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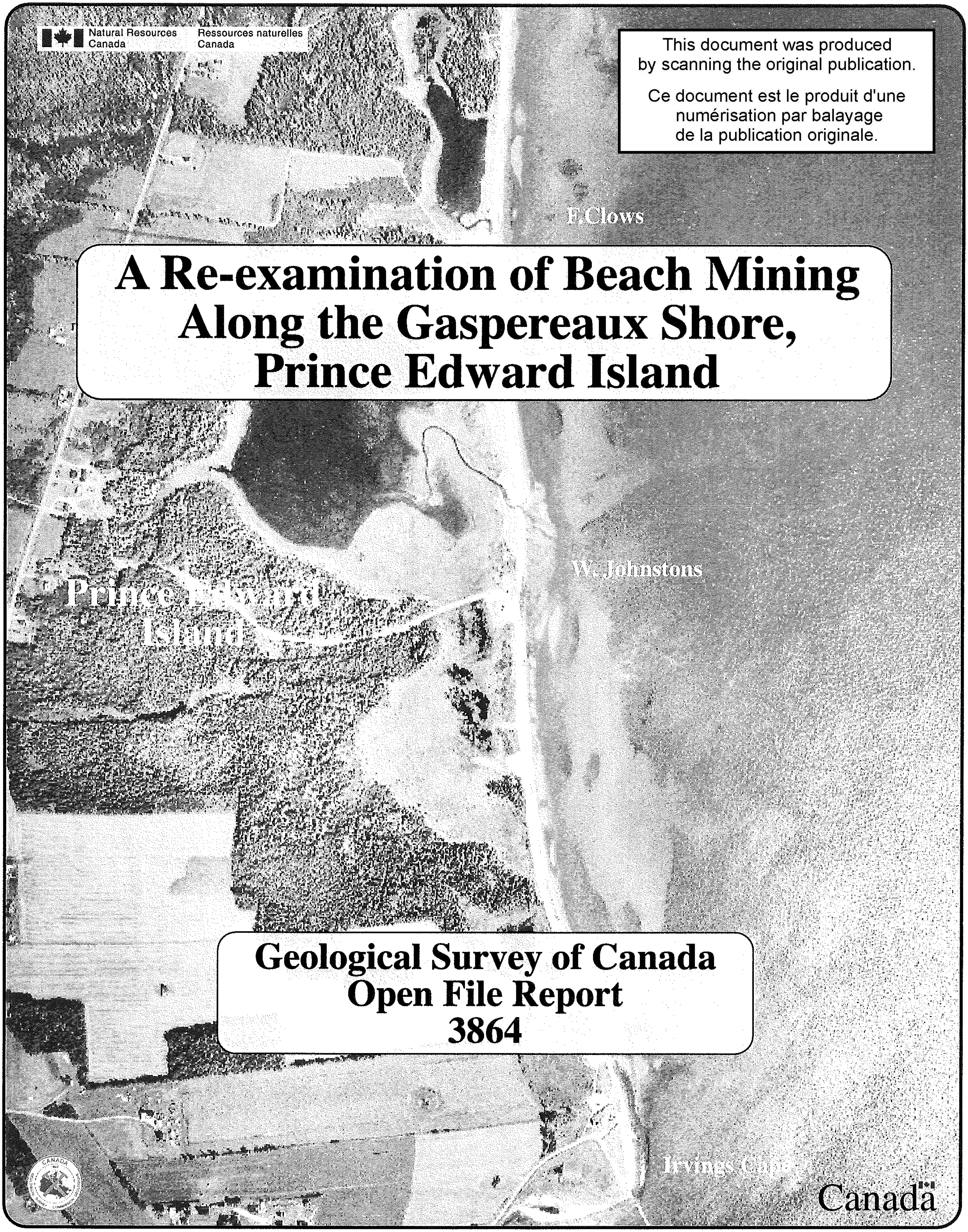
A Re-examination of Beach Mining Along the Gaspereaux Shore, Prince Edward Island



Geological Survey of Canada Open File Report 3864

Canada

A Re-examination of Beach Mining Along the Gaspereaux Shore, Prince Edward Island

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Front Cover.

