GEOLOGICAL SURVEY OF CANADA
OPEN FILE 6268

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R.B. Taylor and D. Frobel

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ABSTRACT

Physical shoreline changes were monitored from1983 to 2008 along the head of South Bay Ingonish and Black Brook Cove, Nova Scotia. The objective was to define typical rates of change for barrier and non-barrier beaches on northeast Cape Breton Island and to assess their recovery from human modifications during the 1970s. Thirteen visits to the area included six detailed surveys of Ingonish Beach and five of Black Brook Cove. Both are coarse-grained beaches fringed by subtidal sand deposits which seasonally move on and off shore. Changes to the coarse component provided the best indication of longer term beach stability while changes in the sand component provided the best indication of short term seasonal changes. An analysis of shoreline changes along the head of South Bay Ingonish was extended back to the 1930s by comparing georeferenced vertical air photos. To quantify short term fluctuations in beach sand accumulation, additional surveys were completed by Parks Canada from May to October, between 1984 and 1992.

Small net changes in beach position and morphology imply Ingonish and Black Brook Cove beaches are in a "dynamic equilibrium" with present wave conditions. Beaches in "dynamic equilibrium" can experience significant local changes during specific storms, but they can recover and restore their physical character as wave conditions change. Since 1936, along Ingonish Beach net retreat at high tide was a maximum of 21 m (0.3m/a). Fluctuations in beach width caused by seasonal sand accumulation at both sites are commonly 10 to 20 m and as much as 36 m. Natural changes along the backshore of these two beaches was minimal except where human modifications were made. Since 1983 the highest parts of both beaches retreated by less than 4 m however changes increased toward the ends of Ingonish Beach where crest elevations were lower. Waves are thought to have overwashed the highest parts of the beaches in storms during 1983, 1991 and 2000. At Ingonish Beach it took roughly six to ten years for the beach crest to naturally repair itself after being cut into and lowered by waves. In contrast, backshore areas excavated and lowered by human activity have not yet recovered after 26 years. Recovery is slow because the supply of coarse sediment is limited. Beaches must readjust their shape and redistribute their present sediment reserves to adapt to larger changes across the backshore.

Shifts in the position and morphology of the nearshore bar complex has important implications for wave dynamics, the initiation of rip currents and physical changes along Ingonish Beach. A close relationship was found between the spacing of cuts along the crest of Ingonish Beach and crescentic bar conditions offshore, but surveys were not frequent enough to define which wave and offshore bar conditions exist when the beach crest is cut and rip currents develop. Future investigations of nearshore bar dynamics are encouraged. The information would improve human safety from rip currents and a better understanding of longshore shifts in beach stability.

Ingonish Harbour Beach, which is a low, coarse barrier separated by a tidal channel is not in equilibrium with present conditions. It was increasingly overwashed by waves after 1975 and was flattened during the late 1983 storm. Since 1936 the northern barrier has migrated 35 to 58 m landward. Reinforcing its core with armour rock and rebuilding its crest to 4 m has halted its migration after 2004.

Physical indicators useful for measuring the seasonal and longer term state of coastal environments within Cape Breton Highlands National Park are discussed and sweep profiles marking the highest and lowest fluctuations in beach sediment over 25 years provide a reference for assessing future changes on these and other similar beaches.

Front Cover: Aerial view from a kite looking north along Ingonish Beach taken by G. Harvey, Cape Breton Highlands National Park on October 24, 2008. The photo illustrates conditions at the time of our 2008 beach surveys when higher energy waves had combed most beach sand offshore (Parks Canada photo IMG 6145, 2008).

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INTRODUCTION

In the early 1980s the Geological Survey of Canada, Atlantic (GSCA) was conducting aerial and ground surveys of the coastline of Cape Breton Island in support of marine oil spill planning and clean-up operations. The effort was triggered by a marine oil spill in the spring of 1979 along southwest Cape Breton Island from the tanker Kurdistan (Vandermeulen, 1980). Aerial photographic surveys using 35mm slides were conducted along the Cape Breton coastline in November 1979 and May 1980 (Taylor and Frobel, 1979, 1980). The first continuous aerial coastal video survey of northeastern Cape Breton Island was completed in 1982 by Petro Canada Exploration Inc. (Woodward -Clyde Consultants Ltd., 1982). A second aerial coastal video survey was completed by the Geological Survey of Canada and the Canadian Coast Guard in the fall of 1992 (Taylor and Frobel, 2001). At the same time representative beach and cliff sites were being selected for long term monitoring of coastal change.

In 1983 park wardens at Cape Breton Highlands National Park, asked the authors to examine the dynamics of a few recreational beaches in the Park and to assist park interpreters in the preparation of walking tours for park visitors. As part of the long term management of Cape Breton Highlands National Park (herein referred to as the Park), questions were being raised about the practice each spring of artificially removing pebble cobble from the upper beach and moving sand upslope to enhance its recreational appeal. This was a common practice at Ingonish Beach between 1971 and 1983 (A. Gibbs, pers comm., 1984). The subsequent loss of sand from the beach to the parking lot during the winter months also became a concern.

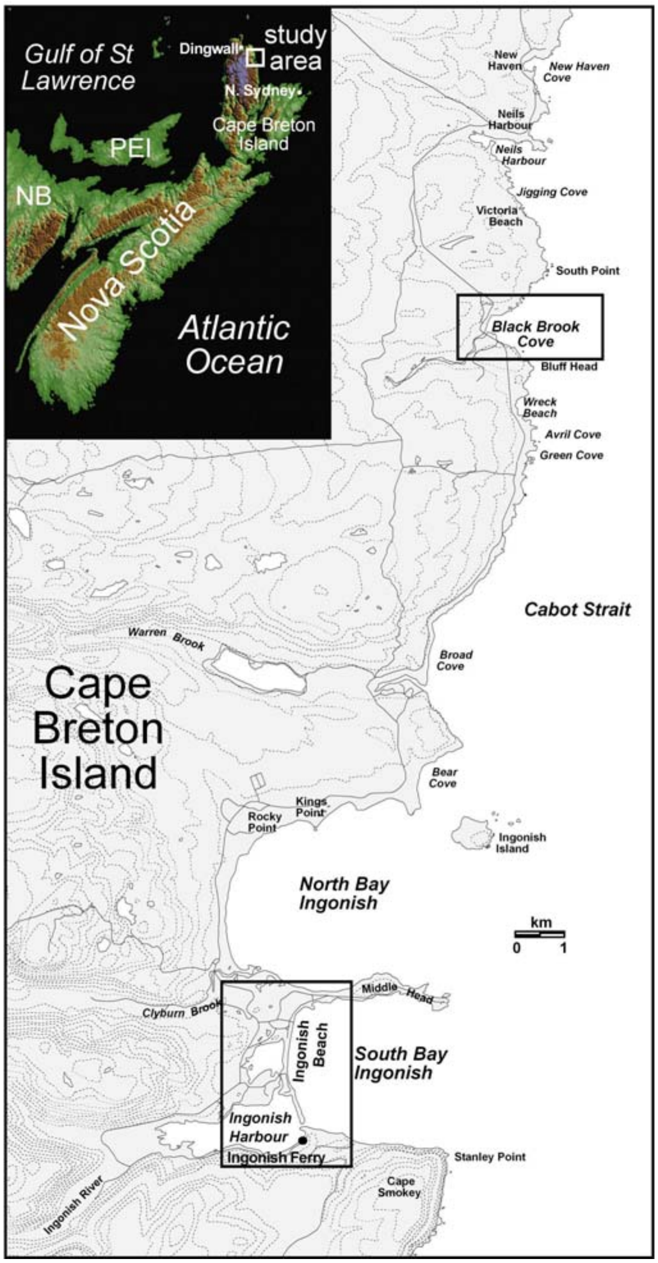
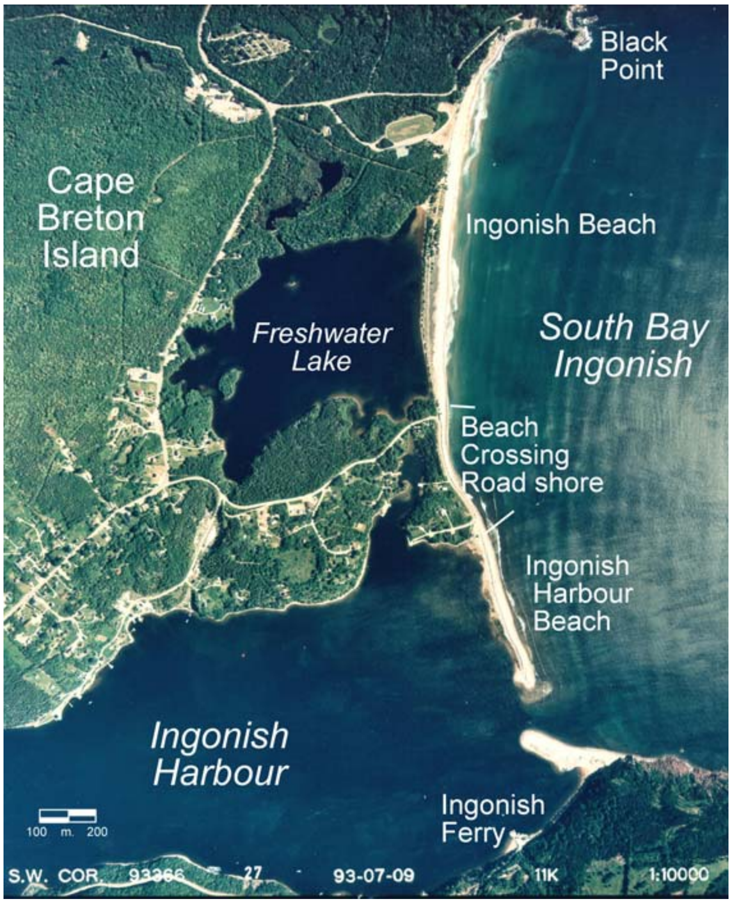


Figure 1. Location map of study area along northeast Cape Breton Island (inset), place names and detailed study sites (boxes) at South Bay Ingonish and Black Brook Cove, Nova Scotia.

Figure 2. Aerial view of the head of South Bay Ingonish and Ingonish Harbour, July 9, 1993 showing the locations of Ingonish Beach, Beach Crossing Road shore, Ingonish Harbour Beach, and narrow peninsulas of higher backshore terrain which connect and anchor the barrier beaches (photo 93366-27 NS Geomatics).



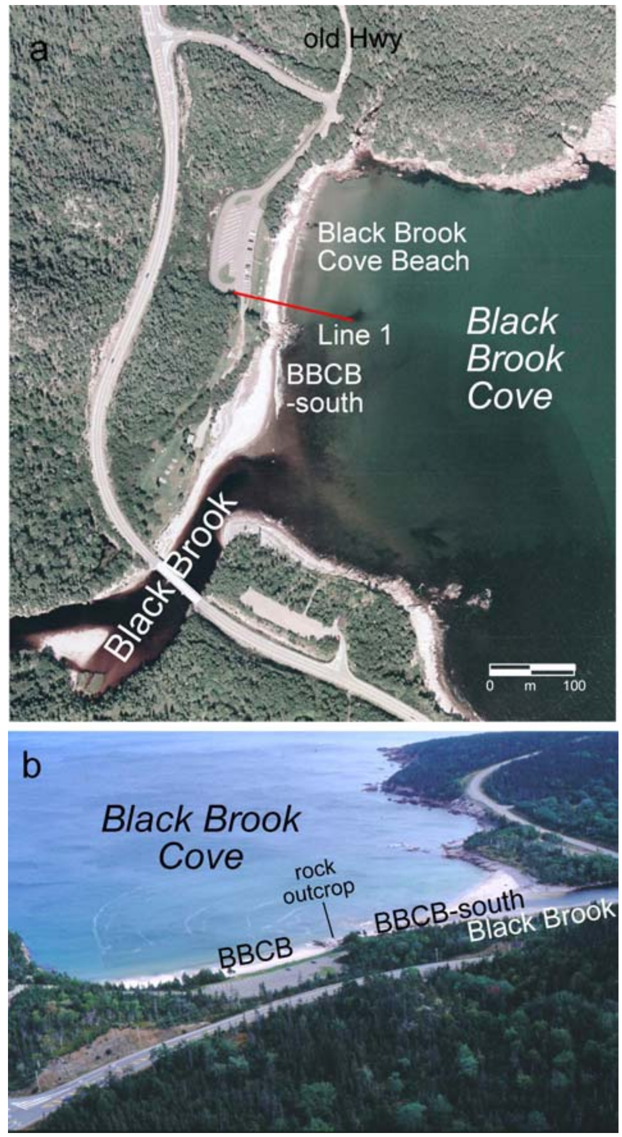


Figure 3. (a) Vertical air photo from 1999 and (b) a 1992 aerial oblique photo looking southeast, showing Black Brook Cove, Black Brook, Black Brook Cove Beach (BBCB)- the main study site and BBCB-south where fewer observations were made.

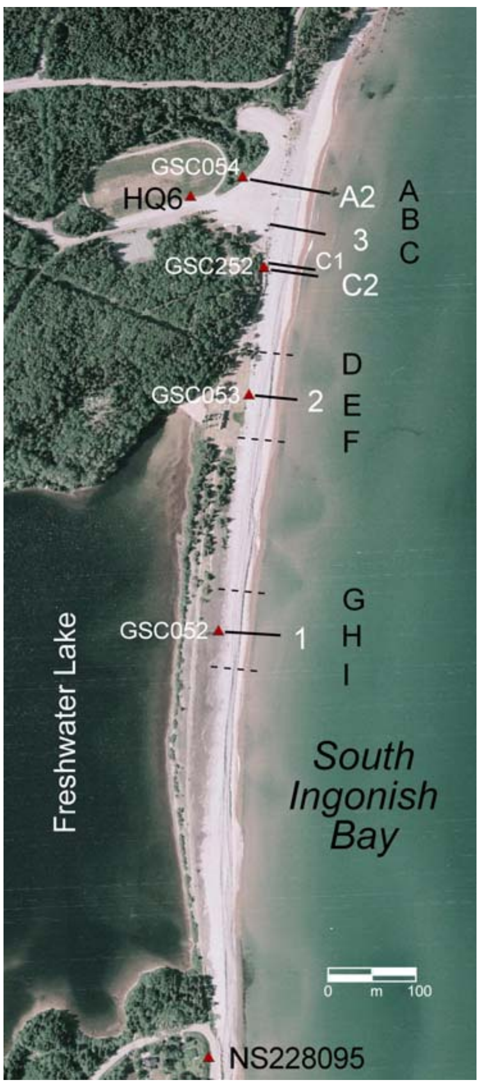
Preliminary visits to Ingonish, Broad Cove, and Black Brook Cove beaches were begun by the authors in 1983 but it was not until after a major storm surge struck this coast on October 29, 1983 that detailed shore surveys were begun (Taylor and Kelly, 1984). Ingonish and Black Brook Cove beaches (Fig. 1, to 3) were chosen for further study as part of the GSCA national shoreline monitoring program. Both sites are situated at the head of bays where subtidal sand deposits seasonally move on and offshore. Ingonish Beach (frontespiece, Fig. 2) provided a good example of a high, pebble-cobble beach with both barrier and non-barrier components. Black Brook Cove Beach was typical of many high, pebble-cobble non-barrier pocket beaches (Fig. 3). Repetitive beach surveys were continued at both sites until 2008 (Table 1, Appendix 1, 2).

This report focuses on the beach dynamics and range of physical changes observed at Ingonish and Black Brook Cove Beaches during a twenty-five year shore monitoring program. Published reports and vertical air photos were used to extend the analysis of shoreline change back to the early 1900s. Impacts of park management activities on natural beach stability and changes are discussed. In addition, seasonal sand fluctuations investigated on Ingonish Beach by Parks Canada (McCarthy, 1989), and reported on by Rhodes (1994), are re-examined and expanded upon. The vertical datum used in these previous studies was updated using more accurate surveying technology, available after 1998.

METHODOLOGY

Repetitive cross-shore surveys at designated locations along a beach are a common method of documenting physical shoreline change. Locations for cross-shore lines are selected at either equal distances alongshore or at sites which represent different beach morphology. At Ingonish Beach, cross-shore survey lines were selected in areas of different beach morphology (Fig. 4, Table 1, Appendix 1). Permanent benchmarks are used to mark the location of cross-shore lines; however, to avoid establishing unsightly markers within the park, natural objects such as trees, signs or corners of buildings initially were used. Unfortunately many of the line markers were knocked down or removed at Ingonish Beach necessitating the establishment of new markers and survey lines. In 1992 survey caps with unique GSC numbers were established on metal reinforcing rod as the most landward marker on each line at Ingonish Beach (excluding Line C2 where a cap was not added until 1998). Most markers were close to ground level and hidden within shrubs away from public view. Where lines had to be re-established and represented the same part of the beach, they were given the same name with a subscript, e.g. line C became C1 or C2 and Line 1 became 1A (Appendix 1, Fig. 4). To obtain another perspective and better understanding of longshore beach changes, surveys were also extended along the beach crest, the highest part of the beach. Longshore crest surveys were begun at Ingonish Beach in 1992 and were repeated in 1998, 2002 and 2008 however it was only in October 2002 when the entire length of the beach to Beach Crossing Road and south along the barrier beach fronting Ingonish Harbour (Fig. 2) were surveyed. All other crest surveys along Ingonish Beach were restricted to north of line 1 (Fig. 4). Long intervals between surveys and their timing in the spring or fall of the year may have missed short term changes and recovery between surveys and changes during other parts of the year.

Survey accuracy has improved significantly since the early 1980s when cross-shore surveys were completed using a range pole, tape measure and abney level. A total station (Geodimeter 140 H) was used to complete the beach surveys in 1992 and later to extend the surveys seaward of low tide. In 1998 dual frequency GPS technology, in Real Time Kinematic (RTK) mode was used. Each line was surveyed along a magnetic compass bearing aligned with two line markers. Surveys were extended from the backshore or lake shore, to a variable distance offshore (wading depth) depending on wave and tidal conditions. All elevations for Ingonish Beach surveys are orthometric, relative to Canadian Geodetic Vertical Datum 1928 (CGVD28) (Table 2). The elevations are tied to provincial high precision monument NS228095 (Fig. 4) which is at an elevation of 7.19 m. At Black Brook Cove Beach only one survey line was established (Fig 3a) and elevations are not as accurate. They are based on a sea level surveyed in 1992 at Black Brook Beach and compared with a water level surveyed in Aspy Bay which was tied into to high precision monument NS 215687 at 25.32 m in Dingwall, N.S. Geographic positions for the survey line at Black Brook Beach were obtained using a hand -held Garmin GPSMAP 76CSx. Detailed information about individual surveys and coordinates of line markers are provided in Appendix 1.



Additional information collected during the field surveys included photographs looking each way alongshore and surface sediment across each survey line. Whenever possible additional observations and photographs were obtained when the authors or other colleagues visited each beach (Appendix 1). Along other parts of South Bay Ingonish only repetitive ground photographs were collected, except in 2002 when a crest survey was completed along the north barrier of Ingonish Harbour Beach.

Figure 4. Location of cross-shore survey lines and high precision provincial monument (NS228095) used to monitor physical changes along Ingonish Beach from 1983 to 2008. Lines 1, 2, and 3 were established in 1983 and lines A2, C1 and C2 in the 1990s by GSCA whereas the other lines (marked with black letters) were established by Parks Canada staff in 1984. Only three Parks Canada lines A, B, and C were resurveyed after 1984. The background air photo (99311-53) was taken June 11, 1999.

In 1984 Parks Canada established three sets of three cross-shore surveys lines (Fig. 4, Table 1) to expand on the GSCA lines. The three lines in each location were roughly 50 m apart. Lines A to C were at the northern end of the beach, line E and H were at GSCA lines 2 and 1 respectively and the other lines were 50 m north and south of those lines (Fig. 4). Lines D to F were established in June 1984 and resurveyed again in August 1984 when three more lines G, H, and I were added along Freshwater Lake barrier. Subsequent beach surveys after 1984 until 1992, were limited to lines A to C. Surveys were completed using standard survey levelling techniques taking measurements at three metre intervals (McCarthy, 1989). The survey lines were marked by wood stakes. For each line, surveys were begun at a select distance from a known marker.

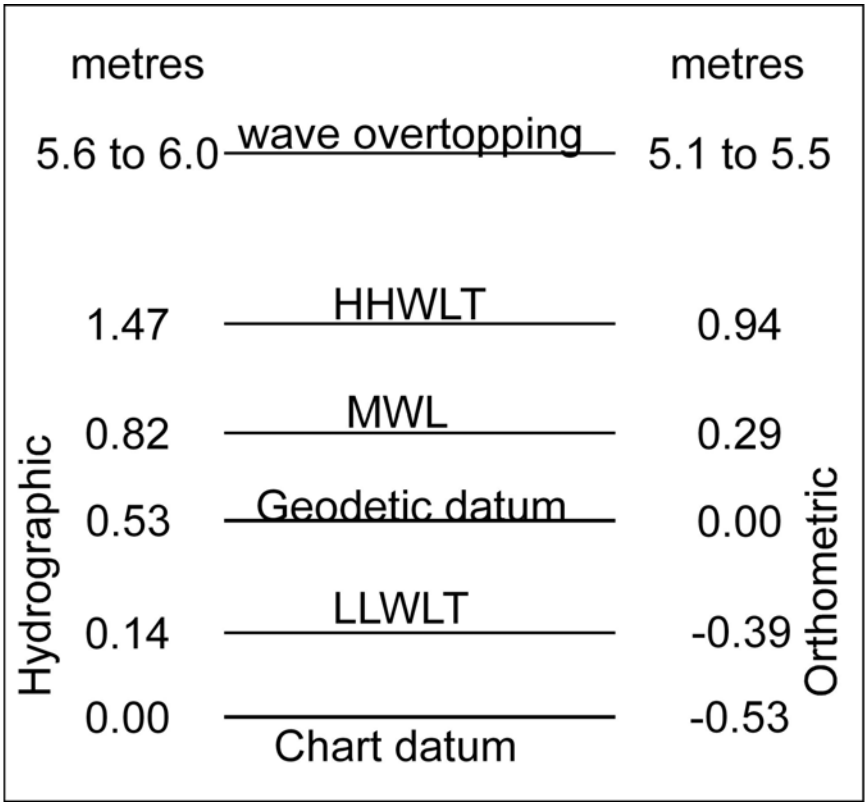
The position and elevation of the first survey point on each line was tied to a benchmark, assumed to be the HQ6 survey monument located on the soccer field (Fig. 4) and a large boulder (pyramid shaped with green stripe) seaward of the walking path, 4 m north of line C. Elevation for the survey cap at HQ6 was given as 12.61 feet (3.84 m) and the rock as 8.9 feet (2.71m). From recent DGPS surveys, the elevation of HQ monument has been updated to 4.01 m (CGVD 28). Therefore elevations from Parks Canada cross-shore surveys were raised by 0.17 m to conform with GSCA beach surveys. No report was available from Parks Canada for surveys completed between 1988 to1992. Survey data, presented in this report was derived from copies of field books provided by Parks Canada.

The analysis of beach changes along South Bay Ingonish was extended back to the 1930s using vertical air photos (1936, 1966, 1975 and 1999, Appendix 3) and ESRI ARCGIS software. Each of the vertical air photos was scanned at 600 dpi and imported into ARCGIS for georeferencing with the 1992 provincial 1:10,000 maps (NAD83) revised in 2004. Shorelines for each year of photography were digitized from the georeferenced images and displayed on 1999 aerial photography.

Table 1. List of cross-shore survey lines established from north to south along Ingonish Beach that were monitored by Parks Canada and GSCA. The time period each line was monitored is shown in brackets. The location of survey lines is provided on figure 4. Additional information about all beach surveys is provided in Appendix 1.

Geological Survey of Canada Atlantic (GSCA)		**Parks Canada**	
Line	**Years**	**Line**	**Years**
A2	(1992- 2008)	A	(1984-1992)
3	(1983- 1992)	B	(1984- 1992)
C1	(1992)	C	(1984- 1992)
C2	(1998-2008)		---------
	--------	D	(1984)
2	(1983-2008)	E	(1984)
	-------	F	(1984)
	-------	G	(1984)
1	(1983-2008)	H	(1984)
	--------	I	(1984)

Table 2. A comparison of shoreline elevations at Ingonish Ferry, NS, relative to Hydrographic Chart datum and Geodetic datum (CGVD28). The separation between the two datums was estimated from values calculated at North Sydney and Dingwall tidal sites south and north of the study area (P. MacAuley, Canadian Hydrographic Service, pers. comm., 2009).



COASTAL PROCESSES

Tides along northeastern Cape Breton Island are mixed, mainly semi-diurnal (MSD). There are two complete tidal oscillations daily with inequalities both in height and time (CHS, 2009). At Ingonish Ferry (tidal station 0630) the large tidal range is 1.34 m and it decreases northward to Dingwall where it is 1.1 m (CHS, 2009). Higher high water large tide (HHWLT) is defined as the highest predicted annual tide. This datum does not include weather influences such as storm surges which are the difference between predicted and observed water levels. Extreme high water levels are reached when large positive storm surges coincide with high tide. The frequency of storm surges in the Maritimes was summarized by Parkes et al. (1997) using tidal data from 1980 to 1995. At North Sydney, south of the study area (Fig. 1-inset), surges above 0.6 m occur on average 3.5 times each year and surges exceeding 1 m were 1 in ten years. Storm surges were most common from October to April. The largest number of surge events was in December (26) and in January (31).

To plot tidal elevations on the beach surveys, the separation between Chart and Geodetic datums is required. There is no information available for Ingonish Ferry. At North Sydney the separation is -0.4 m and at Dingwall N S it is - 0.62 m, (P. MacAuley, CHS pers. comm., 2008).

Therefore the estimate used for Ingonish Ferry was -0.53 m (Table 2) which places lowest low water large tide at our lowest surveyed water level of -0.39 m at Ingonish Beach in 1992. However, this value is only an estimate and should be used with caution until more accurate surveys are completed to confirm the separation values between Chart and Geodetic datums.

Northeastern Cape Breton Island is exposed to large waves from the North Atlantic and Cabot Strait. MacLaren Plansearch (1991) reported a mean and maximum annual significant wave height of 1.4 m and 8.1 m respectively for Cabot Strait based on waverider observations. However along this coast, wave energy is limited by the presence of sea ice for roughly two months each year and at other times because prevailing and dominant winds blow offshore (MacLaren Plansearch, 1991). Environment Canada Ice Central (http://ice glaces.ec.gc.ca) reported for the period 1971 to 2000 that the mean date of freeze-up is Feb. 12 and date of break-up is March 19 for Ingonish Bay and slightly later on April 2 for the shores farther north. Sea ice concentrations during that period were usually 4-6/10ths but were as high as 9/10ths for a week in February. When sea ice drifts through Cabot Strait and is blown onshore it can directly impact shoreline morphology by leaving ice-melt and push ridge features. Frequency of annual winds in Cabot Strait blowing from the NE, E and SE directions total 24.2 %. Cyclonic storms moving up the North American seaboard can intensify into severe northeasters such as the storm of October 1983, or strike as remnants of extratropical storms such as Hurricane Ivan in Sept. 20, 2004 (Taylor and Kelly, 1984, Chronicle Herald, 2004). For the storm of October 1983 which struck hardest between Ingonish and New Haven, Oja (1984) reported winds at Ingonish peaked at 62 km/hr and tides exceeded normal astronomical tides by 0.76 m at North Sydney on October 25, 1983. Seas of 7 to 9 m were also reported propagating into Cape Breton Island. Wave run-up based on debris lines exceeded the beach crest of 5.1 m (CGVD28) at Ingonish Beach and reached the parking lot at 7.0 m (CGVD28) above Black Brook Cove Beach (Taylor and Kelly, 1984). No other major storms were monitored during the study but we do know based on debris lines that wave run-up exceeded the beach crest at Ingonish Beach in the early 1990s and at least once, and likely more, between 1998 and 2008. Debris was deposited by waves across the lower grass terrace at Black Brook Beach on a number of occasions including the storm of October 2000 but it did not reach the parking lot as it did in 1983 (Andy Doherty, pers comm., 2008). Other storms compiled from newspaper reports known to have struck the area are listed in Appendix 4, however unless mentioned, there were no observations of impacts on the two study beaches.

SOUTH BAY INGONISH SHORES

South Bay Ingonish is one of only a few large bays that indent the coastline of northeastern Cape Breton Island (Fig. 1, 2). They resulted from the erosion and partial submergence of lowlands developed on inliers of less resistant Carboniferous beds of gypsum, shale, limestone and sandstone (MacLaren, 1956). Many coastal features are the product of glacial erosion and sedimentation and changes in relative sea level. The outer shores of South Bay Ingonish are high and rocky while the head consists of a series of beaches connected by narrow areas of higher terrain. A till veneer covering much of the area and thick glaciofluvial deposits in the main river valleys are the primary source of sediment for modern beaches (Grant, 1988).

The head of South Bay Ingonish can be divided into four shore segments (Taylor and Kelly, 1984 (Fig. 2, 3): Ingonish Beach, Beach Crossing Shore and Ingonish Harbour Beach. Ingonish Beach, which extends 1100 m south of Middle Head, consists of two segments, a non barrier beach from Middle Head to Freshwater Lake and a barrier beach 760 m long fronting Freshwater Lake. Beach Crossing Road shore is a pebble-cobble beach fronting a road and peninsula of bedrock and glacial material. This shore is an important anchor for barrier beaches extending north and south of it. Ingonish Harbour Beach consists of a north and south barrier separated by a tidal inlet which connects Ingonish Harbour to South Bay Ingonish (Fig. 2). Only Ingonish Beach lies within Cape Breton Highlands National Park.

Ingonish Beach

Little is known about the age or post-glacial evolution of Ingonish Beach. For example, it is not known if Freshwater Lake was gradually damned off by beach deposits as sea level rose, or was damned by glacial deposits, or it developed as a sink hole? Water depths in Freshwater Lake extend to a maximum of 16 m in a small central basin while the general bottom contour approximates 10 m (Kerekes, 1983). Sediment stratigraphy is unknown beneath the lake and the barrier beach fronting Freshwater Lake. There is 3.5 m of beach extending above lake level which means that the beach could be in the order of 13.5 m thick. The barrier could consist entirely of beach deposits or a combination of beach deposits sitting on glacial deposits and /or bedrock.

Assuming Freshwater Lake was damned by beach deposits and using a relative sea level curve developed for the Bras d'Or lakes (Shaw et al., 2009), sea level would have been at roughly -10 m when the beach began closing off Freshwater Lake at 4000 calendar years BP. The roundness of the beach clasts, suggest they have been reworked by waves for a long time, and the backshore morphology suggests Ingonish Beach experienced a building phase both upward and seaward before its recent retreat.

In an earlier assessment of coastal types within Cape Breton Highlands National Park (EERL, 1978) the intertidal beach fronting Freshwater Lake was described as a sand beach and the northern segment was described as a wide sloping sand beach with minor gravel. Both descriptions contrast with what was observed in 2008 and it illustrates the complexity in physical character of mixed-sediment beaches (Fig. 5). Cross-shore survey lines were established to document spatial and temporal changes in physical characteristics. GSCA lines A2, B, and 3, (Fig. 4) represented the northern segment of a wide, mixed sand and pebble-cobble beach with a low lying backshore. Lines 1 and 2 represented the high, pebble-cobble barrier beach fronting Freshwater Lake. Line C1, C2 crossed a narrow beach with a rising backshore that forms an anchor or hinge point for the shores north and south of it (Fig. 2, 4, Appendix 1). A comparison of cross-shore morphology for these locations is provided in Figure 6, Table 3.

Table 3. Physical characteristics of Ingonish Beach, Nova Scotia in October 2008. The survey lines are located on figure 4 and their cross-shore profiles are compared on figure 6.

Line	Beach Width (m)	Elevation (m) of		Beach Slope	
		Beach Crest	Sand	Backshore (°) (Tan Φ)	Foreshore (°) | (Tan Φ)
1	76	5.3	none	22.0 0.405	9.5 0.167
2	87	5.0	0.4	20.5 0.373	4.1 0.072
C2	31	4.4	1.4	19.5 0.355	2.4 0.042
A2	38	4.3	1.6	7.8 0.137	1.8 0.032

Note: Beach width is measured from high tide level landward to the lake shore or beach crest Backshore slope is measured from high tide level to the beach crest. Foreshore slope is measured between high and low tide levels. Elevation is relative to Geodetic Datum (Table 2).

Onshore Physical Characteristics

The backshore is widest along the northern part of Freshwater Lake near Line 2 where it approximates 90 m and narrows at both ends of Ingonish Beach where it is only 38 to 40 m and at Line C2 where the beach has built against a rising slope (Fig. 6, 7a). The backshore has an assymmetrical cross-shore profile with a steeper seaward than landward slope (Fig 6, 7b). The beach is backed by low lying terrain or water except back of line C2, and where it meets the cliffs of Middle Head. The seaward (upper beach) slope decreases toward the northern end of Ingonish Beach where it has been modified by human activity.

The highest portion of the backshore (Fig. 8), known as the beach crest, coincides with the widest area and the lowest backshore exists near the ends of the beach. In 2002, the highest crest was north of line 1, where it was 5.4 m elevation, and it was lowest toward the ends, at just over 4 m (Fig. 8, Table 3). This general decrease in elevation toward the ends of the beach is typical of most swash-aligned barrier beaches.

Forbes et al. (1990) identified and described a number of gravel barrier beach types in southeastern Canada including: Type -1 prograded beach ridge complexes; Type -2 high gravel storm ridges; Type -3 low gravel barriers dominated by wave overwash and Type- 4 trailing spits and fringing ridges. They further recognized that one type of gravel barrier could potentially evolve into another type under certain circumstances. Ingonish Beach is interpreted as a Type -1 prograded beach ridge complex because of its massive size and multiple beach ridges.

