impacting all sites and access to those sites. For the purposes of this discussion, erosion is categorized as occurring due to natural causes (mass wasting, wave attack, etc.), anthropogenic causes (loading slopes and interference with longshore sediment transport), or a combination of both. Tourism-related sites and access are being impacted by coastal erosion through damage to infrastructure. The infrastructure includes trails, roads, wharfs, boat launches, private property (homes), and utility lines. The specific coastal sites and access include The Colony of Avalon, tombolo, Ferryland Lighthouse, Bois Island, The Pool, and gun batteries. Erosion can impact tourist activity by causing inconvenience or necessitating restricted access to sites.

In an effort to reduce erosion via anthropogenic causes, the Town of Ferryland has designated the area from the tombolo to Ferryland Head as a heritage area, where zoning prevents all future development (Town of Ferryland, 2012). This action will help ensure that development pressures are steered away from this area. Marine attack and natural slope processes will continue to cause undercutting and slope movement. However, the restriction of anthropogenic influences will reduce slope processes and movement from loading and drainage issues associated with development.

An investigation of Bois Island and the north shore of Ferryland Head on June 5, 2015 revealed the positions of gun batteries and ordnance, some of which may have been installed as early as the first documented fortification of the island in 1708 (Calendar of State Papers, 1860). These sites are related to the raids and wars of the 1700s and are an important piece of the military and archaeological history of the Province. Cliff erosion is occurring, and has claimed several ordnance pieces and almost all of the 4 Gun Battery.

The history of the island is all but unknown to most tourists who visit the area, as the sites are not presented at a viewpoint for tourists (e.g. story boards), nor are readily visible or accessible from the mainland. The 2 Gun Battery (ordnance pieces displaced by erosion) on Ferryland Head is moderately accessible via a foot trail from the road to the lighthouse. However, the sign that once marked this site is missing and, with no signage along the road to mark the trail and site, tourists are unaware of the site or the unique view of the 8 Gun Battery on Bois Island from this site. The added tourism interest of these sites could be significant. The consequences of the ongoing erosion are the loss of information regarding one of the first colonies in Newfoundland, including military history. Another consequence is related to tourism activity and the tourism experience. Most tourists (and many residents) are unaware of these sites and their significance. Bois Island is an important piece of the history of Ferryland, and, other than some occasional active research interest, is being left to erosion with little documentation.

The road across Ferryland Head Isthmus is the access to Ferryland Head, including Ferryland Lighthouse Picnics, and provides the best view of the south side of Bois Island (from multiple viewpoints). Other than the Colony of Avalon main site and the Southern Shore Folk Arts Council, Ferryland Lighthouse is one of the main tourist destinations in Ferryland. Annually, more than 6,500 visitors and other local users utilize the isthmus. Some of these visitors come just to experience Ferryland Lighthouse Picnics, only to discover the archaeology upon arrival. The NW side of Ferryland Head also provides the closest view of Bois Island including the 6- and 8-Gun Batteries. The area of the isthmus is undergoing erosion and mass movement on both the north and south sides. A breach in the isthmus would be detrimental to the Ferryland Lighthouse Picnics and to the local tourism economy due to the fact that many people who book picnics may also visit the Colony, and may also take in a dinner theatre (Folk Arts Council). This also suggests that a significant decline in tourist activity related to the picnics would likely show in a drop in visitations for the Colony of Avalon and other sites. Additionally, the lighthouse was built in the late 1800s and has significant heritage value. This suggests that the loss of the isthmus would also likely result in the abandonment of the lighthouse, which may then fall into disrepair.

The Colony of Avalon (harbourside) is undergoing erosion of till and colluvium material. This is resulting in the loss of artifacts in the colluvium (and overlying soils) as more of the site is eroded (Dr. B. Gaulton, Per. Comm., November 17, 2015). These artifacts are vital in piecing together the colonization of the area as every artifact piece tells a part of the story. Further loss impacts the overall interpretation of the site.