Aerial view of the Gaspereaux Shore, East Prince Edward Island where the three commercial sediment extraction operations reviewed in this report are located. Beach mining began along this shore in the mid 1970s. By 1987, when this photo was taken, all three sites were actively mined. Sediment extraction was halted at Irvings Cape after 1992, and was not permitted at F. Clows in 1994, 1996 and 1998. Sediment has been extracted every year since 1987 at the W. Johnston site. (Aerial photograph 87228-31, 16 September 1987, Nova Scotia Geomatics, Amherst, Nova Scotia).

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EXECUTIVE SUMMARY

Commercial sediment extraction in the coastal zone has been regulated by the issuance of permits by the PEI Department of Technology and Environment since 1975. The Gaspereaux Shore at the southeast end of the province is one of five areas where mining is approved. Total volumes of sediment extraction on the island have decreased from more than 50,000 m^3 in the 1970s to 20,000 m^3 in the early 1990s. In the late 1970s a review of beach mining activities was completed by Woodward-Clyde Consultants (1980). This report formed the basis for future provincial government policy on coastal sediment extraction. Many things have changed along the Gaspereaux Shore since the 1980 review including: the closure of five commercial extraction sites, the opening of a new site, an increase in extraction rates and the partial removal of a jetty and wave breakwater at Irvings Cape. Dramatic morphological changes along the Gaspereaux Shore in the early 1990s raised local residents' concern about the integrity of the shoreline and the impacts of beach mining. This review of mining activities along the Gaspereaux Shore is the result of those concerns and a request by the PEI Department of Technology and Environment to provide an independent review of beach mining.

This report examines the impacts of sediment extraction on shoreline stability at three sites: Irvings Cape, F. Clows and W. Johnston. The impacts of natural processes and other factors such as the Irvings Cape jetty are addressed and a sediment budget is prepared for the Gaspereaux Shore. The principle sources of information about detailed shoreline changes at the mining sites were permit records and field surveys conducted since 1984 by the PEI Department of Technology and Environment; as well as historical maps and vertical air photographs. Several visits to the field area provided ground truthing for the secondary information. The Gaspereaux Shore includes the shores between Murray Head and Panmure Island (Fig. i), however only the shores between Murray Head and Cape Sharp are discussed in this report.