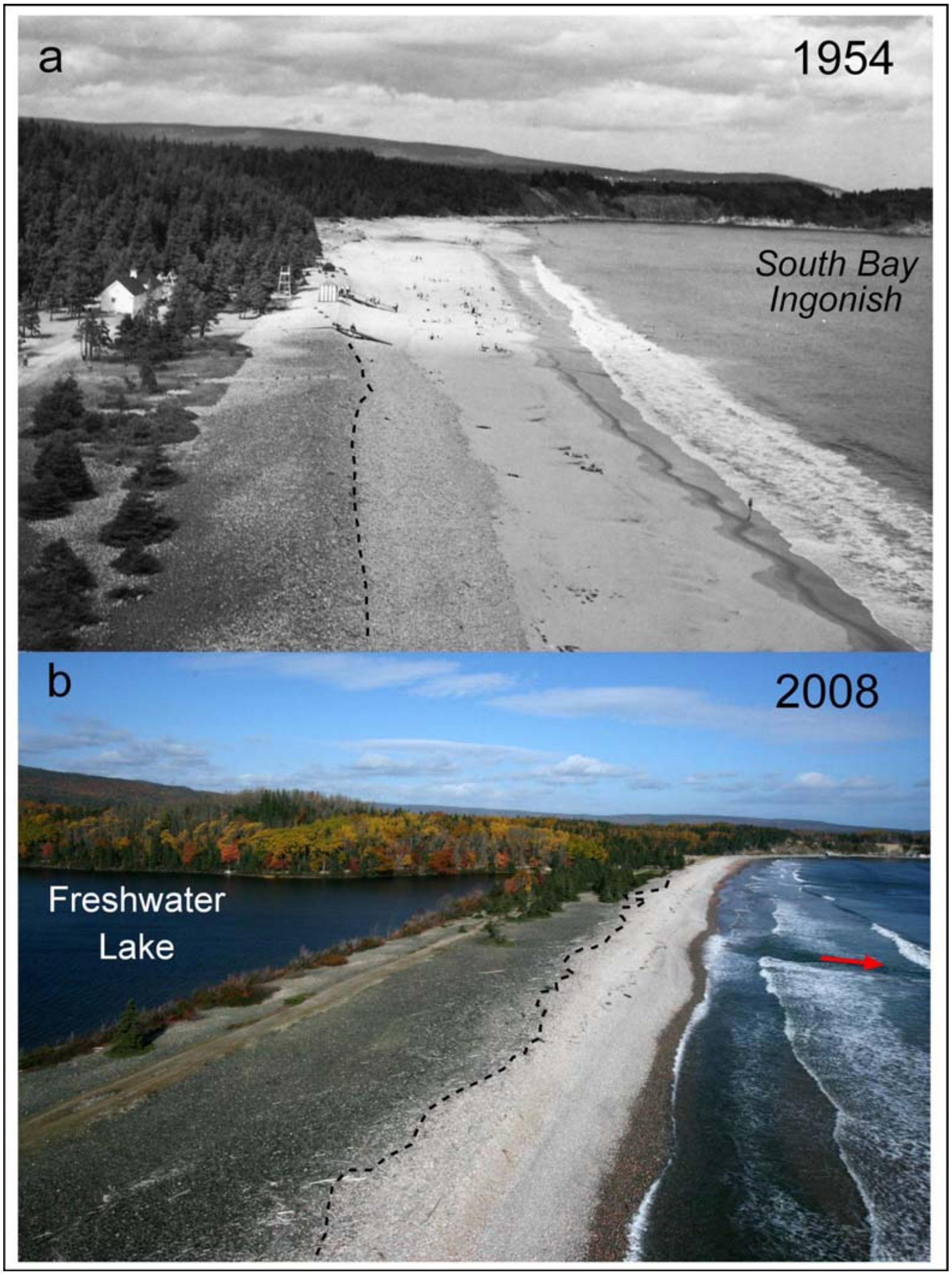


Figure 5. Aerial oblique views looking north of Ingonish Beach (a) in 1954 when a wide sand apron fronted a high pebble-cobble beach (photo 8617, NS tourism) and (b) on 24 October 2008, just before our field surveys when very little sand existed alongshore and a rip current existed off line 1 (arrow) (G. Harvey, Parks Canada, IMG 6145). The most stable portion of the backshore, is marked by trees and cobbles covered by lichens (dark tone). The age of the lichens is unknown. Since 1954 the boundary of lichen covered clasts (dash line) has shifted landward and become less uniform alongshore which suggests increased wave reworking and wave overwash of the upper beach and crest since the 1950s.

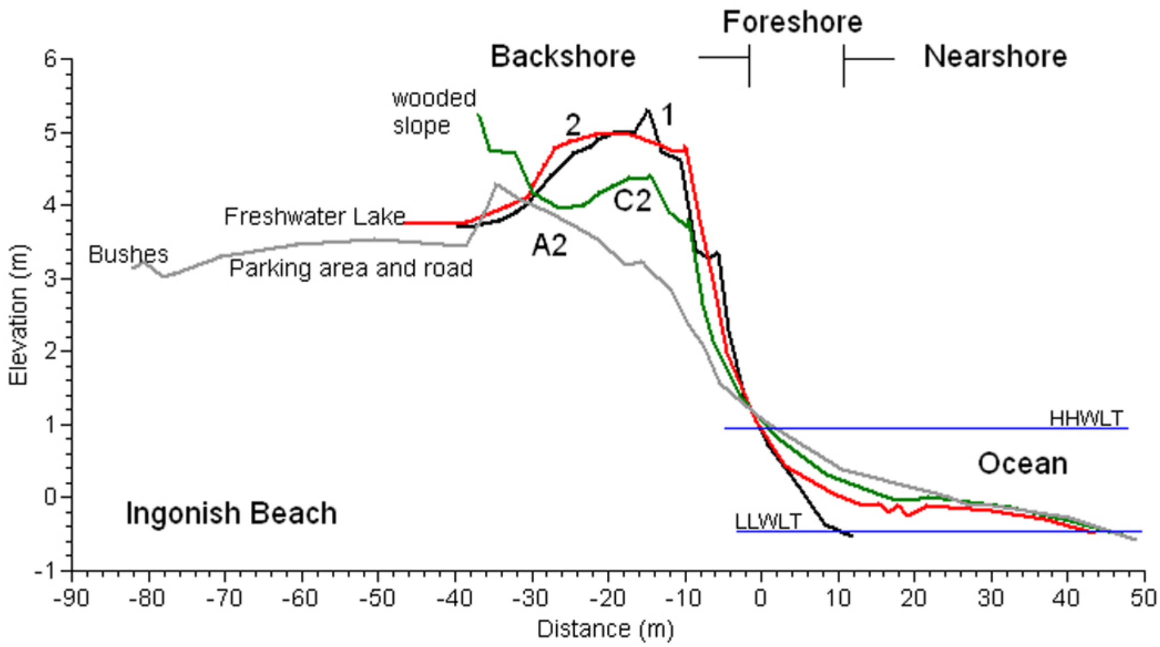


Figure 6. A comparison of cross-shore morphologies observed along Ingonish Beach. Lines 1 and 2 represent the barrier beach fronting Freshwater Lake, Line A2 represents the north shore segment with a low backshore and Line C2 represents the anchor /hinge point between the other two shore segments. The survey lines are aligned where the 1m elevation (~HHWLT) intercepted the beach in 2008.

The extremely steep seaward slope and present erosional character also suggests that Ingonish Beach is switching into a Type-2 high gravel barrier with a single storm ridge.

The northern part of Ingonish Beach, has been more impacted by human activities than the rest of the beach. Isolated high crest areas remain where parts of a wall and dune once separated the beach from the parking lot. The absence of a well developed cobble storm ridge fringing the parking area is attributed to the removal of cobble from the upper beach in the 1970s and early 1980s (Fig.10) and its subsequent lowering during the storm surge of October 1983 (Taylor and Kelly, 1984). Changes in barrier crest profile can occur when waves rework it during episodic storm events (Fig. 9a, b). They are discussed later in this report.

Ingonish Beach consists of well rounded pebble to boulder gneiss and granitic clasts ranging mainly from 25 to > 216 mm (B-axis) (Taylor and Kelly, 1984). There is no modern source of these coarse clasts except from the beach itself. Although sediment samples were not collected, clast size was measured from photographs of surface sediment on each survey line (Appendix 5). The largest clasts form the core of the beach whereas sand forms a temporary cover across the foreshore zone. Swash ridges built across the foreshore consist of smaller clasts than those along the beach crest (Table 4). The largest change in sediment character observed since 1983 was along the northern beach. In November 1983 the upper beach consisted of clasts varying from

41 to 151 mm whereas in 2008 they varied from 41 to 193 mm (Appendix 5). The increased abundance of larger clasts since 1983 is partly the result of waves winnowing away the finer material, and partly because of human modifications to the beach (Fig. 10). The poor sorting also may reflect that all sizes of material have been moved during storms leaving a very disorganized sediment cover. The sand component of the lower beach was not analysed. In the event of a marine oil spill, the oil would penetrate farther downward and persist longer because of the coarse backshore and the oil would have a high potential of burial across the lower beach because of seasonal fluctuations in sand accumulation (see later section).

Where the beach is wide, high and covered by more soil, ie. near line 2 (Fig. 7a) the backshore is wooded. The abundance of trees is probably also enhanced by its proximity to a higher wooded slope back of line C2. Along the more wind-exposed barrier beach fronting Freshwater Lake, the backshore is essentially non-vegetated. It consists of open work cobble with no soil, covered with lichen and a few isolated, stunted trees (Fig. 7a, b). Lichens have been tentatively identified from photographs as *Rhizocarpon geographicum*, one or more *Umbilicaria* species, possibly including *U. polyphylla*, and several other crustose species (pers. comm. S. R. Clayden, 2008). The seaward edge of the lichen-covered cobble coincides with the flotsam driftline where waves have reworked the cobbles, and removed the lichen. We observe lichen covered cobble only on stable backshores of larger and higher gravel barriers. Therefore the presence of lichen suggests the backshore has been stable for many years.

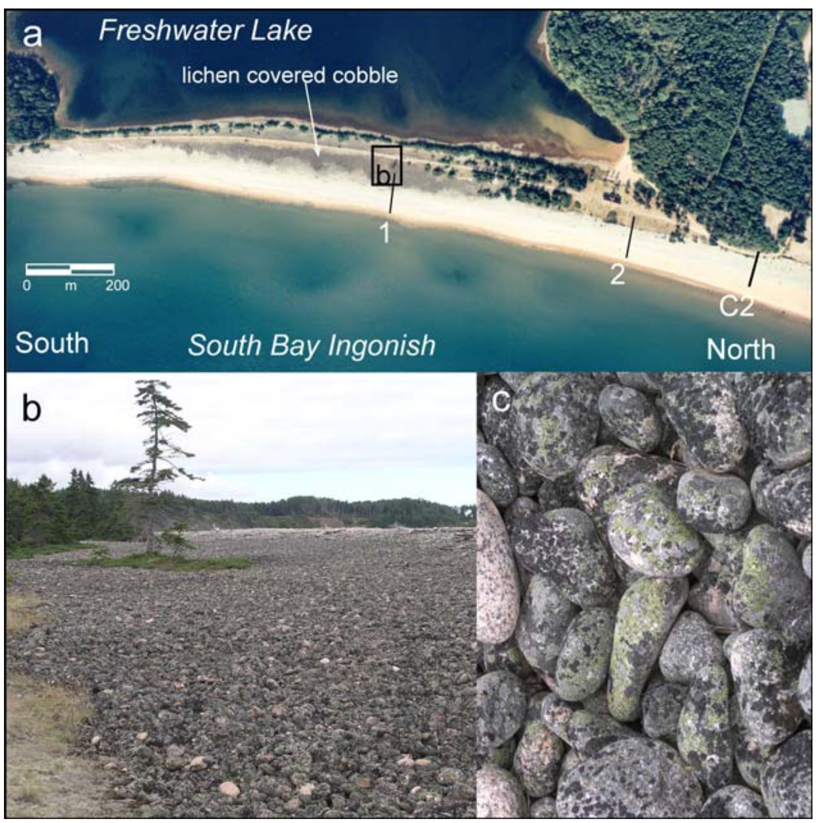


Figure 7. (a) Aerial view taken in 1994 (Parks Canada) of the barrier beach fronting Freshwater Lake showing the distribution of lichen-covered cobbles (dark tone). The diffuse seaward edge of the lichen covered cobble is the limit of wave overwash which extends farther inland north and south of line 1; (b) ground view (marked by square in a) of the lichen-covered cobble backshore slope at line 1 (at tree); and (c) close-up of lichens (including R. geographicum and at least two Umbilicaria species, one U. polyphylla, S. Clayden, 2008 pers comm.).

On Ingonish Beach the extent of lichen covered cobble is diminishing particularly toward the lower south end of the barrier where the lichen is being worn away or buried by beach cobbles moved landward by waves (Fig. 7a).

Drifting sea ice can directly impact Ingonish Beach creating distinctive features. In 1992 when sea ice was pushed onshore and rode upslope, it produced a very smooth slope and left intermittent piles of sediment along the upper beach. A swash ridge (Fig. 9c, lower arrow) which formed along the base of the grounded ice flows, remained as an isolated feature after the ice melted. Most ice-built shore features are short lived. Craters several metres in diameter have existed since 1983 along the backshore near Line 2 (Fig. 9d). Their origin is unknown. They are thought to be the result of sea ice-melt, but also could be the result of subsidence due to ground water drainage, or human activity.

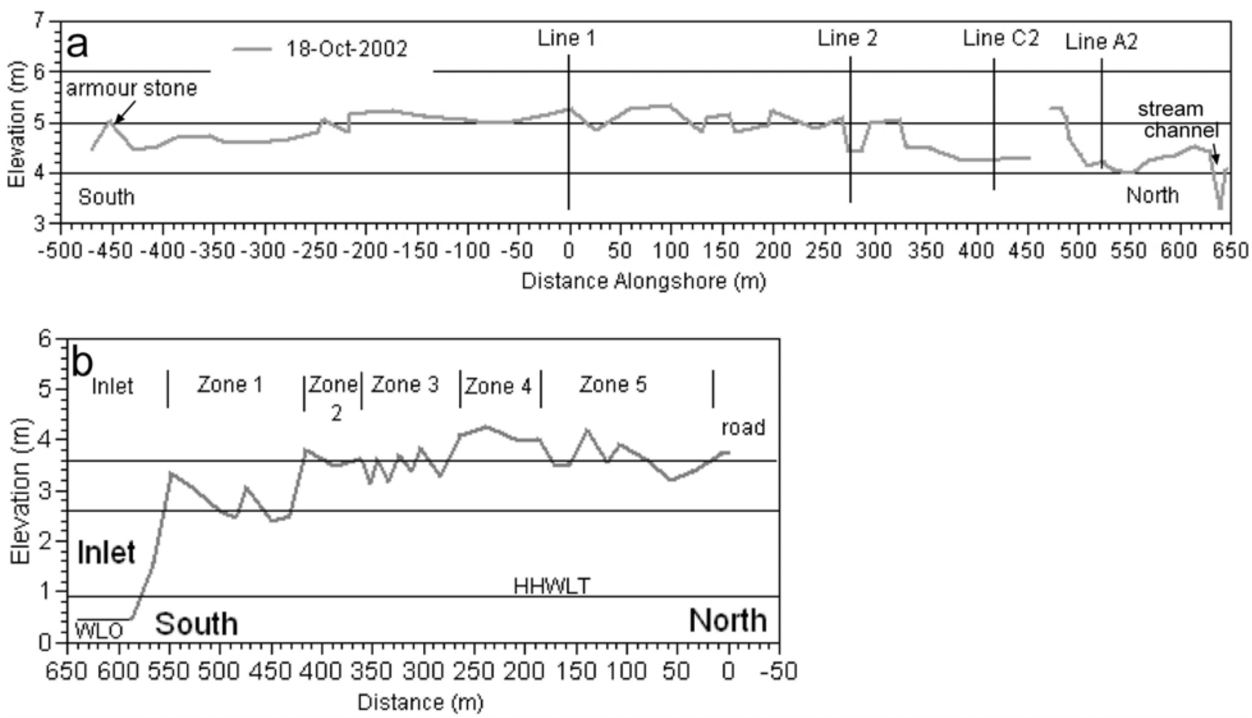


Figure 8. Longshore crest profile for (a) Ingonish Beach from Beach Crossing Road north to the stream cut near Middle Head and (b) along Ingonish Harbour Beach. To understand the graph pretend you are standing offshore looking back along the top of the beach. The highest part of the beach was adjacent to line 1. The high spot between lines C2 and A2 is where a relict stone wall and dune existed adjacent to the parking lot. Beaches greater than 2.6 m elevation have a potential to naturally rebuild where sediment is available (Taylor et al., 2003).

The foreshore or intertidal zone consists of pebble cobble which can be temporarily buried when sand is transported onshore (Fig. 9a, 11). The width of sand accumulating onshore varys longshore both in time and space. Sand accumulation generally increases northward toward line A2 where the foreshore slope decreases (Table 3) and provides more accomodation space for sand building (Fig. 10, 11, Table 3).

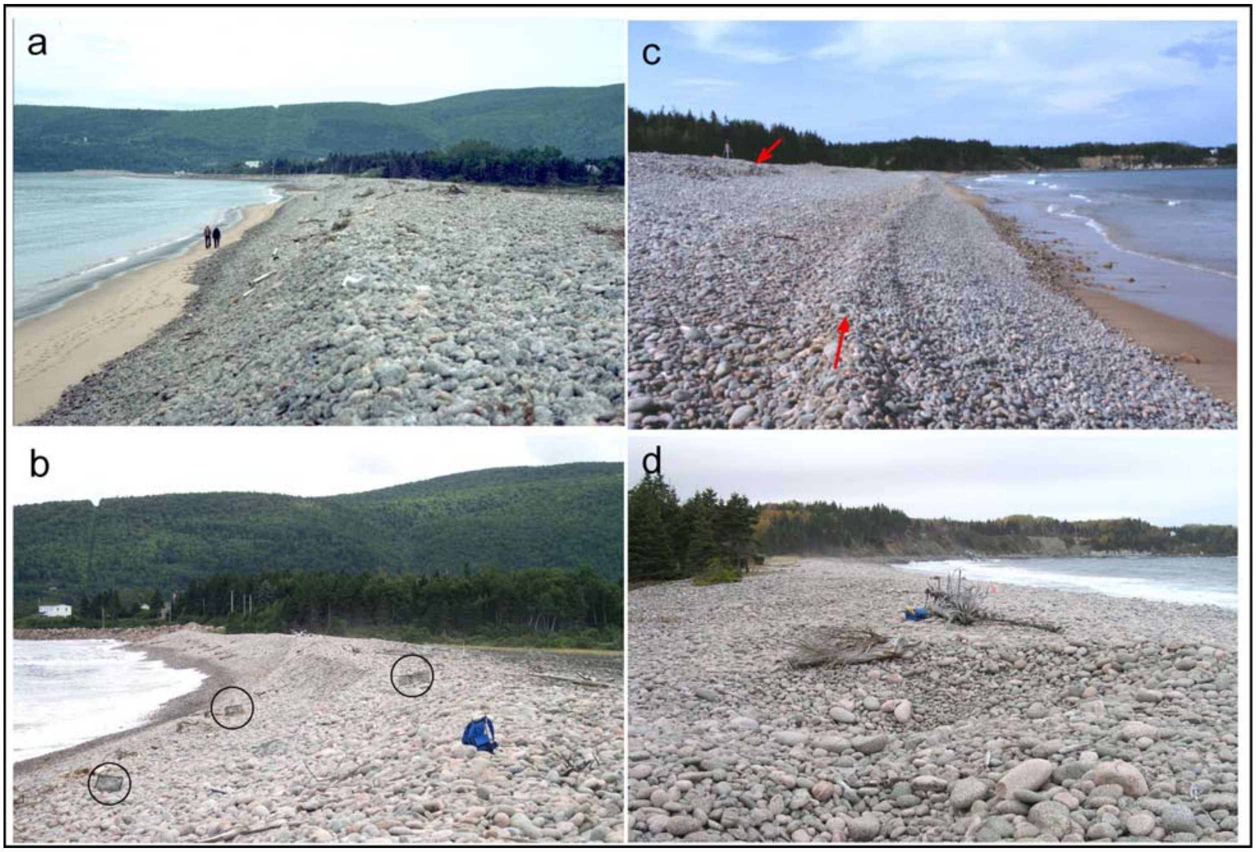


Figure 9. Views along Ingonish Beach looking south from line 1 in (a) June 1984 and (b) November 2008 showing the convoluted beach crest that decreases in elevation southward and the sand apron that can exist during the summer. Lobster traps (circled) provide evidence of a recent storm. (c) smooth upper beach slope in June 1992 caused by sea ice ride-up to the beach crest during the previous winter. Small discontinuous mounds of dirt (upper arrow) mark the upward edge of ice ride-up. The cobble swash ridge (lower arrow) subsequently built against the seaward edge of ice and it remained in place after the ice melted in late May 1992. (d) large craters, formed in the backshore near Line 2 may be caused by sea ice melt, sub-surface drainage or human activities, have persisted for more than 20 years.

Figure 11 illustrates typical sediment phases observed across the foreshore zone including: a coarse concave slope where sand has been removed offshore (Fig. 11a); intermediate conditions where sand collects between swash ridges or within small indentations in the beach plan form (Fig 11b); and a well defined sand berm and runnel developed when larger volumes of sand move onshore (Fig. 11c) Generally the runnel is short lived and is infilled as the berm is pushed higher and farther landward against the cobble slope.   An examination of short-term sand build-up and removal along this shore and its impact on beach stability is discussed later in this report.

Table 4. Range and mean size of surface sediment measured from photographs taken on each beach survey line Ingonish Beach, Nova Scotia. Location of survey lines is shown on figure 4 and photos of clasts are provided in Appendix 5.

Survey line	**Range and Mean (x) clast sizes (mm)**			
(Year)	**Beach Crest**	**Storm Ridge**	**High Tide Level**	**Low Tide Level**
1 (1983)		50-141 (83)	35-53 (45)	
(2008)	38-109 (71)	15-60 (42)		
2 (1983)		46-111 (71)	12-88 (37)	99-216 (154)
(2008)	34-89 (59)		26-80 (50)	
C2				
(2008)		26-51 (38)	26-59 (39)	
3 (1983)		41-151 (98)	25-102 (49)	
A2 (2008)	41-193 (89)		50-112 (83)	

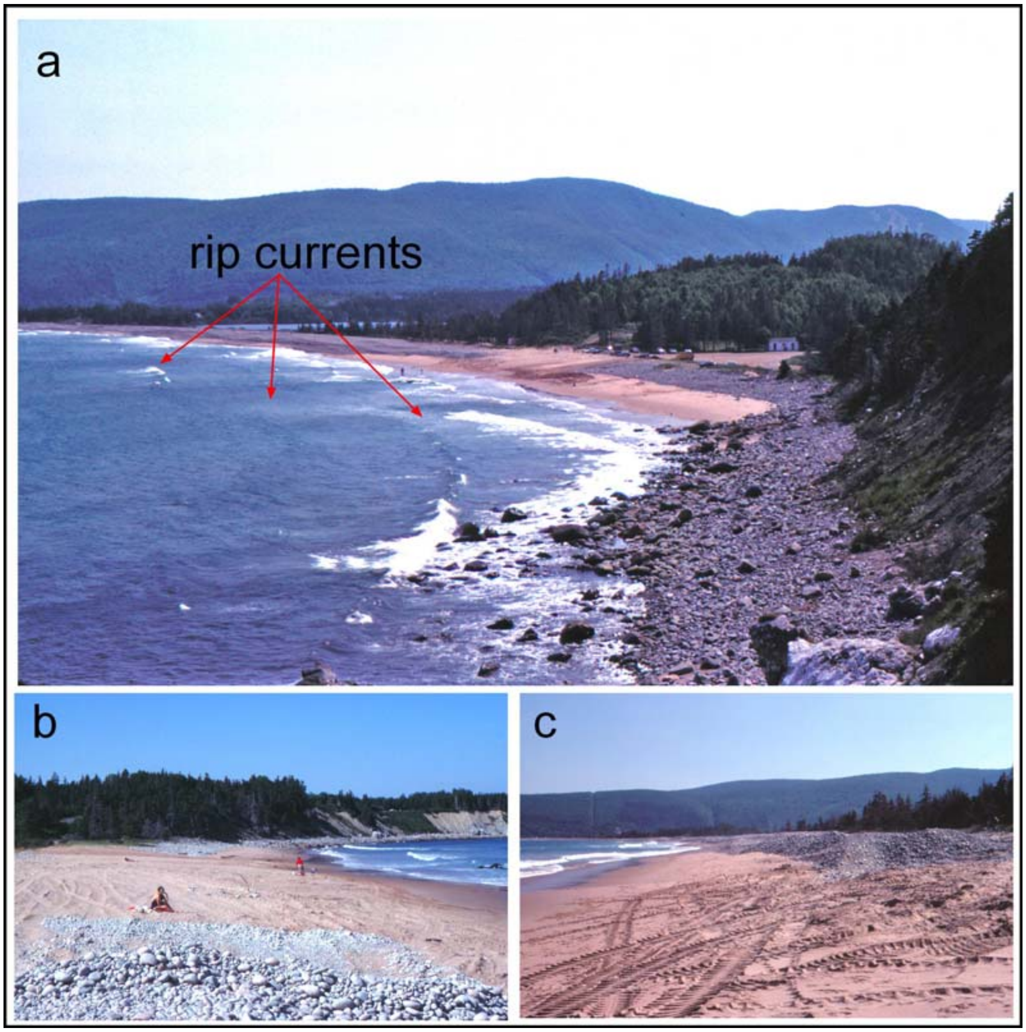


Figure 10. In June 1983 parks staff excavated cobble from the upper beach and pushed sand from the lower beach upslope above high tide level to produce a lower gradient sand beach for the tourists. (a) photo from the lookoff on Middle Head looking southwest showing the significant transfer of sand upslope, and the discontinuous accumulation of sand along the steeper beach fronting Freshwater Lake, (b and c) views north and south from the edge of the excavated cobble ridge showing the distance the sand was pushed upslope by machinery and the extent of cobble excavated from the upper beach.

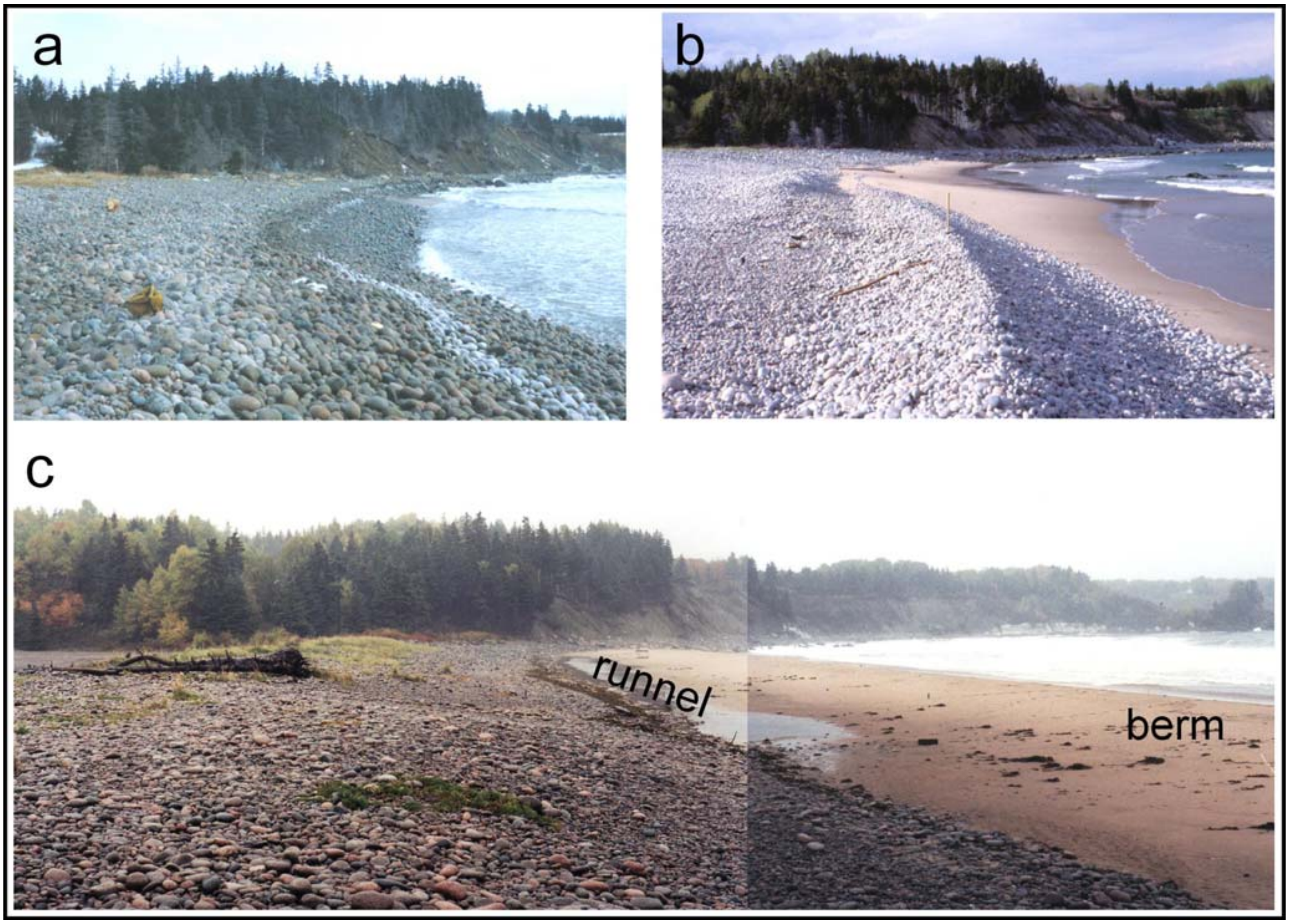


Figure 11. Contrasting lower beach conditions observed along northern Ingonish Beach (a) in March 1983 showing post-winter conditions with a pebble cobble slope before the sand has naturally moved onshore (b) June 1992 when sand had begun moving onshore partially covering a pebble cobble swash ridge which had built against grounded sea ice and (c) in October 2002 showing a well defined sand berm and runnel. A comparison of the beach in March 1983 (a) with October 2002 (c) illustrates how beach width naturally increases in the late summer and fall.

Nearshore Bar System

Although no marine surveys were completed in South Bay Ingonish, some surficial sediment information is reported on old hydrographic charts (CHS, 1980). For example, sand was reported in water depths of 3 and 12 m and at the mouth of the bay in 19 m water depths (Miller and Fader, 1989). The aerial extent and thickness of sand is unknown. Vertical air photographs also reveal a multiple shore-parallel nearshore bar system exists off Ingonish Beach (Fig. 4, 7a, 12, 13). A change in shoreline orientation at Beach Crossing Road shore (Fig. 2, 13) and presence of a shoal extending offshore limit the southward extent of the nearshore bar system. South of Beach Crossing Road shore, the seabed consists mainly of coarse material.

Bathymetric surveys were completed in Ingonish Bay South in 1936 (CHS, 1980, updated 2002), the same year as the first aerial photography showing the nearshore bars (Fig. 12, 13). The only indication of a sand bar was a rise to 8 feet (2.4 m) from 11-12 feet (3.4-3.7 m) water depth (Fig. 12). Assuming the shallowest depth marked the bar crest, it is concluded that the outer bar, in 1936, existed in water depths of 2.4 to 4 m (Chart Datum). The inner bar based on its position relative to shore was in water depths of less than 2 m. In Figure 13 a series of aerial photographs, reduced to roughly the same scale, have been plotted to show temporal changes in nearshore bar morphology. Measurements of nearshore bar morphology provided in Table 5 are estimates derived from this photography. Variations in water levels, lighting and time of photography impact the visibility of the bars and our ability to measure them.

Essentially a two bar system has existed off Ingonish Beach since at least 1936. The outer bar extends 1200 m in length south of Black Point and has a sinuous to crescentic planform. The seaward edge of the outer bar was roughly 200 to 300 m offshore in 1936 and 1966 but in 1999 it was closer inshore (Table 5). The outer bar is located farthest from shore adjacent to Beach Crossing Road shore (Fig.13). The rhythmic wavelength of the outer bar has varied from 150 to 400 m when it becomes more linear, e.g. in 1975 and 1999 (Fig.13, 14, Table 5).