The Pool is undergoing erosion and property damage. The small basin is utilized by fish harvesters and recreational boaters, but also forms the north flank of the lower Colony of Avalon Archaeological Site. Harbour oscillations during normal tidal cycles and surge events create high velocity currents at various elevations which erode fill, damage boats, and undermine site structures, wharves, and cribbing. All previous efforts to mitigate erosion have failed with the loss of further shoreline, fill and property. Further erosion will result in further loss of infrastructure that will eventually prevent safe access for all users. There is a proposal in progress regarding the rejuvenation of The Pool that would see new wharves, docks and a boardwalk. The surge and harbour oscillations will need to be accounted for in design and, if possible, mitigation installed to reduce effects in order for any new infrastructure to prevent erosion. If erosion is not mitigated and infrastructure is repaired, it will be subjected to the same oscillations and resulting erosion, leading to failure.

The lower part of the Colony site (in The Pool) has been partially reconstructed. Even though this area has been subject to excavation and backfilling prior to site discovery in the 1980s, there remains the potential of finding further colony-related artifacts. This area is frequently flooded by high tides, surges and subjected to high velocity currents from oscillations. The flagstone floor of the storeroom has been reconstructed with an extra layer of stone to protect the original surface from erosion (Dr. B. Gaulton, Pers. Comm., November 6, 2015). The extra protective stone and the reconstructed stone walls are showing signs of erosion (stone movement). During several site visits, fill material was observed being transported with currents into The Pool. This erosion has the potential to transport small artifacts into The Pool and harbour under extreme conditions.

The road, tourism and archaeology hub, and private property on the tombolo is currently protected by a breakwater. However, large waves have destroyed former breakwaters, washed over and eroded the road, and have damaged private property. Currently, short duration storms with surge and large waves from the south to southeast cause occasional overtopping of the existing breakwater and some reworking of large armor stone placed seaward of the breakwater. The resulting water and sediment flows across the road surface causes erosion at the edge of the north side of the paved surface, but also results in drainage that transports material from the shoulder of the road into The Pool area. Larger storms of longer duration at high tide or during storm surge will very likely cause considerably more erosion, both seaward and harbour-side of the breakwater. A road breach and the erosion of a channel would cut off access to tourism sites, power, water service, and access to The Pool. The replacement of the road, water line, power lines and the breakwater would also be very costly. The Ferryland Town Plan (Town of Ferryland, 2013) suggests that abandonment of the area may occur if costs are too high for repairs and maintenance. The loss of this road would result in the loss of access to residences, two major tourism sites and The Pool. This could result in the loss of thousands of tourists and related revenues who come to see and experience these sites, and the loss of a small boat basin and associated businesses. The existing breakwater is holding. However, sediment changes seaward, armor stone displacement, overtopping, and the elevated wave scenario in this study show that a possible event where large waves impact during surge conditions at high tide are likely to completely overtop and overwash the breakwater. Depending on the magnitude and duration of a particular storm, a full breach is possible.

South of the breakwater is a segment of the barrier that is heavily impacted by ATV traffic. This section of the barrier is undergoing slow backstepping under sea level rise and large waves, as indicated by many residents. ATV traffic has flattened the storm berm that was created by large waves. If similar large waves that created this berm were to runup the barrier today, overwashing and potential breach may occur, causing flooding on the tombolo. The consequences would be flooding and erosion on the tombolo that would impact the Folk Festival Grounds, Colony of Avalon Foundation Interpretation Centre, Southern Shore Folks Arts Council, and other infrastructure and sites.

The eastern shoulder and supporting bank of Route 10 is undergoing constant erosion due to slope processes in fill material and undercutting by surge and waves. Route 10 is critical for tourism access to all sites including the museum, but also for local transportation. The cribbing that supports the fill slope is failing, causing erosion of the slope that supports Route 10 and a main power line. Efforts to repair two minor slope failures in 2014 have been subject to rainfall effects and surge-wave undercutting. The failure of this route would cut off vehicular traffic to the main tourism hub on the tombolo and Ferryland Head (also to destinations south), increasing the travel distance from St. John's to Ferryland via Trepassey to more than 250 km. This would have a negative impact on tourism activity and associated revenues that provide numerous tourism-related jobs.