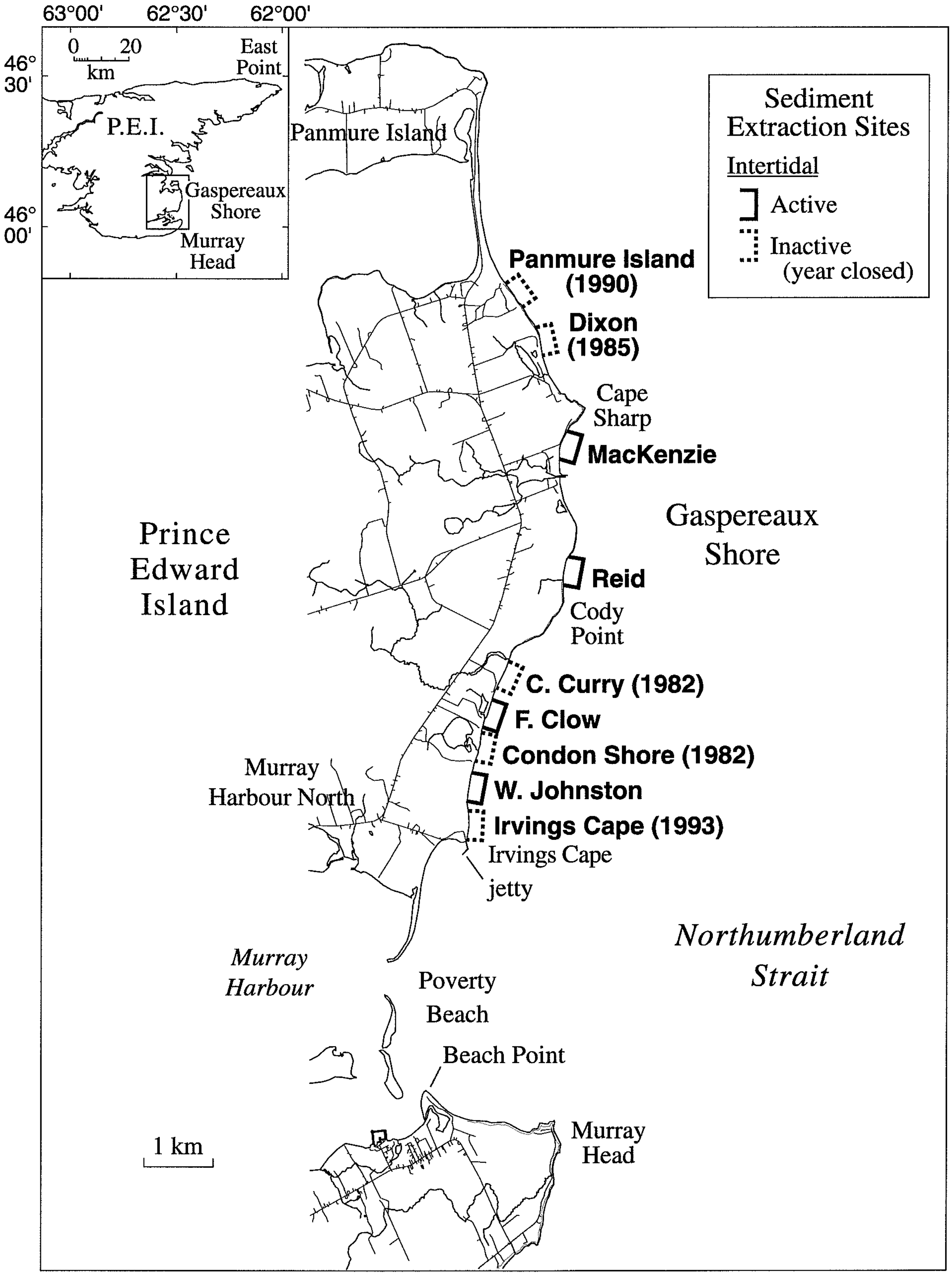
From a geological perspective the Gaspereaux Shore has been evolving rapidly during the past 5000 years when the Northumberland Strait formed and joined the Gulf of St. Lawrence. The shores near Irvings Cape have retreated an estimated 80 to 150 m landward during the past two centuries. Sediment derived from the retreat has been used to infill low backshores, build spits and barriers across the mouths of estuaries, maintain beaches and contribute material to estuarine marshland and marine habitats. Commercial beach mining is a fairly recent and short term activity that could impact the natural evolution of shores. Sediment is necessary to build beaches and enable them to maintain their position against rising sea levels and changing environmental conditions. Beach mining removes sediment from the natural system. The question is whether there is sufficient sediment to support commercial mining without accelerating shoreline changes and the natural evolutionary cycle.

A) Sediment Supply and Loss

- *Sediment is only a renewable resource if there is continued or increased coastal erosion.*

It is concluded, as in earlier studies (Bartlett, 1975; Woodward-Clyde Consultants, 1980), that the primary sediment source for the Gaspereaux Shore is from shore erosion. Between 1955 and 1987 the maximum potential annual sediment supply from shore erosion between Murray Head and Cape Sharp was estimated at just under 14,300 m^3, of which 8,700 m^3 was sand. It is assumed that some sediment is supplied from just offshore, i.e. the shoreface, but information is scarce. The only estimate of sediment supply from the nearshore is made for the area between Irvings Cape and Cody Point where 1700 m^3/a. is supplied.