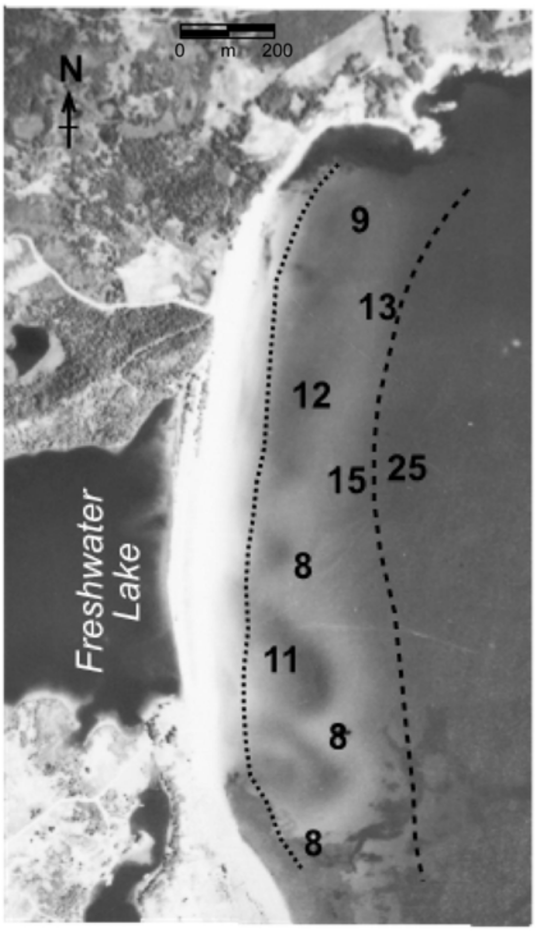


Figure 12. Aerial photo of South Bay Ingonish taken in July 1936 showing the position of nearshore bars. The bathymetry is derived from a 1936 survey (CHS 1980, chart 4365). Depths are in feet, dotted and dashed lines represents the 6 ft and 18 ft isobaths respectively. The two data sets are superimposed using only scaling techniques.

The inner bar exists within 125 m of shore (Table 5). Taylor and Kelly (1984) reported the inner bar in 1983 was only 17-20 m from shore at lines 2 and 3 in water depths of less than a metre. It has a variable longshore crescentic form with intervening channels. On the photos, dark tones in the channels of the inner bar are interpreted as a coarse substrate, rock outcrop or seaweed which suggests the nearshore sand is fairly thin. A more regular rhythmic pattern develops along the northern part of Ingonish Beach and becomes more variable farther south. Crescentic wavelength varied from 50 to 160 m (Table 5). Repetitive air photography shows that the inner bar can shift from a crescentic to a more linear form as it is welded against the beach, e.g. 1994 (Fig. 13).

Repetitive mapping confirmed that both inner and outer bars can shift on and offshore and alongshore (Fig. 14). Although the inner and outer bars are usually separated by at least 100 m, in 1969 the outer bar appeared to extend inshore to the inner bar. When the outer bar is nearly linear the inner bar has a well-defined crescentic pattern, e.g. 1975, and 1999 (Fig.13). Conversely when the outer bar has a better defined crescentic pattern the inner bar is obscured with little defined pattern e.g. 1936, 1969 (Fig.13).

The presence of nearshore bars has major implications for wave dynamics and physical changes onshore. Bars develop just inside of the wave breaker line. Bars found farther offshore are generally developed and modified by larger waves than bars closer inshore. The width and depth of bars filter waves. Higher waves may break and lower ones may not (Carter, 1988). Also, once the focus of wave breaking is transferred to the bar, the bulk of sediment transport takes place along the bar rather than the shore.

The regular spaced arcs of crescentic bars have been commonly attributed to the hydrodynamic forcing by infragravity edge waves (Bowen and Inman, 1969). Recent investigations suggest that crescentic bars form as a positive feedback between breaking waves, currents and evolving morphology (Caballeria, et al. 2002). Shifts in longshore bar position and morphology have important implications for changes onshore (Fig. 15, 16). For example, the horns of the crescents, which point landwards, are zones of deposition associated with low current velocities ie. beach builds seaward, and the deeper channels between the horns are areas of stronger seaward return flows and the potential location of rip currents (Komar, 1976, Short, 1985). Rip currents which are hazardous to swimmers do not occur on all beaches. Rips are characteristic of intermediate beaches dominated by cellular surf zone circulation and rhythmic topography (Wright and Short 1983, Short, 1985). Short described three types of rips: erosion, mega and accretion which are associated with different wave and beach conditions. Weak rips were observed with longshore bar and trough and onshore ridge and runnel conditions. Stronger rips developed with rhythmic (crescentic) bar and beach and transverse bar and rip conditions.

Ingonish Beach is classed as an Intermediate Beach and it has rhythmic nearshore and onshore topography favourable for the development of rip currents. It is not clear which wave conditions develop rips and specific nearshore bar conditions in South Bay Ingonish. Graham Whitty (pers. comm. 2009) who was a lifeguard in 2001-02 reported there were eight rescues of people caught in rip currents in 4 days in 2002. During that time there were two rips but the only strong one was located offshore of the lifeguard hut, i.e. adjacent survey line C2. The rip currents lasted for about two weeks after the storm that generated them. Rip currents have been sighted off Ingonish

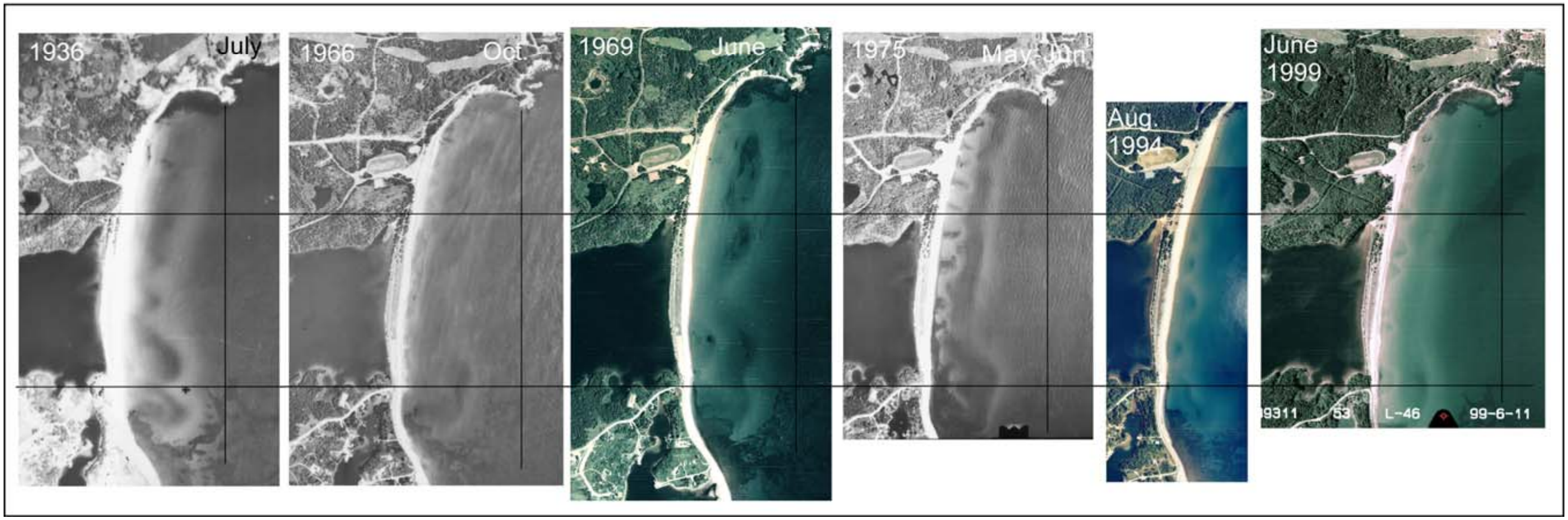


Figure13. A multiple shore parallel bar system and its changes in South Bay Ingonish are revealed on vertical air photographs from 1936, 1966, 1969, 1975, 1994 and 1999. The outer bar has moved farther inshore by 1999 and the inner bar has a crescentic pattern which can become linear and welded onshore along the northern end of Ingonish Beach, e.g. 1994. Grid lines were used for scaling the photos and for visual reference.

Beach on a number of occasions during larger wave conditions (Fig. 10a). During our surveys in 2008 large waves had created a strong alongshore and seaward flows in a channel just north of line 1 (Fig. 5b).

Rip currents and their hazard to swimmers dictates that their presence and associated wave and nearshore bar conditions should be routinely documented by lifeguards and Park staff to develop a better understanding of when rip currents will occur.

Figure14. Nearshore bar positions traced from georeferenced 1975 and 1999 vertical air photos show the relationship between the outer and inner bars. When the outer bar is more linear the inner bar has a well defined crescentic form. The comparison also showed that the outer bar was closer inshore in 1999 than in 1975 and that the inner bar can migrate alongshore.

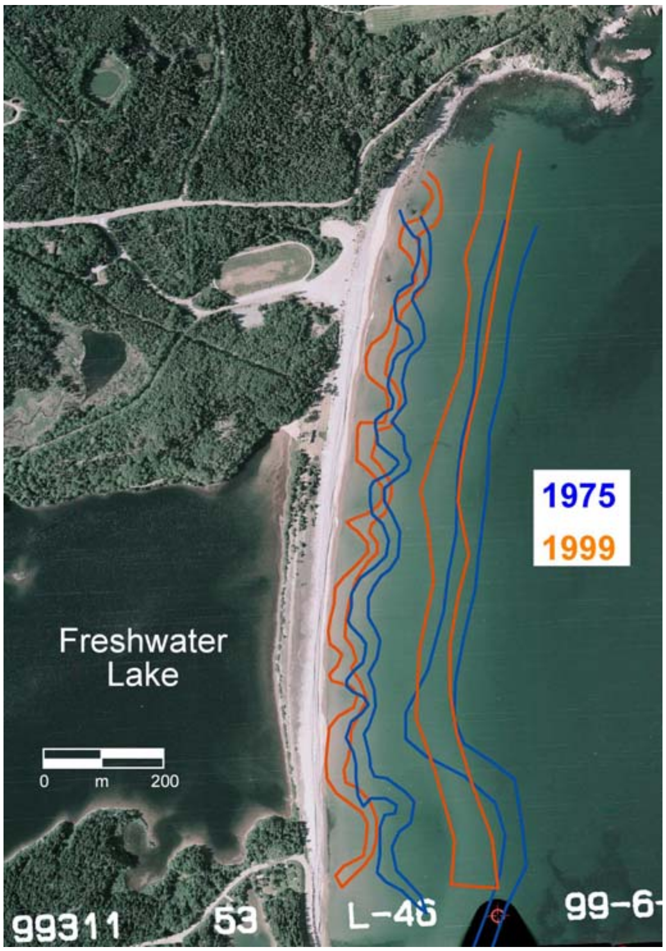


Figure 15. Close-up of inner bar and beach morphology on June 11, 1999 showing the relative position of our cross-shore lines and how the mega beach cusps (cusp horns marked by arrows) mirror the inner bars. In 1999 the temporary access boardwalks (circled) constructed across the beach coincided with the location of bar troughs where the beach (sand) width was narrower.

Table 5. Temporal changes in morphology and position of nearshore bars off Ingonish Beach, Nova Scotia derived from vertical aerial photographs shown in figure 13. Only photos from 1936, 1966, 1975 and 1999 were georeferenced.

Year (month)	Outer Bar		Inner Bar	
	#Distance from Shore (m) (max.)	Wavelength (m)	#Distance from Shore (m)	Wavelength (m)
1936 (Jul)	200-210 (330)	150-290	45-70	no data
1966 (Oct)	195-260 (325)	240-375*	50-100	80-160
1969 (Jun)	240-270 (270)	320-450	110-125	no pattern
1975 (Jun)	230-240 (330)	linear	40-110	80-160
1994 (Aug)	no data	no data	60-120	100-160
1999 (Jun)	190-210 (260)	linear	25-90	50-130

*poor visibility of features in water, # distance is to the seaward edge of visible bar

Shoreline Changes Based on Aerial Photography (1935-1999)

Vertical aerial photography of South Bay Ingonish is available from 1935 to 1999 and was flown at an interval of at least once each decade. A visual comparison of photography from 1936 and 1999 revealed few significant physical changes along this shore. Except for adjustments caused by people, Ingonish Beach has maintained a similar physical character and has migrated slightly landward over the 60-70 years (Fig.13).

Other aerial oblique or general photos taken of the beach in the 1950s and 1960s (Fig. 5a, 16) were compared with photos taken in 2008. They showed the seaward boundary of lichen-covered cobbles (Fig. 5) had retreated and sand accumulation along the barrier beach was less now than in the 1950s suggesting a decrease in sand abundance or a shift in its location. The most dramatic change along the backshore was along northern Ingonish Beach adjacent to the parking area. Vertical aerial photography from 1966 revealed a linear feature resembling a wall separating the parking area from the beach where dunes appeared to have built against it. A ground photo from 1967 showed much of the duneline had been eroded, but it remained higher than in 1983 (note Fig. 16 inset -note the vehicles sit below the backshore crest) when little of the dune and wall remained.

Despite the lack of physical change, it was decided to confirm the visual observations by georeferencing aerial photography from four years: 1936, 1966, 1975 and 1999 and comparing the resultant shoreline positions (Appendix 2). It is well known by park officials and residents that the lower beach can change position quickly because of variations in sand accumulation (Fig. 5, 11) therefore the initial intent was to plot the beach crest position from each year of photography because it is more indicative of major changes. However the beach crest could only be identified clearly on the 1999 photography so the high tide line was used to trace the shoreline position for all years except 1936 when only the waterline was identifiable. Therefore some change since 1936 is attributed to variable waterlines traced.

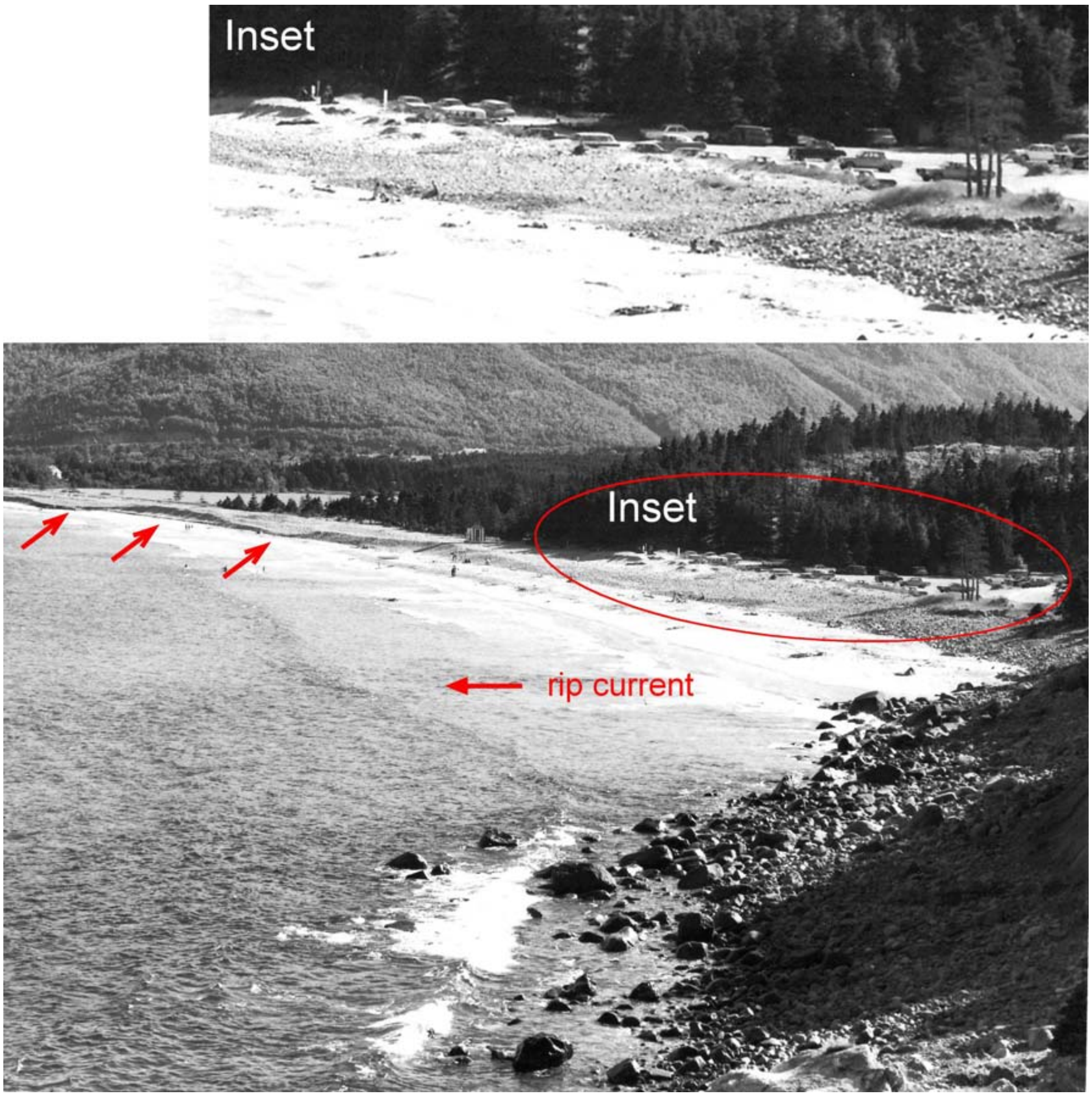


Figure 16. View of Ingonish Beach from the look-off in 1967 showing a rhythmic variation (arrows) in crest elevation along the barrier beach. The longshore variation in crest elevation is a reflection of inshore wave dynamics which is influenced by a nearshore bar system. Inset shows an enlargement of the northern beach with remnants of a duneline, more abundant coarse clasts and a backshore that was higher than vehicles in the parking lot. This contrasts with backshore conditions in 1980s shown on Figure 18.

Between 1936 and 1975 Ingonish Beach retreated an estimated 23 to 28 m landward (Fig. 17). There was little change between 1966 and 1975. By 1999 the beach north of line 2 had built 6 to 12 m seaward of its 1975 position, the barrier beach was unchanged and there was a retreat of 10 m or less toward the south end of Ingonish Beach. Sand accumulation was much greater alongshore in 1999 than in the other years which explains some of the shoreline progradation. Also, a comparison of features surveyed in the field with those mapped on the 1999 photos suggest the shoreline on the 1999 air photo may be 2 to 4 m too far seaward. Between 1936 and 1999 the position of Ingonish Beach (at high tide) shifted landward by 12 to 15 m and as much as 21 m at one location.

The georeferenced shoreline positions confirm our observations of a slow landward retreat (0.3-0.4 m/year) with potential for short term progradation depending on sand accumulation. The photos also confirmed greater shoreline retreat toward the south end of the beach after 1975.

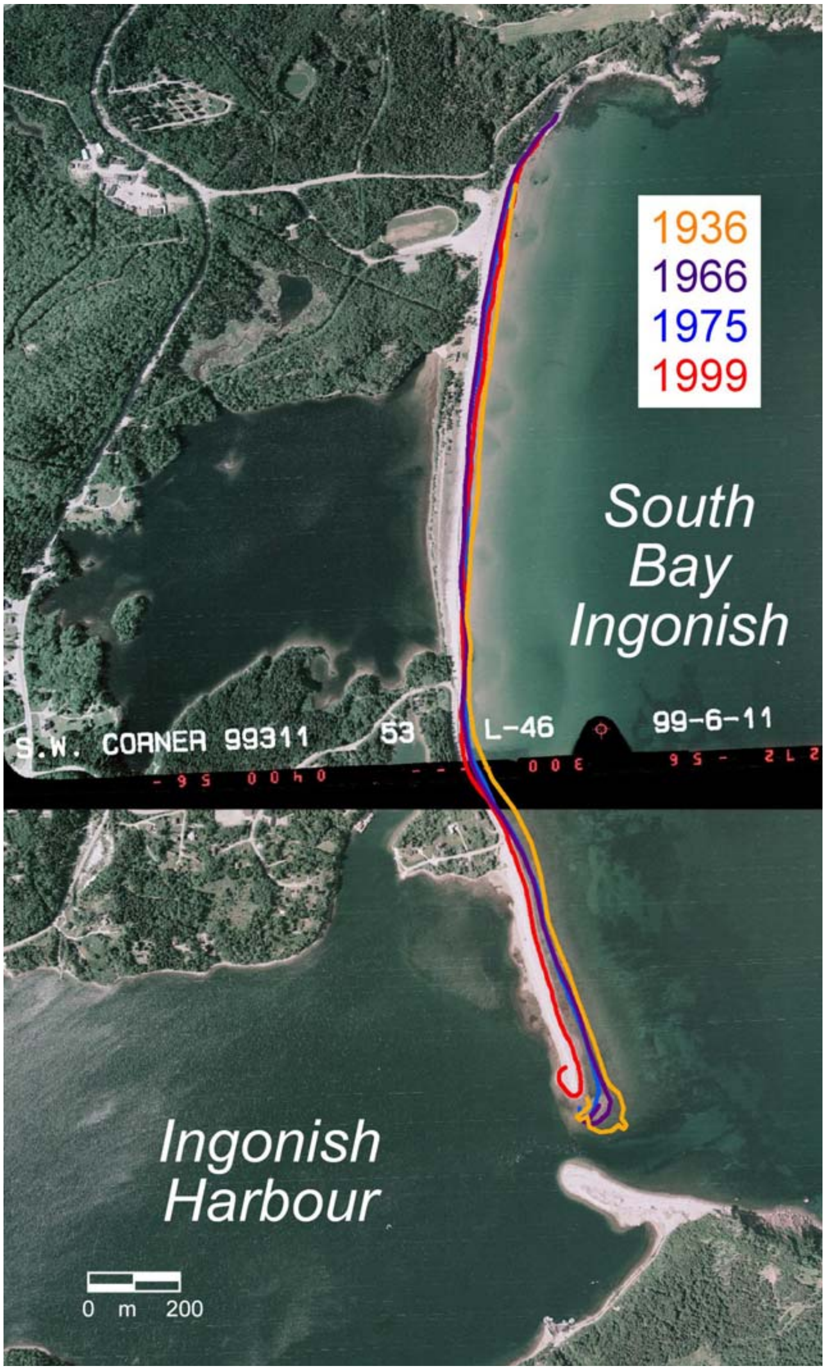


Figure 17. Changes in shoreline position along the head of South Bay Ingonish based on a comparison of vertical air photos from 1936, 1966, 1975 and 1999 (Appendix 3). The air photos were georeferenced using ESRI ArcVIEW software. The most significant shoreline retreat is south of Ingonish Beach.

The shoreline along Beach Crossing Road retreated a maximum of 43 m landward between 1936 and 1999, most retreat occurred between 1936 and 1966 and 1975 to 1999. The shoreline was fairly stable between 1966 and 1975. The backshore was increasingly armoured with large boulders from 1983 to 1994 when the whole shoreline was protected.

Shoreline Changes based on Field Surveys (1983-2008)

A chronology of beach changes from 1983 to 2008 is developed from a number of sources including: visual observations and repetitive photos taken since March 1983; repetitive cross-shore surveys begun in November 1983; and longshore beach crest surveys begun in 1992. Sand movements measured from 1984 to 1992 by Parks Canada staff along the northern end of Ingonish Beach provide an understanding of seasonal changes. The location of cross-shore survey lines described in the text are shown on Figure 4.

Field Observations and Photographs

In 1983, our first year of observations, the objective was to view a wide range of conditions. In March 1983 post-winter conditions existed with some snow remaining; sand was blowing across the backshore (Fig.18a), and the foreshore was a steep cobble slope with no sand (Fig 11a). In June 1983 larger waves reworked the beach producing rip currents in the nearshore as they had in March. Sand was beginning to accumulate across the foreshore (Fig. 10). Parks staff were lowering the backshore by excavating cobble and pushing sand upslope from the lower beach using machinery (Fig. 10). The intent was to mimic and accelerate the natural movement of sand onshore in preparation for summer visitors. Consequences of this action were observed following a large storm surge in late October 1983 when waves planed down the whole beach slope (Fig. 18b) and extensively overwashed the lower backshore moving sediment up to 70 m across the parking lot and flooded the tennis courts farther inland (Taylor and Kelly, 1984). The amount of wave overwash across the backshore decreased southward as the barrier crest elevation increased toward line 1. Many cobbles were tossed across the lawn landward of line 2 but only a few were tossed across the lichen-covered cobble at line 1 .

A survey in June 1984 (Appendix 2, Fig. A2-2a) provided an assessment of beach recovery since the October 1983 storm. Line 1 had retreated; a new beach ridge was built at line 2 and some accretion occurred across the mid to upper beach at line 3. Taylor and Kelly (1984) concluded the changes were the consequence of sediment being moved northward alongshore to rebuild the beach where material had been excavated in June 1983. By June 1984, washover deposits from the parking lot were being piled along the upper beach at line 3 (Fig. 18c). It was in June 1984 that Parks Canada began a beach survey program to monitor the seasonal fluctuations in sand accumulation and the natural recovery of northern Ingonish Beach. Results from this study are discussed later in this report.

By June 1992, when our next cross-shore survey was completed, there was further degradation of the dune and lowering of the upper beach fronting the parking lot (Fig. 18e, Appendix 2, Fig A2-2b) despite some movement of coarse material from south to north as new swash ridges (Fig.

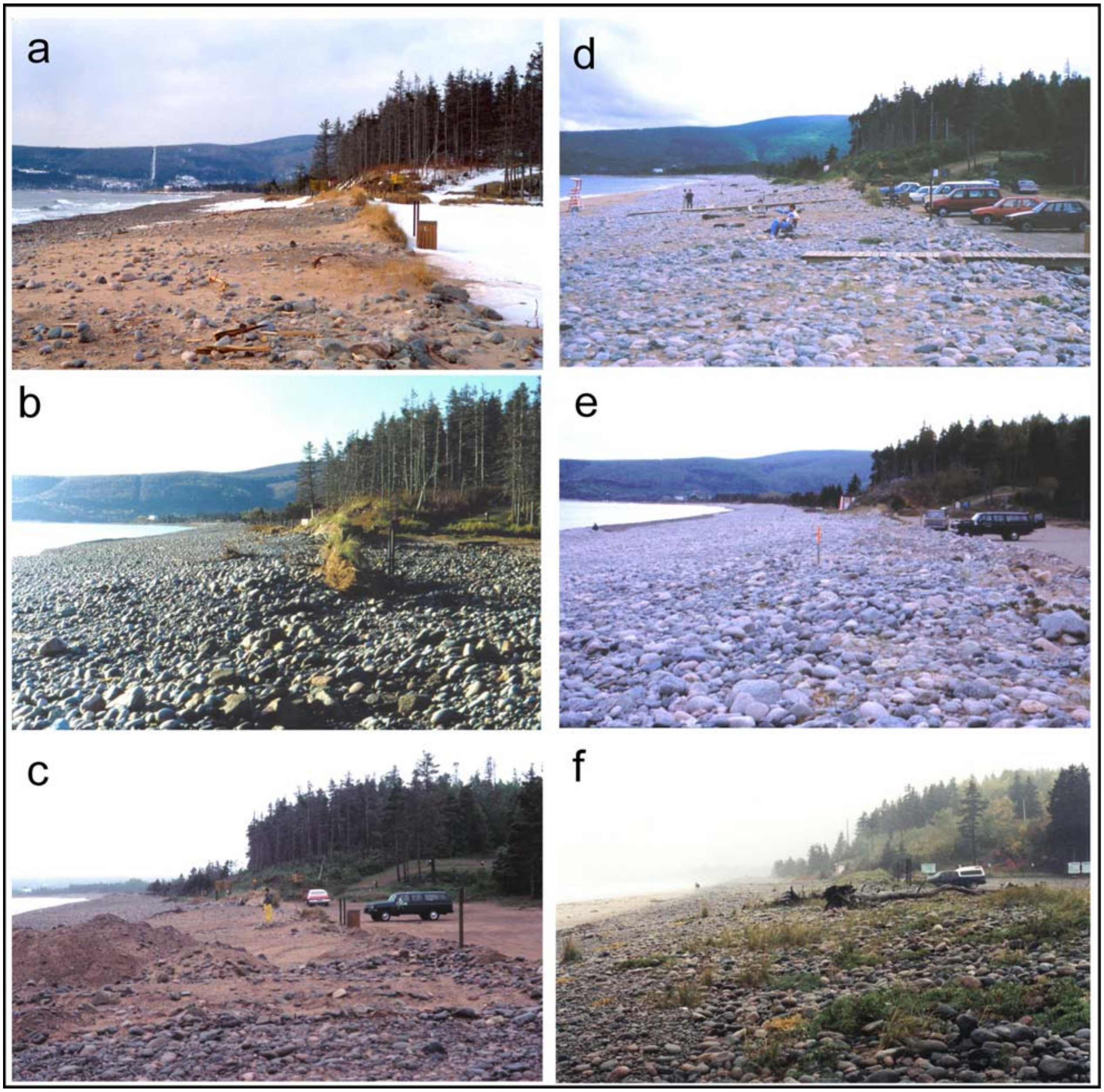


Figure 18. Views looking south along the upper part of northern Ingonish Beach showing physical changes between (a) March 1983, post-winter conditions (b) Nov. 1983 following a major storm surge, (c) June 1984 following the dumping of overwash deposits back onto the beach from the parking lot, (d) August 1987 when sand accumulation was high across the lower beach facilitating the movement of sand landward across the upper beach and parking lot, (e) June 1992 when the backshore ridge was further modified by sea ice and machinery, (f) in October 2002, after ten years with no human modifications the mid-upper beach was infilling and vegetation cover was more extensive.

11b). Surveys across the mid-upper beach in 1992 reflected the impact of sea ice which blew onshore in February and remained until late May 1992 (J. Bridgland, pers comm.1992). Subsequent surveys by Parks Canada showed that ice-built features are short-lived; they were erased by August.

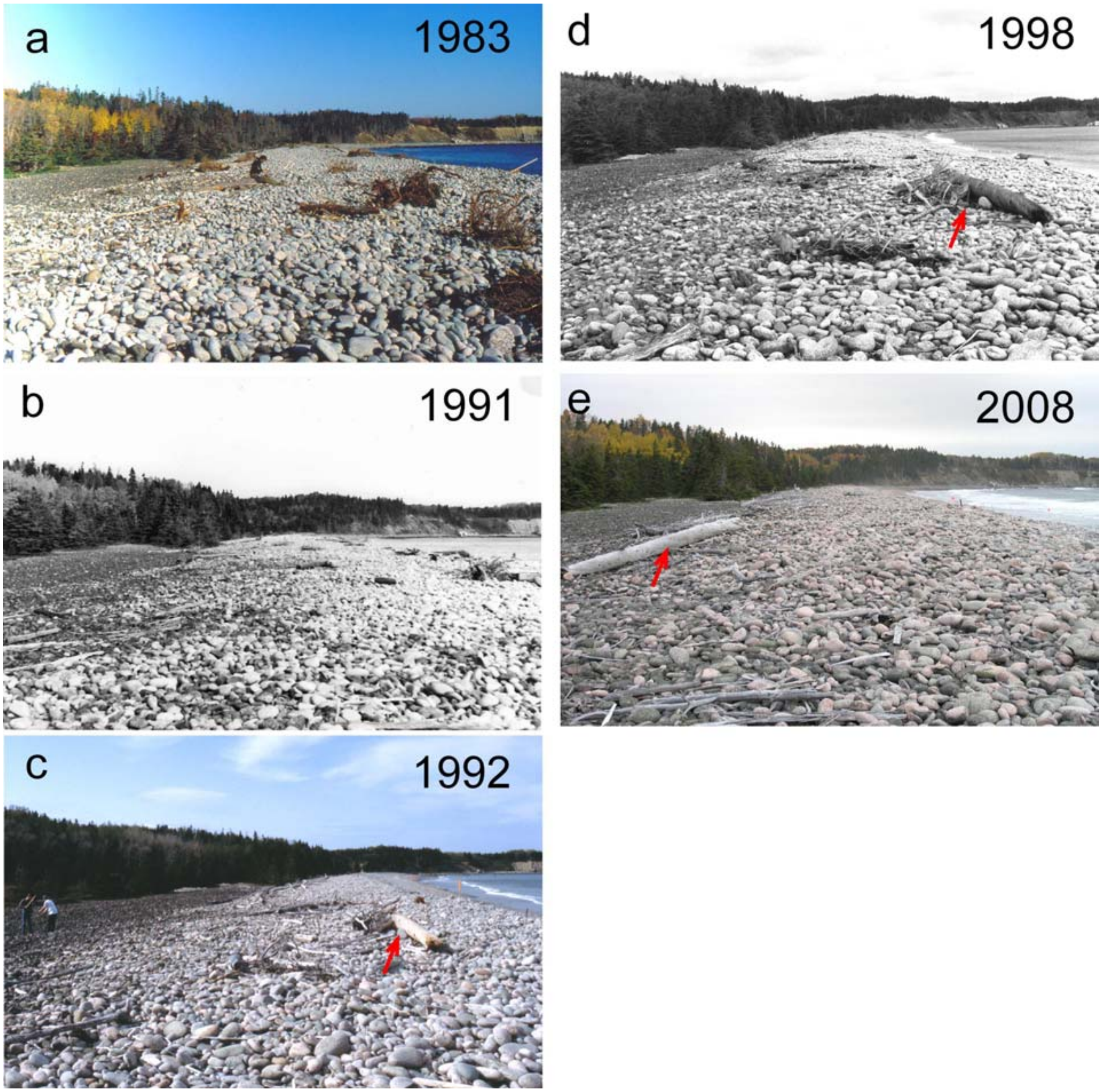


Figure 19. Repetitive views looking north from 1983 to 2008 of the beach crest at line 1. Changes in the boundary of the lichen and non-lichen covered cobbles and in the driftwood lines confirm that waves significantly reworked the crest area between 1991(b) and 1992 (c). Presence of the same driftwood (arrows) in 1992 (c) and 1998 (d) also confirm this was a period when waves did not substantially rework the backshore crest. Photos are from the following dates (a) Nov. 3, 1983, (b) Oct. 26, 1991 (c) June 3, 1992, (d) Oct. 6, 1998 and (e) Oct. 27, 2008.

Between 1984 and 1992, at line 2, the mid to upper beach was severely cut back, the beach crest had shifted 1.7 m landward (Appendix 2 Fig A2-1b) and cobbles were thrown landward burying the backshore bushes and lawn. The upper beach at line 1 also had been modified. Repetitive photographs of backshore driftlines (Fig. 19) show most backshore change occurred between October 1991 and June 1992, possibly during the Halloween storm October 28-30, 1991. Differences in backshore changes are attributed to the position of nearshore bars which can accentuate wave attack at select locations alongshore.

