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# COASTAL MONITORING IN NEWFOUNDLAND AND LABRADOR: 2013 UPDATE

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## ABSTRACT

*The multi-year coastal monitoring program that began in 2011 continued on the Island of Newfoundland and southern Labrador in 2013. The objectives are to: 1) delineate coastal areas at risk from hazards including flooding, erosion and mass movement, 2) assess rates of shoreline erosion, 3) determine changes in beach profiles and 4) assess which physical processes are causing coastal change. To date, 104 sites have been surveyed, of which 57 were studied in 2013. Site selection was based on availability of prior data, ensuring a cross-section of the Province is included, evidence of a hazard, or upon the request of a community.*

*This research uses and builds upon data from a coastal monitoring program conducted by the Geological Survey of Canada (GSC) that began in 1981, and there are several sites with sufficient data that rates of coastal change can be adequately quantified. This report analyzes data collected in 1998 and 2002 by the GSC and in 2011 and 2013 by the Geological Survey of Newfoundland and Labrador (GSNL) for Holyrood Pond, a barrier-beach and coastal-cliff site located on the southern Avalon. Between 1998 and 2011, the flanks of the cliff receded at an average rate of 44 cm per year (cm/a) with a range of 22 to 74 cm/a. Between 1998 and 2013, the centre of the cliff receded at an average rate of 59 cm/a with a range of 19 to 100 cm/a. Results from Holyrood Pond and other sites studied in this program provide additional evidence that coastal retreat is variable and rapid in the Province. When available, coastal monitoring data will be accessible through the Geological Survey's Resource Atlas.*

## INTRODUCTION

Coastal regions are dynamic and fast-changing environments, and are important places of residence; currently 90% of this Provinces' population lives and works there. Natural processes including coastal erosion, mass movement and coastal flooding affect these areas, and when these processes impact places where people live and work, economic damage to roads, breakwaters, houses and other infrastructure happens and low-lying areas can flood (Site #315, Plate 1). Batterson *et al.* (1995, 1999, 2006) and Liverman *et al.* (2001, 2003) thoroughly summarized the history of geological coastal disasters in the Province; examples of coastal hazards include flooding in Placentia and Holyrood Pond.

The rate of coastal change varies spatially and temporally, and the evolution of the coastline is a result of dynamic interaction between the geology and physical geography (such as sediment type and supply, landforms, fetch, topography), climate, and relative sea-level change (Site #309, Plate 2; Forbes *et al*., 1995, 1997; Catto, 2012). There is a need to be able to quantify coastal erosion rates, and to have an understanding of the processes causing this change. This will allow for a better understanding of the impact of present changes and to improve forecasting of change rates (Moore and Griggs, 2002).

Changes in relative sea-level affect coastal stability. Relative sea-level is defined as the sea-level relative to the adjacent continental land mass, and is a function of changes in global sea level (eustatic sea-level changes) and the Earth's crust (isostatic sea-level changes) (Batterson and Liverman, 2010). Relative sea-level has fluctuated in the Province, as is evident from raised marine beaches and submerged tree stumps. During the end of the last glaciation, sea-level rose rapidly as the ice, held in ice sheets, melted into the ocean (Batterson and Liverman, 2010). As the weight of the ice sheets was removed from the land, the land rebounded and started to rise; this process is much slower than the melting of the ice sheets and continues today. Crustal rebound is not uniform in the Province; most of the Island, with the exception of portions of the Northern Peninsula, is subsiding, whereas most of Labrador is rising (Batterson and Liverman, 2010). Rising global sea-levels, coupled with current provincial trends in crustal movement, indicate that relative sea-level is currently rising across most

**Plate 1.** *Surface water flow has resulted in coastal erosion along the main road in Grand Beach, Burin, June 2013. Note the scale of erosion adjacent to geologist standing with a survey pole.*

**Plate 2.** *Sandy Cove beach, near Elliston, photographed in September 2011. As seen in the photo, during the summer months, Sandy Cove is a cobble and gravel beach with a sand apron. During the winter large waves from the north-east transport the sand off the beach face where it is deposited in the embayment. The sand remains in the embayment, and during the spring, waves return the sand to the beach face.*

of the coastal areas on the Island, is stable or rising along the Northern Peninsula and southern Labrador, and is falling along the central and northern Labrador coasts (Batterson and Liverman, 2010). Based on predictions for relative sea-level rise, all areas will experience a rise in relative sea-level; the greatest rise in the Province is predicted for the Avalon Peninsula, where relative sea-level is predicted to rise by over 100 cm by 2099 (Batterson and Liverman, 2010).

This paper describes a multi-year coastal monitoring program. This program (Irvine, 2012, 2013) will provide estimates of rates of shoreline erosion; monitor changes in beach profiles; and define areas at risk from coastal hazards. There are 104 sites located across the Province, which include beach and bluff environments (Figure 1). Site selection included a representation of the differing coastal environment, evidence of a hazard, availability of prior data or on the specific request of a community or stakeholder, such as Norris Point. Analyses of data collected from long-term surveys of the sites will enable quantitative rates of coastal change and the identification of physical and anthropogenic processes resulting in coastal change. For preliminary analysis of rates of coastal retreat in two sites, Point Verde and Kippens, *see* Irvine (2013).

## COASTAL MONITORING PROGRAM, 2013

### LOCATIONS

During the third year of the program, 57 sites were surveyed; 49 previous sites and 8 new sites, one each at the following locations: Sandbanks Provincial Park, Stephenville Crossing, Cheeseman Provincial Park, Point au Mal, Motion Head, Middle Cove, Norris Point and Parsons Pond. There are 104 sites in the coastal monitoring program (Figure 1).

### APPROACH

Coastal surveys used Real Time Kinematics (RTK), a type of surveying capable of collecting precise (millimetre) location data. The use of RTK requires a stationary base receiver (known as a base station), one or more roving receivers that collect data simultaneously with the base station, and a radio. The base station is set up over a survey benchmark with known coordinates and sends its phase measurements through a radio link to the roving receiver(s) (Pardo-Pascual and Garcia-Asenjo, 2005). As the base coordinates are known, the roving receiver is able to determine its coordinates, relative to the base, and make corrections in real time. This allows the system to collect precise relative and absolute position data. The base station must be set up