The road at Freshwater to Meade's Cove is used by residents, but is also heavily used by hikers and backpackers who frequent the East Coast Trail. The road has been overwashed and eroded by previous storm events in several areas. Mitigation in the area includes cribbing, seawall, armour stone and retaining walls. The trailhead to the Sounding Hills Path (East Coast Trail) is located on the southern side of Meade's Cove. The initial 50 m of the trail south of the cove is on the edge of a till cliff that forms the back of a high energy shore-normal barrier. This cliff is experiencing erosion due to freeze-thaw cycles and wave undercutting. A large boulder that partially supported the trail toppled from the cliff in 2013, and many small debris falls were observed. Persons using this trail may not be aware of this risk at the trailhead. Signs have been posted regarding the general risk of hiking along the coast (Figure 6.1). Erosion in this area is ongoing and threatens private property, infrastructure and access for hikers.

Figure 6.1. East Coast Trail - Sounding Hills Path. **Top**: First 50 m of trail with signs at the trailhead identifying Sounding Hills Path and warning of the risk of hiking along coastal areas. **Bottom**: bank erosion (middle of the photo). Note the large boulders which have toppled from the till cliff on the left of the barrier. Photos: The top was taken in August 2014 and the bottom was taken April 2013.

Coastal erosion is impacting various heritage and military sites at Ferryland. These sites provide an attraction for tourists who visit the area for archaeotourism and geotourism. The resulting tourist activity translates into revenues and employment for many residents. Sea-level rise, large waves, and surge will continue to cause erosion at the sites and access routes.

Chapter 7 – Conclusion and Recommendations

7.1 Conclusion

The research investigated, described, interpreted, and presented baseline data and information regarding coastal geomorphology and related coastal processes which are impacting selected coastal sites and access routes at Ferryland. Both the Ferryland Harbour and the Backside Systems show signs of coastal erosion that is or has the potential to impact sites and access routes related to tourism sites. The erosion is caused by freeze-thaw, precipitation, marine attack, and anthropogenic influences that accentuate erosion (e.g. breakwaters that direct waves shore-parallel). Various types of slope processes and undercutting by surge and waves are the dominant factors with longshore transport being responsible for sediment transport. The documented and estimated sea level rise in this area will add to erosion. The following sections present the major findings and recommendations.

7.1.1 Major Findings and Observations

The controls on waves, surge, and currents in the study area vary from the Ferryland Harbour System to the Backside System. The Sill and Bois Island on the northern extent of Ferryland Harbour provide moderate protection from large waves from the NE during low tide and neap cycles. However, this protection diminishes as the tide rises, at high tide, or during surge conditions. Specifically, large wave impact is related to the NE wave approach, tidal stage, and surge. The till veneer and the bedrock of the islands on The Sill are undergoing erosion. Bedrock units erode at variable rates, causing argillite to erode rapidly while others remain relatively intact. Further erosion will decrease the relative elevation of the sill and islands as sea level continues to rise. Even under unchanging storm frequency, this will increase the occurrence of large waves in the harbour, causing higher impact to the shoreline and resulting in erosion and damage to property. In the Backside System, Mad Rocks Sill and Crow Island influence current flow and wave height impact on Ferryland Beach under different wave approach directions. The sill dissipates wave energy and current flow during low and low low water. During high high water and surge conditions, large waves pass through this area and impact the whole face of Ferryland Beach. Bathymetry and landforms (Bois Island, Ferryland Head and Crow Island) allow access for larger waves and alter wave direction respectively to focus energy on specific areas such as Sandy Cove, Back Cove, Ferryland Beach, and Meade's Cove.

The major tourism sites and the type of erosion impacting them have been described and interpreted. The access road and breakwater across the tombolo to The Colony of Avalon Archeological Site, The Pool, The Downs, and Ferryland Lighthouse is vulnerable to wave overwash. The signs of increasing vulnerability is the movement of armour stone away from the front of the breakwater by wave action, presence of a swash ramp and deposition of sediment on the road behind the breakwater, and erosion from overwash on the north side of the road surface. The lower Colony of Avalon site and The Pool is impacted by harbour oscillations which cause high velocity currents. The currents dislodge flagstone, undermine wharf supports, erode the shoreline, and damage boats.

The only access to Ferryland Lighthouse picnics and viewpoints to Bois Island is Ferryland Head Isthmus. Both the north and south sides show to multiple signs of active erosion. The north side of Ferryland Head Isthmus (Sandy Cove) shows multiple signs of active erosion such as slope processes (creep, debris slide, etc.). Signs of undercutting at the toe-of-slope indicate impact of surge and large waves. Further undercutting of the slope will increase slope movement by transporting undercut material away from the toe-of-slope, further destabilizing the gravel road on the isthmus. Road drainage and vehicle loading accentuate the concern by causing further erosion and slope loading respectively. Slope movement is ongoing on the eastern extent of the Back Cove till cliff, threatening the gravel road on the isthmus. Sections of till have been eroded on the upper slopes directly below the road, and undercutting by waves is destabilizing the remainder of the slope.