During the 1990's a number of line markers were lost and new survey lines A2 and C2 were established (Fig. 4, Appendix 1). Fortunately beach changes between 1992 and 1998 were minimal. Sediment accumulation increased in a northward direction alongshore to line A2 where the upper beach was building (Appendix 2 Fig A2-2c)

By October 2002 the beach crest at Line 2 had been repaired and sediment had accumulated across the backshore at lines A2 and C2 (Fig. 18f, Appendix 2, Fig. A2-2d). Upper beach changes may have been the result of a large storm in late October 2000 but it could not be confirmed. Sand accumulation across the foreshore zone remained high in October 2002. A well defined sand berm was also present at both northern lines (Fig. 11c). In contrast, in October 2008 larger waves were combing down and transporting sand offshore at the time of our survey leaving a concave lower beach slope. Beach surveys from October 2002 and 2008 (Appendix 2 Fig A2-2e) illustrate the difference in sand accumulation that can occur across the lower beach at a similar time of year. Farther south between lines 2 and 1 waves had overtopped and maybe overwashed the beach crest at a few locations (Fig.19).

Cross-Shore Beach Surveys

Repetitive cross shore surveys at the same locations from 1983 to 2008 provide a quantitative assessment of beach changes at Ingonish Beach (Table 6, Fig. 20). Longer term trends were derived from changes to the backshore and coarse sediment component whereas seasonal short term changes were derived from changes in sand accumulation across the lower beach.

For the areas surveyed, the maximum beach elevations reached by waves was 5 to 5.5 m at lines 1 and 2 and for sea-ice built features it was 4.9 m near line 2. Over the 25 years the beach crest has moved less than 3.5 m landward along the barrier beach and built seaward by less than 1.7 m along the northern beach at lines C2 and A2 (Table 6, Fig. 20). The largest net retreat across the upper and lower beach was 14 m at line C2 and the only net positive change of 9 m was recorded at Line A2 (Table 6). Fluctuations in seasonal sand accumulation will be examined in more detail later but for the GSCA survey lines, it increased from south to north alongshore. Maximum change in sand width was 20 m and maximum sand thickness was 2.2 m (Table 6). Sand accumulation increased as the foreshore slope decreased from 10° along the barrier beach to less than 2° along the northern beach which increased accommodation space for the sand.

We observed the following changes at individual survey lines. The barrier beach along the front of Freshwater Lake, ie. at Line 1, has experienced a slight net build-up of the beach crest as the beach retreated slightly landward. Across the coarse-grained beach slope net horizontal retreat increased downslope from less than 1 m to 7 m. A maximum retreat of 11.5 m was observed between 2002 and 2008 because of sand loss.

At line 2 the beach crest was overwashed between 1984 and 1992 (most likely between 1991 and 1992) and it was pushed back but by 2002 it was partially rebuilt. Net beach crest retreat was 3.4 m over 25 years. Other beach changes were similar to line 1, the coarse grained beach slope retreated a maximum of 7 m and the maximum retreat was 12.6 because of sand losses between 2002 and 2008.

Repetitive surveys of Lines A2 and C2 only began in 1992 and 1998 respectively but at both locations the beach crest has built seaward (Table 6, Fig. 20). Sand accumulated onshore in all five years of survey and the most sand was observed in October 2002 when a well defined sand berm and runnel developed (Fig. 11c).

It is concluded that Ingonish Beach continues to adjust to human activities conducted across the northern end of the beach in the 1970s and early 1980s. Sediment is accumulating and building the northern beach with pebble-cobble from the barrier beach which is migrating slowly landward.

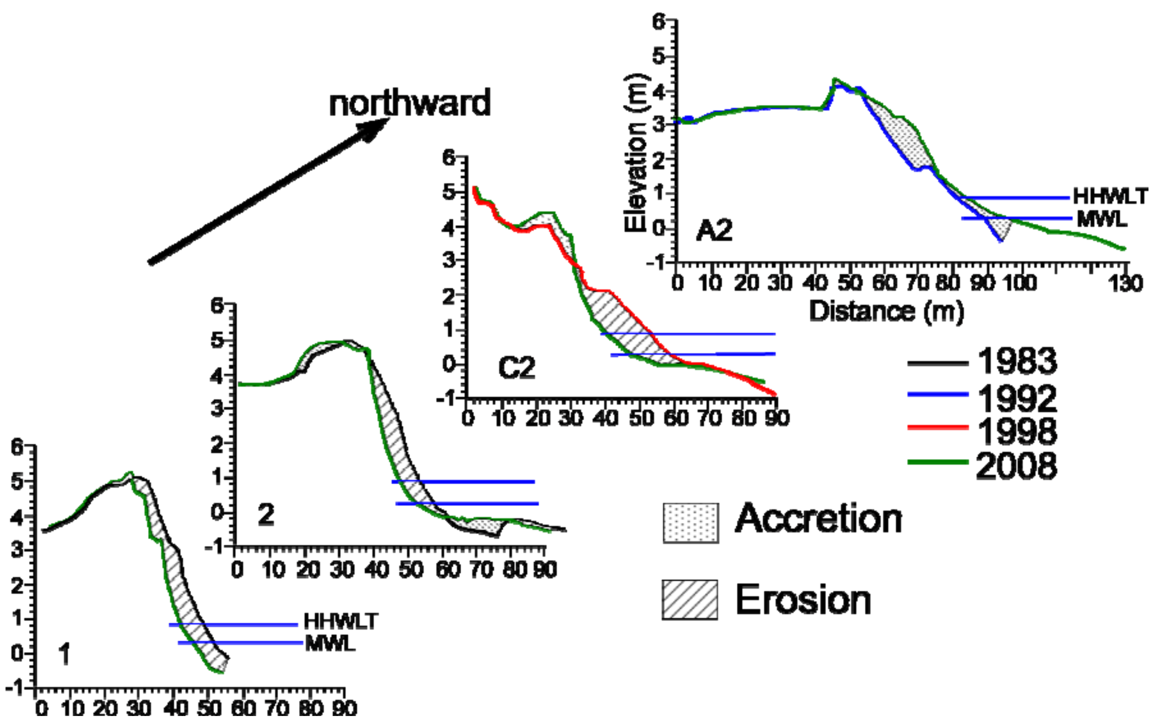


Figure 20. Repetitive cross-shore surveys on Ingonish Beach showing net physical changes and areas of accretion (dots) and erosion (striped) from 1983 to 2008. Location of survey lines is shown on Figure 4.

Longshore Beach Crest Surveys

To obtain another perspective and better understanding of changes alongshore, surveys were also extended along the beach crest. Since the crest lies above the level of normal wave action, any changes in its position or elevation are indicative of significant wave activity, higher sea levels or both, and may signal a change in beach stability (Taylor et al., 1999). From the lookoff on Middle Head, one can often observe a series of quasi-regular highs and lows along the highest parts of Ingonish Beach (Fig. 16). These features which are mapped during crest surveys provide clues about inshore wave dynamics and low areas susceptible to future wave overwash.

Table 6: Net changes in beach crest position and sand accumulation at GSCA survey lines, Ingonish Beach. Repetitive surveys were completed in June or October each year. Plots of net change at each survey line are illustrated in Figure 20.

Survey Line	Net Change in Beach Position (m)			Maximum Lower Beach Change 2002 to 2008 (m)	Maximum thickness of Sand Accum. (m)
	Beach Crest	Upper Beach	Lower beach		
1 (1983-08)	-0.9	-4	-7	-11.5	1.2
2 (1984-08)	-3.4	-2	- 7	-12.6	1.3
C2 (1998-08)	+1.6	-14	-10	-17.5	2.2
A2 (1992-08)	+1.2	+ 9	+ 3	-20.0	1.9

Note: Upper beach is the backshore above high tide level and lower beach is the foreshore zone below high tide level.

For most gravel barrier beaches, the crest extends along the top seaward ridge. At Ingonish Beach, crest surveys followed the top seaward edge of the barrier until north of line 2 where the highest part of the beach shifted landward and it was difficult to choose where the highest natural part of the beach existed. It was along this section that much of the upper beach was removed in the early 1980s and a new ridge was built along the seaward edge of the parking area (Fig. 10, 18). The artificial ridge because of its higher elevation, was surveyed as the beach crest in 1992 whereas in 1998 and 2008 both the artificial and natural storm ridge were surveyed to illustrate their relative position and elevation. The jump in crest position and elevation that exists between lines C1 and A2 after 1992 (Fig. 21, 22) is not real but rather the result of a decision to follow a different crest line.

Crest Position

Repetitive surveys of beach crest position (Fig. 21) illustrate landward or seaward beach migration over time. The largest shift in crest position between 1992 and 1998 occurred between cross-shore lines 2 and C2 where sea ice rode-up the beach and planed off the natural crest in February 1992 leaving the highest part along the landward edge of the beach. By 1998 a well

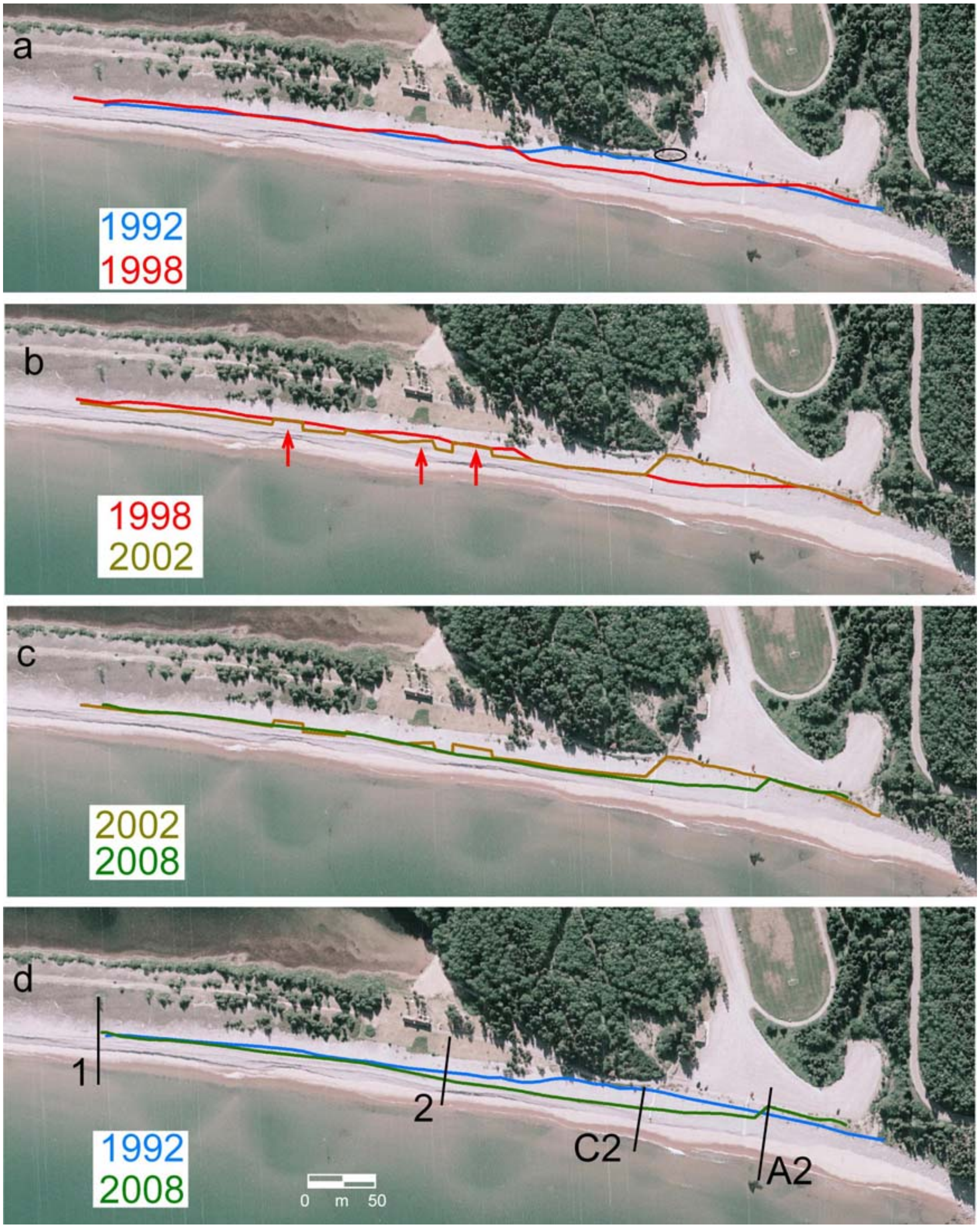


Figure 21. Repetitive surveys of crest position along Ingonish Beach illustrating its landward and seaward migration (a) between 1992 and 1998, (b) between 1998 and 2002, (c) 2002 and 2008 and (d) net changes between 1992 and 2008. For reference the location of cross-shore survey lines, main boardwalks and relic stone wall (black circle on photo a) by the parking lot also are visible on this 1999 air photo. Arrows mark the location of wave cuts in the beach crest in 2002.

defined storm ridge had built farther seaward (Fig. 21a). Farther north the crest survey followed the plowed ridge along the edge of the parking lot. The difference in crest position north of line C2 was not real.

In 2002 waves had developed a series of cuts less than 5 m wide into the barrier beach crest in the vicinity of line 2. The cuts had a spacing of ~50 m and were only 0.6 m deep (Fig. 21b arrows, 22b). Toward line 1 the crest had built slightly seaward.

By 2008 the cuts had been infilled and the position of the remainder of the crest remained unchanged as did the storm ridge surveyed in 1998 between lines C2 and A2.

Over the sixteen years (1992-2008), with the exception of the sea ice event in 1992 and some localized cuts by waves, the beach crest position, north of line 1, has shown little net change (Fig. 21d). Before 1992 beach crest position was only measured at cross-shore lines which indicated changes in beach crest position were greater between 1983 and 1992 than from 1992 to 2008.

Crest Profile

An examination of the entire crest profile of Ingonish Beach surveyed in 2002 (Fig. 8) shows a quasi-rhythmic spacing of low crest areas, e.g. wave washover and wave cuts, at intervals of 80 m and 160 m along the north and south ends of the beach and 50 and 110 m along the central barrier beach. A similar spacing of horns along the crescentic nearshore bars suggests a close association with wave dynamics and changes onshore.

Temporal changes in longshore beach crest profile over time intervals of four to six years are illustrated in figure 22. Changes in crest elevation north of line C2 are only real in Fig. 22d; they are not real figure 22 a-c because different beach ridges were surveyed.

From 1992 to 1998 there was wave overtopping and slight crest building along the highest beach (Fig 22a); from 1998 to 2002 concentrated wave forces at higher elevations produced quasi-rhythmic cuts in the crest and by 2008 they had been infilled creating a resultant smooth profile (Fig 22c). Net changes in crest profile over the sixteen years were small along the central beach with the exception of two locations where the crest was lowered, 150 m apart, (Fig. 22d). Also the crest profile between lines 2 and C2 had become more gradual and lower (Fig. 22c,d arrows) and the crest was building along the northern beach.

Repetitive longshore crest surveys of Ingonish Beach indicate that waves frequently extend to the beach crest and both wave overtopping and overwashing have occurred during the sixteen years. The largest wave overwash events appeared to have occurred in 1983, between 1991 and 1992 and between 1998 and 2002. Storms thought responsible for the greatest changes were the Halloween Storms of October 28-30 1991 and October 28, 29, 2000 (Appendix 4).

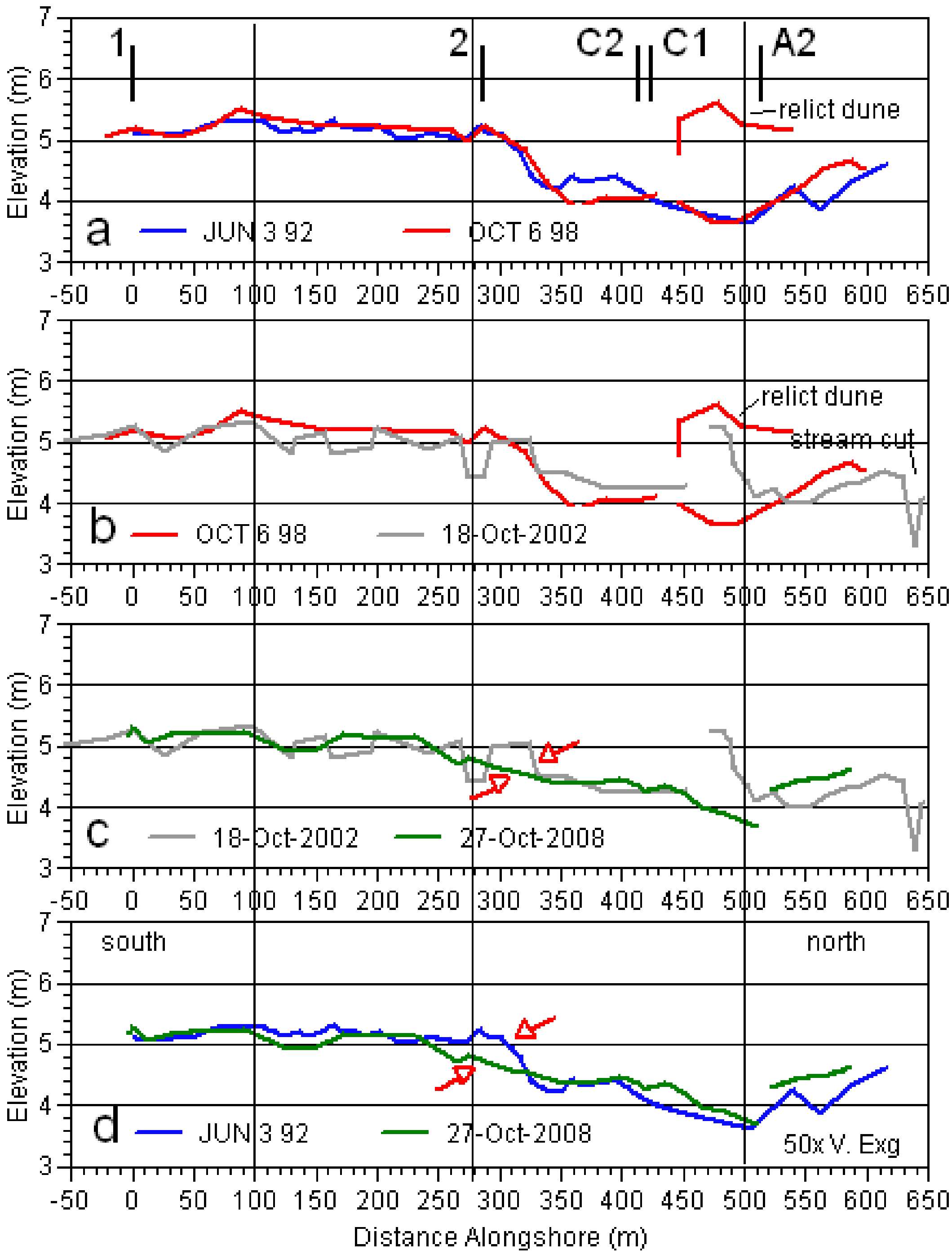


Figure 22. Repetitive surveys along the crest of Ingonish Beach showing changes in elevation caused by waves during periods of high water between: (a) 1992-1998, (b) 1998 to 2002, (c) 2002 and 2008 and (d) net change between 1992 and 2008. The significant decrease in crest slope (arrows in graph d) was attributed to trimming by waves and the transfer of cobble northward for beach rebuilding.

Short -Term Fluctuations in Beach Sand Deposits

After a wave breaks onshore, the swash rushes landward up the beach face carrying sand. As the swash loses its velocity at its upward extent because of gravity, friction and the loss of water seepage into the beach, sand is deposited. The most prominent depositional sand feature observed on Ingonish Beach is a nearly horizontal wedge of sand called the "berm" which builds seaward from the beach (Fig. 23a). Upward growth of the berm depends on wave height and stage of the tides. In some instances, if a crest builds higher as it builds seaward, a shoreward sloping berm develops. Water can pond at the back of the berm forming a "runnel" (Fig. 11c). If enough water collects in the runnel, it can break through low areas of the berm crest and flow back to the ocean as a mini- rip current. This commonly occurs at Ingonish Beach, e.g. 1984, 1989, 1990, 1991.

The timing of sand movement onshore and offshore, the volume of sand accumulation onshore and longshore variations in sand accumulation are important to understand when managing a popular recreational beach. For example it can assist with knowing where to install temporary boardwalks leading from the backshore to the sand foreshore. It also provides guidelines for where shore clean-up crews look for marine oils spills and how deep the oil could be buried.

Cross-shore surveys were begun in 1984 by Parks Canada staff to quantify changes in sand transport particularly adjacent to the main parking area. Surveys were completed every year from 1984 to 1992 with the exception of 1985 and 1986 (Tables 1, 7). During each year two to four repetitive surveys were completed from May or June to late September or October at three cross-shore lines A, B, and C (Fig. 4). A compilation and preliminary analysis of the survey data was reported on earlier by McCarthy (1989) and Rhodes (1994).

The following observations of sand movement onshore are derived from repetitive beach surveys by Parks Canada. Similar trends in sand accumulation were observed at all three survey lines except in 1988 when less berm developed at line C. A sand berm developed on the mid to upper beach in all seven years. It was least developed in 1987 and 1988 and best developed in 1991 when a berm was observed as early as May and it remained all summer until at least October when it attained its maximum size (Tables 7 to 9). Photos taken in 1985 also show a berm formed that year. Sand was present across the lower beach in mid -June and a well defined berm was present and the upper beach was partially covered by wind blown sand by August 20, 1985.

Higher energy storm waves tend to cut back the sand berm, and transport sand offshore leaving a steeper pebble cobble beach. Maximum sand accumulation and berm development occurred most often in late August. In four of seven years a build-up of sand increased from June until September or October (Fig. 11c, 23b). In contrast during three years there was a loss or retreat of the berm in the fall after reaching its maximum size in July and August (Fig. 23c). When all or most of the sand berm is removed by waves a steeper pebble-cobble slope results (Fig. 11a). A seasonal fluctuation in sand accumulation appears to be typical for Ingonish Beach, however

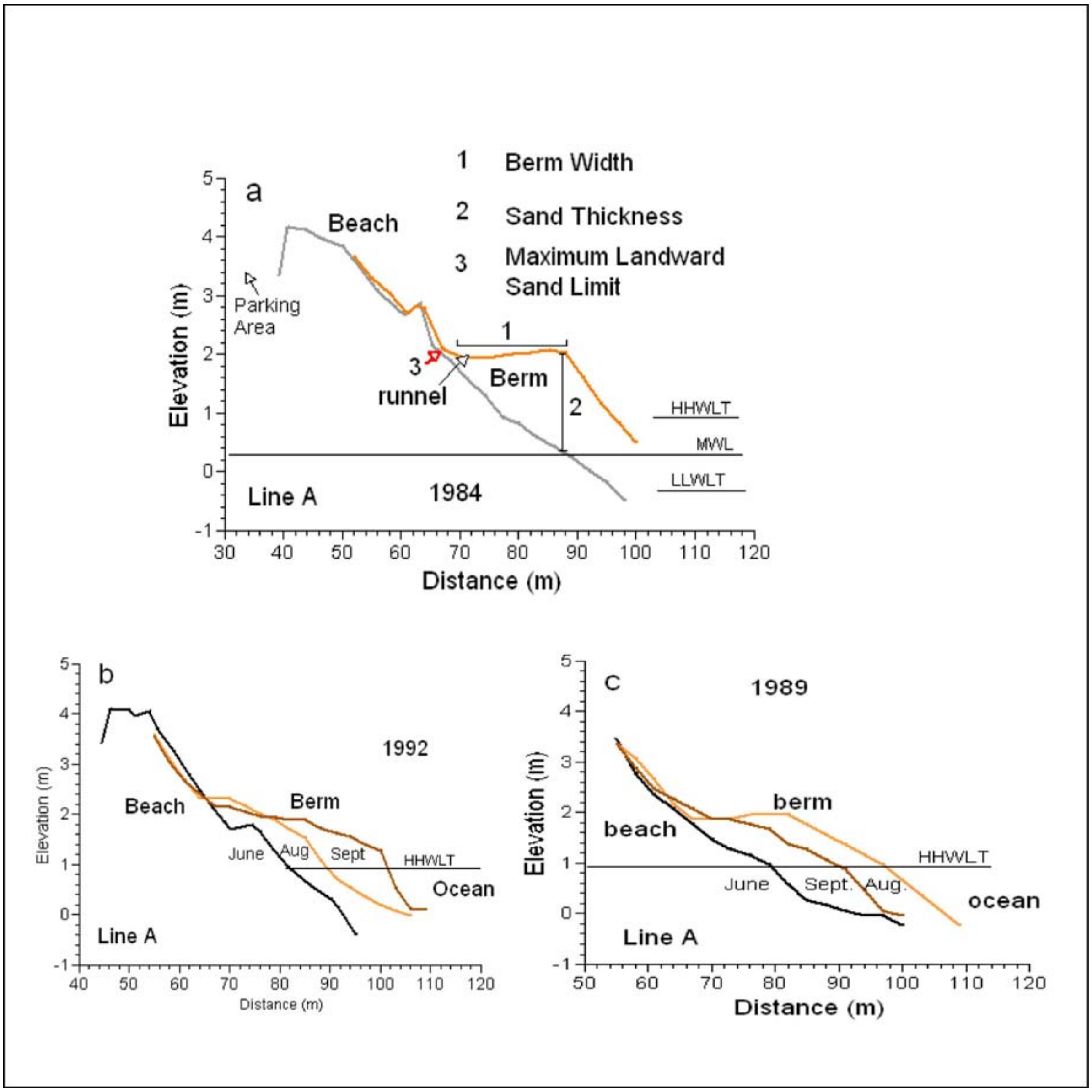


Figure 23. (a) Beach terminology and location where seasonal sand accumulations were measured (refer to table 8) and (b, c) examples of seasonal berm morphology based on repetitive cross-shore surveys at Line A, Ingonish Beach. (b) Progressive berm growth in 1992 and (c) decay of berm after larger wave reworking during Sept. 1989.

along other parts of Nova Scotia a sand berm can develop at any time of the year when more constructional wave conditions exist and no shorefast ice is present.

The length of time a berm exists each year depends on the occurrence of storms which erode some or all of the sand build-up. A storm in late June can severely impact berm growth as shown in 1987 when berm development was the least. Conversely the formation of a well developed berm by early July generally persists until late summer because of the lack of storms in July and August. A sand berm provides a buffer for the backshore against higher energy waves however this protection depends on the duration of a storm. For example, in a 24- hour period of larger waves on October 17-18, 2002, the sand berm was lowered by 0.4 to 1 m along its crest and seaward slope (Fig. 24). An estimated 6000 m^3 of sand was removed along the main sand beach fronting the parking area in that 24 hr period. Longer duration storms can remove most or all of the sand from the lower beach and deposit it at and just seaward of low tide, e.g. 2008 (Appendix 2, Fig. A2-2e, line 2, C2).

The timing and extent of sand build-up and erosion, the average elevation of sand accumulation upslope, berm elevation and thickness of sand at its seaward edge were similar at all three survey lines, A, B and C (Fig. 25, Tables 7-9). However local differences in maximum sand accumulation and berm width were observed. Rhodes (1994) found a strong correlation between beach slope and the width of sand deposits and a poor correlation between slope and the landward elevation of sand deposits. He also illustrated the relatively uniform elevation of landward sand deposits and a slightly rhythmic width in sand deposits alongshore. The width of sand berm was nearly twice as wide at line A/A2 than at line C/C2. The mean width at line A was 21 m and at line C it was 12 m (Table 8).

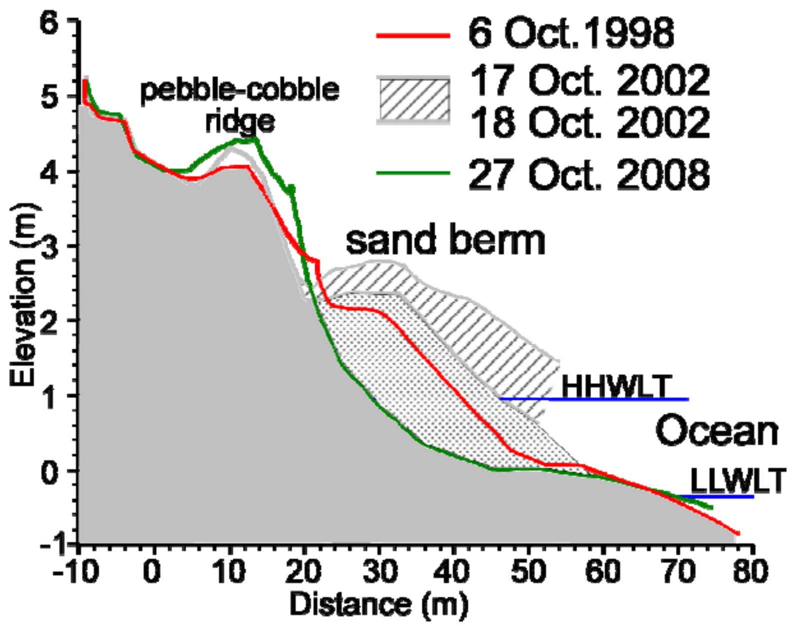


Figure 24. Example of berm development at line C2 in October 1998 and 2002 and its complete removal in 2008. Repetitive surveys in October 2002 (striped) illustrate the volume of sand that can be removed during 24 hours of larger waves. It is estimated based on this survey that the main beach fronting the parking lot lost 6000 m^3 of sand in the 24 hours.

Where the shore has been pushed farther landward creating an "embayed" plan form, the sand has a greater accomodation space to accumulate. Consequently sand accumulation is wider along the more gradual sloping northern end than the steeper Freshwater Lake portion of Ingonish Beach (Table 9). In August 1984 the width of the sand build-up decreased from 14 to 7 m southward from line E (L2) (Table 9).

Table 7. List of dates between 1984 and 1992 when beach lines A, B, C, were surveyed on Ingonish Beach. For each date it is marked whether a berm was absent (no) present (yes), and when it attained its maximum size (max). Blank spaces indicate no surveys.

Years	**May**	**June**	**July**	**August**	**September**	**October**
1984		29 -no		21- max		
1985-86						
1987		12-no	30-max			24-yes
1988		13-no	27-max		23-yes	
1989		17-slight		29-max	29-yes	
1990		18-		30-max	30-yes	
1991	26-yes	22-yes			02-yes	05-max
1992		04-no		06-yes	11-max	

Table 8. Magnitude of sand berms developed across Ingonish Beach at lines A, B, C (1984-1992) and lines A2 and C2 (1998-2002), the thickness of sand accumulation at the berm edge and the landward elevation of the main sand deposit.

Line	Berm Width (m)		Berm Elev. (m)		Sand Thickness (m) at Berm		Landward Elev. of Sand Accumulation (m)	
	Mean	Max.	Mean	Max.	Mean	Max	Mean	Max
A /A2	21	36	1.9	2.2	1.2	1.8	2.1	2.4
B	18	24	1.9	2.1	1.3	1.7	2.0	2.2
C / C2	12	18	2.0	2.7	1.2	2.2	2.2	2.6

Table 9. Sand accumulation measured in early and late summer 1984 at all nine survey lines along Ingonish Beach. The width of sand is the distance from landward edge of sand to the high tide level intersect (0.93 m) and sand elevation was taken at the landward extent of sand.

Survey Line	Max. Landward Extent and Elevation of Sand Accumulation (m)			
	29-June -1984		21-Aug-1984	
	width of sand	sand elevation	width of sand	sand elevation
A	12	2.1	30	2.1
B	16	2.2	32	2.2
C	14	2.0	23	2.1
D	11	2.2	15	2.3
E	10	2.2	14	2.2
F	10	2.1	13	2.3
G	no data	no data	13	2.4
H	no data	no data	8	1.9
I	no data	no data	7	1.7

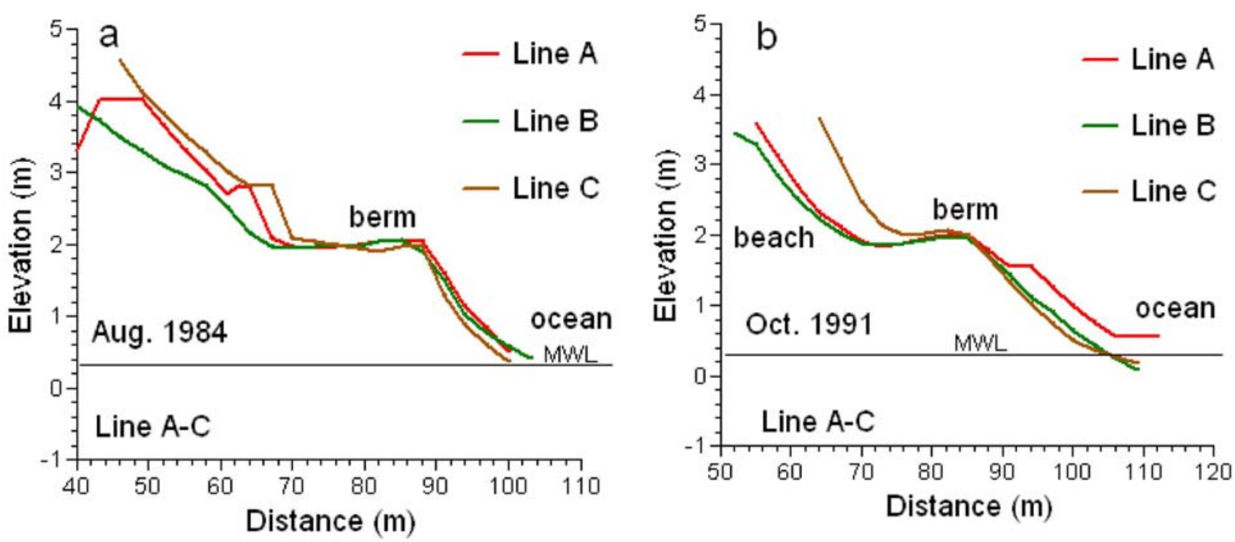


Figure 25. Examples of three cross-shore survey lines A, B, C showing their similarity in berm position and morphology. The top seaward edge of the berms were aligned for these plots.

