Coastal Stability and Flooding at Grand Étang Fortress of Louisbourg Nova Scotia

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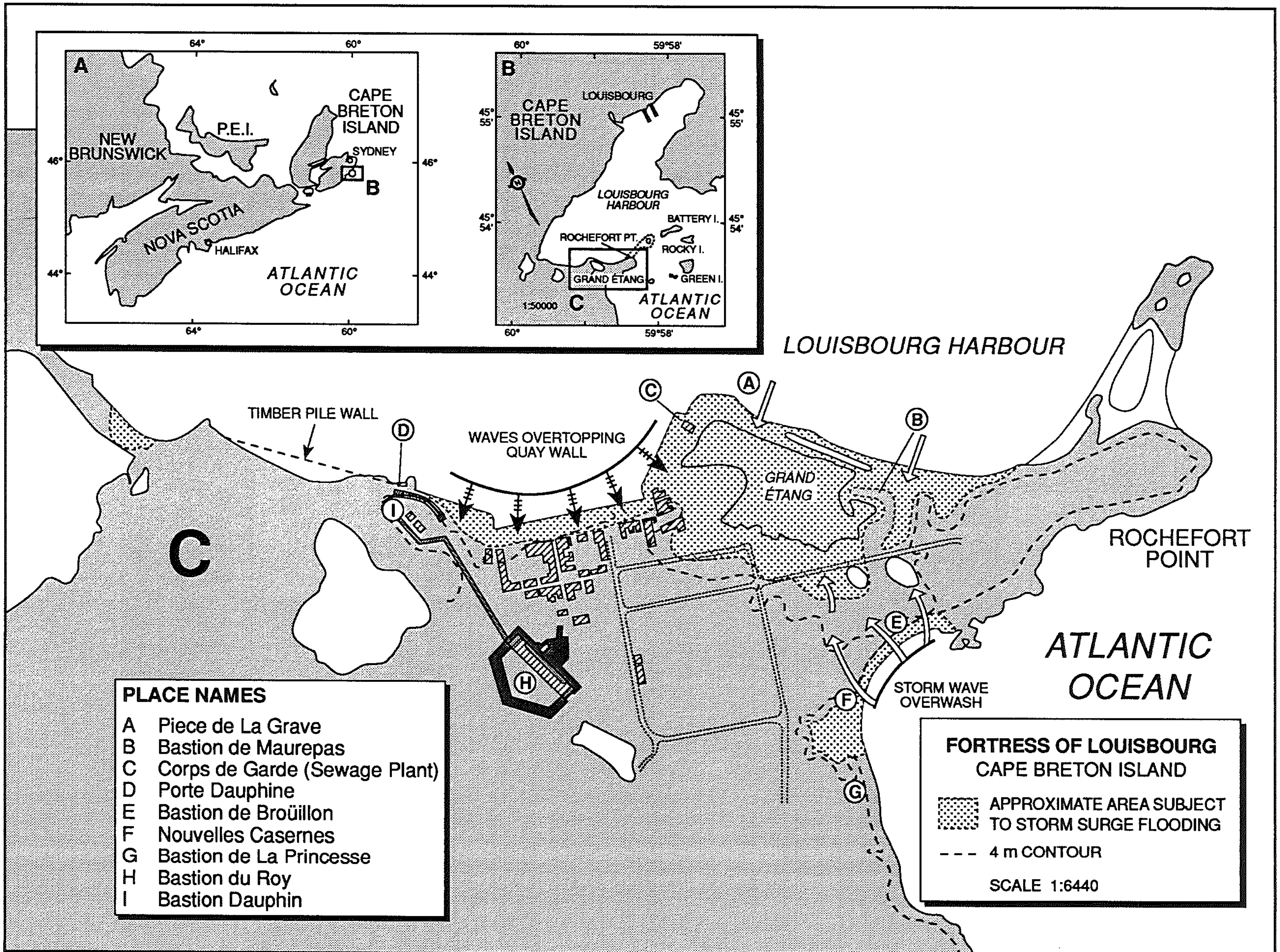
ABSTRACT

A snow storm with strong northeasterly winds struck Cape Breton Island and Louisbourg on February 1, 1992. Large waves and loose sea ice pounded the seawalls and overwashed the small gravel barrier beach at Grand Étang, causing widespread flooding of the lower fortress. Flood levels of 3.32 m above Hydrographic chart datum were recorded, the highest since the flood of November 1976. A lowering of the beach crest at Grand Étang barrier has increased the potential for even greater flooding and damage to operational facilities at the fortress. An analysis of past flooding events shows that they occur mainly during fall and winter northeasterly storms. Flooding occurred when sea level reached 2.1 to 2.27 m (above chart datum) at Louisbourg. The higher sea level was the consequence of strong northeasterly winds, storm surges of more than +0.6 m, and large, long period deep water waves. This report describes the morphology and evolution of Grand Étang barrier beach, flooding events and addresses the question of rebuilding Grand Étang beach versus alternate solutions to the flooding problem.

INTRODUCTION

Extensive flooding of Grand Étang and several buildings in the lower part of the fortress of Louisbourg occurred during a storm on January 31- February 1, 1992. Most of the flooding was attributed by Parks staff to wave overwashing of the barrier beach which fronts Grand Étang, and to a lesser extent, overwashing and wave spray through the cales in the quay wall (Fig. 1, 2). A post-storm beach crest survey of the western part of Grand Étang barrier showed that it had been lowered by 0.1-0.5 m (0.3 to 1.5 ft) along a 60 m (200 ft) wide zone of wave overwash (Fig. 2, 3). Since the barrier beach protects Grand Étang from the sea, questions were raised about its stability and the potential for its complete failure if another major storm occurred. Water damage to historic and operational buildings was a primary concern of park officials. Flooding of the sewage plant (Corps de Garde, Fig. 2a) and its shut down following a late spring or summer storm, would have a major impact on park operations during the peak tourist season.

Figure 1. Location and site maps of the fortress of Louisbourg with place names referred to in the text and the approximate area subject to flooding when sea levels reach 3.3 m (11 feet) above chart datum as they did in November 1976 and February 1992 (from Fig. 5, PWC, 1985).



Public Works Canada applied for funds from the federal government to reinstate the barrier beach to pre-storm elevations. Their immediate plan was to add coarse (200-300 mm) non-beach granular material to the beach crest. The material would then form the foundation of any larger flood protection structure that might be added in the future, if warranted by increased flooding. In the meantime, park officials became concerned about the proposed flood protection plans, especially the introduction of non-beach material to Grand Étang beach. They were worried about both the short and long term effects of the plans on the integrity of the barrier beach and the archeological resources of the site. They questioned whether: 1) if left alone, the barrier beach would re-establish itself naturally? 2) if the beach was not restored, would a channel form through it and allow the sea to enter Grand Étang, causing accelerated flooding and damage? and 3) if large shore protection material was introduced to the beach would it upset the stability and dynamic equilibrium of the beach and cause other negative, ie erosion, affects to the barrier or other locations alongshore? Public Works Canada (PWC) sought advice on these issues from the Coastal Group at the Atlantic Geoscience Centre, a division of the Geological Survey of Canada (GSC). A one day visit was made by the author and Alan Anderson (Public Works-Parks Canada, Halifax) to Louisbourg on March 9, 1992. The following report is based on a brief onsite investigation and meeting with Parks Canada officials, and background information derived from a variety of sources including information provided by Public Works Canada staff at the fortress of Louisbourg.