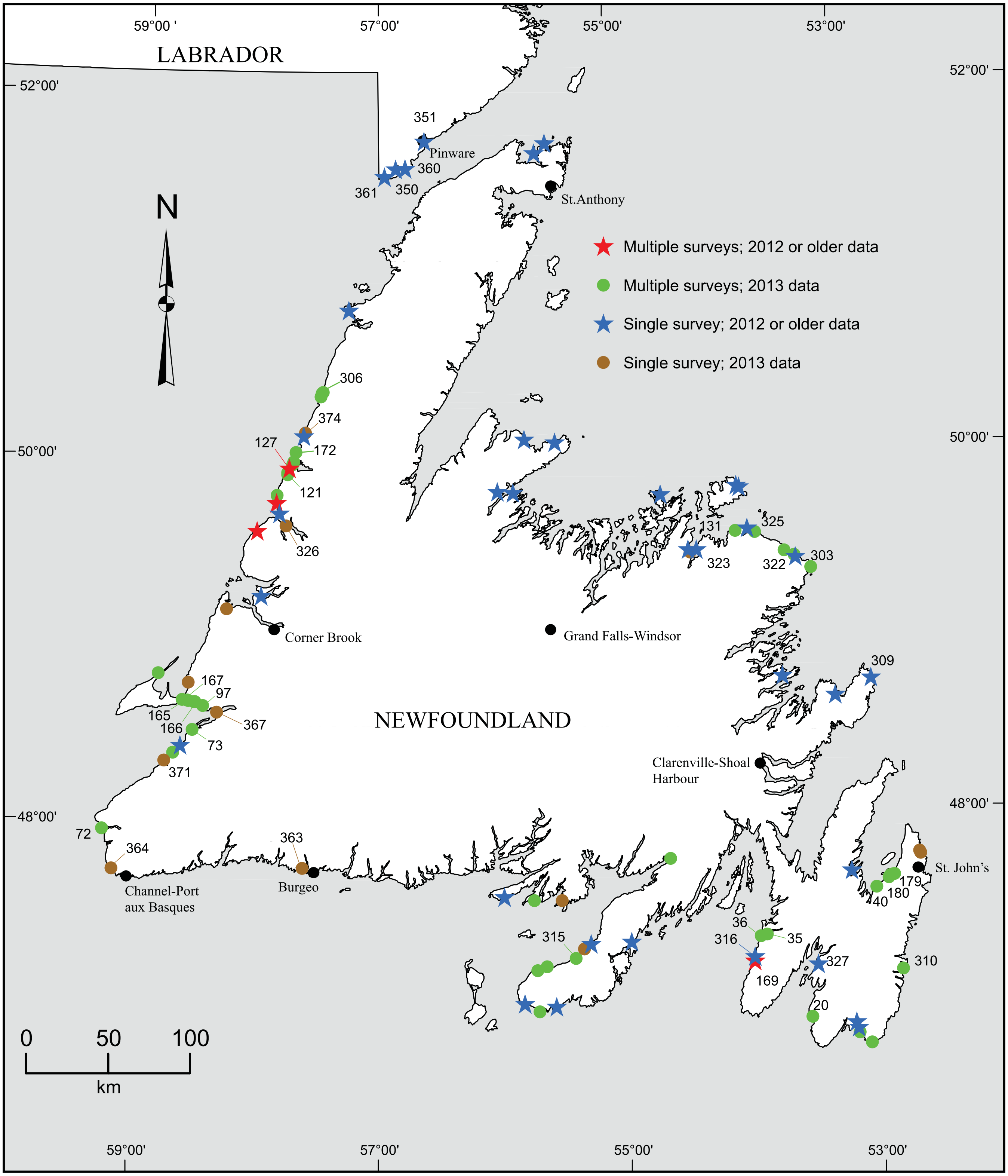


**Figure 1.** *There are 104 coastal monitoring sites for the Island of Newfoundland and southern Labrador. Stars show sites with data prior to 2013; red stars show sites that have been surveyed more than one time, and blue stars show sites with only one dataset. Sites surveyed in 2013 are shown by circles; green circles have sites that have been surveyed more than one time, and brown circles show sites with only one dataset. Numbered sites are referred to in the text.*

in line-of-sight of the roving receiver(s), and within 15 km of the surveyed site (Dail *et al.*, 2000).

## FIELD METHODS

The survey used a Leica GS09 Global Navigation Satellite System (GNSS) RTK (Plate 3). The base station is set up over a permanent survey benchmark having a known position; the radio link is set up next to the base station. Two roving receivers, each equipped with an antenna collects location data: a radio modem to receive the phase measurement from the radio; and a hand-held computer used to enter site information, such as sediment type, geographic feature(s) *etc.* At most sites, a second survey benchmark having a known position was used to verify the accuracy of the data.

At each site, the clifftop and base, seaward edge of vegetation, infrastructure, areas of slope movement and beach features including the backshore, crests, cusps, sediment changes and/or the waterline were surveyed. Transects were surveyed at most of the monitoring sites. To conduct a transect, one or two survey pins attached to a two-foot (0.61 m) long piece of rebar were hammered flush with the ground at the landward end of the transect. At clifftops, the survey pin was installed well back from the cliff edge, and at beach sites the survey pin was installed landward of active beach processes. For cliff surveys, a transect (following a compass bearing) was surveyed from the survey pin, down the cliff face (if possible), across the beach and to the water. For beach locations, transects (following a compass bearing) were walked from the survey pin at the back of the beach, across the beach and to the water line. Measurements were taken about every metre.

## DATA ANALYSIS

Upon returning from the field, for each site, point data from the two roving receivers were downloaded and integrated in Leica Geo Office software. For sites that had been surveyed more than once, data were exported from Leica Geo Office as a shape file into ArcGIS. For cliff-monitoring sites, using the Points to Line tool in ArcGIS, a line was created representing the location of the top and/or base of the cliff. Erosion rates were calculated for the clifftop and cliff base along transects normal to local cliff trend at a set interval, such as two metres. To determine changes in beach profiles, graphs plotting elevation change against distance from the survey pin to the ocean were generated in MS-Excel, and there was the comparison of the data from the different surveys.

Reliable estimates of long-term coastal change require regular measurements over a minimum of five years (Liverman *et al*., 1994) and many sites included in the monitoring program require additional data for shoreline-change analysis. Several sites on the Avalon Peninsula and the west coast of Newfoundland that were surveyed by the GSC and the GSNL have sufficient data, including Holyrood Pond, which is described below.

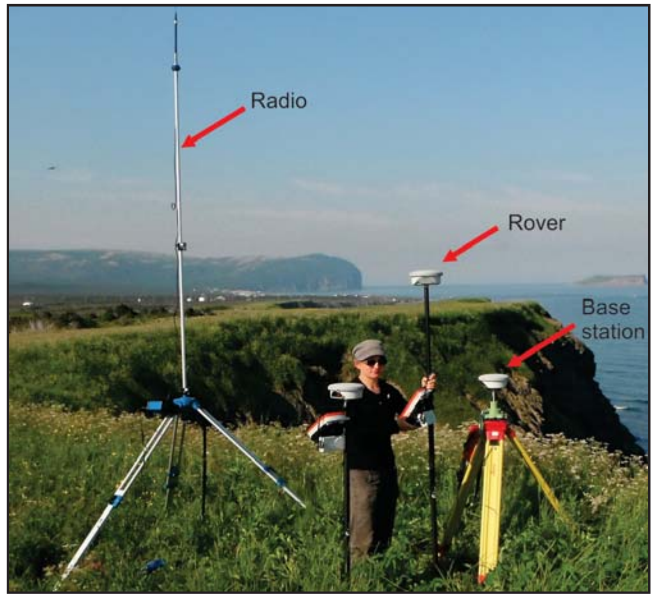


**Plate 3.** *Real Time Kinematics (RTK) survey equipment: The base station is the yellow tripod, the radio is the blue and silver tripod, and roving receivers are the black pole held by the author and black pole in foreground.*

## CASE STUDY: HOLYROOD POND, AVALON PENINSULA

Holyrood Pond (Site #20) is located in St. Mary's Bay, an indentation along the southern coast of the Avalon Peninsula (Figures 1, 2). St. Mary's Bay extends to the southwest and is exposed to the south and southwest; it has a fetch greater than 2000 km. The beach is about 5.5 km long, and 2 km wide, extending between the communities of St. Vincent's and St. Stephens (Figure 2). The northern 2 km of the beach consist of the Holyrood Pond barrier, a pebble and sand beach overlying till on bedrock, which forms the sill of the Holyrood Pond fjord. There is a wooden seawall on the northwestern section that provides protection to a road that runs parallel to the barrier; this road had been flooded in the past during storms (Plate 4).