A plot of all surveys for a given location when the berm was at its maximum development provides a range of morphological changes observed between 1984 and 1992. The plot is often referred to as the "sweep" profile which illustrates an envelope of "normal" variations documented at a site for a given period of time. If repetitive surveys extend over many years the envelope can provide a reference tool. Beach changes observed in the future that fall outside of this envelope would be considered abnormal and possibly signal a shift in beach stability. The sweep profile for line A shown in figure 26a is considered representative of sweep changes at lines B and C as well. At lines 1 and 2 more of a sand ramp built against the steeper cobble slope than a horizontal berm (Fig. 26b). Since 1983 although there were years with substantive sand accumulation none matched the width of sand shown in 1954 (Fig. 5a).

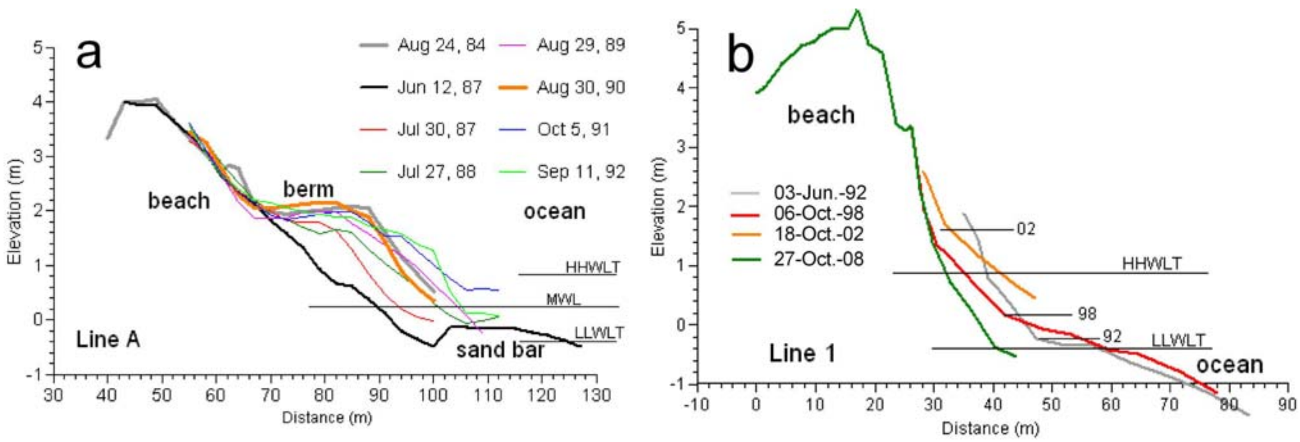


Figure 26. Sweep profiles of sand deposits observed at (a) Line A showing when a maximum sand berm was recorded each summer and fall from 1984 to 1992 and (b) Line 1 when a sand ramp built against the steeper beach. The highest level of sand is marked for each year in graph b. The June 1987 profile in (a) represents the pebble-cobble beach profile when no sand had accumulated on the beach and is stored in a sand bar just offshore. The October 2008 profile in (b) represented a time of high energy waves when no sand remained on the beach.

Knowing seasonal fluctuations in sand accumulation along northern Ingonish Beach can be applied to decisions on how long temporary boardwalks for beach access need to be built. For example at lines A and B sand accumulation started an average of 23-25 m seaward of the beach ridge (top) along the main parking area. At line C in most years, sand extended upslope to 27 m seaward of the walking path but in 1998 and 2002 when sand accumulation was high, the edge of sand was only 23 m from the path.

Ingonish Harbour Beach

Ingonish Harbour Beach includes a north and south barrier beach cut by a tidal inlet which in 1999 was 142 m wide. North barrier was 566 m long and south barrier was 327 m long (Table 10, Fig. 2, 17, 27). The inlet consisted of a 55 m wide navigational channel and a shoal extending south from north barrier. All field observations since 1983 were restricted to north barrier.

Figure 27. Aerial view on 30 September 1992 of South Bay Ingonish showing the north barrier of Ingonish Harbour Beach and the tidal inlet (foreground). The change in shoreline orientation south of Beach Crossing Road Shore, is a major factor in controlling the southern extent of the sand bars present off Ingonish Beach.

Physical Characteristics

North barrier beach which is 25 to 66 m wide consists of coarse material from pebble to boulder size and some armour rock. Maximum water depths in Ingonish Harbour are 18 m which are only slightly deeper than Freshwater Lake.

In 1982 north barrier crest height was only 2.5 to 2.7 m above mean high tide level (NS Lands and Forests, 1982). In October 2002 the beach crest elevation varied from 2.5 m to 4.2 m (CGVD28) (Fig. 8b). The barrier beach, based on its physical morphology in 2002 was subdivided into five longshore zones (Fig. 8b). Along zone 1, closest to the inlet, where the crest is less than 3 m, the beach had been extensively overwashed by waves leaving an abundance of boulders. A 1.4 m high cut into and across the barrier beach marked the north edge of this longshore zone (Fig. 8b). In contrast, along beach zone 4 where the barrier crest was more than

4.0 m elevation, there was only minor wave overtopping. Along zones 2 and 3 the barrier crest varied from 3.5 to 4.0 m howeverbarrier morphology indicated different wave reworking. Along zone 3, waves had cut narrow well defined washover channels to a base elevation of 3.1 to 3.3 m, while along zone 2 there was more wave overtopping and only one wide washover channel existed. Along zone 5, closest to Beach Crossing Road, the barrier crest was generally less than 3.6 m elevation and it was characterized by widely spaced, wider washover channels. Sea level at the time of the survey was at 0.43 m. In 2003-04 the barrier crest was built-up by heavy machinery to a design elevation of 3.8 to 4 m, which will be discussed later.

Shoreline Changes Based on Air Photographs and Published Reports

Since the late 1800s, the inlet and barrier beaches have been impacted by human activities (Fig. 28). Fournier and Lajoie (1984) provided a historical overview of natural and artificial changes to the tidal inlet. From 1873-1876 a tidal channel 60 m wide, extending 4.3 m below low tide was improved by Department of Public Works. The northern side of the channel was protected by a 150 m long pier which received extensive damage from storms during its existence (1882, 1918, 1939....). Several pier reconstruction and beach protection programs were conducted after 1870. By 1936 two pier structures remained on north barrier at the north side of the inlet (Fig. 28a, 29).

Air photos from 1936, 1966, 1975 and 1999 were georeferenced using 1:10,000 provincial maps and ESRI Arcmap software to allow an analysis of shoreline change (Fig. 29). A lack of control points prevented georeferencing of south barrier. Measurements along that shore should be considered estimates.

Between 1936 and 1999 the channel opening increased by roughly 50 m but the navigational channel kept a fairly constant width (Table 10). Changes at the inlet were the result of the south barrier building northward and north barrier decreasing in length as it retreated northward (Table 10). North barrier decreased in length by 90 m over the sixty-three year period leaving a shoal off its south end (Fig. 29). The largest northward barrier retreat was close to 50 m between 1975 and 1999.

A large arcuate-shaped deposit back of north barrier which resembles a flood tidal deposit provides evidence that a tidal channel may have existed across north barrier. Between 1936 and 1966 north barrier had retreated by 11 to 18 m and its south end had curled more into Ingonish Harbour. This shoreline configuration may have been controlled by relict pier foundations. Large lobe -shaped deposits visible along the backshore in 1975 (Fig. 29) provided evidence of increased wave overwash after 1966. North barrier was pushed landward by 4 to11 m and its distal end was wrapped inward around the back of the barrier. During the October 1983 storm the barrier beach was extensively overwashed by waves and flattened. In 1999 the backshore was straighter and narrower than in 1975. The change is attributed to a higher beach crest which was raised up by machinery in the mid to late 1980s by bulldozing sediment from the backshore (Fig. 30b). Landward retreat along north barrier increased by 7 to 38 m southward alongshore. From 1936 to 1999 net shoreline retreat varied from 35 to 58 m and its south shore shifted 90 m northward.

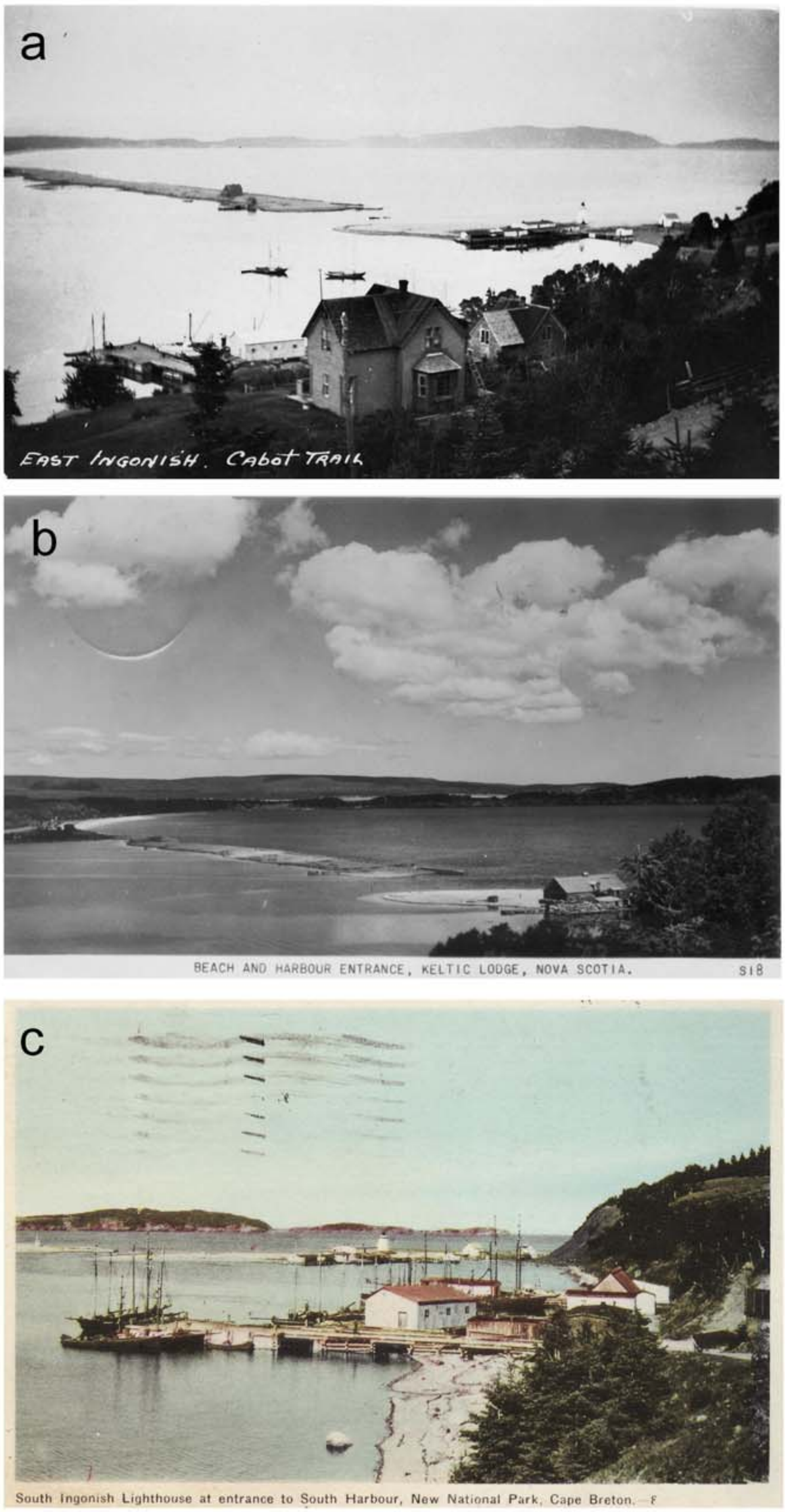


Figure 28. Views of Ingonish Harbour Beach and tidal channel from postcards circa 1940s. There was no postmark on (a) but the wharves and buildings on south barrier are similar to those observed on the 1936 vertical air photos, (b) postmark 1950, the building was gone from the north barrier but the wharves remain intact, (c) view of wharf and lighthouse at Ingonish Ferry (postmark 1949).

Table 10. The following measurements were from common points on air photos and depth sounding charts by DPW (Fournier and Lajoie, 1984). Detailed beach morphology was difficult to distinquish on the 1936 air photos so values for that year are estimates. Measurements on north barrier were completed using air photos georeferenced using ESRI Arcmap software.

Year	Width (m) of opening	Length of Barriers (m) South	North	Width of (m) North Barrier
1936	91	247	658	66
1944 (soundings)	118			
1947 (soundings)	103			
1966 (soundings)	98			
1966	118	282	636	40
1975	126	307	615	53
1978 (DPW)	*88*			
1981 (DPW)	*63*			
1983 (DPW)	*162*			
1999	142	327	566	35

During the same time interval,1936-1999, the south barrier of Ingonish Harbour Beach became narrower and was elongated by roughly 80 m in a northerly direction. Buildings and a lighthouse existed along the backshore until possibly 1983 (Fig. 28c) when they were damaged during the fall storm. By 1994 only the foundations of structures and a small wharf remained and by 1999 the structures were gone and the southern end of the barrier was being overwashed by waves.

Human Interventions

Fournier and Lajoie (1984) list seven bathymetric surveys of the tidal channel between 1944 and 1983. The channel was dredged 3 times after 1966 (in 1968, 1979 and 1982) and it is believed the material was disposed on south barrier. The absence of sediment deposition across the tidal channel led Fournier and Lajoie (1984) to conclude that natural hydraulics are capable of maintaining the channel with little siltation when channel cross-section was between 132 m^2 and 306 m^2. Possible solutions proposed for improving the navigational channel included: do-nothing but remove the remains of the old breakwater, or stabilize the ends of the barrier with training walls of armour stone and revetment to maintain a channel cross-section that allows self-flushing.

Over the last twenty years local fishermen and residents had requested Ingonish Harbour Beach be built up or reinforced to protect their facilities along the inner harbour. At least two studies were completed as a result, including Fournier and Lajoie (1984). A major storm in 2000 which caused considerable damage to wharves, sheds and other property intensified the appeal to the provincial and federal governments for action. Community meetings and reconnaissance surveys of the beach took place between October 2002 and February 2003. The consensus from the meetings was that a beach maintenance program would be the best course of action to restore the shoreline to the same level of protection provided before the 1980s. Our beach survey in

October 2002 (Fig. 8b) was part of that investigation.

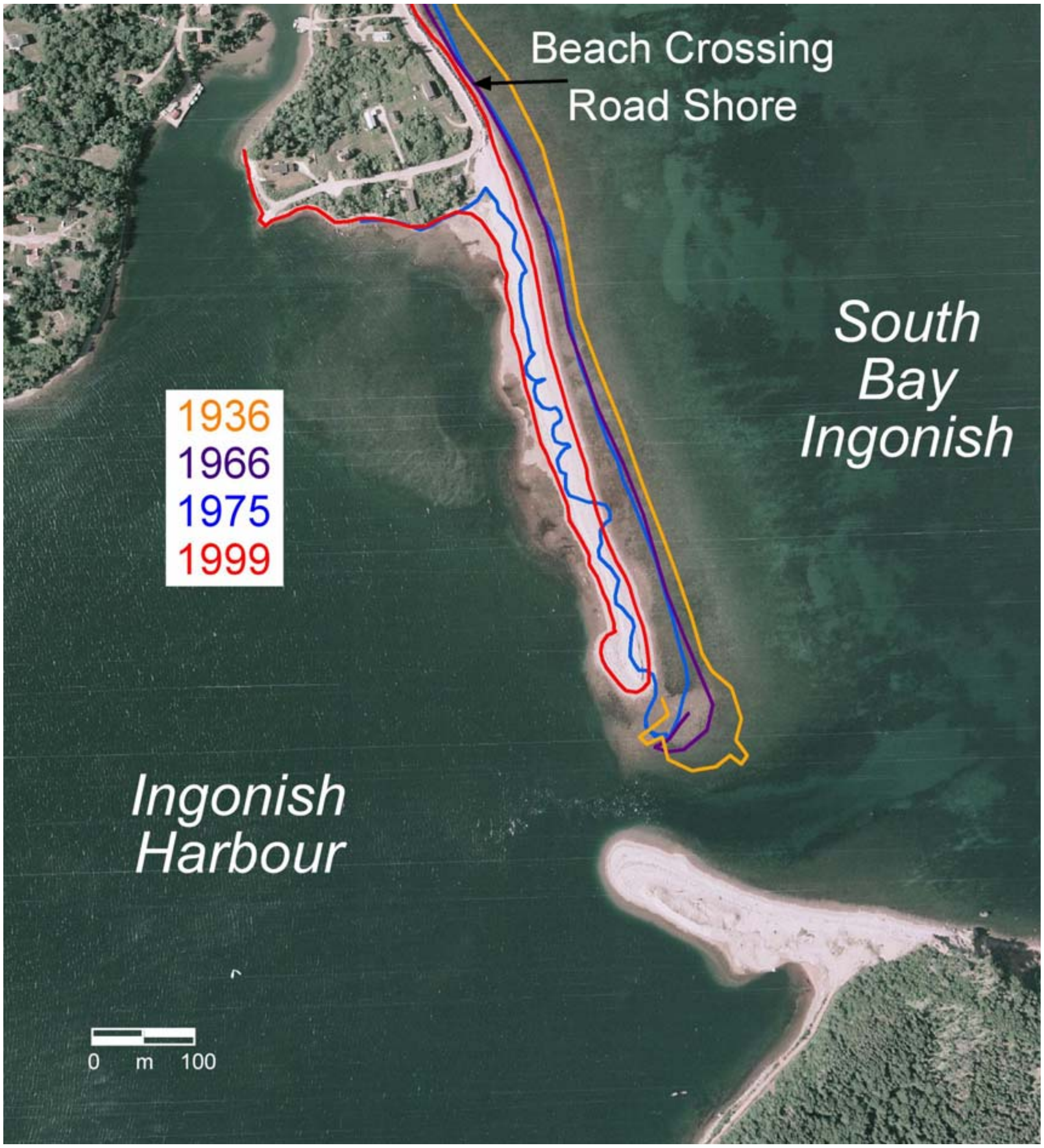


Figure 29. Aerial photo of Ingonish Harbour Beach in 1999 showing the landward migration of north barrier and northward migration of the tidal channel since 1936 (orange) when two wharves existed at the end of the barrier. Other shorelines shown include: 1966 (purple), 1975 (blue) and 1999 (red). The shoreline position mapped in 1936 was the waterline whereas shoreline positions on other dates used the high tide position therefore some difference is attributed to comparing different sea levels.

Concepts developed by Taylor et al. (2003) for assessing the stability and resilience of gravel barrier beaches to wave overwash during storms were applied to Ingonish Harbour Beach. Beach resilience was based on barrier crest elevation and sediment availability for beach re-building. Gravel barriers with elevations greater than 2.6 m have a good to excellent potential of naturally rebuilding themselves where sediment is available (Fig. 8b). Beaches above 3.6 m elevation have a slower recovery rate than lower beaches which are frequently reworked by waves. Once a barrier falls below 2.6 m elevation it can rebuild but only by building farther landward. Natural rebuilding of Ingonish Harbour barrier beach was limited because of a lack of sediment supply. It was recommended that if the barrier beach could be built to a 4 m elevation or higher it would reduce wave overwash and lessen damage to the inner shores, especially if the core of the beach was reinforced.

Barrier Beach Reinforcement Project 2003-04

This is a brief project summary. Additional details about the beach reconstruction program are available in Carey Geoenvironmental Engineering (2004). Objectives of the beach reconstruction project were to restore the barrier beach by raising its elevation, improving its continuity, reinforcing its core, yet maintain its natural outward appearance and allow natural processes to rework it as before. Improvements to the barrier beach were designed to protect residences and coastal infrastructure along the shores of Ingonish Harbour. A ten year annual inspection and maintenance program was proposed as part of the project (Carey Geoenviromental Engineering, 2003).

Construction took place between December 2003 and early February 2004 by D.W. Matheson and Sons. The primary reinforcement activity was near the distal (south) end of north barrier where 2.5 to 5 tonne armour stone was placed along the top of the barrier beach and then covered with natural beach cobble with a design slope of 6 to 1 horizontal to vertical. The design elevation of the barrier beach crest was at 3.8 to 4.0 m (CGVD 28) and 10 m wide. Armour and filter stone was quarried and hauled from Middle River, Victoria County and borrow (beach) material was derived from stock piles on south barrier, Ingonish Harbour. Quantities of material reported used were 2,548 tons of armour stone, 1,260 tons of filter stone and 4,752 tons of borrow material (Carey Geoenvironmental Eng., 2004). A haul road was constructed along the barrier beach and removed after north barrier was reconstructed. A major storm in early December 2003 nearly breached north barrier and caused significant erosion.

Post-construction survey lines were established across north barrier for monitoring changes to the beach in subsequent years. Beach elevations of 3.9 to 4.0 m with slopes of 5 to 1 horizontal to vertical were surveyed in November 2004. Despite several storms no serious damage was noted. No surveys of the beach have taken place since then (E. Carey, 2009 pers. comm). By October 28, 2008 we observed evidence of wave overwash at the north end where a low beach crest existed. Farther south the crest was higher and more continuous with vegetation covering the backshore. Closer to the south end of the barrier there was evidence of water flowing through the armour rock forming very narrow washover channels however the armour rock and crest remained intact.

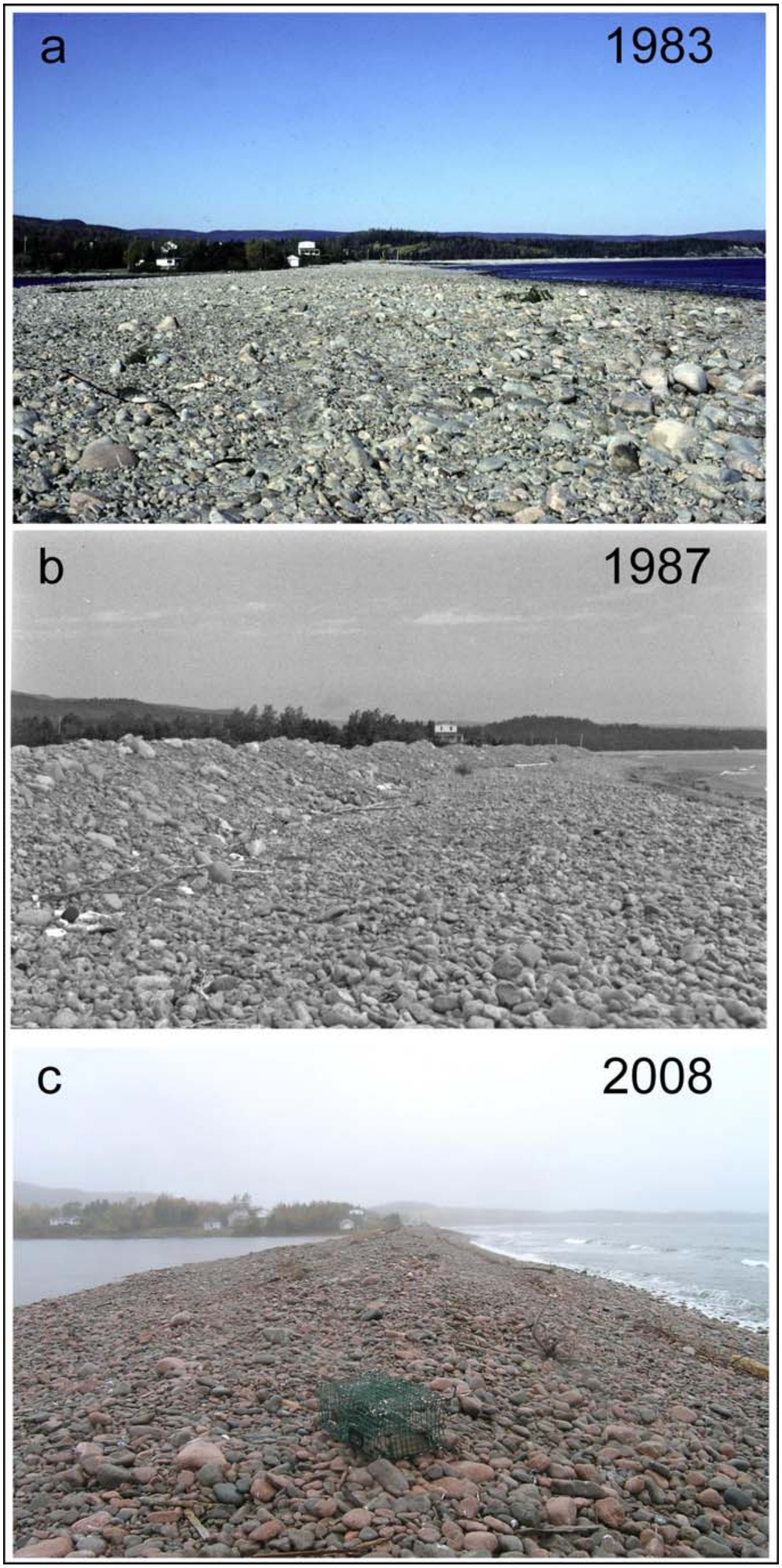


Figure 30. Views looking north along north barrier Ingonish Harbour Beach in (a) November 1983 just after it was flattened by a late October storm; (b) June1987 after sediment had been bulldozed seaward from the backshore to increase crest elevation and (c) August 2008, four and half years after the barrier had been reinforced and rebuilt at its southern end. The photo in (c) is taken from a position farther landward than in (a and b).

BLACK BROOK COVE SHORES

Black Brook Cove is located 14.5 km north of South Bay Ingonish, between the headlands of South Point and Bluff Head (Fig.1). The northern shore of Black Brook Cove is high, steep bedrock whereas the southern shore, although consisting of rock outcrops, is lower and has a larger abundance of sediment derived from glacial deposits (Grant, 1988) and possibly from Black Brook (EERL,1978).

Marine geology surveys have not been completed within Black Brook Cove although it is reported by EERL (1978) that sand and gravel are found offshore. Water depths of 11 m exist between the outer headlands (CHS, 1974). Closer inshore at the head of Black Brook Cove the seabed consists of sand of an unknown thickness. The continuity of the deposit is affected by variations in discharge and direction of flow from Black Brook which has the second largest drainage system (67.4 km^2) in the national park (EERL, 1978). Aerial photographs taken roughly 30 years apart in 1936, 1966 and 1999 (Fig. 32) show that a wide sand deposit nearly closed off the stream mouth in 1936, but was breaking apart by 1966 and was not visible in 1999 (Fig. 3a, 31). Field observations confirm that sand can intermittently rebuild on coarse shoals across and adjacent to the river mouth. For example, in June 1983 stream flow was forced northward and cut back the beach, whereas in August 1985 flow was more to the south and the beach was fringed by a wide sand foreland (Fig. 32). Sand also plugged the river mouth in 1992 (Fig. 3b).

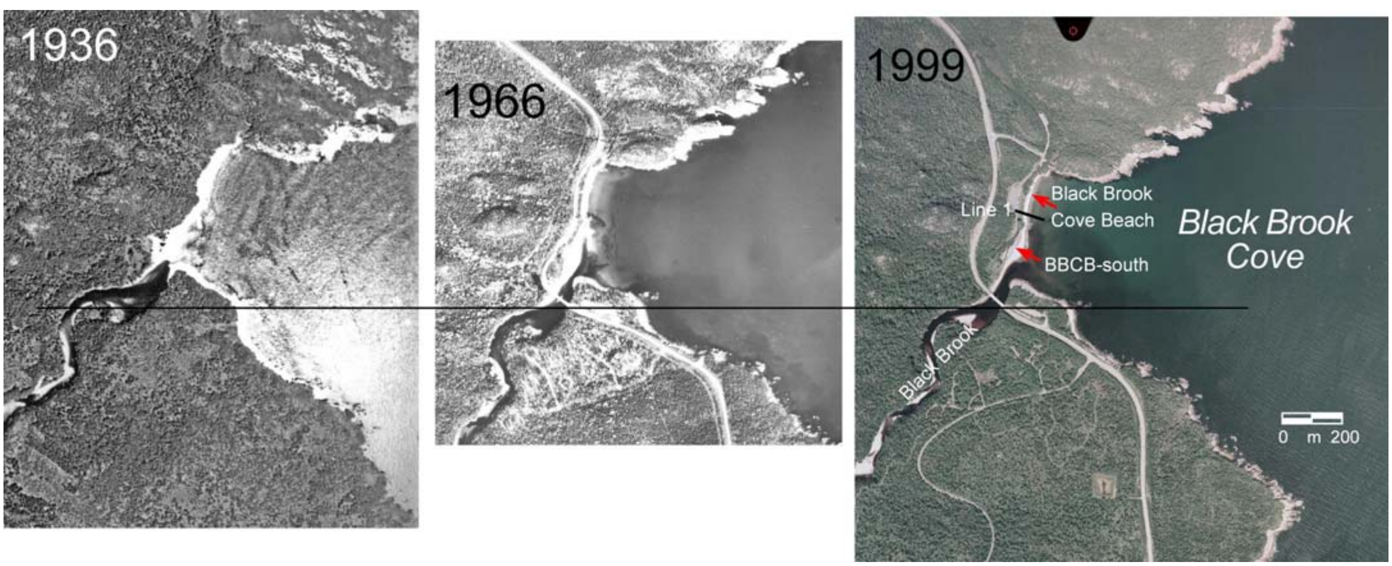


Figure 31. Sequence of vertical air photographs of Black Brook Cove at roughly the same scale in (a) 1936, before the coastal highway, (b) 1966 with the coastal highway and (c) 1999 after the highway had been moved farther landward in the early 1970s. Sand deposits accumulating at the mouth of Black Brook stream appear to have decreased over the 63 years but they may just shift back and forth in the Cove as shown in 1999 when they were at the north end.

Black Brook Cove is less than 0.5 km wide at its head where the shoreline is divided into two parts by a rock outcrop that extends offshore (Fig. 3). To the north lies our main focus, a 125 m long, pebble-cobble beach with a rising backshore which we refer to as Black Brook Cove Beach (BBCB). To the south is another pebble cobble beach backed by a low backshore that extends to the base of the main highway. We call it BBCB south.

Black Brook Cove Beach

Black Brook Cove Beach (BBCB) is a small swash-aligned, pebble-cobble beach fringed by a sand apron (Fig. 3, 31). Easy vehicle access makes it a very popular recreational site and its backshore has been modified for parking and picnic activities. No previous detailed studies of this beach are known. Field surveys were begun in November 1983 just after a major storm surge and a total of five cross-shore surveys were completed between 1983 and the last survey in 2008 (Appendix 1). Detailed field surveys of beach change were limited to one location, line 1 (Fig. 3, 31c, Table 11, Appendix 1, 2); only visual observations were completed at BBCB-south.

Onshore Physical Characteristics

Black Brook Cove Beach is constrained by rock outcrop at both ends (Fig. 3, 31). The backshore is man-made, consisting of two terraces (Fig. 33). The lower terrace is grass-covered and the upper one is a paved parking lot. Until the early 1970s the upper terrace was part of the coastal highway which was built on artificial fill covering the landward edge of the natural backshore just beneath the lower terrace (Fig. 34). A comparison with a non-barrier portion of Ingonish Beach, i.e. Line C2, confirms the lower terrace at Black Brook Beach is at approximately the same elevation as the natural beach crest on Ingonish Beach (Fig. 33).

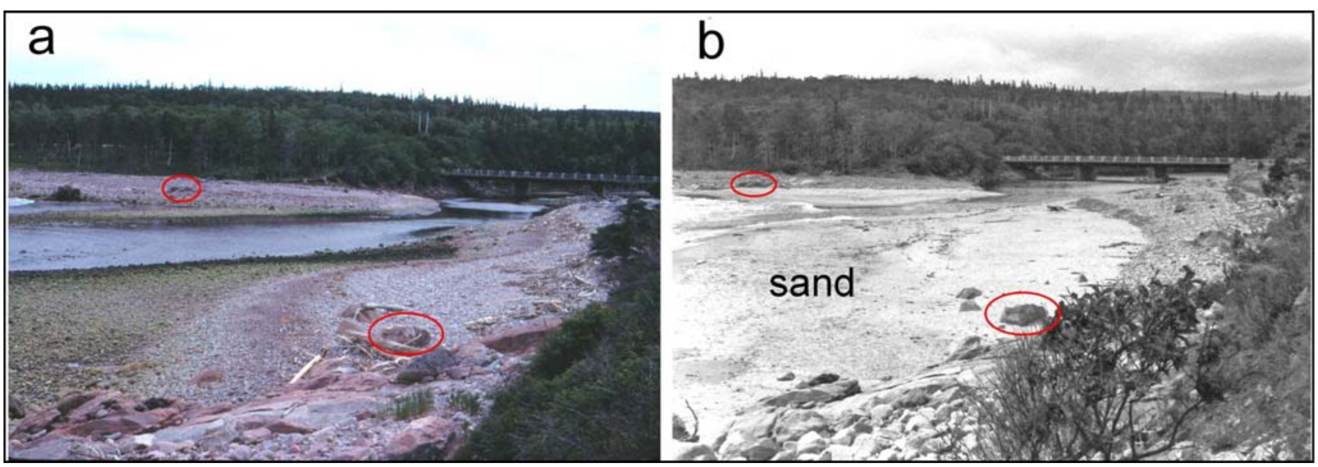


Figure 32. Views westward along the shore at BBCB-south in (a) June 1983 when the stream was directed north along the picnic park shore and (b) in 1985 when the stream flowed farther south allowing sand to accumulate along the park shore. The same rock outcrops are circled on each photo for visual reference.