GRAND ÉTANG BARRIER BEACH

Background

Grand Étang barrier is a sandy-gravel beach which links a corner of the Quay walls at Piece de la Grave to the shores of Rochefort Point, the western headland of Louisbourg Harbour (Fig. 1). Rochefort Point is a low headland composed of a variable thickness of till (0-7 m) over bedrock. Several rocky islets including Battery Island, Rocky Island and Green Island lie just offshore of the headland (Fig 1, inset). A gravel shoal extends offshore from Rochefort Point to Battery Island, partially sheltering the Grand Étang barrier from direct wave attack from the south.

Figure 1 is taken from a site map of the fortress of Louisbourg which was based on 1961 aerial photography. Elevations on the site map, as well as the survey data provided by PWC, were in imperial units. Beach survey data was relative to Geodetic datum which is equivalent to present mean sea level. Geodetic datum is

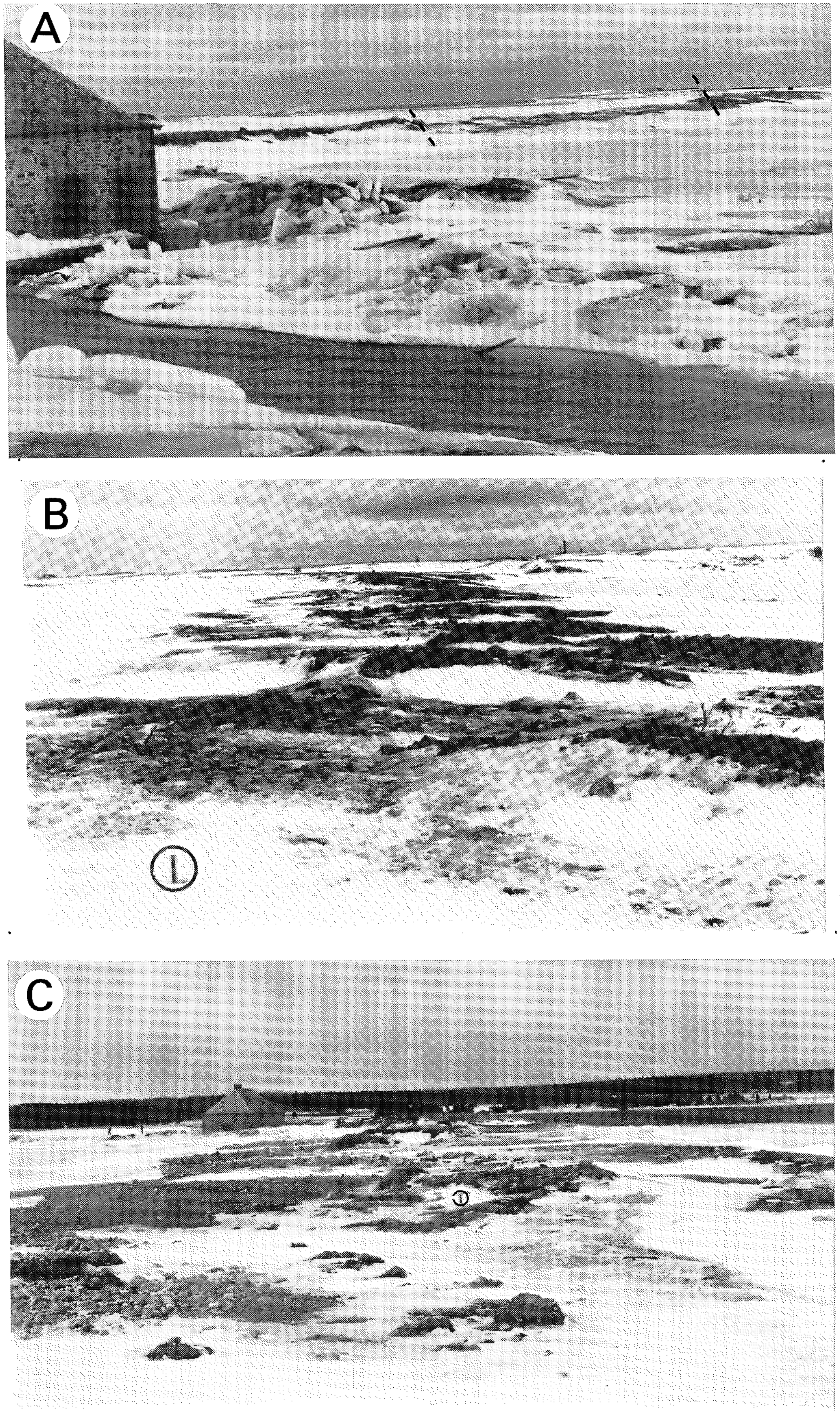
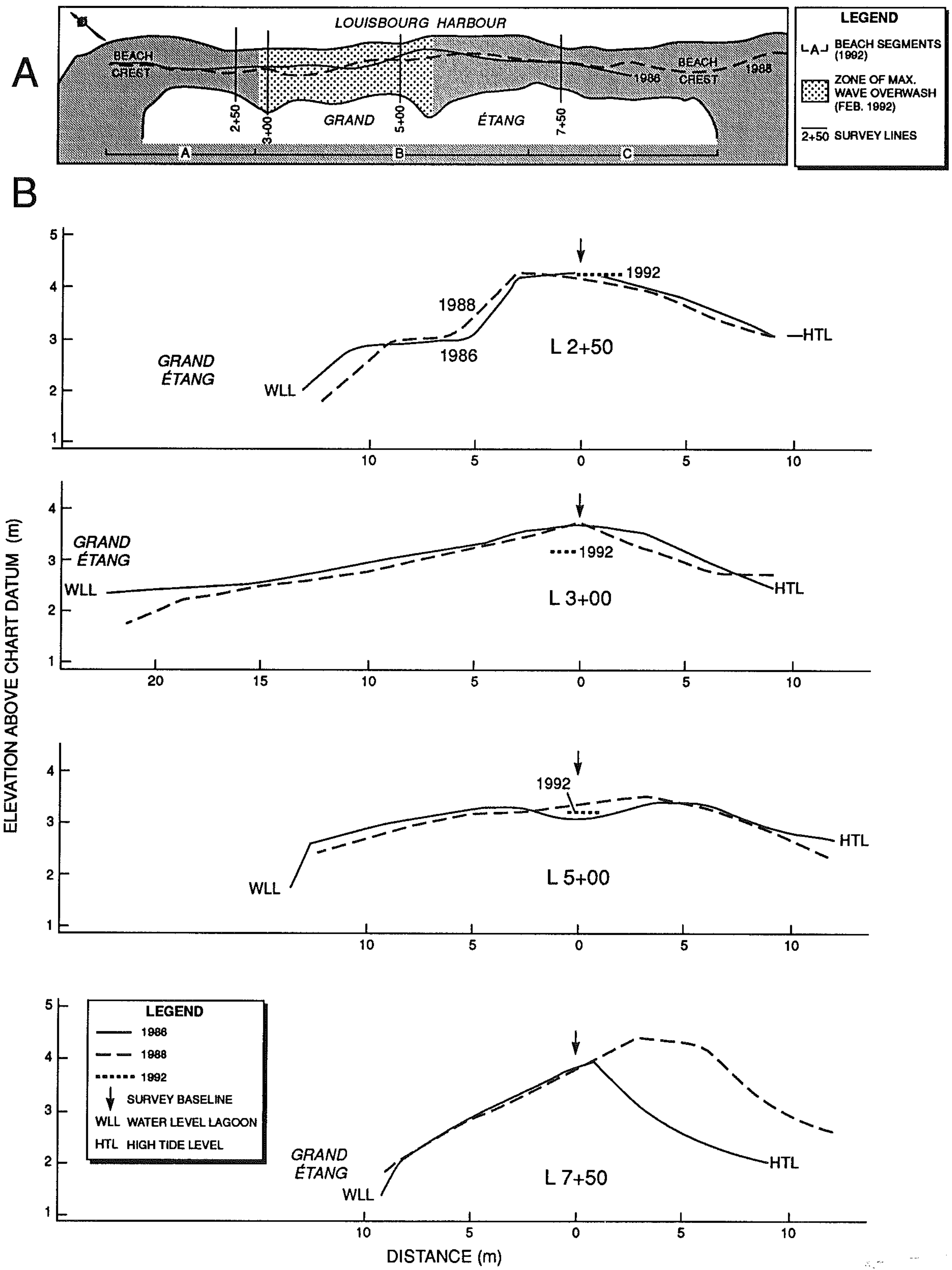