Southeast of the barrier are bluffs of glaciofluvial sediment that are eroding, and feeding the barrier beach system (Forbes, 1984, 1985; Liverman and Taylor, 1994; Plate 5). The bluffs are 25 to 35 m high, are non-vegetated, and composed of gravel and sand beds overlying till. Gullying is visible on the cliff face. Cliffs west of St. Vincent's are also

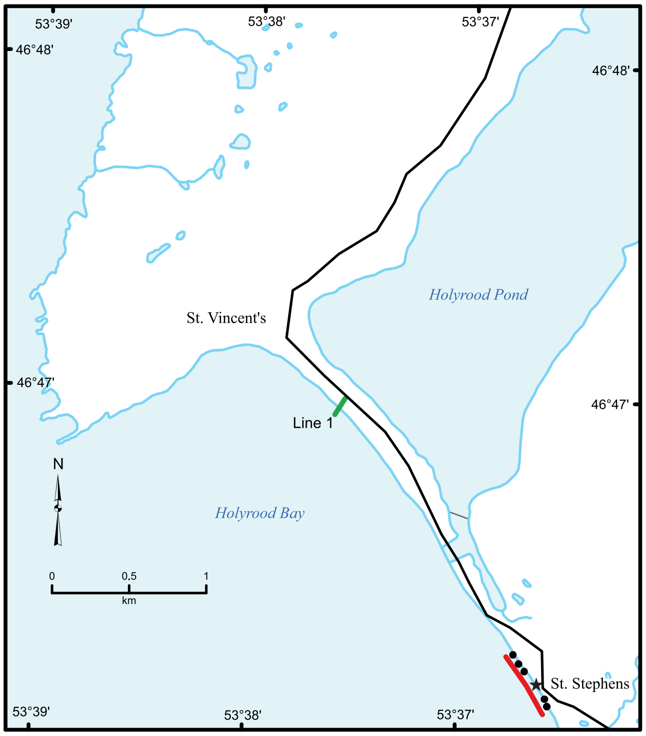


**Figure 2.** *Location map of Holyrood Pond, showing location of survey pins (black dots), surveyed portion of the cliff line (red line) and transect Line 1 (green line). Star is the location of photo shown in Plate 5.*

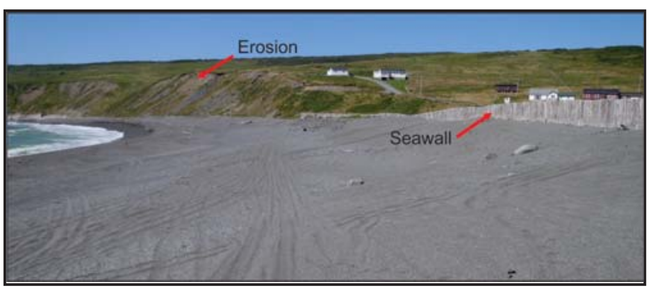


**Plate 4.** *Holyrood Pond barrier, August 2013. View looking northwest toward the community of St. Vincent's from transect Line 1. Note the wooden seawall and eroding cliffs in the background.*

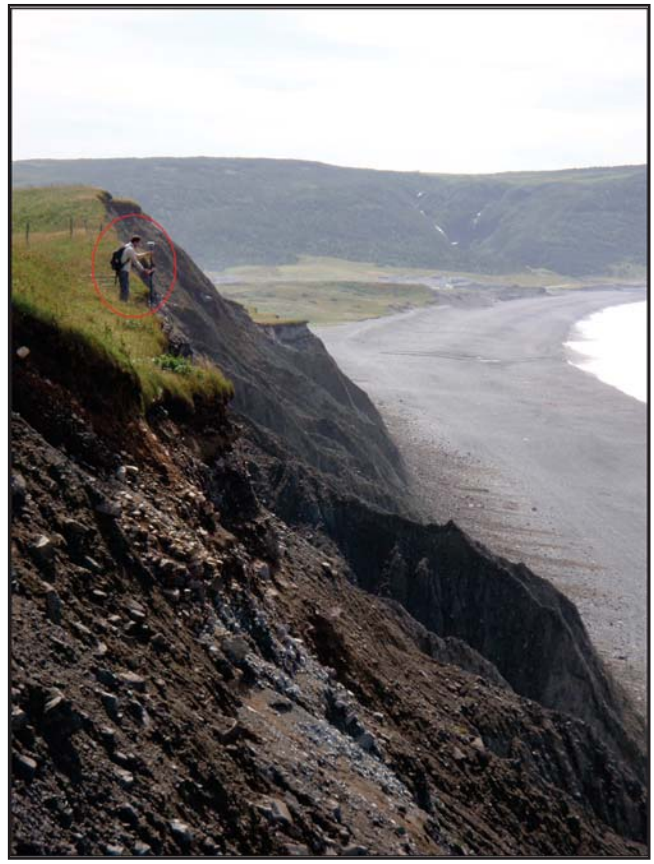

**Plate 5.** *Surveying the cliff edge (surveyor is circled in red for scale) of the unconsolidated bluffs at Holyrood Pond, August 2013. View looking southeast toward the community of St. Stephens. Surface run-off is causing gullying and erosion on the cliff face, and waves are removing sediment from the base of the cliff. Longshore transportation of the sand and gravel is feeding sediment to the Holyrood Pond barrier to the west of the bluffs. Location of photo is marked with a star on Figure 2.*

contributing sediment to the Holyrood Pond barrier (Liverman and Taylor, 1994; Plate 4). The area is underlain by sandstone and shale turbidites (Unit $P_3$st, Colman-Sadd *et al.,* 1990).

Ice covered the area during the last glaciation, with ice retreating approximately 12 000 years ago. During ice retreat, sea-level was higher, and marine limit was around 25 m asl (Rogerson and Tucker, 1972). The land is currently subsiding at Holyrood Pond at a rate of 0.2 cm/a (Batterson and Liverman, 2010). Based on global sea-level rise and local trends in crustal rebound, relative sea-level is projected to rise by 40 cm by 2049 and by over 100 cm by 2099 (Batterson and Liverman, 2010).

The GSC and the GSNL surveyed the Holyrood Pond barrier and cliffs of unconsolidated material, between Holyrood Pond and St. Stephens. The GSC installed two metal-survey pins in the cliff in 1993; one was located in 2011 (GSC 395) and the other survey pin (GSC 396) could not be found. Measurements were taken of the cliff edge on nine lines normal to baseline, and a short-term retreat rate of 30 cm/a was estimated over a 20-month interval, August 1982 to April 1984, by the GSC (Forbes, 1984).

The GSC surveyed about 500 m of the cliff edge in 1998 with a RTK (D. Forbes, personal communication, 2011). In 2011, the GSNL installed four survey pins on the clifftop, and surveyed the flanking section of the cliff edge as well; the central section was surveyed in 2013 (Figure 2). Based on GSC and GSNL data from 1998, 2011 and 2013, a comparison was made between the clifftop position from 1998 to 2011 (flanking sections) and 1998 to 2013 (central section) (Figures 3, 4). Between 1998 and 2011, the flanking section of the cliff edge at Holyrood Pond eroded, having an average retreat rate of 44 cm/a, ranging from 22 to 74 cm/a (Figures 3, 4). Between 1998 and 2013, the central section of the cliff edge eroded at an average rate of 59 cm/a, ranging from 19 to 100 cm/a.