Bois Island has been identified as a significant site regarding archaeological and military history. The Island is undergoing erosion on till cliffs which support gun batteries and other sites. All batteries are undergoing erosion, with the 4-Gun Battery almost completely eroded. At least two ordnance pieces have been eroded, with two more in transit down the till cliff. All the gun batteries have been mapped and photographed to emphasize the relatively unknown significant archaeological and military history, and to highlight erosion at these sites. From qualitative evidence, erosion is dependent on exposure, and NE and easterly facing cliffs are eroding faster than S and westerly facing cliffs. Archaeological research should emphasize the sites where erosion is impacting existing ordnance sites or where the former sites have been eroded, as indicated by displaced ordnance on the rocky shoreline.

The modal morphology and sedimentology of Sandy Cove, Back Cove, Ferryland Beach, and Meade's Cove have been described and interpreted with the dominant wave direction and currents which shape them. The barriers at Sandy Cove, Back Cove, Ferryland Beach, Meade's Cove, and the barrier adjacent to Route 10 show geomorphic and sedimentological changes from calm periods to periods with large waves and surge. Refracted waves from the Narrows are dominant on Sandy Cove, normal waves from the south are dominant on Back Cove, and easterly to southerly waves dominate Ferryland Beach and Meade's Cove. The dominant current direction along the barriers are easterly at Sandy Cove, non-detectable at Back Cove, easterly at Ferryland Beach North (breakwater), southwesterly at Ferryland Beach South (Freshwater), and non-detectable at Meade's Cove. Berms build and accretion occurs during calm periods, creating convex profiles and, in some cases (BP-5) a wider barrier face. Berms are eroded and material transported seaward of the beach step during large waves and surge that results in concave profiles. According to local knowledge, Etheridge (2005), and Wright (2004), this is the typical pattern for barriers in this area. During the two year study period, the calm periods occurred during late Spring and Summer, while the stormier period has taken place during Fall and Winter.

According to local knowledge and previous work (Wright, 2005), Ferryland Beach has changed in sediment structure and geomorphic properties over the last century. Overwash fans are present between BP-7 and BP-11. This information suggests backstepping and a foreshore-surf zone change from a gradual sandy foreshore to the steep cobble and pebble beach step, as observed in the present study. Profiles indicate a mostly shore-normal reflective system in the south and a shore-oblique reflective system in the north at the breakwater. The flattening of the storm berm between BP-7 and BP-11 on Ferryland Beach increases the risk of overwashing via runup from large waves. This is of particular concern when the barrier profile is concave with no berms (that would slow or prevent runup).

The major cause of erosion in The Pool is multiple oscillations occurring at all stages of tides and surge. The oscillations observed and measured are not all caused by visible surface waves into Ferryland Harbour or wind forcing. This suggests the presence of water movement generated by deep water waves entering through The Narrows, the only deep access to the harbour. Harbour oscillations are responsible for erosion in The Pool, the lower Colony of Avalon site, and along the north shoreline of the tombolo. The oscillations and related currents undermine structures, erode material from the shoreline causing infilling of the Pool, and cause damage to motor vessels.

The baseline statistics on tourism activity are highlighted to show that Ferryland has a vibrant tourism economy with an estimated 90,000 visitations generating over an estimated $2 million annually. Increasing local interest and the identification of existing sites has the potential to further expand into the geotourism and archaeotourism areas. The area has a very rich cultural heritage that is showcased through the Folk Arts Council Dinner Theater, local museum, and many other attractions. Ferryland Harbour has a wealth of military history dating from the 1700s. This relatively unknown history has substantial archaeological and tourism value. The economic value of archaeological sites such as the Colony of Avalon and Bois Island is very difficult to evaluate. The same holds true for the access to the historic Ferryland Lighthouse and the tombolo where culture and heritage is promoted for entertainment and education.