Figure 2. (a) View from the Quay wall of Corps de Garde (Sewage plant) at left and the backshore of Grand Étang barrier beach. The section of beach cut down during the February 1992 storm is outlined by dashed lines. Views toward the south (b) and toward the north (c) of the overwashed central section of Grand Étang barrier showing its degraded crest morphology following the February 1992 storm (photo - March 9, 1992). The wooden stakes (circled) mark the baseline of the 1992 survey.

Figure 3. (a) Plan map of Grand Étang barrier beach showing the three morphological zones observed in 1992, changes in beach crest position between 1986 and 1988, and location of cross-beach survey lines. (b) Cross-sectional beach surveys at selected lines showing the changes in beach morphology between 1986 and 1988. Elevations measured along the baseline after the February 1992 storm are marked on lines 2+50 to 5+00. Beach progradation at line 7+50 is attributed to the addition of dredged material in June 1987.



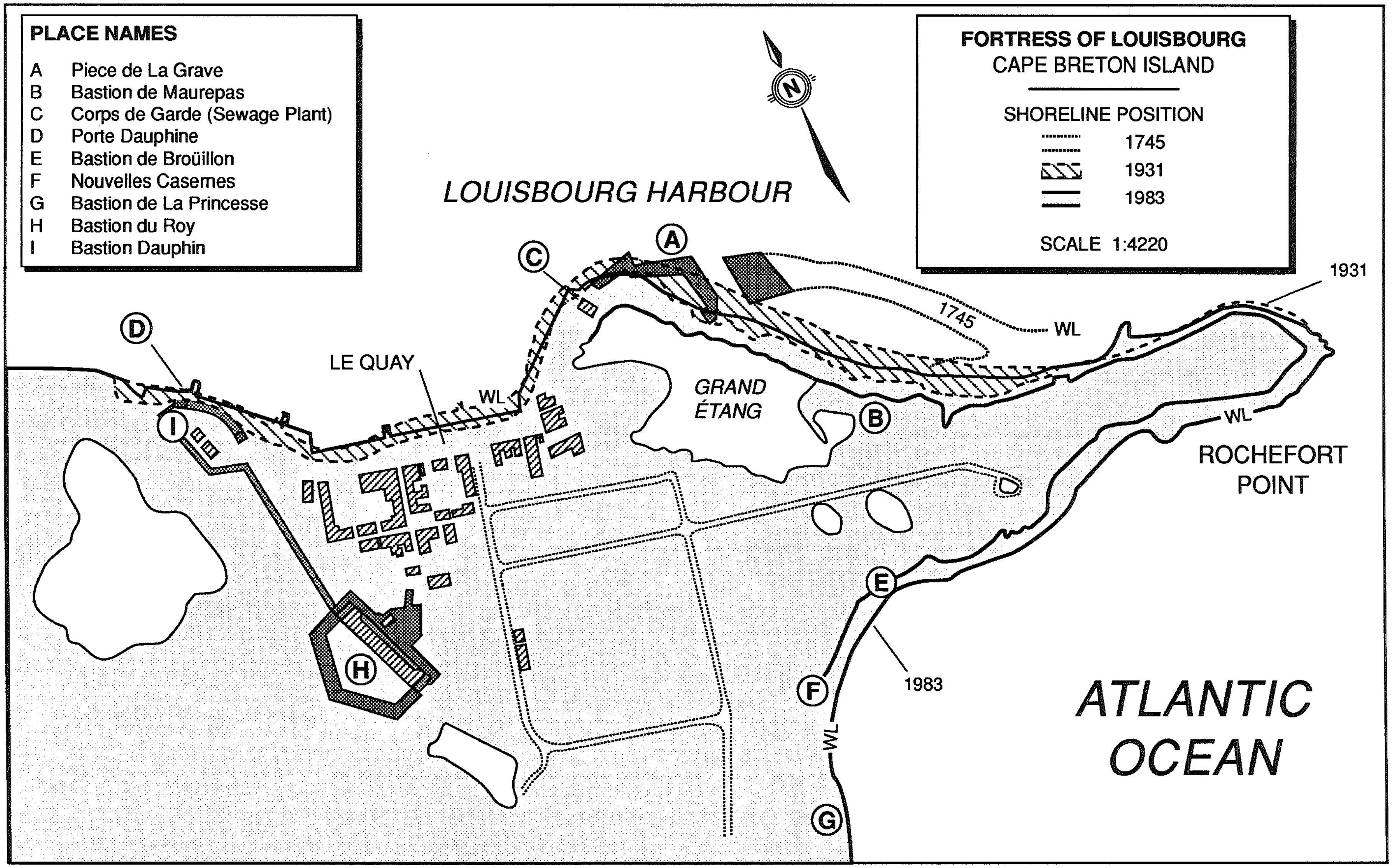
0.91 m (3 ft) above Hydrographic chart datum which is equivalent to present lower low water. In 1720, chart datum was 0.90 m (2.956 ft) below present chart datum, calculated on the basis of relative sea level rise (PWC, 1985). Baseline and cross beach surveys of the Grand Étang barrier were collected by Public Works Canada in 1985, 1986, 1988, and a partial baseline survey was completed following the storm on February 1, 1992 (Fig. 3). These surveys provide the bulk of the information presented in this report. All information has been converted to metric units in this report; however, imperial units are included. Elevations cited are relative to Hydrographic chart datum (lower low water).