A shore-normal transect (Line 1) was conducted on the Holyrood Pond barrier in 1998 and 2002 by the GSC, and in 2013 by the GSNL from the seawall to the waterline (Figure 2). The profile of the transect was similar in 1998, 2002 and 2013 with the exception of vertical accretion in the lower foreshore in 2013 compared to 1998 and 2002 (Figure 5).

At Holyrood Pond, surface water is creating gullies in the permeable sand and gravel of the cliff, and waves are eroding sediment from the base of the cliff. The average rate of cliff erosion for the period between 1998 and 2011 (44 cm /a) and 1998 and 2013 (59 cm/a) was higher than the average rate of erosion measured by the GSC between 1982-1984 (30 cm/a), suggesting that rates of cliff erosion are increasing. The similarity in the profile of the transect of Line 1 in 1998, 2002 and 2013 supports Forbes's (1984) conclusion that the sediment eroding from the cliffs south of the beach is being transported to the Holyrood Pond barrier. As long as the cliff continues to erode and contribute sediment, the barrier will be maintained and will continue to provide flood protection to the road.

Route 10, the only road connecting the communities on the southern Avalon, is within 18 m of the current cliff edge, and will be at risk of erosion in approximately 30 years if current erosion rates continue. Projected impacts of climate change for eastern Newfoundland include more intense precipitation, with an increase in extreme precipitation and an increase in the maximum precipitation over 3-, 5- and 10-day periods. The winter months are expected to be warmer, consequently winter precipitation will move away from snow and fall as rain (Finnis, 2013). These changes will likely result in an increase in cliff erosion due to increased surface water flow and relative sea-level rise will result in an increase in the risk of erosion of the base of the slope from waves.

## PROCESSES CAUSING COASTAL CHANGE

### Waves

Waves transport sediment into, off and along a coastline, resulting in sediment deposition or erosion, and is strongly influenced by nearshore topography, wave direction and wave energy, sediment supply, and sea-level change. When a wave reaches shallower water, it collapses and dissipates energy, which causes sediments to move either shore-parallel, shore-normal (90° to shoreline) or shore-oblique (Catto, 2012).

Generally, during the winter months, larger, higher energy waves will transport sediment seaward from a beach face, resulting in the beach becoming steeper and a decrease in sediment volume. In the summer months, lower energy waves deposit this sediment back up onto the beach face as long as the sediment is still in the embayment. This cyclical pattern of erosion during the winter months and accretion during the summer months occurs at beaches surveyed in this program including Great Barasway (Site #316) and Ship Cove (Site #169; Liverman *et al.,* 1994) and Sandy Cove (Site #309, Plate 2).

Beaches may be fed from coastal cliff sources, with rocky headlands restricting longshore transport of sands and gravel. This occurs at Stephenville beach, where the unconsolidated cliffs on the outer portion of St. George's Bay are feeding sediment to the beach at Stephenville, and Indian Head restricts farther transport of the sediment (Site #97, Plate 6). Barrier beach systems on the Avalon Peninsula, such as the barrier beach system at Holyrood Pond (Site #20), are also maintained by longshore transportation of material.

Sediment is eroded from the base of coastal bluffs, in particular in environments with narrow beaches, fine-grained sediment and no natural armouring, which are exposed to high-energy waves; such sediment transport occurs at Sandbanks Provincial Park (Site #363, Plate 7), Conception Bay South (Site #180, Plate 8), St. George's area (Flat Bay, Site #73 and Kippens, Site #166) and Norris Point (Site #326). Erosion results during a storm surge that coincides with a high tide (Moore and Griggs, 2002). A storm surge during a high tide in March 2013 eroded beaches in the Conception Bay South area; there was significant sediment transported at Lance Cove beach (Site # 40) and the barachois beach near the Royal Newfoundland Yacht Club in Conception Bay South (Site #179, Plate 9).

### Groundwater Flow

Groundwater flow can lead to erosion on unconsolidated coastal bluffs, and sources of groundwater include precipitation and run-off from paved surfaces. Water will percolate downward, with water moving downward faster in larger grained material compared to finer grained material (O'Neill, 1985; Figure 6). Coastal bluffs in the Province are not uniform in terms of sediment composition and may have

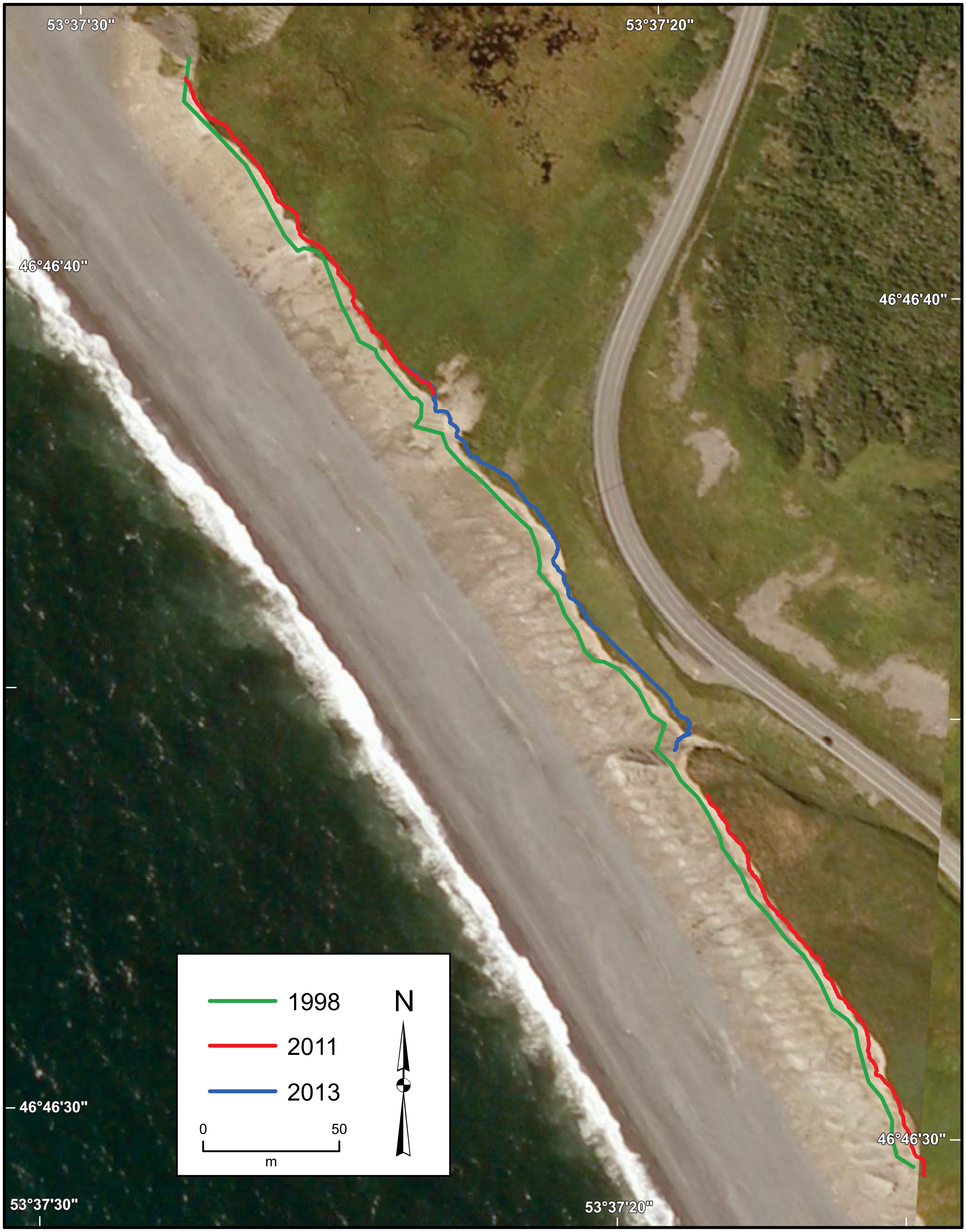


**Figure 3.** *Location of cliff edge at Holyrood Pond in 1998 (green), 2011 (red) and 2013 (blue) superimposed on an airphoto.*