Below the grass terrace the pebble-cobble beach is natural and is reworked by waves. The upper beach varies from convex to concave in shape with either a smooth featureless slope or one marked by swash ridges built by waves to varying elevations controlled by tide levels. The slope and character of the foreshore or intertidal zone depends upon the presence or absence of sand. When sand is absent, the foreshore has a concave slope varying from 9 to 12 degrees (tan θ: 0.160- 0.217), as observed in 1983 (Fig 35a, 36a-c). When sand accumulates on shore, the width of the foreshore increases by 10 to 14 m farther seaward and its slope is 3 to 5 degrees (tan θ: 0.090), e.g. in 1985 and 1992 (Fig. 35b 36d,e). The highest sand recorded was built to an elevation of 1.82 m and a thickness of 1.3 m (Table 11).

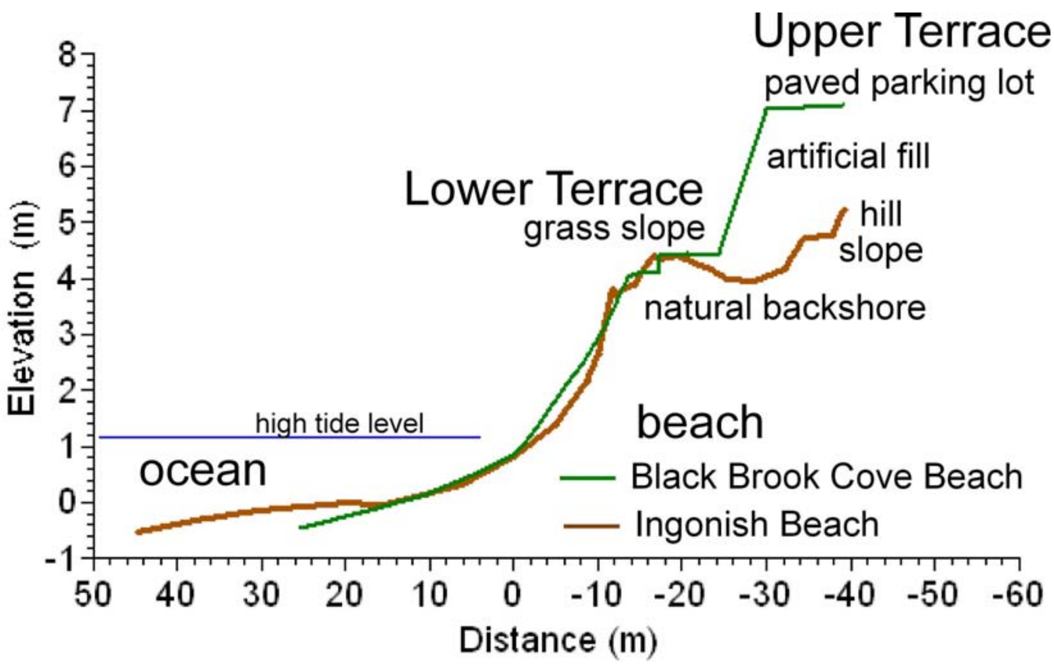


Figure 33. A comparison of beach profiles from Black Brook Cove (BBCB) and Ingonish beaches. The lower grass terrace at BBCB, interpreted as the original backshore, is at the same elevation and position as the natural backshore at line C2, Ingonish Beach. The upper terrace, where the paved parking lot presently exists, was built up with artificial fill as part of the coastal highway.

Within the wave breaker zone the seabed either consists of pebble, cobble or sand. When sand was present, large sand ripples (4-Jun-92, Fig. 37b) and a low sand bar were observed. When the sand was pulled farther offshore during higher energy wave conditions, it was very difficult to survey the full extent of sand. Cross-shore surveys in 1992 and 1998 (Fig. 37b) represent the typical range in subtidal conditions and the survey in 2008 represents an intermediate stage when not all of the sand had been pulled offshore.

The beach consists of well rounded pebble and cobble of granite and gneiss lithology. Typical clast size varies from 20 to 166 mm (b-axis) which is similar to the sediment on Ingonish Beach.

Boulders exist at the base of the beach but are often covered by sand. In 2008 the pebble-cobble at HTL were a less uniform size varying from 20-110 mm (b-axis) and about half the mean size of clasts measured at the highest storm ridge (48 to 110 mm, Appendix 5). In the event of a marine oil spill, the oil would penetrate into the coarse upper beach and could be buried across the lower beach because of seasonal fluctuations in sand accumulation.

Table 11. Specific beach characteristics and physical changes measured from cross-shore surveys completed at Black Brook Cove from 1983 to 2008. A comparison of repetitive beach profiles is provided in Appendix 2.

Date	**Max. Debris Elev. (m)**	**Beach Crest Position (m)***	**Beach Width (m)#**	**Landward Position of Sand (m) *Distance**	**Elev.**	**Foreshore Slope (°) | (tan θ)**
1-Nov-83	4.4 to 4.7	0.0	23	0.0	-0.36	12.5 0.22
4-Jun-92	1.7	0.0	35	14.1	1.82	5.2 0.09
6-Oct-98	3.5 to 3.8	0.0	23	-5.7	-0.84	9.1 0.16
30-Oct-08	4.1	-0.3	34	8.7	0.91	3.4 0.06

*Distances are relative to 1983 position along the survey line (+ is seaward and - is landward)
Beach width is measured from the grass scarp to low tide level.

Shoreline Changes Based on Aerial Photography (1936 to 1999)

A comparison of vertical aerial photographs taken roughly 30 years apart in 1936, 1966 and 1999 show very little change in the natural shore planform (Fig. 31). The largest physical changes are detected at the mouth of Black Brook and BBCB-south and where park and road infrastructure has been relocated. In 1936 the shoreline was overexposed on the air photos making it very difficult to distinguish details alongshore or offshore. Similar rock outcrops identified along the shores suggest BBCB may have narrowed slightly from 1936 to 1966 and has remained fairly similar between 1966 and 1999. Some erosion of backshore till was observed, however increased density of trees along the north end of the beach and similar beach position relative to rock outcrops confirm a lack of significant shore retreat. Sand extends to much the same distance offshore in 1966 and 1999 but is more concentrated along the northern part of Black Brook Cove in 1999 (Fig. 31c).

In 1936 BBCB nearly completely sealed off the mouth of Black Brook (Fig. 31a). Photos from 1969 and 1999 provided further evidence of a variable build-up of sediment at the river mouth and the progressive shift of a lobe of sediment farther seaward along BBCB-south (Fig. 31). Some of the changes observed at the mouth of Black Brook are also impacted by changes in the stream channel just upstream of the highway bridge.

Figure 34. Postcard showing Black Brook Cove Beach in the 1950s (postmarked 1957). A wide sand foreshore and pebble cobble upper beach fringed the coastal highway which was built along the back of the natural backshore. After the road was moved landward in the early 1970s, the former road was widened into a parking area and grass was laid across the backshore (see Fig 3b).

Shoreline Changes Based on Field Surveys (1983-2008)

When our field surveys began in June 1983 the beach had a steep slope with a storm swash ridge. The lower beach was more concave and small beach cusps were developing (Fig. 36a). The presence of flotsam and gravel cusps along the upper beach suggested that wave run-up commonly reaches the edge of the grass terrace. This was confirmed in October 1983 when the coast was struck by a severe Northeaster that produced a storm surge of 0.76 m in Sydney (Oja, 1984; Taylor and Kelly, 1984). Our first cross-shore survey of this beach was on November 1, 1983 immediately after that storm so only repetitive photographs from June and November 1983 provide an estimate beach change (Fig. 36a, b).

During the October 1983 storm, the entire beach slope was combed down and grass sod was rolled landward as the lower terrace was cut back 1-2 m landward. Small pieces of debris were tossed up to the parking lot terrace at 7 m elevation but the main wave debris line (consisting of cobbles, boulders and flotsam) was at the back of the lower terrace at 4.4 m elevation (Fig. 37, 38a). Concrete steps and a large culvert pipe at the south end of the parking lot were severely undercut by waves. Damage to park facilities was much greater along the lower shores of BBCB-south than at BBCB. Cobbles were littered across the lawn to the picnic shelter and flotsam was washed to the base of slope below the main highway and bridge (Fig. 38b). Although physical damage to the low backshore was minimal, the 1983 storm illustrated the vulnerability of the picnic area to flooding during storm surges and the need for adaptive measures when renewing the infrastructure.

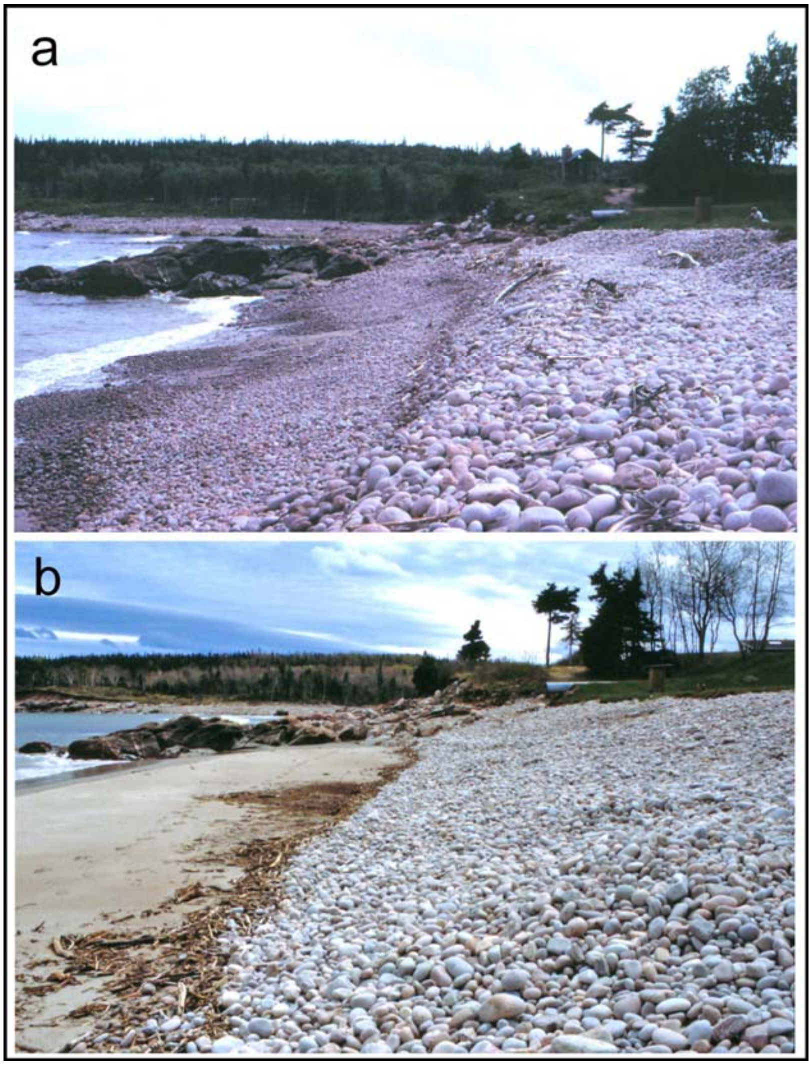


Figure 35. Repetitive photos looking south at line 1, Black Brook Cove Beach illustrating its physical character (a) without sand after the October 1983 storm and (b) with sand, in June 1992.

By June 1984 when the next beach survey was completed the grass terrace had been cleared of debris left by the storm. Cobbles tossed across the grass were returned to the beach. The entire beach slope was smoothed out by machinery and the erosional bank along the grass terrace was infilled with cobble (Fig. 36c). Within a few days of artificially smoothing out the beach, waves began forming a new swash ridge near high tide level (Fig. 36c, Fig. A2-3, Appendix 2) and the beach was returning to a natural profile. No negative impacts were observed on shoreline stability as a result of this human activity.

By 1992 (possibly during the Oct. 28-30, 1991 storm) waves had reworked the beach to at least the grass terrace where the eroded bank had reappeared and the upper beach was cut back and carved into a concave profile. Upper beach retreat was the largest recorded from the five surveys. June 4, 1992 was also a time when the highest accumulation of sand was recorded (Fig. 35b, 36e, 37b). A well defined sand berm had developed and the thickness of sand over cobble reached 1.3 m. In contrast, Ingonish Beach still consisted of many ice-built features in June and sand accumulation onshore was delayed. The build-up of sand at BBCB provides a buffer protecting the upper beach against large waves. When the sand is carried offshore it also triggers wave breaking.

James Bridgland, Parks Naturalist reported that BBCB was severely impacted by Hurricane Hortense in September 1996 but it is unknown if the beach changes surveyed in 1998 were the consequence of Hortense or other storms occurring between 1996 and 1998 (Fig. 36f, 37). Sometime after 1992 the upper beach and grass terrace were scoured down; however, the upper beach had been rebuilt by mounds of pebble cobble and wood debris by October 1998 (Fig. 36f). Repetitive surveys from 1992 and 1998 show mid to upper beach rebuilding to pre-1992 levels and the edge of the grass terrace was cut deeper by 1998 (Fig. 36e-f, 37b, A2-3, Appendix 2). The whole upper beach was reworked by large waves and the occurrence of gravel mounds either suggested waves had formed cuspate deposits or sea ice had been involved during one or more storm events. Just prior to our survey in October 1998 the waves had combed most of the sand offshore leaving only a veneer of sand across the lower foreshore. Most sand remained below low tide level (Fig. 37b).

The next visit to the beach was not until 2002 (Fig.36g) and the next cross-shore survey was not until 2008 (Fig. 36h, 37a). In October 2000 a northeaster with heavy rains struck the area. Sections of the Cabot Trail were closed due to flooding. Waves caused widespread deposition of pebble-cobble and debris across the grass terrace (Andy Doherty, Parks Canada, pers. comm. 2008) which was removed and piled at the far north end of the beach (Fig. 39). The metal culvert at the south end of the beach was also replaced after the storm. At the low beach area adjacent to Black Brook the picnic shelters and backshore were completely covered by foam (Danielson, 2007) which required machinery to remove it.

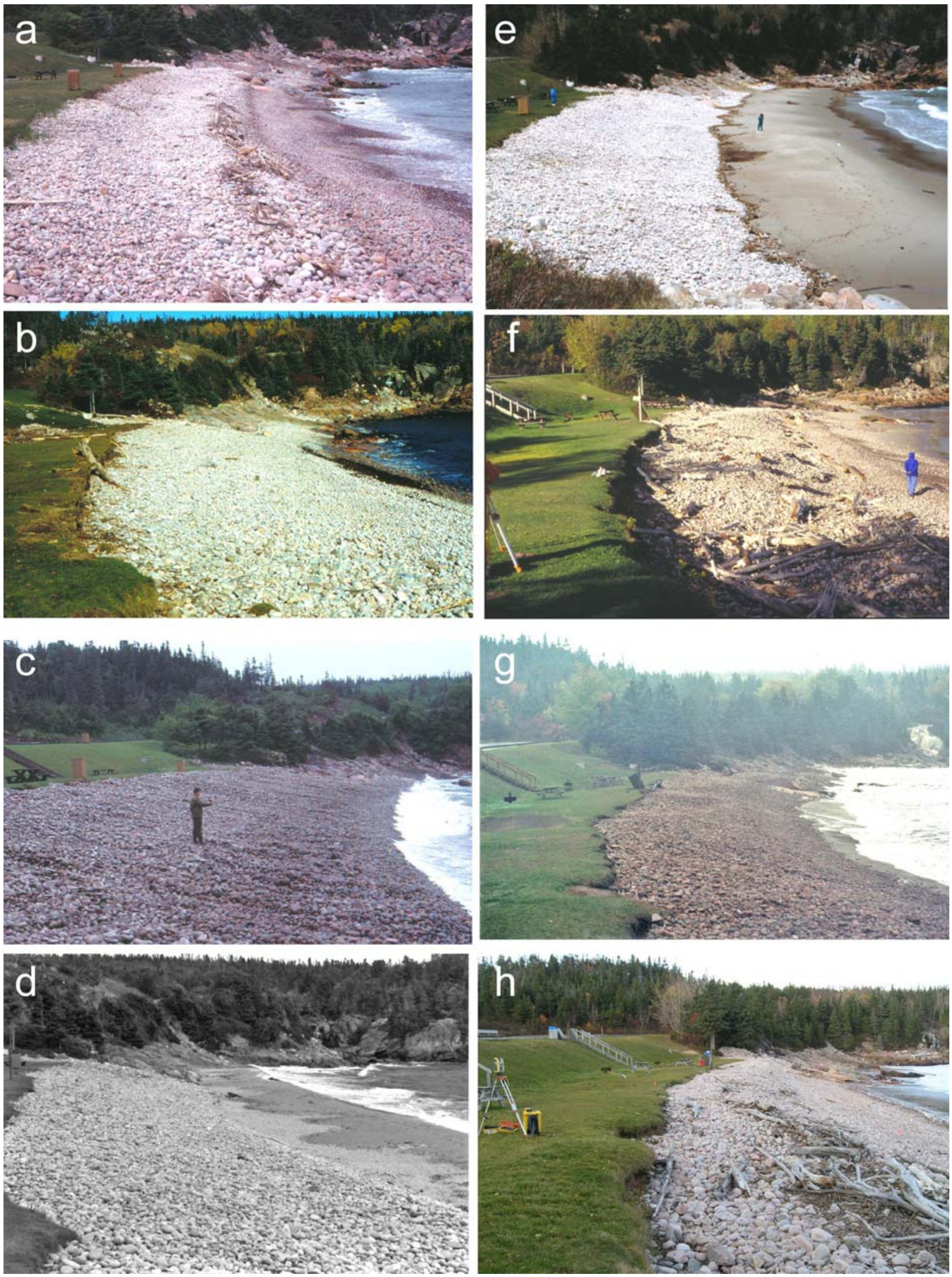
A much smoother, convex pebble cobble upper beach slope existed in October 2002 and the bank at the edge of the grass terraced was infilled (Fig. 36g). Our visit in 2002 was during a period of stronger winds and waves. Sand was being pulled offshore although some sand remained providing conditions similar to those of 1998. The lack of irregularity, swash ridges, and debris across the upper beach on October 18, 2002 suggested waves had not reached the upper beach recently. A comparison of photos from 1998 and 2002 showed the grass terrace, north of the survey line, was trimmed back slightly and also confirmed net retreat of the grass terrace during the October 2000 storm also was small (Fig. 36f-g).

In late October 2008, when the next survey was completed, there had been several days of strong waves from the SE. As a result a large amount of sand had been pulled offshore but the remaining sand was more than we observed in 1998 and in 2002. Re-exposure of the bank along the grass terrace indicated that waves had reached that level after 2002 and had subsequently rebuilt the upper beach just seaward of the grass terrace (Fig. 36h, Fig. A2-3, Appendix 2).

Black Brook Cove Beach is reworked by very large and powerful waves, however net physical change over 25 years has been minimal. The grass terrace was eroded back most during the October 1983 storm before our surveys began. Since 1983 the net retreat of the grass terrace was only 0.3 m at our survey line; slightly more to the north and south of the line. Our repetitive cross-shore surveys may have captured the impacts of the October 1991 storm and one during or just prior to 1998 but they missed the storm of October 2000. In any case, the lack of net upper beach change illustrates that this beach can naturally rebuild after storms and human modification, ie 1984. Net change in upper beach width during the 25 years was only 2 to 3 m and across the lower beach it was 12 to 18 m because of fluctuations in sand accumulation (Fig. 37a).

Maximum sand accumulation measured during the five surveys was 1.3 m in 1992 when sand extended upslope to an elevation of 1.82 m. A comparison with beach photographs from August 1985 (Fig. 36d, e) suggested sand accumulation was higher in 1985 than 1992 therefore the maximum sand accumulation also was not captured in our surveys. In 1983 and 1998 the base of the beach slope consisted of boulders which marked the base of mobile sand. It was reported (Andy Doherty, pers. comm. 2008) that sand can cover the base of Black Brook Cove Beach at any time of the year especially after a period of strong offshore winds. Sand is pulled offshore whenever there are strong onshore waves striking the beach. Surveys in 1992 and 1998 recorded sand as much as 40 m seaward of the beach and the thickness varied by 0.5 m in those years (Appendix 1, Fig. A2-3, Appendix 2).

Figure 36. (next page) Views northward along Black Brook Cove Beach showing different types of morphology observed from 1983 to 2008 and the processes which produced them: (a) June 1983 large swash ridge-moderate waves, (b) November 1983,-upper beach smoothing -post-storm (c) June 1984-upper beach smoothed by machine and (d) August 1985-lower beach -maximum sand accumulation, (e) June 1992 -lower beach with sand berm, (f) October 1998-post storm -upper beach cut bank and hummocky storm ridge, (g) October 2002 -post storm -upper beach smoothing and (h) October 2008 bank cut and upper beach ridge left as moderate waves reworked the mid to lower beach.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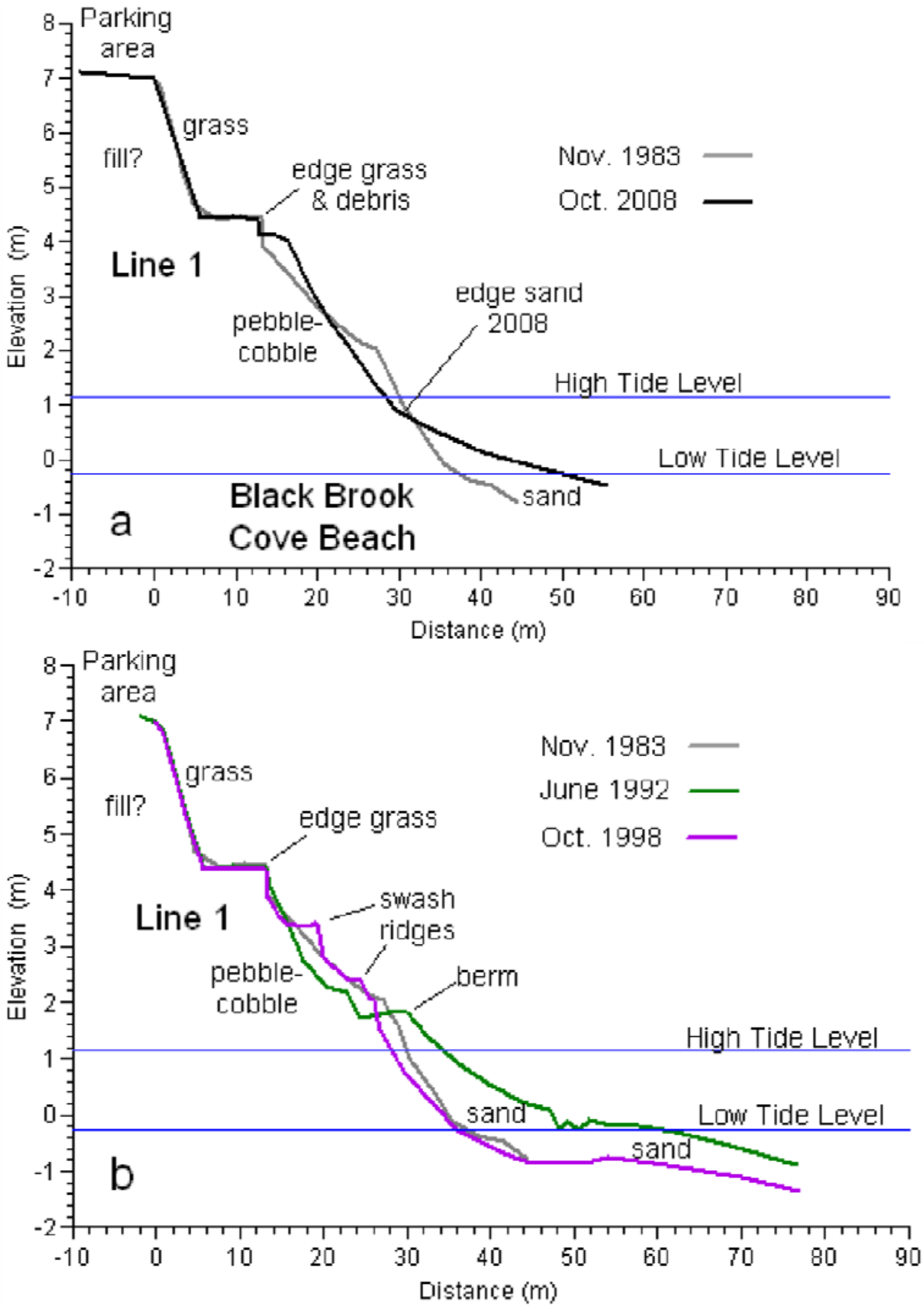

Figure 37. Repetitive surveys of Black Brook Cove Beach at line 1 showing (a) net change between 1983 and 2008, and (b) beach changes during the 1990s compared to 1983. A sweep profile showing the maximum range of change observed at this site is shown on Fig. 41a. All survey lines completed at this site are plotted in Figure A2-3 Appendix 2.

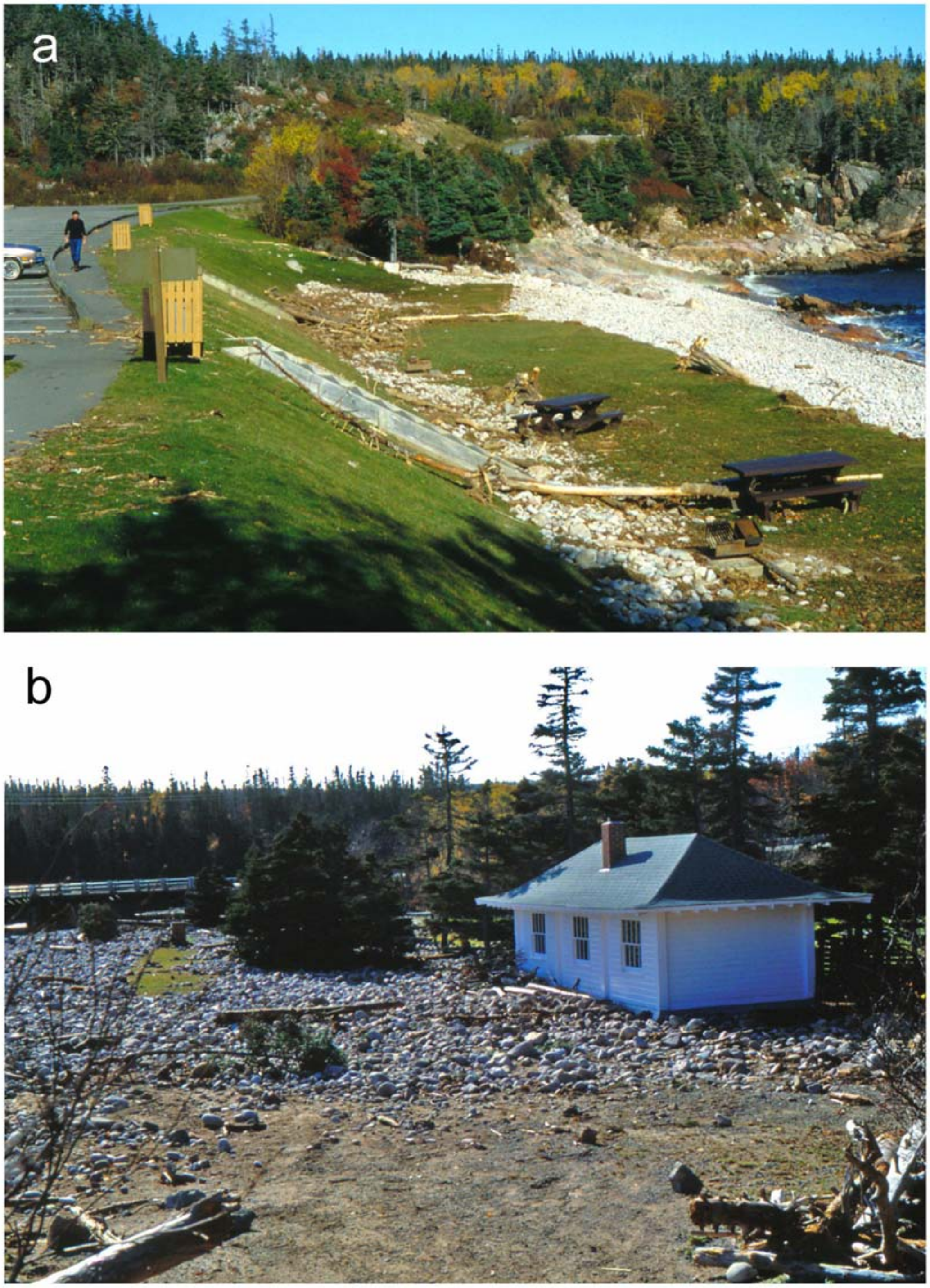

Figure 38. Views of the damage caused by the storm surge October 26, 1983. (a) cobbles and debris carried up the smooth grass slope to 4 and 7 m elevation on BBCB and (b) cobbles and flotsam were carried landward against the picnic shelter and base of the highway along BBCB-south.

Figure 39. Pile of sediment and flotsam at the north end of BBCB which was cleared from the lower grass slope after the October 2000 storm (A. Doherty, 2008, pers comm). Sediment and debris deposited across the grass terrace or parking lot when cleared should be returned to the natural beach to facilitate post-storm beach recovery.

South Black Brook Cove Beach

The south end of the picnic park between the rock outcrop at BBCB and the highway bridge (Fig. 3, 31) consists of a low, flat backshore that can be severely impacted by fall storms e.g. October 1983 and 2000 (Fig. 38b). No quantitative measurements were collected along this shore however repetitive vertical photographs of the site (Fig. 31) revealed some changes related to the discharge and direction of flow from Black Brook. By 2008 driftwood was trapping sediment along the upper beach and promoting beach build-up (Fig. 40). The higher beach ridge may protect the lower backshore from waves during smaller storms but the backshore remains low and vulnerable to flooding and deposition of debris during larger storms that extend over several days.

Figure 40. Views of Black Brook Cove Beach-south picnic park in October 2008 (a) toward the highway bridge and (b) from the bridge showing its build-up as it migrates landward. Driftwood has facilitated the trapping of sediment along this beach crest.

DISCUSSION

In this investigation we have examined two types of mixed sediment beaches located within embayed settings along the rugged northeast coast of Cape Breton Island. Ingonish and Black Brook Cove beaches are part of Cape Breton Highlands National Park where management plans must be developed to monitor ecological integrity and diversity and to provide a safe, enjoyable experience for visitors. Knowing what criteria to monitor and what decisions should be taken to ensure the natural environment and human enjoyment can be challenging. Monitoring of these two beaches over twenty-five years provides some insights into their natural state and where human interventions have or have not had significant impacts on shoreline stability. Management of coastal resources is only effective if those making the decisions have an understanding of the geological framework and both the long term evolution and seasonal fluctuations of different shore types. The discussion consists of a series of questions.

1) What is the geological architecture of these shores, their relationship with adjacent terrestial and marine environments and the implications for future coastal stability?

The physical character of a coastline and arrangement of individual shore types are critical pieces of information for understanding coastal stability, particularly in areas of coastal submergence, such as Nova Scotia. Beaches develop along the land-sea interface where sediment is available and topographic conditions promote the collection and storage of sediment. As sea level rises, the general prognosis is for beaches to be eroded or pushed landward unless sediment supply is sufficient to allow them to build seaward or upward. As rock shores, and those more resistant to change, become submerged, their presence will continue to influence and control local wave dynamics.

Black Brook Cove and Ingonish beach are situated at bayhead locations where sediment should naturally collect. The outer shores of these bays are rocky with no source of an abundant sediment supply. Both beaches are composed of well rounded pebble, cobble, and sand which were derived mainly from local glacial deposits. The roundness of clasts suggests they have existed and been recycled within the littoral system for a long time. At the beach surface there is a clear separation of the sand and gravel components. At depth, the beaches consist of both sand and gravel which has consolidated over time and provides increased resistance to wave forces. As a barrier beach begins to migrate, the sediment package becomes less consolidated and increasingly easier for waves to move it in the future.

Sand and gravel are reported offshore within both bays but their distribution and thickness are poorly documented. Onshore the beaches are linked and anchored by small areas of higher relief that contain glacial deposits which could supply sediment to these shores. Unfortunately most are small or have been armoured to reduce shore erosion. Armouring of shorelines protects the backshore but it also cuts off the supply of sediment for adjacent beaches. The lack of new sediment supply from shoreline erosion means that these beaches must adjust their position, shape or redistribute their own sediment to adapt to changing environmental conditions, e.g. rising sea level or sediment extraction by people. The length of time required for a beach to adjust depends on local conditions. For example, the north end of Ingonish Beach, where the beach crest was artificially lowered and large amounts of sediment were swept inland by waves and wind across the low backshore, has not yet recovered to its pre-human intervention condition after 26 years. At Black Brook Cove, where a high backshore and rock outcrops trap sediment onshore, the beach recovered within a year from human modifications after the 1983 storm. Cobble tossed across the backshore during the storm was returned to the beach and was used to infill the scarp cut along the grass terrace. This replenishment assisted beach recovery.