It is worth mentioning at the outset that the changes in beach morphology observed at Grand Étang beach are the result of both natural and man-induced activities. For example, plans of the fortress in 1745 show an artificially constrained channel or sluiceway cut through Grand Étang barrier at Piece de la Grave (Fig 4). Today there is only a narrow sluiceway that joins Grand Étang to Louisbourg Harbour just west of Corps de Garde (Fig 1). During restoration work on the fortress in the 1960s, it was reported that gravel was taken from the Grand Étang barrier for fill but this has not been confirmed. Access roads were built along the seaward side of the quay when the walls were being rebuilt (1971-photo CAS 75256-103). During the later stages of reconstruction, excess fill material was put back along the northern end of the barrier. This debris still remains in 1992. In June 1987 sediment was dredged from along the base of the quay wall, west of Piece de la Grave, where it had accumulated as a result of longshore sediment transport. The dredged material was added to the southern portion of Grand Étang barrier, presumably to raise the crest elevation and reduce wave overwash.

Evolution

Grand Étang barrier beach is not a large feature (Figs. 2, 4). In 1986 and 1988 it was only 275 m long and 18 to 41 m wide from high tide level (HTL) to lagoon water level (WLL). Plan maps of 1745 show a barrier roughly 400-450 m long and 24-38 m wide which fronted a much larger Grand Étang (Fig. 4). Between 1745 and 1931 the seaward beach face retreated landward an estimated 46-65 m, at an average rate of 0.2 to 0.3 m /a. Between 1931 and 1983, the seaward face retreated landward 12 to 26 m, or 0.2 to 0.5 m /a. Similar retreat rates of 0.5 m /a (1.5-1.6 ft /a) were calculated using air photos from 1931, 1961 and 1974, in an earlier report (PWC, 1985). Comparing air photos from 1971 and 1983, the rate of retreat appears to have increased to 0.4 to 1.0 m /a. During this period the beach crest shifted 16 m landward along the southern part of the barrier and

Figure 4. Between 1745 and 1983 Grand Étang barrier beach migrated just over 100 m landward. In 1931 a beach fronted most of the fortress but during the 1960s and 1970s the fortress walls were rebuilt as shown in 1983. Changes in shoreline position were derived from the 1745 historic site map (PWC, 1985) and vertical air photos A3476-29 (1931) and 83310-61 (1983), National Air Photo Library, Ottawa. The landward line of each shoreline position marks the seaward edge of vegetation.



the shores farther south (Fig. 1). On all air photos taken since 1931, there are well defined backbarrier fan structures which suggests that wave washover is a major mechanism for transferring sediment landward.

Beach crest elevation of Grand Étang barrier was shown on site maps, prepared in 1961, to be 4 m (PWC, 1985). Ground surveys of the beach in 1986 and 1988 showed that the crest elevation increased from a mean of 3.8 m to 4.0 m. The increase in 1988 is attributed to the addition of dredged material along the southern end of the barrier in June 1987 (Fig. 3, L 7+50). Following the February 1, 1992, storm a partial beach crest survey was completed. The survey indicated that the crest from cross-beach lines (L) 1+50 to 8+50 (Fig. 3) had decreased to 3.5 m.

The beach crest also can vary in elevation and form alongshore. In 1986 and 1988 the crest elevation varied by as much as 1.8 m (Table 1). The northern end of the barrier extended to above 4 m whereas the wave washover channels, crossing the central part of the barrier, formed the lowest part of the barrier. Between 1986 and 1988 the beach crest became more crenulate (Fig 3a); it moved an estimated 3 m landward along the central barrier and shifted 2 to 6 m seaward along the southern sector (Fig. 3b). Backbarrier elevations became slightly lower along most of the beach between 1986 and 1988.

Although the crest height of Grand Étang barrier has increased with rising sea level during the past 200 years (PWC, 1985, Fig. 6) the sediment supply appears to have decreased. Apart from the addition of dredged material to the crest along the southern part of the barrier, there is little evidence elsewhere that the beach crest has substantially aggraded in the past few years.

Present Morphology

On March 9, 1992, Grand Étang barrier consisted of three distinct morphological segments (Fig. 3a). The northern segment which was the highest consisted mainly of artificial fill (sand to cobble material). It had a flatter, compacted beach crest bounded by steep landward and seaward slopes (Fig. 3b, L2+50). Barrier crest width from the top edge of the icefoot to top of the backbarrier washover fan was only 12-15 m. Wave overtopping occurred along this section during the February 1992 storm and waves scoured and cut back the beachface nearer the quay walls.

The central portion of the barrier was lower, wider and bounded by more gradual slopes than the northern segment (Fig. 3b, L3+00, 5+00). Pronounced

Table 1. Temporal changes in barrier beach morphology at Grand Étang, Louisbourg, N.S. Measurements were derived from the 1961 site map and beach survey lines 1+50 to 8+50 collected by Public Works Canada staff at Louisbourg (T. Meagher, Pers. Comm., 1992).

Year	1961	1986	1988	1992
Barrier Width (m)	29 to 41	19 to 41	19 to 41	------
Barrier Crest Elevation (m)[1]	4.0	3.8 (2.9 - 4.7)	4.0 (3.5 - 4.6)	3.5 (3.0 - 4.3)
Seaward slope [2]	-----	4.6 to 13.9	6.2 to 12.5	------
Backshore slope [2]	-----	2.6 to 12.3	2.9 to 12.1	------

[1] elevations have been converted to Hydrographic chart datum by adding 0.9 m to the original measurements which were related to Geodetic datum. ( ) range of elevations.
[2] slope in degrees, calculated between beach crest and approximate high water level.