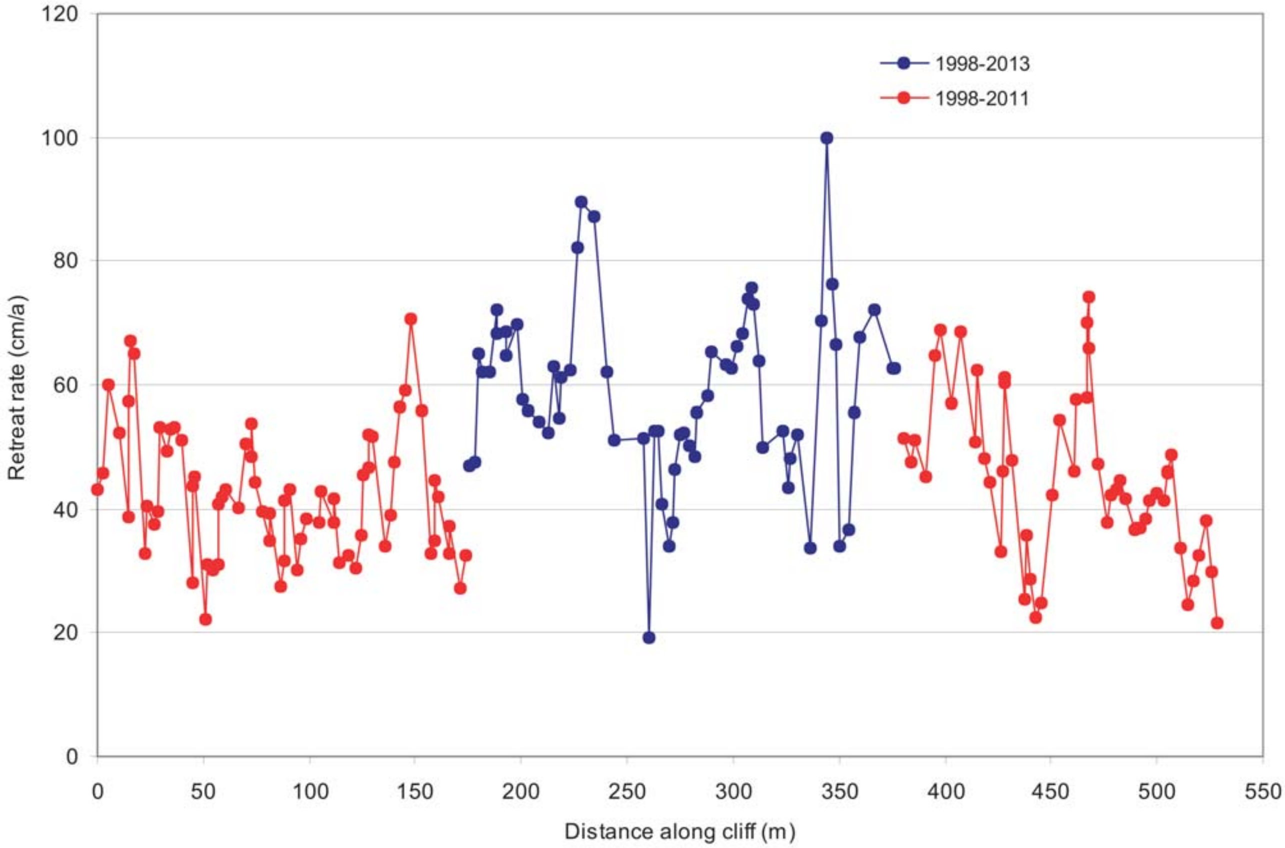


**Figure 4.** *Cliff erosion as a function of distance along the cliff edge at Holyrood Pond between the years 1998 and 2011 (red line), and 1998 and 2013 (blue line). The entire cliff edge retreated during this period: the cliff edge of the flanking sections receded at an average rate of 44 cm/a, with a range of from 22 to 74 cm/a between 1998 and 2011. The cliff edge of the central section receded at an average rate of 59 cm/a, with a range of 19 to 100 cm/a between 1998 and 2013.*

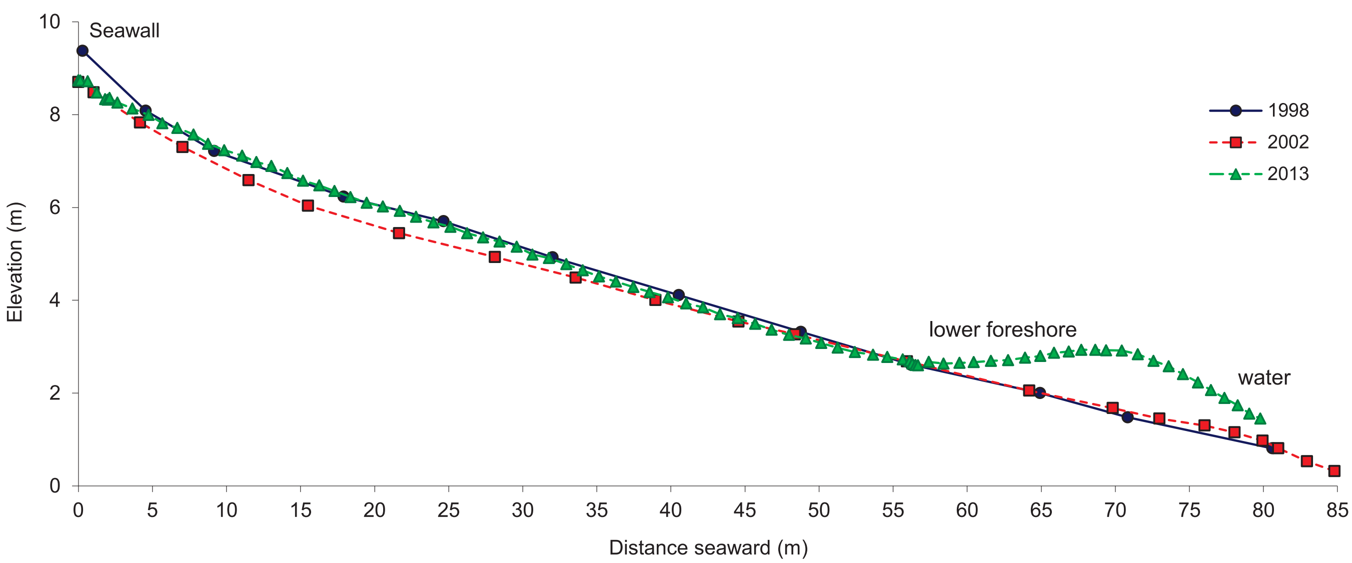


**Figure 5.** *Beach profile at transect Line 1 in 1998 (purple line), 2002 (red line) and 2013 (green line). Between the three years, the profile was invariant with the exception of vertical accretion in the lower foreshore in 2013 compared to 1998 and 2002 survey years.*