Relative sea level rise has been estimated using the latrine at the Colony of Avalon site. The rate is estimated at 3.2 mm/y, from an estimated rise in relative sea level of 1.25 m from 1621-24 to present. The sea level rise is comparable with that estimated from tide gauge data from St. John’s in recent decades (Catto, 2012).

There are many types of mitigation measures in use and other areas which need mitigation measures. Erosion mitigation measures exist throughout the study area. However, more are needed to mitigate erosion in specific areas. Mitigation measures are in various states of disrepair along Route 10, at the Isthmus (roadside), at the main breakwater on Ferryland Beach, between BP-15 and BP-18, and at Meade's Cove. Without enhanced maintenance and repair, or replacement with more robust engineering measures, surge and large waves will undoubtedly cause further erosion in these areas, which would negatively impact tourist access to sites. Mitigation measures are needed at the identified supporting slope of Route 10, The Pool, the Colony of Avalon Harbourside, Sandy Cove, Back Cove, and the gap between The Downs to the breakwater.

The Town of Ferryland conducts in-house erosion repairs on roads and embankments along the tombolo, Ferryland Head Isthmus, Freshwater, and Meade's Cove. A combination of paid services and volunteer efforts make this possible. However, quantitative data regarding planning, implementation, and monitoring (including costs) for mitigation in the study area were not available.

Other observations include the wealth of local knowledge and willingness of residents to share that knowledge, the increase in tourist traffic noted by residents and business owners, and erosion and damage to infrastructure near Coldeast Point. Residents, fish harvesters, tourism operators, and town officials of Ferryland are genuinely interested, willing to participate in the investigation of coastal erosion and its impacts on the tourism activity, and are active in repairing damage caused by erosion. Numerous accounts and examples of storms, surge, wind, hurricanes, mass wasting, water currents, erosion, flooding, military history, archaeology, and many more topics were shared to enhance local understanding of the system. Information was shared from the municipal, provincial and federal governments, Memorial University officials and researchers, and local knowledge that proved essential for assessment of site-specific erosion and recognition of previous events.

The increased traffic in and through the area as observed during this study is, in part, due to the increased emphasis on geotourism at Mistaken Point Ecological Reserve. More people are expected to travel from St. John's on Route 10 via Ferryland, as it is the shortest travel distance to the reserve. The reported tourism numbers are based on recorded visits, rather than actual tourist visits including those who do not pay or register at sites, a much higher number.

The area of the old fish plant and government wharf is exposed and receives very heavy wave impact. The sediment distribution in this area changes with every large storm event, with sediment deposited by large waves and longshore transport piled up near and against the seaward wall of the fish plant. Waves and erosion have destroyed the former dock around the fish plant and rendered the government wharf all but unusable.

The information presented in this study adds to the existing data and reports on coastal processes, erosion, archaeology, and tourism activity at Ferryland. The methods and resulting interpretation can be used to establish baseline information and future monitoring in other coastal communities and areas. It provides basic and detailed information that can be used for education and awareness regarding coastal erosion.

7.2 Recommendations

To protect the health and safety of tourists and residents, and to decrease the risk of tourism-related site and private property damage or loss, the following recommendations are made.

An interdisciplinary team of experienced professionals including the disciplines and fields of: coastal geomorphology, geology, archaeology, military history, civil engineering, government regulators, and others should be assembled to work on various issues and concerns in the study area. Such a team would be able to assess each site based on tourism site and activity, coastal processes, and mitigation, allowing development of a long-term monitoring plan.

The archaeology and military history of Bois Island should be investigated further, and Bois Island identified as a formal historic site. Because thousands of tourists travel over the gravel road from the tombolo to the lighthouse every year, it is recommended that information boards be placed on the tombolo, The Downs, and Ferryland Head that describe Bois Island's history, with site photos, to inform visitors that the site is distinct from the earlier Colony of Avalon. This would enhance the tourism experience through further site interpretation and may encourage more people to walk out over The Downs to read and see history. The ordnance pieces at risk of erosion (6-Gun Battery) and the pieces that have been displaced to the shoreline by erosion (4-Gun Battery and 2-Gun Battery on Ferryland Head) should be assessed and documented. Eventually, these pieces at the shore will be lost through enhanced corrosion from seawater, mechanical breakdown due to wave action, or transport into deeper water via strong longshore currents under surge conditions.