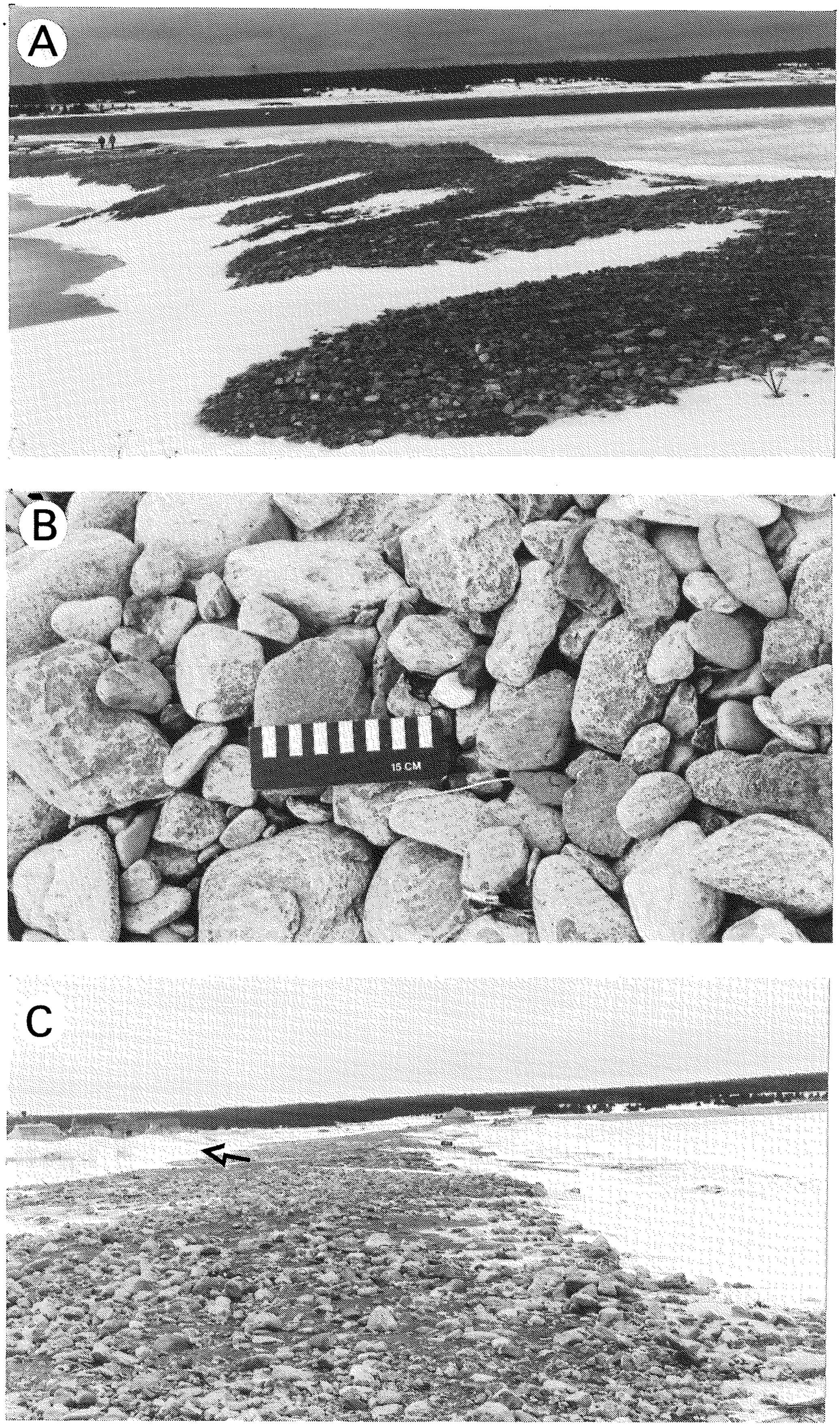


Figure 5. Photographs of Grand Étang barrier, March 9, 1992. (a) well defined washover channels with levees and discrete fan structures at the highest part of the beach. (b) beach crest composition is subangular pebble-cobbles of 40 to 100 mm diameter. (c) farther south where the beach crest is lower wave overwash was much more extensive with few channels. Sediment is now accumulating against the historic embankments (arrow) of Bastion de Maurepas.

wave overwash channels with a relief of 0.6-0.9 m were separated by narrow ridges of relict beach crest (Fig. 2 b,c). Pebble-cobble clasts had been deposited on the backslope forming low gradient washover fans which were partially covered by ice and snow. An icefoot which extended above high tide level also masked the seaward beach slope (Fig. 2b,c) .

The southern section of the barrier had a higher beach crest and a seaward slope which varied from a stepped profile with an upper scarp to a more gradual sloping ramp (Fig. 3b, L7+50). Washover lobes with well defined levees marked the highest portion of the barrier while more extensive overwash deposits covered the lower beach farther south (Fig 5a,c). The alignment of the better defined washover channels was northeastward along the long axis of Louisbourg Harbour. The crest material consisted of angular to subangular pebble cobble clasts of 40-100 mm size (Fig. 5b).

South of Grand Étang barrier the drift-aligned beach had infilled low lying pond areas and built against the erosional scarps of higher ground. A small gravel foreland had developed adjacent to the shoal which extended offshore to Battery Island. The beach crest sediment became larger, less well sorted and more angular toward Rochefort Point which is the only major source of new beach material. Debris from the February 1992 storm was deposited at the top of the first headland which has an estimated elevation of 4 to 5 m above chart datum.

PROCESS ELEMENTS

Grand Étang barrier beach lies within the relatively sheltered environment of Louisbourg Harbour. Maximum effective fetch for locally generated waves is only 2.1 km to the northeast. More importantly, Grand Étang beach is reworked by refracted, long period Atlantic Ocean swell after it passes through the narrow harbour entrance, and by reformed waves after they break across Battery Island shoal (Fig. 1). There is no known wave data for Louisbourg Harbour, but it was estimated that by the time the swell waves reach the quay walls of the fortress, they are reduced to 1/5 th of their deepwater height (PWC, 1985, p.11).

Tides at Louisbourg are mixed semi-diurnal with a large range of 1.7 m (CHS, 1992a). The closest ports where tides are continuously monitored are Point Tupper to the southwest (note: Pt Tupper was shut down in April 1992) and North Sydney to the northeast (Fig. 1). Positive storm surges can occur along this coast, particularly during periods of persistant northeast winds (Galbraith, 1979). Such was the case during the February 1, 1992 storm when a positive surge of 0.83 m was recorded at Point Tupper (Table 2). Water levels in Grand

Étang are not monitored therefore there is little information on maximum water level fluctuations and rates of drainage either by natural seepage through the beach or through the narrow sluiceway that connects Grand Étang to Louisbourg Harbour. At the time of the 1986 and 1988 beach surveys the lagoon water level was less than 1.5 m above chart datum (low tide level). Maximum water levels of 2.7 to 3.3 m above chart datum (Table 2) were recorded during flooding events.

Sea ice forms in the winter within the sheltered areas of the harbour including the shores of Grand Étang barrier. An icefoot develops when larger snowfalls coincide with very cold temperatures. On March 9, 1992 the storm icefoot was building seaward, as slush and brash ice was pushed onshore by small 13 second period waves.