Figure i. Place names and location of beach mining sites along the Gaspereaux Shore, east Prince Edward Island. Digital base map from1985 air photos, obtained from Information Technology and Geomatics Service, PEI Provincial Treasury, Charlottetown, PEI.



- *The Gaspereaux Shore includes a number of sediment transport compartments or cells which should be differentiated when calculating detailed sediment budgets.*

Three longshore sediment transport compartments were defined along the Gaspereaux Shore on the basis mainly of geomorphological evidence. They include: (1) Murray Head to just north of Cody Point; (2) the embayment south of Cape Sharp; and (3) the shores north of Cape Sharp to Panmure Island (Fig. i). Furthermore, compartment 1, was divided into four subcompartments of sediment transport: Murray Head to Beach Point, Poverty Beach and its associated shoreface and tidal channel deposits; Poverty Beach to Cody Point and the small embayment north of Cody Point. When assessing the impacts of beach mining it is important to understand the potential for sediment replenishment and where the material is supplied from. For example, the total input of sand along shore component 1 is estimated at 10500 m^3/a however roughly 1900 m^3/a of the sediment is supplied from the subcompartment south of Poverty Beach and would not reach the shores where the commercial mining operations are taking place. It is also concluded that sediment contribution from the subcompartment just north of Cody Point, to the shores farther south is minimal because it has a net sediment deficit of 240 m^3/a (excluding inputs from offshore). The deficit is attributed to the presence of a commercial beach mining operation within the subcompartment.

- *Sediment depletion (mainly mining) was greater than sediment supply between the north end of Poverty Beach and Cody Point for the period 1955 to 1987.*

Between 1975 and 1998 the average annual volume of sediment extracted by commercial mining for the Gaspereaux Shore was just over 7900 m^3/a. For the shores south of Cape Sharp the volume was just under 7800 m3/a and for the shores south of Cody Point the volume was 5725 m^3/a. Sediment supply from onshore and offshore sources between Cody Point and Poverty Beach, is an average of 6140 m^3/a. The estimates for sediment supply are maximum values. In reality not all sediment eroded from onshore is immediately supplied to the downdrift shores. Sediment delivery takes time as sediment moves both north and south alongshore under varying wave conditions. It is recognized also that sediment supply will vary up or down for short time periods. Some sediment is also trapped within natural features and environments such as backshore dunes, wetlands and/or nearshore bars. An estimate for the volume of sand trapped in the backshore is 688 m^3/a. The average net sediment balance for the shores between Cody Point and Poverty Beach is estimated at just under -300 m^3/a.

It is also recognized that sediment budgets are only estimates and should be used only as a guide. There are several unknowns, particularly about sediment transfers from the nearshore, and the rate of shoreline erosion after 1990, which make quantitative conclusions less precise. Nevertheless since the mid 1970s the only significant net shoreline progradation was adjacent to the Irvings Cape jetty. There is evidence of some small areas of short term beach progradation, such as just north of W. Johnston mining site in the 1980s, but the general trend has been shoreline retreat.

- *Much of the sediment eroded from Poverty Beach spit between 1955 and 1990 was redistributed and accumulated in the new tidal inlets as flood delta deposits.*

Between 1969, when the first inlet formed, and 1974, the volume of sediment accumulating at the tidal deltas was greater than the volume of sediment gained from changes in Poverty Beach. It is concluded that the excess sediment was derived from farther alongshore or from offshore. By 1987 the volume of sediment accumulating in the flood deltas was nearly equivalent to the loss of sediment from Poverty

Beach which suggests that there was no longer an abundance of sediment supplied from farther away. However continued growth at the distal end of Poverty Beach, after the inlets formed, suggested that some sediment was being transferred along the nearshore bars to the end of the beach. Poverty Beach appeared to be cannibalizing sediment in an attempt to repair the breaches. It is estimated that Poverty Beach was reduced in area by 132,800 m^2 between 1955 and 1990. Assuming the thickness of beach removed was 2 m, the volume of sediment lost would be 265,600 m^3. The volume of sediment gained within the flood tidal delta by 1987 was 274,700 m^3. The volume of sediment accumulated in the ebb delta by 1987 was 99,300 m^3.