It was not so obvious what factors trapped sand off Ingonish Beach. There were stories that a wharf structure that once existed trapped the sand, but the only structures built alongshore were at the end of Ingonish Harbour Beach far beyond the location of sand. Beach Crossing Road and its relic shoal extending offshore appear to be critical for maintaining the sand bars off Ingonish Beach. Therefore the preservation of Beach Crossing Road shore and shoal has much greater implications for the shores of South Bay Ingonish than merely protecting the local road.

Both Ingonish and Ingonish Harbour barrier beaches are backed by deep basins. If these barrier beaches break apart or develop low washover areas where sediment can be transported into the basins, or the barriers are pushed into the basins, much of their inherent sediment will be used to infill the deep water and less will be available for building the beach above high tide level. Therefore, if new supplies of sediment are not available, these barriers could become much lower or submerged, leaving the inner lake and harbour shores increasingly exposed to wave attack. More knowledge of beach stratigraphy and whether the barriers are built on a bedrock sill or glacial material would provide a better understanding of how vulnerable these shores are to future breakdown and landward migration.

2) What is the significance of gravel versus sand components on the longer term stability of these shores?

Ingonish and Black Brook Cove beaches, depending on when they are visited, could be described as pebble-cobble or sand beaches. The coarse component forms the core and permanent structure of the two beaches while the sand component forms a more temporary /seasonal protective covering along the front of the beach. In most cases the sand extends offshore as a subtidal deposit. The coarse component provides the best indicator of longer term beach change whereas the sand component is a better indicator of seasonal and short term changes.

Photos from 1954 show a wide expanse of sand fronting Ingonish Beach along Freshwater Lake. Similar widths of sand beach have not been observed in the past 25 years but the reason for the decrease of sand is not known. Seasonal accumulations of sand can increase the width of Ingonish and Black Brook Cove by 10 to 20 m and in some cases by more than 30 m. Fluctuations in sand accumulation onshore and bar morphology offshore are responses to local wave conditions. When the sand is present onshore it provides a buffer for the backshore against wave attack. However sand is easily eroded and pulled offshore, as observed in 2002 when an estimated 6000 m^3 of sand was removed in a 24 hr period. If higher energy waves do not persist, the sand, if sufficiently thick and wide, can protect the beach core from larger change. Even when the sand is pulled offshore it protects the beach by causing waves to break farther offshore. There is increasing evidence, ie. similar spacing, that the quasi-rhythmic cuts along the crest of Ingonish beach are closely related to the position and morphology of offshore bars. It is not known how the offshore bar morphology is affected by different wave conditions. The loss of offshore sediment reserves would have serious implications for shoreline stability.

3) What are the differences in longer term shoreline changes along barrier and non-barrier beaches with subtidal sand deposits?

Barrier beaches are those with water on both sides such as Ingonish Harbour Beach. Most beaches are non-barrier and are backed by land.

In an embayed setting, such as our study sites where subtidal deposits are better confined, the landward dispersal of subtidal deposits is greater along a low barrier than a non-barrier beach. High barrier beaches are similar to non-barrier beaches. Subtidal deposits become trapped against them and are deposited upslope across the backshore by wave run-up. Sediment thrown onto the backshore that remains within the reach of waves can be recycled and pulled downslope for repairing eroded sites. However where the overwash debris is trucked away or removed from the littoral system, sediment reserves are depleted. Therefore it is important if beach sediment is thrown across or against human infrastructure, to realize first that your infrastructure lies within a hazard zone and secondly that the sediment be returned to the beach, not piled in the woods. The distance sediment is transported landward across both types of beaches is a function of the backshore elevation and vegetation cover. For example, sediment was deposited higher across the grass slope and parking lot at Black Brook Cove and only just beyond the path at Ingonish Beach (Fig. 41a) because of the presence of trees and shrubs. Sediment was transported farthest landward across shores with a low backshore, ie. Ingonish Beach (Line A2, Fig 41b).

Over decadal or longer time scales, it is the difference in shoreline retreat of barrier and non-barrier beaches that impact the containment and dispersal of subtidal sand deposits. Barrier beaches migrate landward as sediment is deposited in the backbarrier lake or lagoon by wave overwash or via tidal channels cut through the barrier beach. Sediment dispersed into the lake forms the foundation for building future marshes and beaches. Non-barrier beaches move landward as the backshore is eroded. Where glacial deposits form the high backshore, new sediment can be eroded by wave run-up and added to the littoral system. This is not the case with barrier beaches which are backed by water.

Subtidal sand deposits have existed off Ingonish and Black Brook Cove beaches for more than 70 years and any changes to shoals or rock outcrops which confine these deposits could result in sediment dispersal alongshore, possibly into Ingonish Harbour and accelerated shoreline changes.

4. How do the magnitude and type of changes observed along the barrier beach portion of Ingonish Beach compare with changes occurring along other barrier beaches monitored in Nova Scotia?

Given similar exposure and wave conditions, wave impact on the stability of coarse barrier beaches is a function of the barrier elevation and size. The higher it is, the less wave overwash and beach migration that occurs. In comparison with other types of pebble-cobble barrier beaches surveyed in Nova Scotia, Ingonish Beach was higher, wider, and steeper. There was less wave overwash and more wave overtopping which is more constructive but barrier crest repair was slower because conditions which allow waves to reach such elevations occurred less frequently. There are a number of barrier beach types in the province as discussed on page 9 of this report. Type -1 and -2 barrier beaches are high, but Type -1 is wider, and Type-3 barrier beaches are low and frequently overwashed by waves. Figure 42 compares changes at three types of barrier beaches: Ingonish Beach (type-1) with Miseners- Long Beach (type- 2) and Cow Bay Beach (type-3) near Halifax. A type-3 barrier beach in the study area is Ingonish Harbour Beach.

The capability of Ingonish beach to rebuild after localized upper beach changes was very good but slow. Miseners- Long Beach retreated landward as sediment was transferred to its backshore (Fig. 42b, Table 12). Its capability of crest rebuilding is good but as its crest elevation decreases the beach may evolve into a more mobile type- 3 barrier. Both Miseners -Long Beach and Ingonish Beach are fringed by a sand where vertical fluctuations in sediment movement were similar (Table 12). Crest elevation along Cow Bay and Ingonish Harbour beaches has fallen below a critical elevation where wave overwash and landward retreat increases. Barrier retreat is also accelerated because of reduced sediment compaction which occurs with more mobile beaches. Typical rates of landward beach crest retreat over a 15 year period increased from 0.1 m/a for type-1 barriers, 0.5m/a for type-2 and 1 to 4 m /a for type-3 barrier beaches.

5) What physical aspects could be monitored to provide an indication of coastal health and stability?

There are a number of physical indicators that could be used to measure seasonal and longer term conditions along shores similar to Ingonish and Black Brook Cove Beach in the park.

a) An indicator of pebble -cobble barrier stability and vulnerability to landward migration is the condition of its crest and backshore. There are several ways to document backshore condition. Repetitive photography from the same location over time or conventional surveying can document the relative and actual elevation and longshore uniformity of the barrier crest. The higher, wider the beach crest and better its uniformity alongshore the better its long term stability. Another method is to monitor the seaward boundary of lichen- covered cobble clasts across the backshore. Changes in the boundary provide evidence of increased wave overwash from storms which indirectly provides evidence of reduced crest elevation and reduced beach stability. Lichen-covered cobble clasts are found along the backshore of the highest and most stable barrier beaches, e.g. central Ingonish beach. This coastal lichen environment is a unique and poorly documented environment within Atlantic Canada.

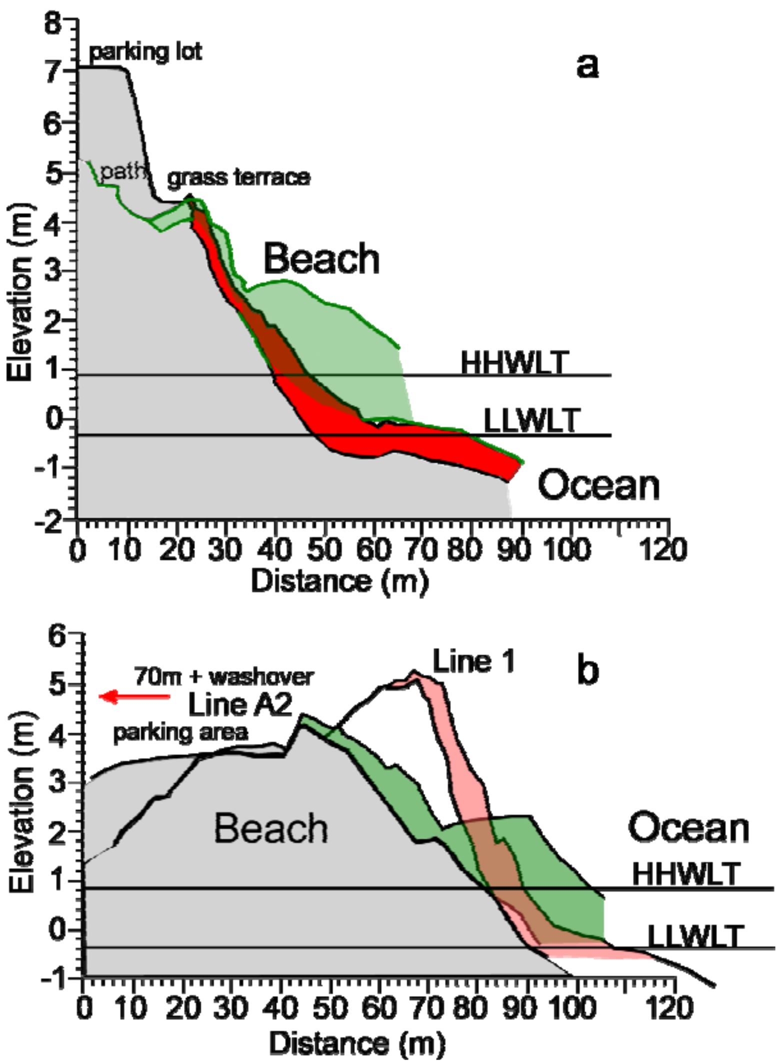

Figure 41. Sweep profiles of (a) two non-barrier beaches -Black Brook (red) and Ingonish (green) and (b) two segments of Ingonish Beach illustrating the horizontal and vertical limits of change observed during a 25 year period (1983-2008). Sediment was tossed higher (to the parking lot) at Black Brook Beach and only to just above the path at Ingonish beach because of trees and shrubs. For the beach lines shown in (b), A2 was flooded and covered by overwash deposits farther because of its low elevation. At line 1 the higher barrier was only impacted to just landward of its crest and sand accumulation was restricted farther seaward.

Table 12. A comparison of physical beach changes over a 15 year period at different types of gravel barriers (a) Type -1 Ingonish, Type -2 Miseners -Long Beach and Type- 3 Cow Bay and Ingonish Harbour beaches. Miseners and Cow Bay beaches are located just east of Halifax, NS.

Barrier Beach Type & Location	**Barrier Beach Crest**		**Vertical Adjustments in Sediment at Low Tide (m)**
	Landward Retreat (m)	**Elevation Change (m)**	
Type 1- Ingonish	1.7	0.2	1.0
Type 2- Miseners-Long	7.2	-0.3	0.8
Type 3- Cow Bay	57.0	-1.0	n/a
-Ingonish Harbour	25 to 38	-1.7	n/a

In conjunction with barrier crest observations it is useful to document the presence and size of backshore wave washover fans (lobe of sediment extending from backshore into lakes or lagoons). A change in the frequency and landward position of these sediment lobes provides an indication of barrier beach stability and rate of landward migration. Fewer washover fans and less change in landward fan position provide evidence of barrier beach crest rebuilding and increased barrier beach stability and/ or an absence of storms causing wave overwash.

b) A completely mixed composition of sand to boulder clasts across a backshore, e.g. Ingonish Harbour Beach, is an indication of recent reworking by high energy waves capable of moving the full range of sediment present. The presence of smaller discrete swash ridges with better sorted sediment indicates lower wave energy conditions competent of transporting only select sizes of material.

c) Where repetitive cross-shore surveys of a beach have been collected for many years they can provide the range of potential changes that can occur. Sweep profiles of beaches which mark the highest and lowest fluctuations in beach sediment movement over a specific time provide a reference for assessing future beach changes. If the change occurs outside the envelope of previous changes then it is considered abnormal and causes of the change should be investigated. Cross-shore lines already established across Ingonish and Black Brook Cove beaches (Fig. 41, Appendix 1, 2) provide reference sites for future surveys.

d) The presence of a wide, well developed sand berm across the upper foreshore zone is an indicator of sand movement onshore. The lack of a sand berm on our study sites is an indication that higher energy waves have transported sand offshore. The presence of a wide sand berm in late June along Ingonish Beach can be an indicator of better than usual beach sand conditions for the upcoming tourist season because storm conditions which remove sand are uncommon in July and August.

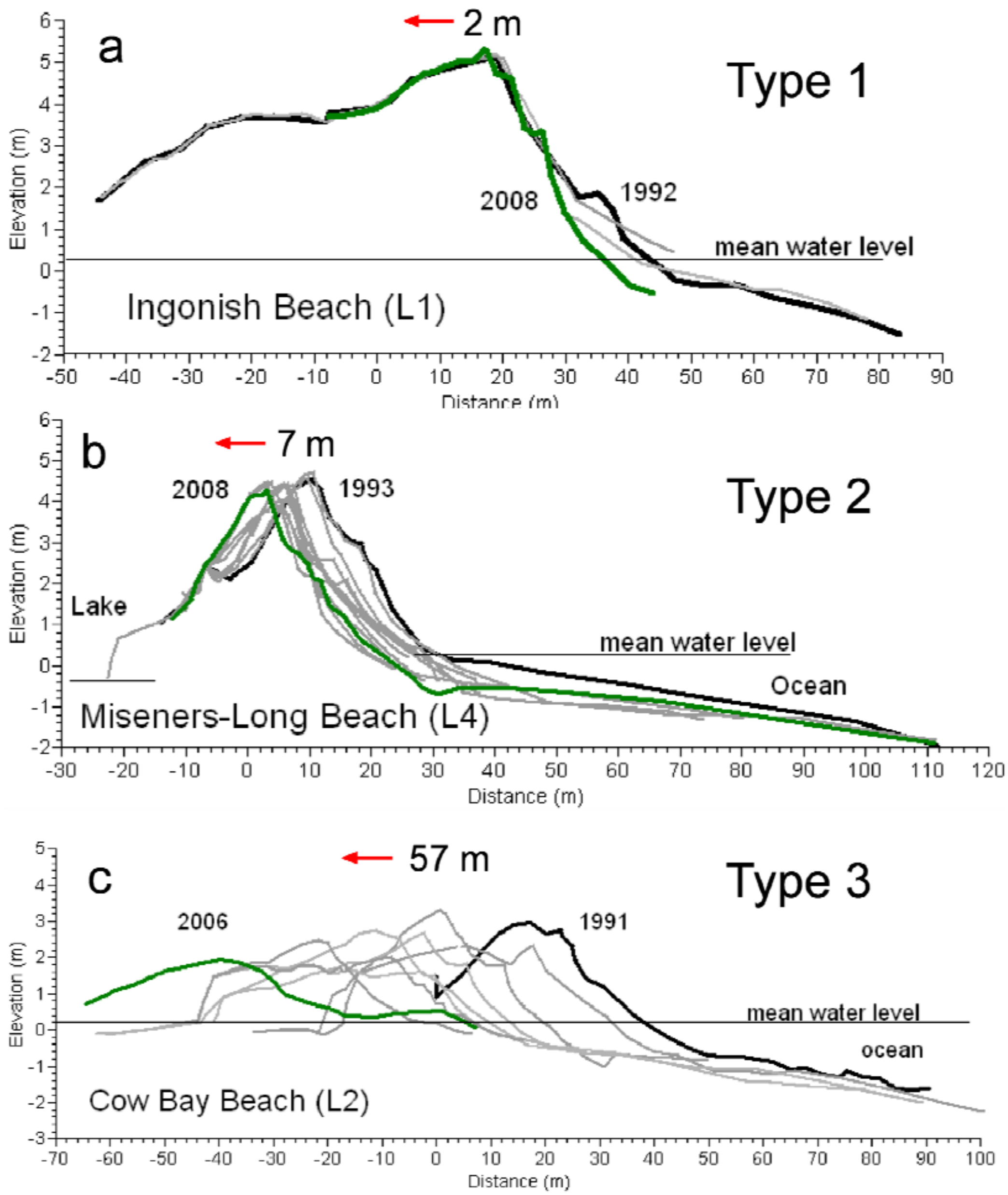

Figure 42. Rates of landward beach migration and their resilience to change can vary significantly for different types of gravel barriers. Barrier size, crest elevation and exposure to different process conditions, ie tidal range and waves, are critical factors. Changes at Ingonish beach are compared with two beaches located near Halifax, NS from early 1990s to 2006/08 (a) Type 1 -central Ingonish Beach crest changes were less than 2 m but natural rebuilding was slower (b) Type 2 Miseners Long Beach- short interval episodic retreat of 7 m but faster rebuilding and (c) Type 3-Cow Bay Beach rapid crest retreat of 57 m. Frequent wave overwash and less compacted material increased beach mobility, yet crest rebuilding was rapid. Ingonish Harbour Beach is a Type 3 barrier. It experienced rapid breakdown and retreat of 25 to 38 m until artificially reinforced in 2004.

6) What are some impacts of human interference on the natural coastal system and some practical applications the present study can offer for management of Ingonish and Black Brook Cove beaches?

In the 1970s and early 1980s there was an effort to force nature's hand by mechanically moving sand upslope for the enjoyment of the public. Although this was terminated in 1983 there are lessons to be learned from the practice. The action did mimic natural processes, but the sand was pushed too far upslope where wind could blow it inland. Furthermore, coarse material along the top of the beach was removed which weakened its core and made it vulnerable to wave overwash. This study confirmed that sand accumulates best where there is a more gradual beach slope and an embayed plan form, e.g. north Ingonish Beach, which is what Parks Canada was trying to create. However, the actions have had long term implications for the whole beach.

The elevation and distance upslope sand accumulates across Ingonish Beach and when it occurs was documented. In the event of a marine oil spill, information about seasonal sand accumulation provides shoreline clean-up crews with valuable information on how deep the oil could be buried when sand is moving onshore. The information also provides a reference for planning where and how long access boardwalks need to built. For example, at lines A and B (Fig. 4) the sand limit was an average of 23 to 25 m seaward of the beach ridge along the main parking area. At line C2, the sand began 27 m seaward from the walking path and when sand accumulation was higher in 1998 and 2002, the edge of sand was 23 m from the path.

Park infrastructure should not be built within the zone of storm surge flooding and wave reworking nor on present beaches. However if structures are present, i.e. picnic shelters, barbecue pits, recognition that they exist within a hazard zone is important so that appropriate funds are allocated for repair from storms and that plans for future infrastructure take into account the environmental changes predicted as a consequence of climate change, i.e. accelerated sea level rise.

Mechanical (human induced) changes to the upper beach and backshore have much longer impacts than mechanical changes across the lower beach. For example the crest and upper beach has not recovered to its pre-modified condition 26 years after the removal of coarse material was stopped. Also, removing the coarse component across the upper beach lowers the beach crest and increases the vulnerability of backshore areas to damage and flooding by wave overwash. Impacts from mechanical smoothing of Black Brook Cove Beach after the 1983 storm were erased as soon as waves reworked it.

At Ingonish Harbour Beach where the crest was less than 4 m high, the beach was migrating rapidly landward and becoming smeared out as a shoal. Observations have shown that wave overwash is reduced where the beach crest is higher, but there is difficulty in duplicating the consolidation of older natural beaches when raising crest elevations. At Ingonish Harbour Beach the crest was raised to near 4 m and the core of the beach was reinforced with armour rock before being covered with natural beach sediment. This action has proved effective for a number of years but such actions will always require maintenance over the long term as sea level continues to rise.

The presence and importance of offshore bars on wave dynamics in South Bay Ingonish and resultant upper beach morphological changes were highlighted in this study. Furthermore the configuration of the inner bar and the position of the horns extending onshore provided information of where the sand beach would be widest. This has implications for where temporary access boardwalks should be established.

The offshore bar and beach conditions in South Bay Ingonish are conducive for the development of rip currents which have been identified near the north end and near line 1 by a distinct change in the pattern of breaking waves onshore, a change in water colour (darker where rips exist) and a strong, seaward return flow of water from the beach. Increased awareness of rip currents and the posting of their presence increases public safety. Lifeguards should document which wave conditions produce rip currents their duration and where they most frequently occur.

CONCLUSIONS

- Ingonish and Black Brook Cove beaches are located at bayhead locations. Ingonish Beach is a barrier beach, the other is a non-barrier beach. Both beaches consist of mixed sediment from sand to boulder size-clasts. Both have a well defined separation of their surface sand and gravel components. The coarse component, ie the backshore and crest, provides the best indication of longer term shoreline change whereas the sand component is the best indicator of seasonal and daily change.

- Over the past 72 years (1936-2008) Black Brook Cove and Ingonish beaches have experienced a slow landward migration. Ingonish Beach has retreated 12 to 15 m and at one location as much as 21 m at high tide, ie. 0.3 m/a. Black Brook Cove Beach has narrowed slightly since 1936. These beaches are in a "dynamic" equilibrium with waves reworking them. By "dynamic" we mean that these beaches can experience significant local changes during specific storms but they can recover and restore their physical character as wave conditions change. Shores identified in a phase of disequilibrium, ie. experiencing larger scale beach retreat, include Beach Crossing Road shore and Ingonish Harbour Beach which retreated 43 m and 38-58 m (0.5 to 0.8 m/a) respectively at high tide level, since 1936.

- The massive size and height of central Ingonish Beach reduces its vulnerability to wave overwash and rapid shoreline migration. From 1983 and 2008 the barrier crest of Ingonish Beach and upper beach of Black Brook Cove migrated < 4 m landward while the northern part of Ingonish Beach has rebuilt seaward by < 2 m. The highest parts of Ingonish beach were impacted by storms in the fall of 1983, 1991 and 2000 and it took roughly 6 to 10 years for the beach crest to naturally rebuild after being cut into and lowered by waves. In contrast, Ingonish Harbour Beach is a very low gravel barrier which was pushed tens of metres landward by wave overwash. Since the beach was reinforced with armour rock and built higher in 2003-04 landward barrier migration has slowed. Black Brook Cove Beach, is subject to episodic wave attack at its upper limit but can rebuild and mask the retreat if sediment is locally available and has not been taken out of the littoral system or naturally transported longshore to adjacent shores.

- Seasonal fluctuations in sand accumulation across the lower beach can increase beach width by 10 to 20 m and a maximum of 36 m. The thickness of sand onshore varied from 1.2 to 2.2 m. Sand can accumulate on shore at any time of year in response to specific wave conditions, however it most often accumulates by late August and persists until late September -October when wave energy conditions intensify during the fall and winter. The onshore sand component buffers the backshore against wave attack, particularly during storms of short duration when not all sand is removed.

- Subtidal sand deposits are the source of sand found onshore. Sand deposits have been identified at the head of Black Brook Cove and the northern part of South Bay Ingonish since the first aerial photography in 1936. At Black Brook Cove the sand shifts within the cove in response to wave and river flow conditions. At South Bay Ingonish local topography and oceanographic conditions control the offshore bar complex. Rhythmic cuts in the beach crest, and formation of beach cusps and sand features onshore have a longshore spacing similar to the wavelength of the crescentic sand bars.

- Rip currents can develop along Ingonish Beach. When and how long the rips occur is not well documented. Rip currents can be extremely dangerous for swimmers. The potential occurrence of rips should be posted at the beach. When lifeguards are present, they should document when and where rip currents form along Ingonish Beach and what wave and offshore bar conditions exist at the time of their occurrence. Monitoring of rip currents would improve human safety and an awareness of the close relationship between offshore bar conditions and beach stability. At Black Brook Cove during periods of larger waves, there is a very strong offshore flow which we can attest to after our survey equipment was pulled away from us and carried quickly offshore in 2008.

- There is a requirement for national parks to develop indicators for measuring the health of different ecological environments. Physical indicators that could be used to measure seasonal and longer term conditions within coastal environments of Cape Breton Highlands National Park include: position of the seaward boundary of lichen-covered cobble along backshore of high barrier beaches; the frequency and size of backshore washover features; barrier beach crest elevation and continuity; upper beach sediment character; cross-shore profile relative to established sweep zones; and the timing of sand build-up onshore.

- Management of coastal resources is only effective if those making the decisions have an understanding of when and how the shores were built and their present evolutionary phase of development. Human manipulations of the upper beach, crest and backshore have not fully recovered after 26 years whereas modifications across the lower beach (excluding sediment extraction) were short lived where waves quickly readjusted the beach slope to natural conditions. Human interference with natural shorelines should be avoided but if necessary it should be completed with a full understanding of the negative and positive implications of the actions.

- To build a better understanding of future coastal stability, knowledge of beach stratigraphy and sediment reserves within South Bay Ingonish would provide the architecture that the beaches were built on or against, their age and an estimate of potential sediment supply available for future beach building. Documentation of the backshore lichen community found on high coarse barrier beaches, the species present, their growth rates and possible age, would increase our understanding of the largest coarse barrier beach structures in Atlantic Canada and a habitat that is quickly disappearing as sea levels rise and waves erase these unique habitats.

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APPENDIX 1

Beach surveys and geographical information needed for relocating and resurveying cross-shore lines established along Ingonish and Black Brook Cove Beaches, Nova Scotia.

Field surveys were completed from 1983 to 2008 by the Geological Survey of Canada (GSCA) at Ingonish Beach (Site 1512) and Black Brook Cove Beach (Site 1513), NS. Field survey data is archived with the authors at GSCA, Dartmouth NS.

Dates when field surveys were completed at Ingonish and Black Brook Cove beaches between 1983 and 2008. Observations included collecting visual and photographic evidence of shoreline changes and detailed surveys included a resurveying of some or all cross-shore beach lines, and since 1992 they included beach crest surveys along Ingonish Beach.

Date	**Ingonish Beach**		**Black Brook Cove Beach**	
	Observations	Detailed Surveys	Observations	Detailed Surveys
23-March-1983	✓			
24-Jun-1983	✓		✓	
02-Nov.-1983	✓	✓	✓	✓
14-June-1984	✓	✓	✓	✓
20-Aug-1985	✓		✓	
30-Jun-1987	✓		✓	
02-Aug-1987	✓			
26-Oct-1991	✓		✓	
03-June-1992	✓	✓	✓	✓
06-Oct.-1998	✓	✓	✓	✓
17-Oct.-2002	✓	✓	✓	
07-Aug.-2008	✓			
27-Oct.-2008	✓	✓	✓	✓

INGONISH BEACH

SITE NO.	SHORE TYPE	GEOGRAPHIC NAME	COUNTY	PROVINCE	NTS REF	HORIZONTAL DATUM	VERTICAL DATUM
1512	Beach	Ingonish Beach	Victoria	Nova Scotia	11K/9	NAD 83 Zone 20	ORTHOMETRIC

Beach Access: From Sydney, follow the Cabot Trail north along the east coast of Cape Breton. Just north of South Ingonish Harbour is Ingonish Beach. Follow the highway through the town and proceed 0.9 km past the stone gate house to CB Highlands National Park (information centre) and turn right at the sign for Ingonish Beach and Highlands Links Golf course. Turn right at the first road 0.2 km from highway and proceed to parking area at Ingonish Beach. Control BM HQ No. 6 is near the south edge of a soccer field. Line A2 is in the shrubs between the soccer field and north side of parking area and lines C2, 2, and 1 are farther south alongshore (Fig. A1-1).

SITE 1512 INFORMATION

LINE	MARKER TYPE	NORTHING (N83)	EASTING (N83)	ELEVATION	LATITUDE	LONGITUDE
A2	GSC 054	5169697.983	699635.350	3.375	46° 39.077	60° 23.447
1	GSC 052	5169173.847	699607.806	4.260	46° 38.798	60° 23.485
2	GSC 053	5169445.527	699642.764	4.304	46° 38.930	60° 23.457
C2	GSC 252	5169593.232	699660.097	5.456	46° 39.008	60° 23.442
NSBM28095	CAP	5168680.949	699596.425	7.190	46° 38.517	60° 23.516
HQ 6	PLATE	5169675.483	699575.558	4.007	46° 39.054	60° 23.506

Note: 2008 coordinate positions and elevations based on NS BM 28095 surveyed with Dual frequency RTK Differential GPS. Elevation (m) is the top of line markers

DISTANCE BETWEEN LINES:

LINE 1 TO LINE 2:	274 m
LINE 2 TO LINE C2:	149 m
LINE C2 TO LINE A2:	108 m
LINE A TO LINE B:	50 m
LINE B TO LINE C:	50 m

BENCHMARK HISTORY:

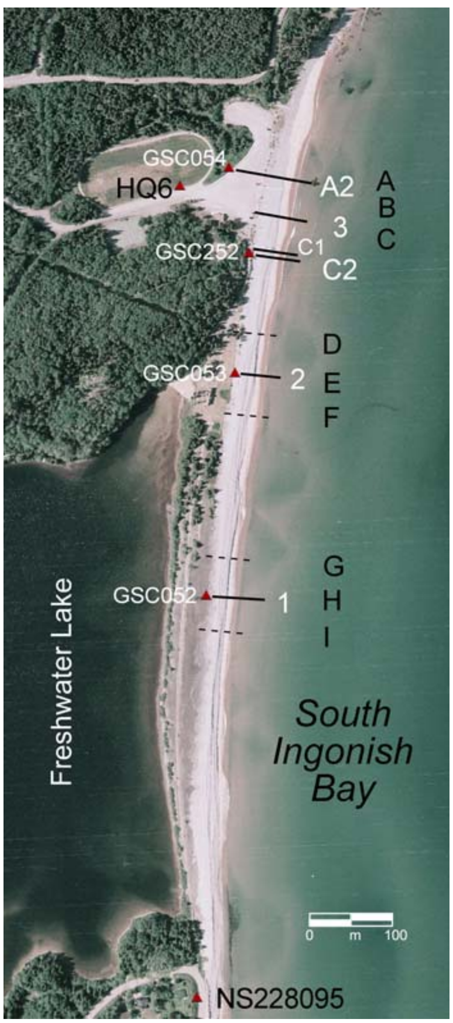
Three survey lines were originally established in 1983 by the GSC (lines 1, 2 and 3) and re-surveyed in June 1984. In late June 1984, the Parks Service established a set of 9 lines (A to I) along the beach (Figure A1-1). GSC Lines 1 and 2 corresponded to lines H and E respectively. Line B was established just beside line 3. The Parks Service lines were identified by 2x2 stakes. Lines D to I were not resurveyed after 1984. In 1992, GSC benchmarks (052, 053 and 054) were established on lines 1, 2 and A2 respectively. In 1998 boulder at line C1 was disturbed so established new Line C2 with GSC 252 just south of old line C1; BMs for line B(3) were not reestablished because the old bathing house was torn down.

Parks Canada Survey Lines

Line A survey starts 55m east of BM (BM=HQ6\) HQ No. 6 plate is located on playing field adjacent to parking area elevation 12.61 feet engraved in plate but is actually 4.007 m elevation. Line A is roughly same location as GSC Line A2. Line B survey starts 82 m east of a BM (HQ6). Line C survey starts 4 m south of pyramid rock with green stripe (BM Line C1) and 18 m seaward of BM (pyramid rock dislodged in 98). Parks Canada Line C was 4 m south of GSC Line C (Fig. A1-1).

Geological Survey of Canada Lines

Line 1: BM0 is lone spruce tree 8.9 m seaward of a path extending along the back of the barrier beach; and GSC 052 cap was established 11.71 m seaward of BM0.



Line 2: BM1 (Metal 3/8" rod=32 cm at side of tree stump) Tree stump is 17.4 m seaward of paved path and 3.8 m landward of seaward edge of grass. BM0 (GSC 053) 0.3 m lwd of BM1.

Line A2: BM1 (GSC 054) established 2.5 m landward of wood 2x2 in shrubs back of north side of parking area.

Line C2: BM1 (GSC 252) located at base of hill in alders landward of walking path.

Figure A1-1. Location of survey lines established along Ingonish Beach, NS. Red triangles mark the location of benchmarks. Black letters are Parks Canada and white letters are GSCA survey lines.

BLACK BROOK COVE BEACH

SITE NO.	SHORE TYPE	GEOGRAPHIC NAME	COUNTY	PROVINCE	NTS REF	HORIZONTAL DATUM	VERTICAL DATUM
1513	Beach	Black Brook	Victoria	Nova Scotia	11K/9	NAD 83 Zone 20	Orthometric

BEACH ACCESS: From Sydney, follow the Cabot Trail north along the east coast of Cape Breton. 15-20 km north of Ingonish (15-20 km) is Black Brook Cove. After crossing the bridge at Black Brook turn right onto the road leading to Black Brook Cove picnic area. Turn right at the "T"-junction and go to the south end of the parking area. The survey line was initially marked by 3 wood guard rail posts and by 1998 marked by 5 road posts which block access to the south end of the picnic area. The seaward road post is BM1 (Fig. A1- 2). Align beach survey line with the 5 posts.

SITE INFORMATION (2008):

LINE	BM TYPE	Northing (NAD83)	Easting (NAD83)	ELEVATION
1	Wood Post	5183713	703572	7.02

Note: All elevations are based on water level surveyed in 1992 and corrected to geodetic using -0.456 m based on Aspy Bay survey data. Positions Obtained Using 2D GPS (hand -held Garmen).