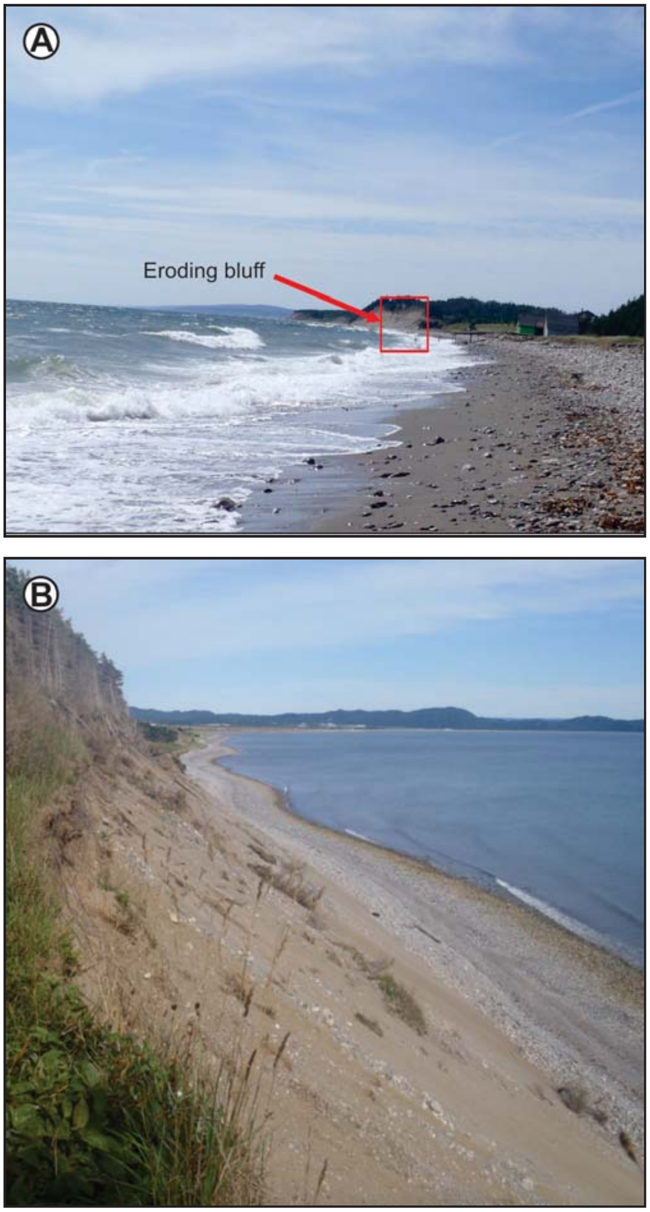


**Plate 6.** A) *The beach at Stephenville, on St. George's Bay, looking west toward bluffs. B) Detailed view of the eroding bluff in Kippens, looking east toward the beach at Stephenville. The beach at Stephenville is being fed by eroding glaciofluvial bluffs along the outer portion of the bay, as long as sufficient sediment is supplied to the beach it will be maintained.*

**Plate 7.** *This coastline at Sandbanks Provincial Park is at risk of erosion from waves and wind. The beach is narrow and there is kelp along the base of the banks, providing evidence that waves reach the toe of the sand banks during high tide, resulting in erosion. As the beach is sandy, the sediment is transported off the beach by waves. High winds also cause erosion of sand off the dunes.*

**Plate 8.** *Erosion (outlined in red on photo) from wave action is occurring at the base of a coastal bluff in Conception Bay South. During winter months, waves reach the base of the coastal bluff and remove the finer grained sediment from the toe of the slope, causing the bluff to be undercut. The boulders on the beach provide protection from waves, as they dissipate the incoming wave energy. As the fine sediment in the bluff erodes, the boulders will fall out of the bluff, and rest at the base of the bluff, providing protection to the toe of the slope.*

a mixture of sand, gravel, cobbles, boulders, clay and silt. Moderate to high concentrations of clay and silt will form a barrier to groundwater flow; water will not be able to seep downward and will flow laterally along the top of the clay or silt layer and thence exit the bluff as a seep or a spring. The sediment above the impermeable layer may become saturated and unstable, and may fail as a slide or slump (Forbes *et al*., 1995). Sites where groundwater flow is resulting in erosion in unconsolidated coastal bluffs include Daniels Harbour (Site #306), Parsons Pond (Site #374), St. Pauls (Site #172), Gulls Marsh (Site #121), Romaines (Site #165),