B) Physical Impacts of Commercial Sediment Extraction from the Intertidal Zone

- *There is a permanent loss of sediment from the coastal environment.*

Sediment extracted from the shores during mining operations is permanently removed from the natural coastal environment. The total volume of sediment extracted from the shores between Cody Point and Irvings Cape since 1975 is estimated at 131,650 m^3. This volume is equivalent to a beach 525 m long, 5 m thick and 50 m wide. The beach changes caused by mining can be temporarily masked with the redistribution of sediment from adjacent shores but to replace the mined sediment, an equivalent volume of new sediment, e.g. from bedrock or shore cliff erosion, must be added to the coastal zone.

- *The mining sites are supplied by sediment from adjacent shores and shoreface.*

The volume of sediment extracted since 1984 when beach surveys were begun was 28,550 m^3 from Irvings Cape and 18,800 m^3 from F. Clows. Yet, the net change in sediment volume was only -250 m^3 at the Irvings Cape site when mining stopped in late 1992, and just under -6000 m^3 at F. Clows by 1998. During 1997-1998 the net loss of sediment was 1300 m3 at the W. Johnston site. Therefore these sites are naturally resupplied with sediment, although the quantity appears to depend on local shoreline conditions. Between 1984 and 1993 there were only three years at Irvings Cape and two years at F. Clows when sediment supply exceeded sediment extraction. On average only half the sediment extracted is replenished at the Clows and Johnston sites each year. In contrast, at Irvings Cape, the total volume of sediment supplied nearly equaled the volume extracted between 1984 and 1993. The improved situation at Irvings Cape is attributed to the presence of a concrete jetty which impeded longshore sediment transport and trapped sediment.

- *Much larger volumes of sediment are required to offset the loss of sediment from the sites during mining operations than with no mining.*

During years of beach mining the average volume of sediment supplied at Irvings Cape was just over 3000 m^3/a. After mining stopped, the volume of sediment supplied to Irvings Cape varied between 500 and 1300 m^3/a, 2 to 6 times less than when mining was active. In fact, after mining was stopped there was a net loss of sediment averaging 74 m^3/a but the balance was negatively skewed by the large loss in one year, 1996-1997.

- *Accelerated beach, dune and shoreface erosion occur at and adjacent to the mining sites.*

The shores and shoreface adjacent to the commercial excavation operations contribute to the replacement of some or all of the excavated material (Fig. ii). For example, during low wave conditions (Fig. iib) most of the excavated area is re-supplied by sediment from the adjacent beach, and subtidal zone and little comes from the backshore. During higher wave conditions (Fig iic) more sediment is derived from the upper beach and backshore as the waves extend farther upslope and pull sediment downslope. Waves also transport sediment into the low backshore through the dune cuts. Sediment transfers from the areas closest the excavated area in turn are partially infilled by sediment from farther alongshore or offshore. The domino effect of taking sediment from adjacent shores continues until new sediment is added from erosion of shore cliffs or intertidal rock outcrops.