Ferryland Head Isthmus will need more frequent monitoring and assessment regarding erosion, vehicle loading, and road stability. In the interim, vehicular traffic should be limited to ATV (including side-by-side) and very limited motor vehicle activity only. The gate across the eastern extent of Ferryland Head Isthmus should be removed and placed on the western extent of The Downs so as to block all non-essential (other than Town and Ferryland Lighthouse personnel) vehicular traffic from travel onto the isthmus. The new gate position would not increase walk distance for picnickers as they currently use the parking area on the west side of the isthmus. The new gate position would serve to keep heavy motor vehicles from driving along the road on the isthmus to the existing gate, only to have to reverse back up the western grade. This results in significant loading on the road and slopes, especially during wet conditions.

The Pool area and the Colony of Avalon are essential tourism interests in Ferryland and for provincial history. The erosion occurring at the Colony of Avalon harbourside needs mitigation such as a breakwater to limit erosion. The combination of freeze-thaw cycles and wave-current undercutting will require specific mitigation. The Ferryland Harbour Authority, Colony of Avalon Foundation, fish harvesters, Southern Shore Folk Arts Council, recreational boaters, land owners, and others need to work together on a long-term management plan to mitigate current erosion impacts by harbour oscillations and surge events, and to plan for ongoing sea level rise. Plans and designs for new structures should account for these erosional effects. The data and interpretation in this study can be used as a baseline.

The Department of Transportation and Works is responsible for Route 10. All maintenance should be documented in order to allow future assessments and, where necessary, improve mitigation efforts to cope with mass movements and marine processes. Ideally, a long term plan should be developed to assess, repair, monitor, and document all works on and adjacent to Route 10 with a focus on drainage-runoff control, slope stability, and coastal erosion. Immediate work should focus on cribbing repair and slope stabilization with toe-of-slope armor.

A detailed investigation of Crow Island was not completed in this study. Therefore, a detailed survey of the island is recommended to assess erosion rates and to further understand the refractive and reflective effects of the island and surrounding rocks on waves. The island and Mad Rocks Sill provide critical interference, preventing the largest of waves from reaching Ferryland Beach. In addition, this large grass-covered island near the Colony of Avalon may contain artifacts related to Colony, military, or Beothuk activities.

The breakwater area of the tombolo should be assessed for further enhancements and monitoring conducted on a more frequent basis (after each large wave or surge event). The 15 m gap between the eastern edge of the breakwater and the unconsolidated cliff on the Downs should be armored, with a minimum diameter of 2 m armour stone, to help prevent very large waves and surge from eroding this section, causing a breach through the breakwater. The armour stone seaward of the breakwater should be assessed after every large surge-wave event, especially at spring tides. Displaced armour stone should be replaced along the breakwater in order to break the force of wave impact.

An education and awareness initiative should be designed and implemented to create awareness regarding the compaction of barriers and increased erosion, due to ATV and other motorized vehicles that flatten and compact the storm berm on Ferryland Beach. The full height of the storm berm should be maintained to help prevent overwash.

A team including a coastal geomorphologist and a civil engineer with significant coastal experience should be consulted regarding the overtopping and overwashing events in The Valley section (culvert and outfall) and the low section to the south (BP-16 to BP-18). This assessment should also include Meade's Cove and Quarry Brook, and the East Coast Trail along the top of the till cliff backing Meade's Cove barrier. A decision is needed as to rerouting this section of trail due to the erosion and pedestrian safety hazards.

In both the Ferryland Harbour System and the Backside System, the sediment budget should be monitored closely to assess the impact of shoreline armoring, establishment of groynes, and other sediment trapping or current diversion techniques. Trapping sediment in one segment of shoreline may cause accelerated erosion elsewhere.

There is a high degree of stakeholder interest in coastal processes, impacts, and tourism activity. Public engagement with all stakeholders is essential in providing the best possible direction for the mitigation and adaptation in Ferryland. With such engaged public interest and high priority placed on the tourism industry in Ferryland, it is recommended that new infrastructure development or installation of major mitigation measures be coordinated through the environmental assessment process via the Environmental Assessment (EA) Division of the Department of Environment and Conservation. Project registration may not be required for some coastal projects. However, if significant public interest is present, then an EA review may prove critical in providing input and direction from a full range of government and private industry professionals.

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