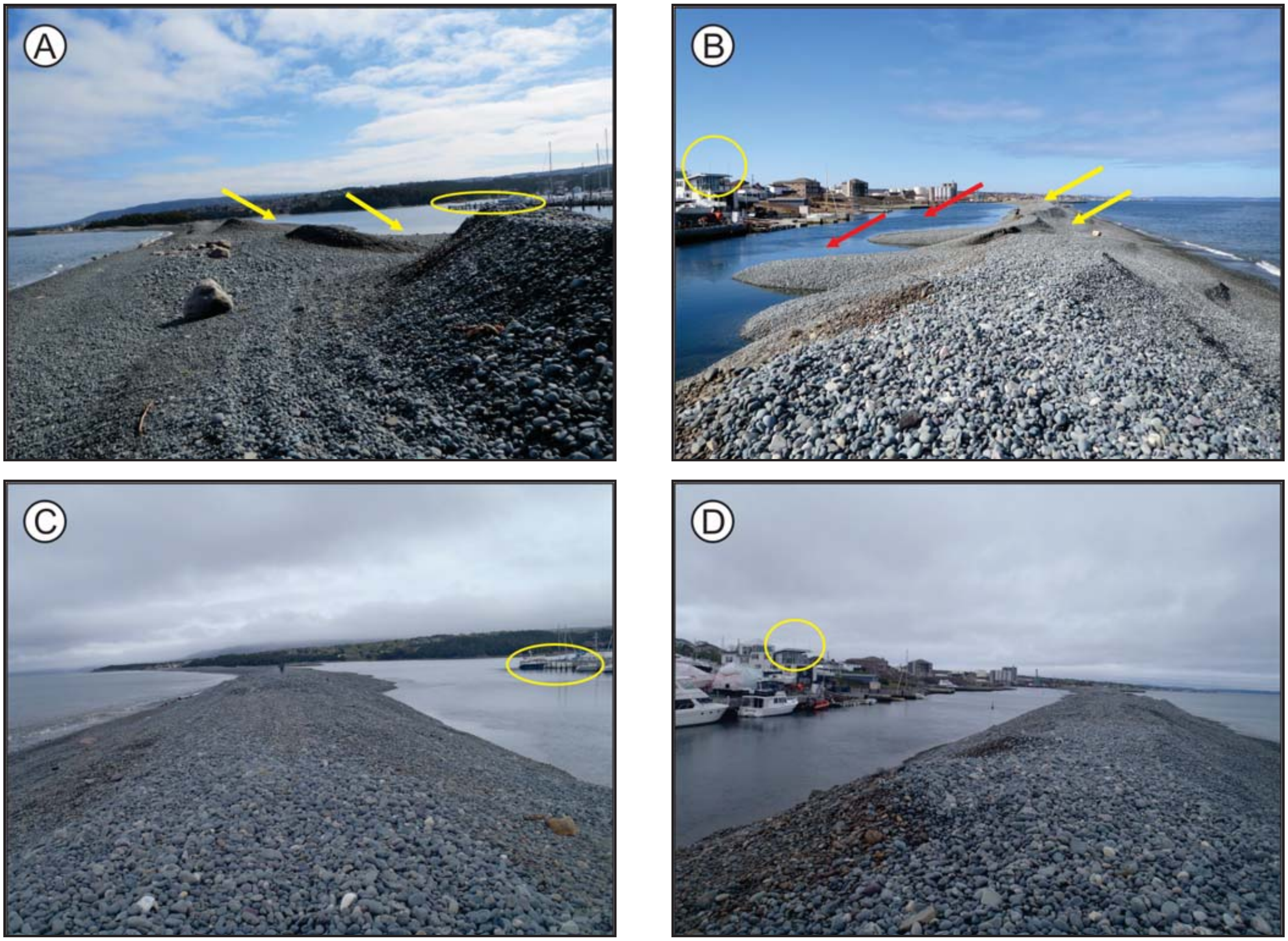

**Plate 9.** *Effects of significant erosion by storm waves. On March 29, 2013, a storm surge coincided with a high tide in Conception Bay South, and the barachois beach system in the Town of Conception Bay South was breached as waves waved over the barrier as seen in (A). Note large breaches in the beach crest highlighted by yellow arrows. Sediment from the beach crest was moved landward as seen in (B), and highlighted by red arrows. No major damage occurred, but the barrier provides protection to the Royal Newfoundland Yacht Club and low-lying areas inland, which include infrastructure such as houses, docks, boats and roads, and all were at risk during the storm. After the storm, the Royal Newfoundland Yacht Club repaired the breaches in the breakwater and re-built the beach system. Photos (C) and (D) show the same area as (A) and (B), respectively, after the area was re-built in April 2013. Points of reference (the end of the pier in A and C, and a building in B and D), are outlined in yellow.*

Kippens (Site #166), Crabbes River (Site #371) and Norris Point (Site #326, Plate 10 (*see* Figure 1)).

### Surface Run-off

Water flowing over a bluff face leads to erosion, as sediment is transported from the face of the slope down to the toe. Surface run-off is evident on the sandy cliffs at O'Donnell's (Site #327) and Ferryland (Site #310) on the Avalon Peninsula (Figure 1); these sandy bluffs are more susceptible to erosion from surface run-off than bluffs of silt and clay, such portions of the cliffs at Norris Point (Site #326) and Daniels Harbour (Site #306). Gullies form on the bluff face due to surface run-off, as observed in the unconsolidated bluffs along St. George's Bay (Site #73), Romains Brook (Site #165), Grand Codroy (Site #72), Parsons Pond (Site #374, Plate 11), and on the Avalon Peninsula at Point Verde (Site #35 (*see* Figure 1)).

### Wind

Wind moves and deposits sand, creating sand dunes, and examples in Newfoundland include Codroy Valley (Site #72), Western Brook–Broom Point (Site #127) and J.T. Cheeseman Provincial Park (Site #364) on the west coast; Lumsden (Site #322), Musgrave Harbour (Site #325) and

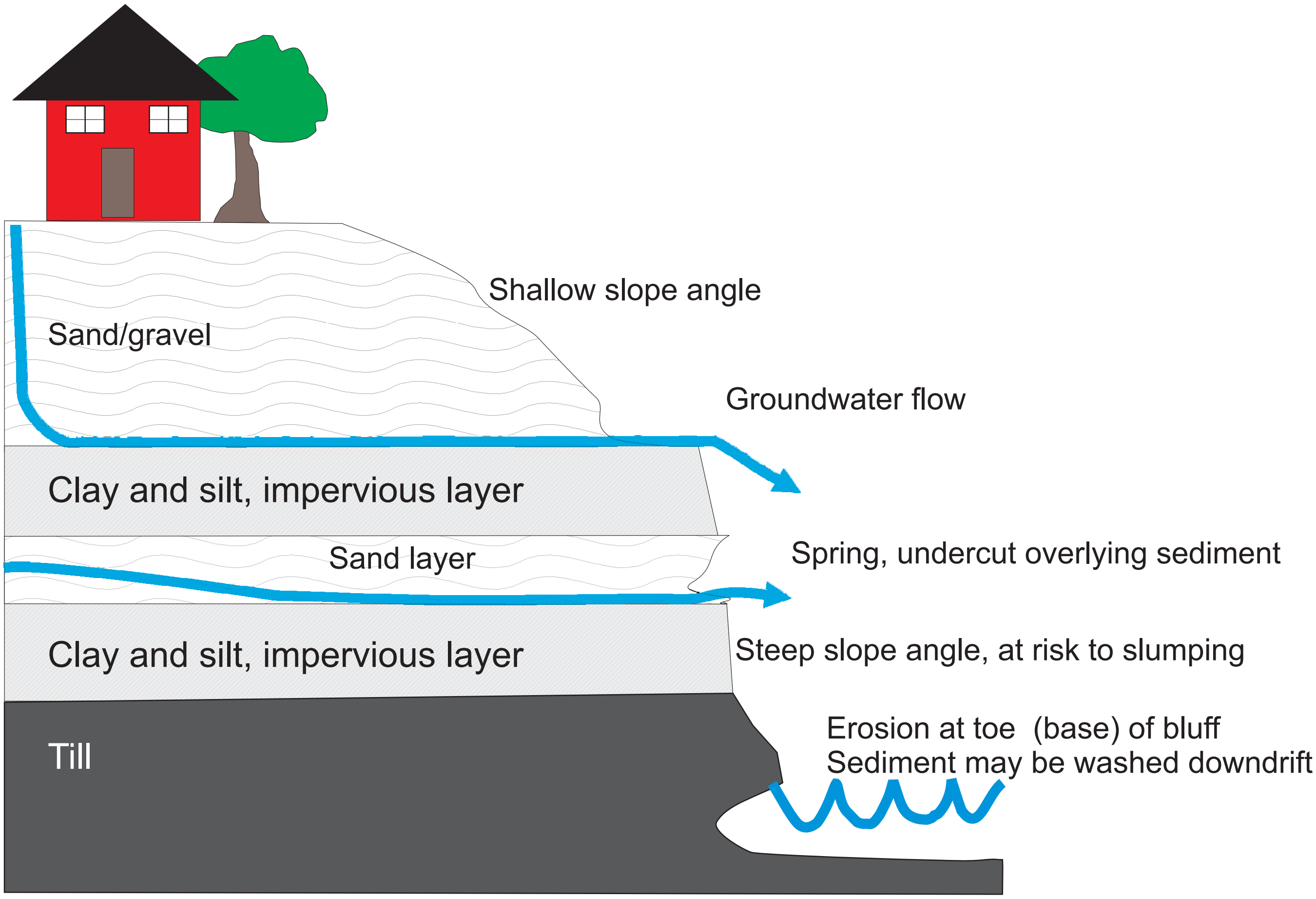


**Figure 6.** *Coastal bluffs generally comprise a range of material in Newfoundland and Labrador. Water will be able to percolate downward through sand and gravel, but will move laterally when it reaches an impervious clay/silt layer. Water will exit the slope through seepage or springs. Sand and gravel layers have a shallower slope angle, and are not resistant to erosion from wind or water. Clays and silt are more cohesive; generally, they will have a steeper slope angle and will be prone to slumping when saturated or undercut. At the toe of the slope, waves remove sediment, causing the base of the cliff to be undercut (modified from O'Neill, 1985).*

Cape Freels (Site #303) on the northeast coast; and Sandbanks Provincial Park (Site #363) on the south coast (Figure 1). In Labrador, dune environments include those at L'Anse-Amour (Site #361), Pinware (Site #351), L'Anse-au-Clair (Site #360) and Forteau (Site #350) (Figure 1). The development, maintenance and topography of these dunes are dependent on wind velocity and direction, amount and species of vegetation cover, soil moisture and presence of driftwood.