Extensive flooding at the Fortress of Louisbourg has been recorded on at least six occasions since 1974 (PWC, 1985). After each flood event, water levels were measured on the inner walls of the sewage plant (Corps de Garde, Fig. 1). Unfortunately, the precise dates of flooding from 1974 to 1976 were not listed, only the month or season were recorded (PWC, 1985). Nevertheless, one is able to determine the date when the flooding occurred by examining the historic climatological records from Sydney and Louisbourg, and the tidal records from Point Tupper and North Sydney (Fig. 1). To assist in understanding why flooding occurs at Louisbourg, the climatic and oceanographic conditions (Table 2) when flooding took place in the past, were summarized on Table 2.

<u>October 1974</u>: No date given for the flooding but flood levels of 2.89 m probably occurred during the major storm which struck Cape Breton Island on October 20-21 (Gates and Amirault, 1974). At Point Tupper a maximum surge of 1.09 m was associated with strong northeast winds. The resultant water level of 2.56 m was the highest on record for this location (Table 2). The positive surge was short lived. It was followed by a negative surge of 0.84 m as winds swung around to the southwest.

<u>October 1975</u>: No date given for the flooding. It could have occurred on October 2 when the maximum monthly precipitation of 52 mm fell, but more likely on October 31 when the strongest hourly winds from the northeast to northwest were recorded (Monthly Record, 1975). Surge levels were higher at North Sydney than Point Tupper on October 31, but both stations recorded maximum water levels of 1.77 m. The maximum recorded water level at Point Tupper during October was 1.94 m on October 7. It is actually hard to believe flooding occurred at all in Louisbourg given the low elevation of the water levels (Table 2).

TABLE 3. A comparison of climatic and oceanographic conditions when flooding is known to have, or have not, occurred at the Fortress of Louisbourg, Nova Scotia. The dates of events which caused flooding in 1974, 1975 and the spring of 1976 are not confirmed. They are based on climatic records only. Chart datums were raised by 0.39 m at Point Tupper in 1984 and by 0.28 m at N. Sydney in 1988. Consequently observed water levels at both tidal stations were adjusted accordingly to maintain a constant datum. Information was derived from a variety of sources including: Atmospheric Environment Service, Bedford N.S.; Monthly Record 1974 to 1990; MEDS, Environment Canada; and COWLIS (CHS 1992b).

Date	Wind (Sydney) Direction (degrees)	Wind (Sydney) No hrs >40 km/h	Max.Vel. (km/hr)	Precipitation (Louisbourg) (mm)	Deep Water Waves Height (m)	Deep Water Waves Period (sec)	Tides (Pt. Tupper) Storm. Surge (m)	Tides (Pt. Tupper) Water Level (m above CD)	Tides (North Sydney) Storm Surge (m)	Tides (North Sydney) Water Level (m above CD)	Flood Level (Louisbourg) (above CD) (m)	Flood Level (Louisbourg) (above CD) (ft)
Events with Flooding												
1974												
Oct. 20-21	30-240	14	90	32	2 to 5#	6 to 7 #	1.09	2.56	0.49	1.52	2.89	9.48
1975												
Oct. 31	10-330	14	71-100	33	0.5 to 3#	3 to 7 #	0.19	1.77	0.61	1.77	2.94	9.65
1976												
Mar. 17-19	80-280	14	71	0	no data	no data	0.74	2.46	0.84	1.98	3.17	10.40
or June 12-14	20-340	12	56	04	no data	no data	no data	2.05	no data	1.68	-----	------
1976												
Nov. 18-21	50-240	17	50	83	6 to 8	10 to13	1.50	2.27	0.64	1.97	3.36	11.02
1983												
Oct. 25	40-70	23	74	70	8 to 9	no data	0.60	2.19	0.67	1.83	2.75	9.02
1992												
Feb. 1-2	60-90	19+	59	19	5 to 7.2	10 to 12	0.83	2.01	0.68	1.59	3.32	10.89
Events with no Flooding												
1985												
Jan 7	260-270	4	44	0	5 to 7.2	10 to 11	no data	1.38	0.33	1.57	---	---
1989												
Sept. 8-11	220-22	0	17	64	4 to 5*	15*	0.15	1.07	0.18	0.85	---	---
1991												
Oct. 28-30	20-80	47	67	??	5 to 6	10 to 14	0.60	1.80	0.62	1.69	---	---

* gauge broken, data only available on one day   # hindcast values

Spring 1976: No date given for the flooding. The two largest storms to strike Nova Scotia in early 1976 were on February 2 (Groundhog Day) and on March 17-19. No major storms when maximum hourly winds and precipitation coincided,were found between April and June 1976 (Monthly Record, 1976). However, strong winds coincided with highest water levels of 2.05 at Point Tupper on June 12-13 and large rainfalls occurred on two occasions, May 2 and June 25 (Monthly Record, 1976). It is concluded that the flooding at Louisbourg occurred during either March 17-19 or June 12-14, 1976.

November 19, 1976: Persistant strong northeast to southwest winds produced moderate to large seas, dropped up to 83 mm of precipitation at Louisbourg and set up maximum monthly water levels of 2.27 m at Point Tupper and 1.97 at North Sydney (Table 2). This storm was analysed in the earlier report by PWC (1985). Flood level crested at 0.32 m above ground level outside the sewage plant, the highest on record at 3.36 m (11.02 ft).

October 25, 1983: A strong northeasterly struck Cape Breton Island causing extensive damage to several fishing communities near Ingonish on NE Cape Breton Island and Gabarus just southwest of Louisbourg (Taylor and Kelly, 1984; Oja, 1984). Large amounts of precipitation coincided with a positive storm surge of 0.76 m at North Sydney and 0.60 m at Point Tupper.

February 1, 1992: Strong northeast to east winds and loose sea ice battered the quay walls at the Fortress of Louisbourg causing extensive damage and flood levels of 3.32 m. Sedimentary structures on Grand Étang beach showed that waves had overtopped its entire length. Folowing the storm the beach crest elevation varied from 3 to 4.3 m (Table 1). Sea ice flowed through the lower fortress ripping off a gate and flowed back to the sea through Cale de l'Etang, which has an elevation of 2.5 m (8.19 ft) above chart datum. The gate was later found onshore, just north of Porte Dauphine (Fig. 1). At Point Tupper, the storm surge exceeded 0.6 m for 7 hours and peaked at 0.83 m (2.0 m above datum). The storm surge was 0.15 m less at North Sydney. The storm also dropped large amounts of snow (Table 2).

An examination of conditions during recent large storms which did not produce significant flooding at the fortress helps to quantify the critical conditions when flooding commences (Table 2). Park officials at Louisbourg documented, using video, the wave conditions at the fortress during the storms of January 1985, and October 1991 when wave spray and debris were thrown through the cales of the quay but little flooding was recorded at the sewage plant. During Hurricane Gabrielle, in September 1989, extremely large swell pounded the outer coast but little flooding was reported at the fortress of Louisbourg because of the absence of strong winds, and the absence of a significant positive storm surge and high water levels.