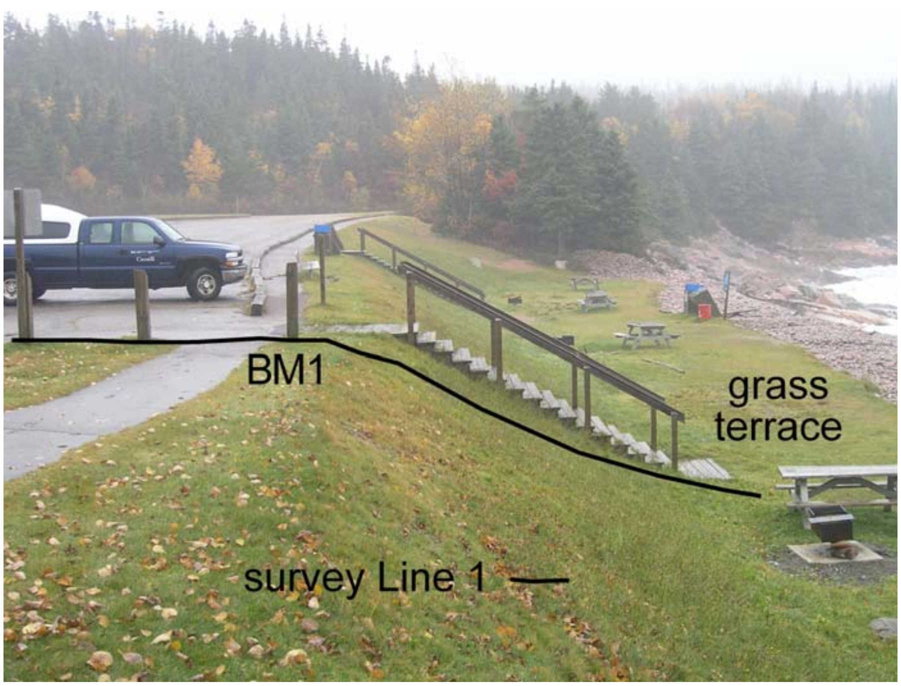


Figure A1-2 showing the location of beach survey line 1 at Black Brook Cove Picnic site. The survey line is aligned with the five wood posts.

APPENDIX 2

Plots of repetitive surveys completed at Ingonish and Black Brook Cove beaches from 1983 to 2008

Ingonish Beach

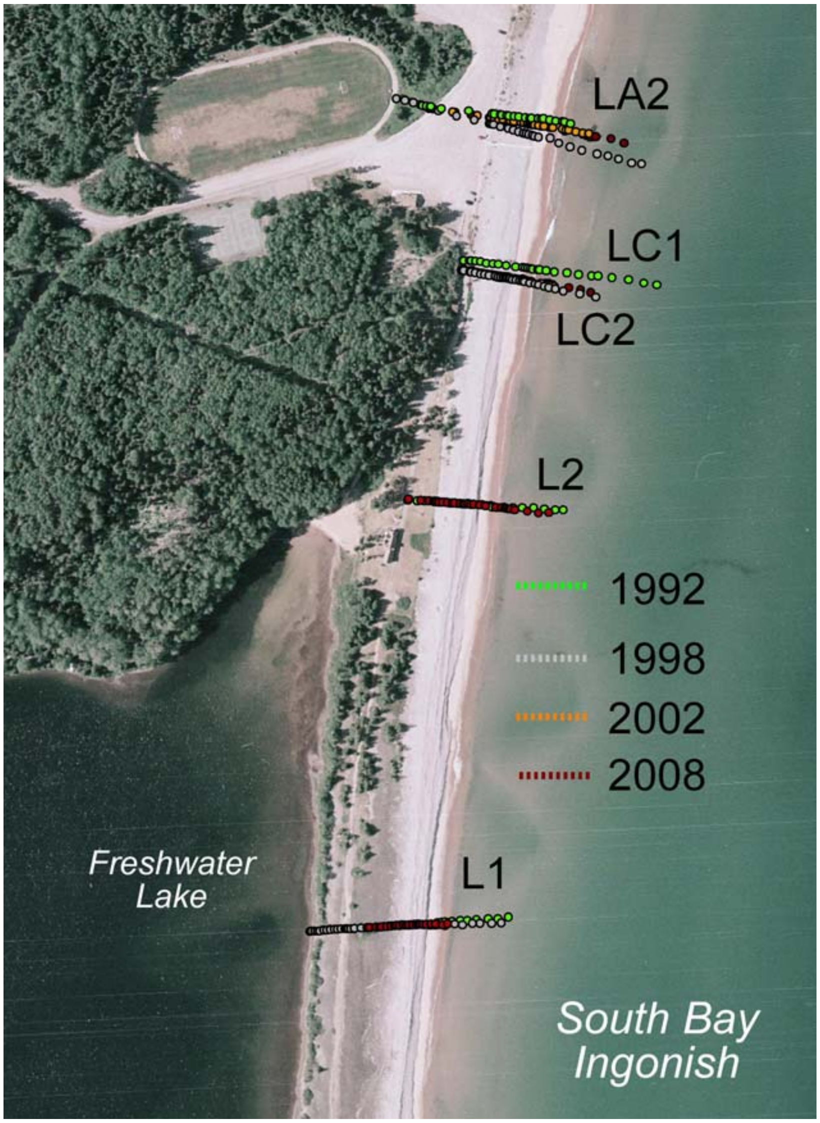


Figure A2-1. Positions of repetitive surveys across Ingonish Beach from 1992 to 2008 showing the seaward extent of each survey and its position relative to others. Where the alignment of repetitive surveys is good the determination of physical change is most accurate. Problems of alignment were worst toward the seaward end of Line A2.

Repetitive surveys of cross shore lines established at Ingonish Beach showing net physical changes between (a) 1983-1984 (b) 1984-1992, (c) 1992-1998 (d) 1998-2002 and (e) 2002 - 2008. The location of survey lines is provided on Fig A1-1, Appendix 1.

Figure A2-2a-c Ingonish Beach (1983-1998)

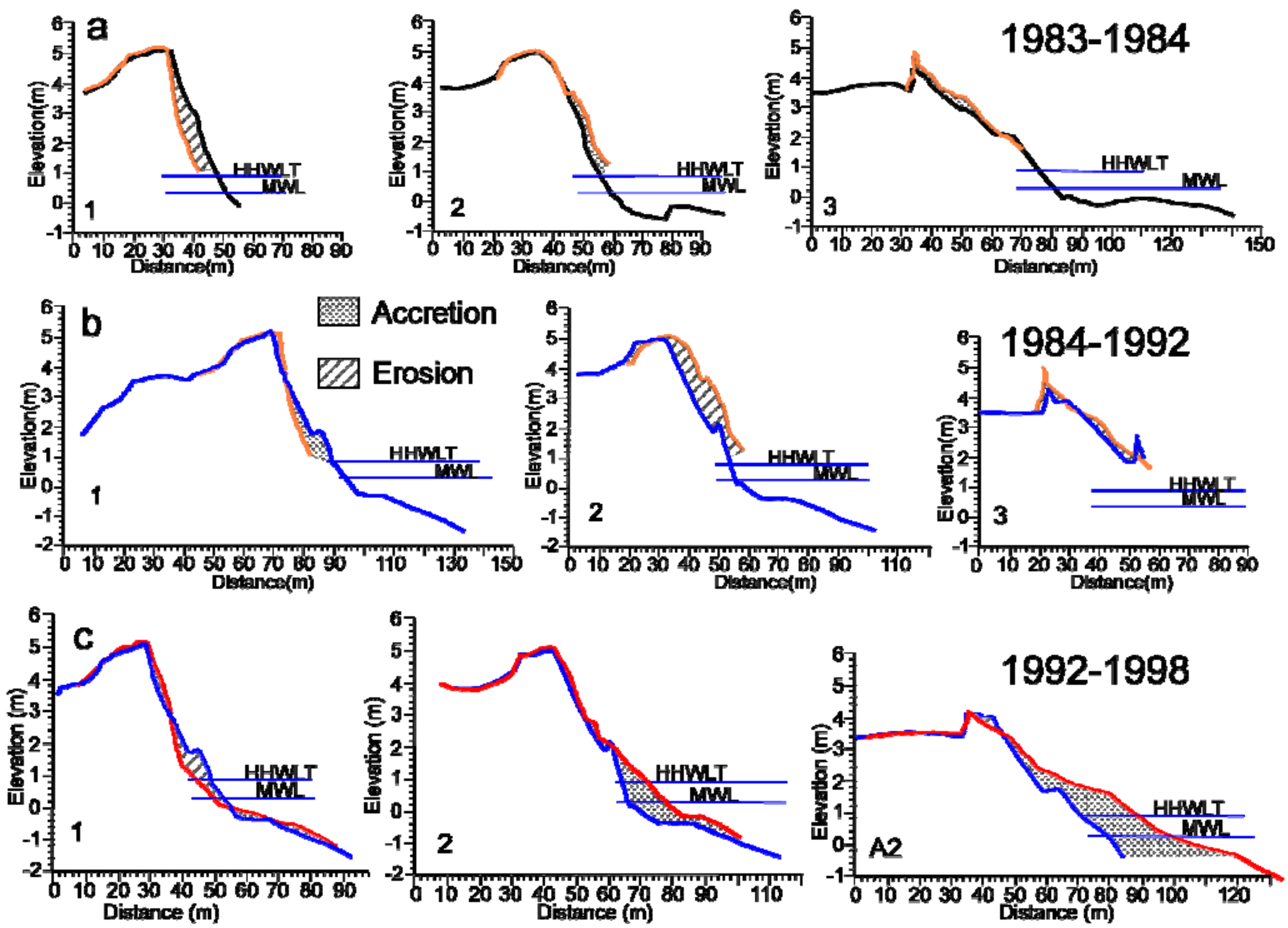


Figure A2-2d Ingonish Beach (1998-2002)

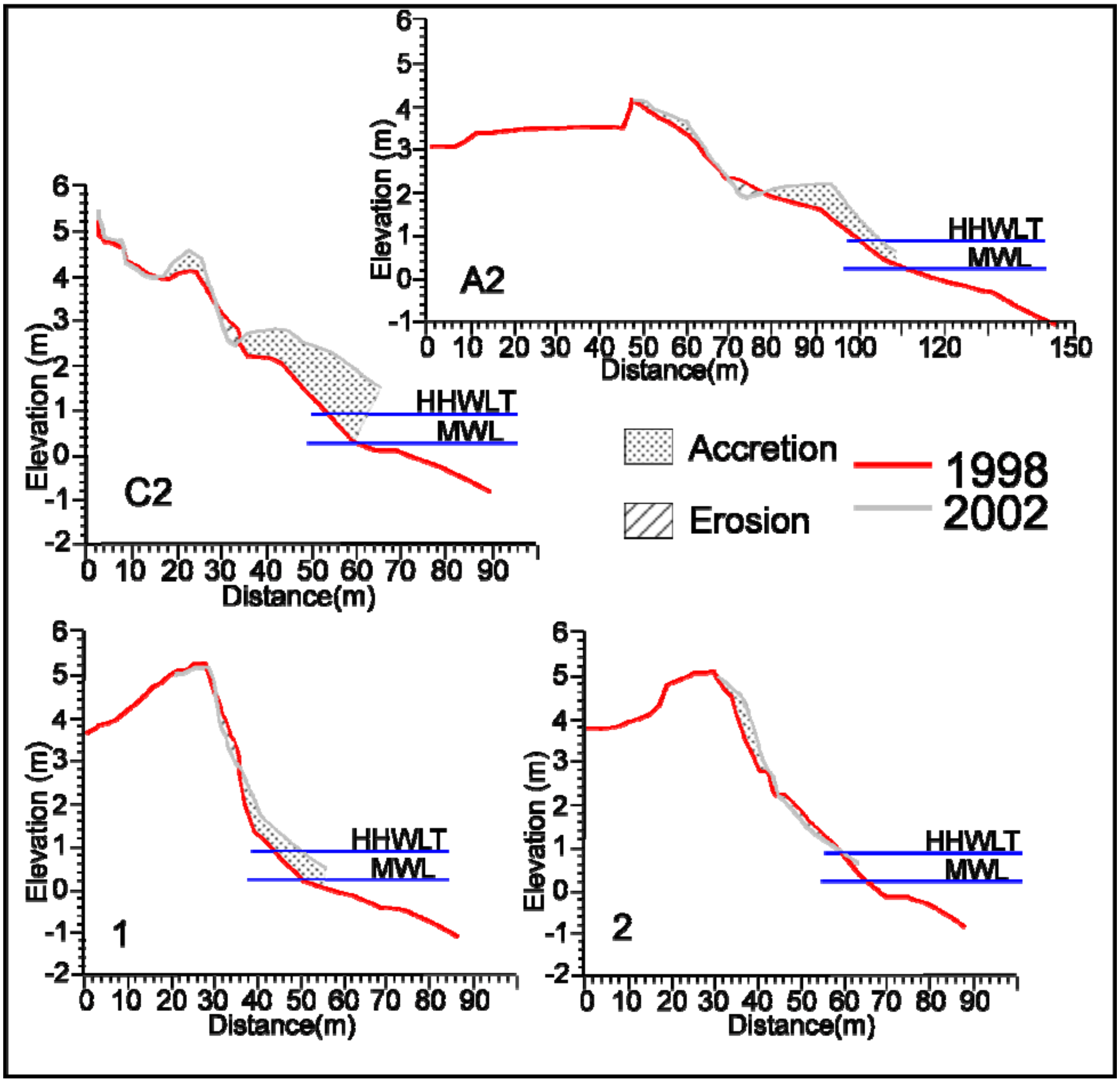
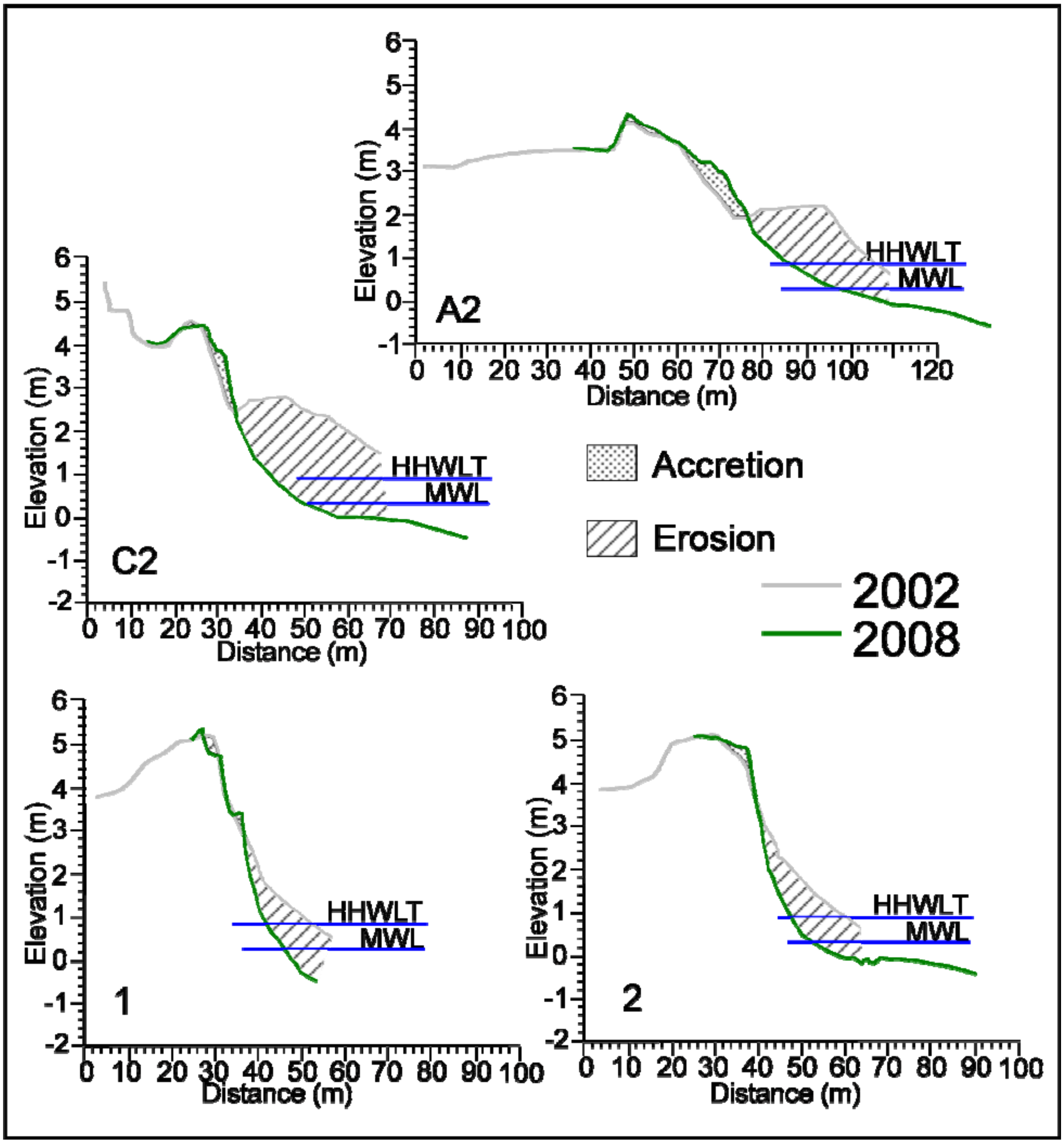
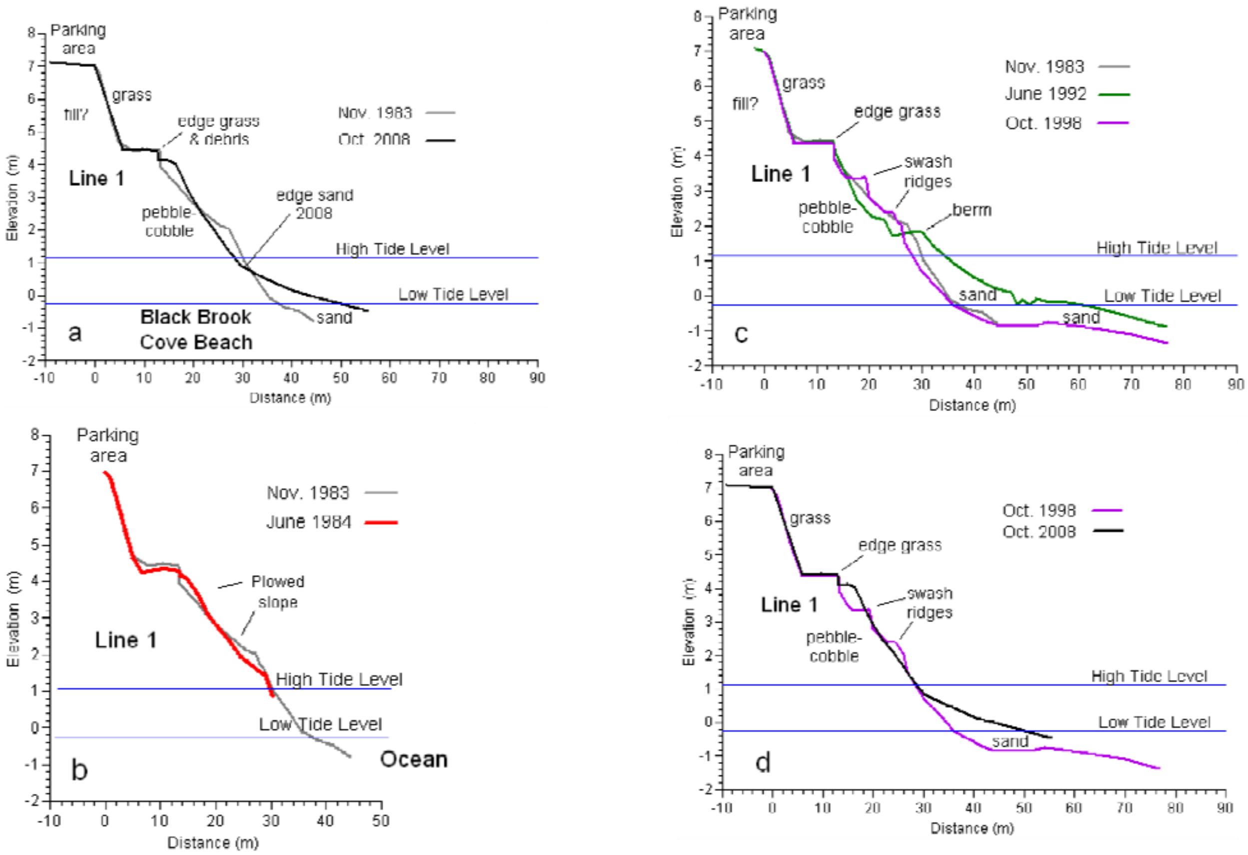


Figure A2-2e Ingonish Beach (2002-2008)



Black Brook Cove Beach

Figure A2-3. Repetitive surveys of Black Brook Cove Beach at line 1 showing (a) net change between 1983 and 2008, (b) beach recovery and manipulation by June 1984 after the October 1983 storm, (c) beach changes during the 1990s compared to 1983, and (d) net beach changes between 1998 and 2008.



APPENDIX 3

Vertical air photos used in the analysis of shoreline changes from 1936 to 1999 along South Bay Ingonish and Black Brook Cove, NS.

Air photos from South Bay Ingonish were georeferenced against digital provincial 1:10,000 scale maps using ARCINFO.

South Bay Ingonish

Date	Time (GMT)	Photo Numbers	Scale	Film Type	Source
21-July-36	no data	A5425-4	1:15,300	Black & White	NAPL
15-Oct-66	no data	A19640-99	1:14,500	Black & White	NAPL
24-June-69	12:40-12:43	A30201-63	1:15,840	Black & White	NS Geomatics
May-June 75	no data	75303-182,244	1:12,700	Black & White	NS Geomatics
09-July-93	12:06	93366-27	1:10,000	Colour	NS Geomatics
13-Aug-94	no data	HM94033-64,65	1: 4,000	Colour	Parks Canada
11-June-99	20:00-20:08	99311-109, 53	1:10,000	Colour	NS Geomatics

Black Brook Cove Beach

Date	Time (GMT)	Photo No.	Photo Scale	Film Type
23-July-36	no data	A5430-57, 59	1:15,000	B&W
15-Oct-66	no data	A19792-29, 30	1:20,000	B&W
18-July-69	11:53-12:00	30206-48, 49	1:15,840	B&W
03-Sept-99	16:05-16:10	99327-150,151	1:10,000	Colour

APPENDIX 4
List of storms known to have impacted northern Cape Breton Island, Nova Scotia from 1983 to 2006.

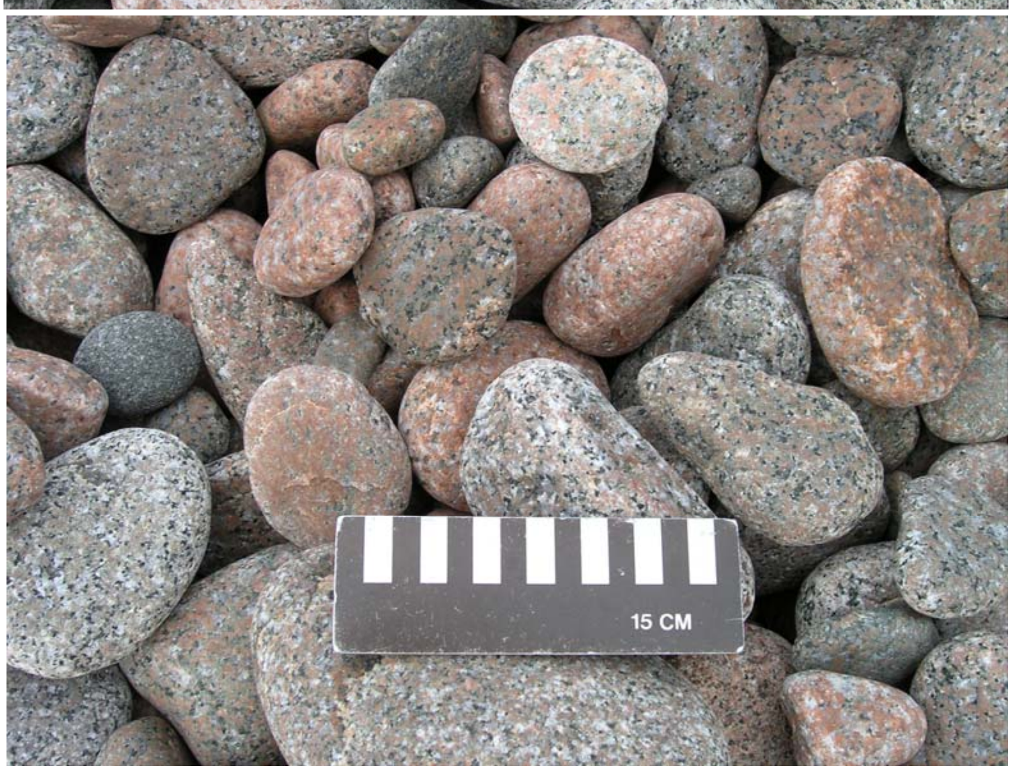
(Impacts to South Bay Ingonish and Black Brook Cove were only documented for storms in bold).

October 25, 1983	Northeaster -high winds exceeded 50 km/hr at Ingonish, high waves & storm surge 0.76 m at N. Sydney (Taylor and Kelly, 1984)
October 28-30, 1991	Halloween storm Northeaster -high winds and seas, storm surge at Sydney but near low tide.
February 2, 1992	Sea ice event and storm surge sea ice remained alongshore until May 1992
December 30, 1993	high sea levels produced off Cheticamp
September 14, 1996	Hurricane Hortense high winds- reach 161 km/hr surge ~0.75 m at N. Sydney near high tide
July 12, 1998	surprise storm strikes lobster fishermen in east CBI
January 21, 2000	high sea levels at Cheticamp
October 28-29, 2000	high rain and flooding along Cabot Trail, large debris at Ingonish Beach and high sea levels at Cheticamp
October 28, 2002	heavy rains, 58 mm in Ingonish
December, 2003	storm nearly breaches barrier beach at Ingonish Ferry (Carey Geoenvironmental Engineering 2004).
September 20, 2004	Northeaster, remnants of Hurricane Ivan, 6-8m waves Cabot Strait, 120 km/hr winds at St Paul Is. heavy rain falls, Queen Mary 2 cancels stop in Sydney
December 27, 2004	large snowfall and high sea levels off Cheticamp
February 1, 2006	Louisbourg and highlands impacted e.g. Beach Crossing Road (J. Bridgland, pers. comm.) -very high winds and snowfall of 44 cm Sydney.

APPENDIX 5
Photos of beach sediment used to measure clast sizes at cross-shore survey lines, Ingonish and Black Brook Cove Beaches, NS.

Photos were taken in October 2008 of sediment at cross-shore survey lines, at Ingonish Beach, NS. Clast size measured from photos is provided in table 4 of the report.

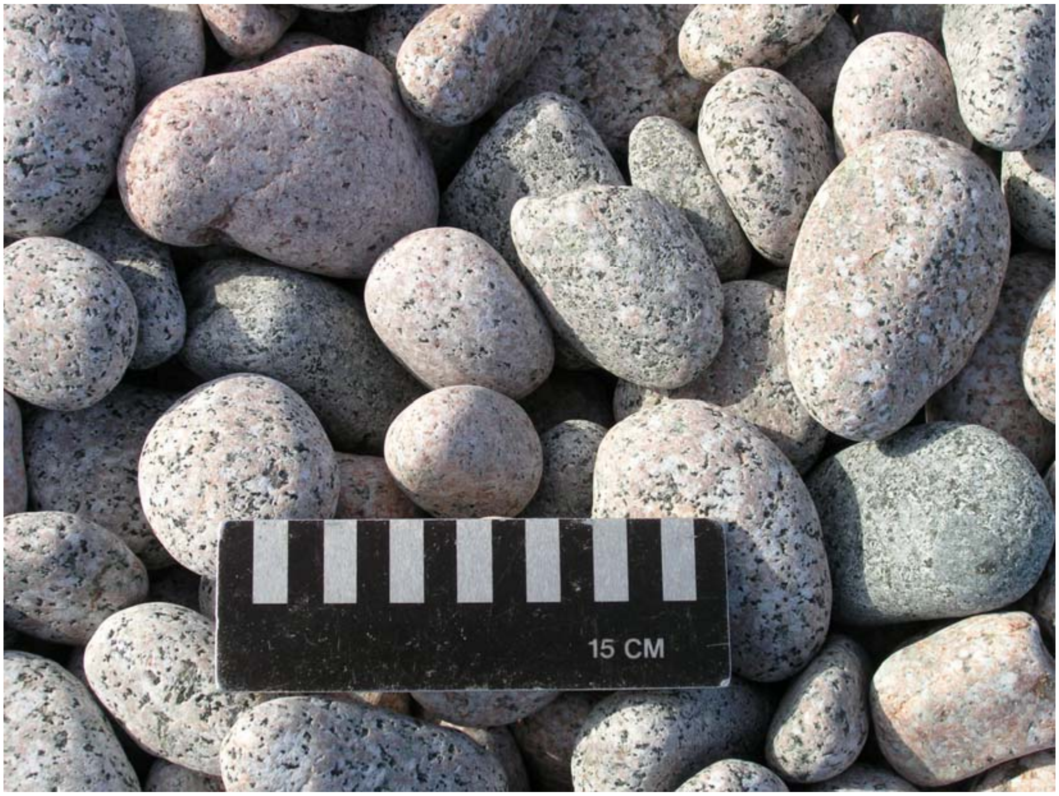
Line 1
Beach Crest
(PA 273291)



Line 1
High tide swash ridge
(PA273292)

Line 2
Beach Crest
(PA273306)

Line 2
High Tide level
(PA273307)



Line C2
Beach Crest
(PA303570)

Line C2
High Tide Level
(PA303569)

Line A2
Upper Beach
(PA303572)

Line A2
High tide level
(PA303571)

Photos were taken in October 2008 of sediment at Line 1, Black Brook Cove Beach, NS. Clast size measured from photos is provided in the text.

Line 1
Storm Ridge
(PA 283343)

Line 1
High Tide level
(PA283342)

APPENDIX 6

Seasonal sand accumulation measured by Parks Canada from 1984 to 1992, at lines A to C, Ingonish Beach, Nova Scotia.

Line A	Berm		Sand Elevations and Thickness (m)		
Year	Width (m)	Elev. (m)	* Distance From Backshore	Max. Lwd Elev. (m)	Thickness at Swd Berm Edge
Aug-1984	21	2.0	24	2.10	1.6
July-1987	9	1.8	27	1.97	0.9
July-1988	15	1.6	27	1.92	0.4
Aug.-1989	15	2.0	24	1.87	1.4
Aug-1990	15	2.2	24	2.06	
Oct.-1991	21	2.0	21	2.33	
Sept. 1992	36	1.9	24	2.32	1.3

* Distance from top beach ridge at parking lot to landward edge of main sand deposit

Line B	Berm		Sand Elevations and Thickness (m)		
Year	Width (m)	Elev. (m)	* Distance From Backshore	Max. Lwd Elev. (m)	Thickness at Swd Berm Edge
Aug-1984	24	1.9	21	2.2	1.5
July-1987	15	1.7	21	2.1	1.3
July-1988	15	1.6	24	1.9	1.0
Aug.-1989	21	2.1	21	2.2	1.8
Aug-1990	18	1.8	21	2.0	1.3
Oct.-1991	21	1.9	21	1.9	1.7
Sept. 1992	12	1.9	30	2.1	0.6

* Distance from top beach ridge at parking lot to landward edge of main sand deposit

Line C	Berm		Sand Elevations and Thickness (m)		
Year	Width (m)	Elev. (m)	* Distance From Backshore	Max. Lwd Elev. (m)	Thickness at Swd Berm Edge
Aug-1984	18	2.0	27	2.1	1.2
July-1987	12	1.7	27	2.0	0.9
July-1988	3	2.0	27	1.8	0.8
Aug.-1989	15	2.0	27	2.2	1.1
Aug-1990	12	2.1	27	2.3	0.7
Oct.-1991	12	2.0	27	1.8	
Sept. 1992	18	1.6	27	2.4	1.0

* Distance from seaward edge of walking path to landward edge of main sand deposit

lwd -landward swd -seaward

APPENDIX 7

Glossary of Select Terms Used in the Text

backshore The upper beach zone above high tide level which is reworked by waves or covered by water only during exceptionally severe storms or unusually high tides

barrier beach is a beach backed by water or wetland, e.g. marine or freshwater, whereas a non-barrier beach is backed by a rising backshore of rock and/or sediment.

break-up is when sea ice disappears in a given coastal area.

chart datum is a plane below which the tide will seldom fall which is the plane of lowest normal tides.

foreshore or intertidal zone The lower beach zone regularly covered by the rise and fall of the tides, ie. between ordinary high and low tide levels.

freeze-up is the time when sea ice appears in a given coastal area.

nearshore is an indefinite zone extending from low tide level seaward from the shoreline commonly to depths of less than 20 m.

overwash a mass of water representing part of the wave uprush that runs over the top of the beach usually during storms or exceptionally high tides.

prograding shoreline*:* A shoreline that is building outward into a sea or lake by sediment deposition and accumulation.

significant wave height (Hs) is the average height of the one-third highest waves of a given wave group.

swash-aligned barrier beach is a beach that is aligned near right angles to the prevailing direction of waves.

swash ridge is a ridge built by waves near the limit of wave uprush.

washover material is sediment deposited by the action of wave overwash, usually as an extensive cover across the backshore or in the form of small lobes on the landward side of barrier beaches.

Abbreviations
CGVD28: Canadian Geodetic Vertical Datum 1928
HHWLT: Higher high water large tide
LLWLT: Lower low water large tide
MWL: Mean water level

NOTES