Blowouts (a hollow or depression in a pre-existing sand deposit formed by wind erosion) are common in sandy environments with high wind and wave energy (Hesp, 2002), such as at Lumsden (Site #322) and Western Brook–Broom Point (Site #127, Plate 12) (Figure 1). Human activities, such as ATV use or foot traffic, or disturbances from water, make an area more vulnerable to blowouts.

Wind can also remove material from bluffs comprising sand, and causing erosion, such as at the monitoring sites at Point Verde (Site #35), Kippens (Site #166), Bayview Heights (Site #167), Flat Bay (Site #73), Norris Point (Site #326) and Ferryland (Site #310) (Figure 1).

## CONCLUSIONS

The results of the program support that the coastline in the Province is changing at a variable and rapid rate. Erosion rates ranging from 0.20 cm/a to 1 m/a are estimated for unconsolidated coastal cliffs, such as Holyrood Pond. Regular surveys will be required to have an understanding of the range and mean coastal-recession rates for different types of coastal environment, and to increase the confidence of current estimations. Based on observations from field studies, wave action, groundwater flow, surface run-off and wind are the primary physical processes leading to coastal change.


**Plate 10.** *Cliff at Norris Point showing the contact (dotted red line) between two sediment types: sand and gravel overlying silt and clay. Sand and gravel are more susceptible to erosion from water and wind than the silt and clay. Silt and clay are more cohesive and will have a steeper slope angle, but will slump and fail if saturated or undercut.*

Data are being organized into a database that will be accessible through the on-line Geological Survey Resource Atlas (http://gis.geosurv.gov.nl.ca/). Future work will involve coastal monitoring on a regular (every one or two years) basis to allow for estimates of current and future change of coastal erosion to be made for all sites.

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**Plate 11.** *Gullying in the coastal bluffs at Parsons Pond. These bluffs are composed of silt and clay (darker sediment with a steeper slope angle) and sand and gravel (lighter sediment with a shallow slope angle). Sand and gravel are highly susceptible to erosion from water and wind. Silt and clay are more resistant, but may fail when saturated. Note surveyor at base of cliff (circled in red) for scale, and exposed pipes.*

**Plate 12.** *Surveying a blow-out in Western Brook–Broom Point, Gros Morne National Park.*

## REFERENCES

Batterson, M. and Liverman, D.
2010: Past and future sea-level change in Newfoundland and Labrador: Guidelines for policy and planning. *In* Current Research. Newfoundland Department of Natural Resources, Geological Survey, Report 10-1, pages 129-141.

Batterson, M., Liverman, D., Ryan, J. and Taylor, D.
1999: The assessment of geological hazards and disasters in Newfoundland: an update. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 99-1, pages 95-123.

Batterson, M., Liverman, D. and Taylor, D.
1995: The assessment of geological hazards and disasters in Newfoundland. *In* Current Research. Newfoundland Department of Natural Resources, Geological Survey, Report 95-1, pages 55-75.

Batterson, M., McCuaig, S.J. and Taylor, D.
2006: Mapping and assessing risk of geological hazard of the northeast Avalon Peninsula and Humber Valley, Newfoundland. *In* Current Research. Newfoundland Department of Natural Resources, Geological Survey, Report 06-1, pages 147-160.

Catto, N.
2012: Coastal erosion in Newfoundland. Atlantic Climate Adaptation Solutions Association, 150 pages.

Colman-Sadd, S.P., Hayes, J.P. and Knight, I.
1990: Geology of the Island of Newfoundland. Newfoundland Department of Natural Resources, Geological Survey, Map 09-01, scale 1: 1 000 000.

Dail, H.J., Merrifield, M.A. and Bevis, M.
2000: Steep beach morphology changes due to energetic wave forcing. Marine Geology, Volume 162, pages 443-458.

Finnis, J.
2013: Projected impacts of climate change for the Province of Newfoundland and Labrador. The Office of Climate Change and Energy Efficiency, 134 pages.

Forbes, D.L.
1984: Coastal geomorphology and sediments of Newfoundland. *In* Current Research, Part B. Geological Survey of Canada, Paper 84-1B, pages 12-24.

1985: Placentia Road and St. Mary's Bay: field-trip guide to coastal sites in the southern Avalon Peninsula, Newfoundland. *In* Proceedings, Canadian Coastal Conference 85, St. John's, National Research Council of Canada, Associate Committee for Research on Shoreline Erosion and Sedimentation, pages 578-605.

Forbes, D.L., Orford, J.D., Carter, R.W.G., Shaw, J. and Jennings, S.C.
1995: Morphodynamic evolution, self-organization, and instability of coarse-clastic barriers on paraglacial coasts. Marine Geology, Volume 126, pages 63-85.

Forbes, D.L., Orford, J.D., Taylor, R.B and Shaw, J.
1997: Interdecadal variation in shoreline recession on the Atlantic coast of Nova Scotia. Canadian Coastal Conference 1997, pages 360-375.

Hesp, P.
2002: Foredunes and blowouts: initiation, geomorphology and dynamics. Geomorphology, Volume 48, pages 245-268.

Irvine, M.
2012: Coastal monitoring in Newfoundland and Labrador. *In* Current Research. Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 12-1, pages 191-197.

2013: Coastal monitoring in Newfoundland and Labrador: 2012 update. *In* Current Research. Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 13-1, pages 43-54.

Liverman, D., Batterson, M. and Taylor, D.
2003: Geological hazards and disasters in Newfoundland–recent discoveries. *In* Current Research. Newfoundland Department of Natural Resources, Geological Survey, Report 03-1, pages 273-278.

Liverman, D., Batterson, M., Taylor, D. and Ryan, J.
2001: Geological hazards and disasters in Newfoundland and Labrador. Canadian Geotechnical Journal, Volume 38, pages 936-956.

Liverman, D.G.E., Forbes, D.L. and Boger, R.A.
1994: Coastal monitoring on the Avalon Peninsula. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 94-1, pages 17-27.

Liverman, D. and Taylor, D.
1994: Surficial geology of the St. John's (NTS 1N) and Trepassey (NTS 1k) map areas. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey, Open File NFLS (2422), Map 94-230, Scale 1:250 000.

Moore, L.J. and Griggs, G.B.
2002: Long-term cliff retreat and erosion hotspots along the central shore of the Monterey Bay National Marine Sanctuary. Marine Geology, Volume 191, pages 265-283.

O'Neill, C.T.
1985: A guide to coastal erosion processes. Cornell Cooperative Extension Information Bulletin 199. Ithaca, NY, 15 pages.

Pardo-Pascual, J.E. and Garcia-Asenjo, L.G.
2005: New methods and tools to analyze beach-dune system evolution using real-time kinematic global position system and geographic information systems. Journal of Coastal Research, Special Issues Volume 49, pages 34-39.

Rogerson, R.J. and Tucker, C.M.
1972: Observation on the glacial history of the Avalon Peninsula. Maritime Sediments, Volume 8, pages 25-31.