The northeaster of October 28-30, 1991 was rated as extreme by Dolan and Davis (1992) however its rage was felt more along southwestern Nova Scotia and the northeastern seaboard of the United States (Taylor, in prep) . The absence of flooding at the fortress during the October storm was attributed to the short duration of the surge above 0.6 m, and its timing which coincided with low to mid tide rather than high tide.

A comparison of storm surge elevations with flood water levels recorded at the sewage plant at Louisbourg shows that flood levels are much higher. Therefore they can not be directly equated with surge levels as was suggested in the PWC (1985) report. There is insufficient information to correlate beach crest elevation with the storm surge levels but if one assumes a beach crest elevation of 3 to 4 m then flooding occurs when water levels rise to within one metre of the crest height. The information also points out the significance of the combined impact of large, longer period swell and local wind waves in carrying the seawater over the beach crest during these storm events.

DISCUSSION

Several concerns were raised at the start of this report about the future stability of Grand Étang barrier beach, the potential for further flooding and what can be done to prevent future flooding. This section addresses some of those concerns.

1) *when does flooding occur at the Fortress of Louisbourg?*

On the basis of information on storms analysed, it is concluded that northeasterlies occurring between October and March are the primary driving force causing the flooding at the fortress. The persistance of strong NE to E winds for more than 12 hours produces a positive storm surge which varies in height depending on local coastal conditions. For instance, during some storms sea ice cover in the bays may be sufficient to dampen the wave energy. The lowest water level (above chart datum) when flooding was recorded at Louisbourg (excluding the October 1975) was 2.01 m at Point Tupper and 1.52 m at N. Sydney. Transferring these elevations using the differences in geodetic elevations between the tidal reference ports and Louisbourg, flooding commences when water level reaches 2.10 to 2.27 m (above chart datum) at Louisbourg. The locally generated waves combined with the longer period large swell overtop the beach, and large amounts of precipitation that often accompany the storms aggravate the coastal flooding. The greatest damage to the Fortress occurs when sea ice breaks loose and combines with waves to batter the quay and timber pile walls (Fig. 1).

2) if left alone, would Grand Étang barrier re-establish itself naturally?

In the next few months it is anticipated that some minor recovery of Grand Étang beach will occur following the melting of the icefoot, but beach crest elevations may not reach pre-storm elevations. Evidence from several other beaches along the Cape Breton coast has shown that the gravel beaches can rebuild themselves naturally following breaches during spring melt or major storms; however, they mend best where there is abundant sediment to resupply the beach. At Grand Étang there is a scarcity of sediment as shown by the continued landward retreat of this barrier and adjacent shoreline.

During the next eighty years, relative sea level is predicted to rise as much as 45 cm (Shaw et al., 1992). It is anticipated assuming a scarcity of sediment, that Grand Étang barrier will not greatly increase in elevation as sea level rises; therefore, it will continue to retreat landward at a rate of 0.5 to 1.0 m/a, as it has in the past. It will retreat through a rollover process of wave overwash and back barrier sediment deposition. There may be short periods of stability as the beach builds against submerged ridges within Grand Étang (PWC, 1985 bathymetric surveys section 1, 2) or as the barrier builds against the higher, relict embankments of Bastion de Maurepas (Fig. 1, 5c). New sediment may be released for beach building as the Bastion is eroded but it may not be sufficient to slow the landward retreat of the northern part of the barrier.

3) *if the beach was not restored, would a channel form through it and allow the sea to enter Grand Étang, causing accelerated flooding and damage?*

Since October 1991 several major storms have combed down the beaches of Atlantic Nova Scotia and made them vulnerable to new storm wave attack. Grand Étang barrier is one of those beaches in a very vulnerable state because of its low central crest. Yet in February 1992 when flood levels at the sewage plant reached 3.32 m (10.89 ft) above datum, which is at or just above the lowest part of the barrier crest, no permanent channel was formed. Nor was a channel formed through the barrier during similar high waters in November 1976 (PWC, 1985). Even if a major breach did occur there are no large streams entering

Grand Étang to generate sufficient tidal flushing to maintain a channel. Therefore, in the short term, a complete breach of Grand Étang barrier is not anticipated. However, in the long term, as the barrier retreats landward, the size of Grand Étang (pond) will diminish along with its capacity to retain flood waters which may result in increased flooding.

4) *What are the chances of flooding shutting down the operational facilities during the peak tourist season of June to September?*

This is difficult to predict with certainty. Grand Étang beach lies within a relatively sheltered wave setting and the season when the most severe northeasterlies occur, ie. October to March has passed (Dolan and Davis 1992). Therefore the probability of flooding by wave overwash, such as occurred in February 1992, is much lower in the summer than in the fall and winter when tropical and extra-tropical storms move northward along the Atlantic coast.

5) *What approaches could be used to reduce flooding of the Grand Étang area and damage to operational facilities?*

There are essentially three approaches to reducing the impact of flooding to the operational facilities in the Grand Étang area: 1) move the operational facilities inland or raise the equipment to a higher elevation in the buildings; 2) improve the drainage of Grand Étang and 3) raise the crest elevation of Grand Étang barrier beach.

One solution is to move the operational facilities, such as the sewage plant, to higher ground farther inland, where they would be less vulnerable to wave attack and flooding by the sea. An alternative would be leave the facilities where they are and either build protective flood levees around them and the lower fortress, or raise the equipment in the buildings to a higher elevation. In doing so, one must consider the present rate of relative sea level rise which is 36 cm / century. None of these solutions would solve the problem of flooding but it would prevent damage to equipment required to run the historic park.

Flooding at Grand Étang is attributed to the ponding of water, mainly from wave overwash, but also from the accumulation of precipitation / groundwater runoff during storms. If Grand Étang barrier beach is built higher by artificial means to reduce wave overwash, it will also act as a better levee or dam to rising water levels due to precipitation. This presents a dilema because a higher beach crest may actually worsen some flood situations.

A real solution to the flooding problem at Grand Étang is to improve the drainage of water from the low lying area particularly during northeasterly storms and large rainfall events. It is readily acknowledged by local PWC staff that the present sluiceway is ineffective during much of the time because of blockage by gravel and debris. The rate of natural seaward directed seepage also is thought to be low because of the higher sand content of the backbarrier washover deposits. Much of the flooding problem could be eliminated with the installation of a much faster system of water pumps or a more efficient drainage system. Once the drainage problem is remedied then solutions for maintaining the integrity of Grand Étang barrier could be examined.

The third method to reduce flooding at Grand Étang barrier would be to reduce wave overwash by increasing the elevation of the beach crest. On the basis of the storm surge data, the crest should be raised to at least 3.3 m (1 m above lowest surge water level of 2.3 m when flooding occurred) above chart datum or higher.

The beach crest can be raised with the addition of non beach material such as boulder rip rap or large granular clasts as proposed by PWC. Initially this material would reduce wave overwash, however the introduction of much larger non-beach clasts, particularly to the seaward beach slope has often led to an imbalance in the natural system. The problem is that the smaller sediment is more easily moved by waves than the larger non-beach clasts. The waves will readjust the natural beach materials and beach slope to compensate for the larger clasts. The seaward beach slope is steepened and there is often increased erosion at the ends of the larger clasts. It is more desirable to widen and increase the height of the barrier by adding sediment which is similar in character to the beach sediment.

One source of sediment for beach nourishment is the sediment which naturally accumulates along the seaward side of the quay walls. The addition of this dredged material to the southern end of Grand Étang barrier in June 1987 appears to have been very successful in building that end of the barrier (Fig. 3b). However, there needs to be a better documentation of the 1987 beach nourishment program and its impact. How much sediment and what type was added to the beach? Where was the sediment deposited? What were the net impacts of the program? The last series of cross-beach surveys was in 1988. Is there sufficent sediment accumulating in front of the quay walls to dredge on an annual or biannual basis? An additional factor at Louisbourg is its historic significance. Will the dredging or the use of heavy machinery damage historic artifacts? Beach nourishment programs can be very successful as shown in the

United States. Also, they can be a costly and ongoing business and answers to the above questions are required before a nearshore dredging - beach nourishment program is renewed.

Another source of natural fill is the wave overwashed deposits at the back of the barrier. These deposits are derived from the original beach crest and now form the foundation for the beach as it moves landward. It would be better if the backbarrier deposits were not removed, but where sediment is scarce and the beach crest must be increased, it is a potential source of material. The practise of using backbarrier deposits to raise the beach crest is not well documented. The operation of scraping the overwashed material to the beach crest would have to be done carefully so that the rest of the beach was not damaged by heavy machinery. Also, the digging could not extend below the overwashed deposits and into pond sediment where historic artifacts lay and the digging would have to avoid relict man-made structures within the beach.

If the beach crest is rebuilt, it must be built wide enough to prevent landward directed seepage through the base of the new ridge at high tide. The exact composition of the present washover deposits is unknown at Grand Étang barrier, but a relatively high proportion of sand is expected. A rough calculation shows that 1644 m^3 of sediment would be required to build a 9 m wide beach crest to an elevation of 3.6 m along 150 m of beach (Appendix 1). There is only an estimated 658 m^3 of sediment available from the backbarrier slope and washover fans. Therefore either an additional 1000 m^3 of dredged material would have to be used, or the length or breadth of the rebuilt beach would have to be reduced. The rebuilding of the beach crest will probably not prevent flooding during major storm surges such as the February 1992 storm, but it will reduce it. A reduction in wave washover could mean a slower rate of barrier retreat which in turn could provide more time for archeologists to recover historic artifacts around Grand Étang before the area is flooded naturally by rising sea levels.

Given the prediction that over the next 80 years relative sea level will continue to rise and the anticipation that the outer coast will naturally retreat landward, and become reorganized, decisions have to be made now as to whether all or parts of the fortress of Louisbourg are to be protected from the sea. At present there is some land around the fortress which can be used in the design of creative shore protection structures or levees, at or inland, of the present shoreline. In time that land will be gone.

RECOMMENDATIONS FOR FURTHER STUDY

1. Determine whether the flood levels measured at the sewage plant were the result of water ponding behind the barrier beach and quay walls. If so, examine the drainage capability of the present sluiceway and investigate better and faster ways to drain the lowland around Grand Étang during storm events.

2. Establish a tide gauge in Louisbourg Harbour to monitor storm surge elevations and confirm what differences, if any, there are between surge levels observed at Point Tupper and North Sydney, and at Louisbourg. Also, the establishment of a wave gauge within Louisbourg Harbour would provide useful information on the shallow water wave climate which would be needed for any future major shore protection project.

3. Document in detail the dredging and beach nourishment program of 1987 at Grand Étang. Resurvey Grand Étang barrier beach along formerly established lines to better define the crest elevations, cross-beach morphology and sediment composition. The surveys would also provide information on the net affects of beach nourishment at the south end of the barrier. The surveys should extend to at least lower low water (chart datum) and preferably lower at the backshore to determine the extent and thickness of overwash deposits. Beach surveys of Grand Étang should be completed at regular intervals, e.g. spring and fall, and following major storms.

4. The monitoring of shoreline erosion (as done by Mr. Charles Burke, Parks Canada) should be continued along both the outer and harbour shores using permanent markers. The information will help to confirm when the greatest erosion occurs and whether the rate of erosion is increasing as the study of air photos from the period 1971-1983 suggests.

5. If the low central section of Grand Étang barrier beach damaged during the February 1992 storm does not recover naturally in the next few months, then it should be raised to an elevation at least as high as the adjacent beach crest to reduce the magnitude of future wave overwash. The sediment used should closely resemble the natural size of the beach sediment. If there is insufficient sediment to dredge seaward of the quay walls then overwashed backbarrier sediment could be used. If Grand Étang barrier beach is modified, then the work should be extremely well documented to better assess whether similar actions should be taken in the future.

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APPENDIX 1

Estimates of Sediment required for rebuilding Grand Étang barrier beach

1. Using the February 1992 baseline survey of Grand Étang barrier the area of beach that would require rebuilding would be 150 m (500 ft) long, (Line 2+50 to 7+50), 9 m (30 ft) wide and 1.0-1.5 m (1-5 ft) thick to extend the crest height to 3.6 m (12 ft). A total estimate of 58,050 ft^3 (1644 m^3) of material would be required. The calculations of sediment for each line segment includes 25 ft to each side of the line. Imperial units were used in the original beach surveys.

LINE NO.	AMOUNT OF FILL REQUIRED	(cu. ft)	(cu. m)
2+50	1.0'x 50'x 30' =	1500	42.5
3+00	4.5 x 50 x 30 =	6750	191.1
3+50	3.0 x 50 x 30 =	4500	127.4
4+00	5.0 x 50 x 30 =	7500	212.4
4+50	4.5 x 50 x 30 =	6750	191.1
5+00	4.3 x 50 x 30 =	6450	182.6
5+50	4.4 x 50 x 30 =	6600	186.9
6+00- 7+50	4.0 x 50 x 30 =	18000	509.7
	Total	58,050	1643.7

2. The estimated amount of overwash deposits available for fill using the 1988 cross-profiles is a maximum of 23,250 ft^3 (658 m^3).

LINE NO.	AVAILABLE OVERWASH DEPOSIT	(cu ft)	(cu m)
3+00	3.0'x 50'x 40'=	6000	169.9
3+50	2.0 x 50 x 20 =	2000	56.6
4+00	2.5 x 50 x 30 =	6250	176.9
4+50	3.0 x 50 x 20 =	3000	84.9
5+00	2.0 x 50 x 10 =	1000	28.3
5+50	0.5 x 50 x 50 =	1250	35.4
6+00	1.5 x 50 x 20 =	1500	42.5
6+50	1.5 x 50 x 30 =	2250	63.7
7+00-7+50	no sediment should be removed	-----	-----
	Total	23,250	658.2