A decrease in the fluctuations of sediment gained and lost at the mining sites since the early 1980s suggests that the natural abundance of sediment in the adjacent beaches, dunes and shoreface has decreased. As the abundance of sediment decreases, the beach gradient increases and wave attack accelerates along the backshore dunes. Since 1984 the mean dune and beach retreat at F. Clows was just over 1 m/a with a maximum of 1.4 m/a at the north end of the site. The mean rate of dune recession was nearly 8 times higher than the longer term value published by LRIS (1988). At the Irvings Cape site, the mean rate of dune retreat during mining was 0.65 m/a which was 16 times higher than after mining stopped and 3 times higher than the long term rate (LRIS, 1988). At the Johnston site, the rate of dune retreat was more than 6 times the longer term average (LRIS, 1988). The area of backshore cleared for stockpiling sediment and vehicle access increased over time at all sites. Only the operator at F. Clows made an effort to rebuild an artificial berm at the top of the beach to lessen wave overwash. Dune recovery was only observed after mining was stopped at Irvings Cape and dune erosion was much less in the years permits were not granted at the other sites.

During non-mining years the increased abundance of sediment resulted in a wider beach which protected the dunes against wave attack. Where the sediment gradually accumulated across the upper beach, it facilitated the growth and spread of dune vegetation, as at the Irvings Cape site. Between 1955 and 1990 the width of sand just offshore of and between the mining areas were fairly similar but the sand deposits appeared thinner and the area of broken bottom expanded suggesting a decrease in sediment abundance across the nearshore.

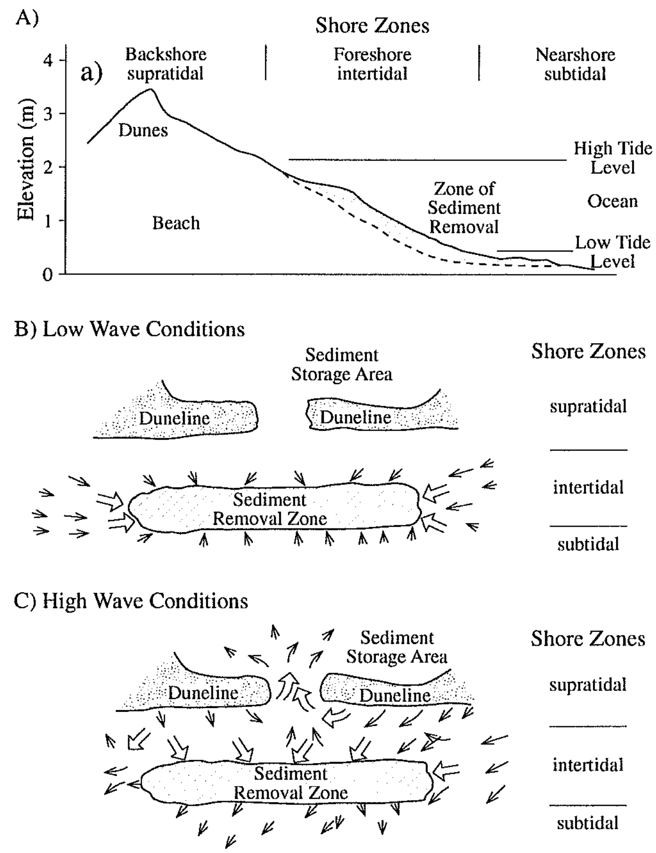


Figure ii. Sketch of the shore zones in (a) profile and (b, c) plan view showing the redistribution of sediment by natural processes after beach mining. (B) During low wave energy conditions excavated sediment is replenished by sediment close to the excavation site. During high wave energy conditions waves can erode sediment from the backshore dunes or transport sediment farther onshore through dune cuts or offshore away from the excavation site. The size of the arrow is proportional to the quantity of sediment transported and its direction of movement.

- *Beach changes were more irregular and the vertical fluctuation or sweep zone of the beach was greater during years of mining than non-mining.*

The upper and lower limits of beach change were more confined at Irvings Cape during years of non-mining. Cuts in the beach were more irregular and deeper, and changes along the duneline more irregular during years of mining. Some of these differences are attributed to different mining practises used by operators.

After mining was stopped at Irvings Cape in late 1992, a more natural cut and fill sequence was observed across the lower to mid beach followed by a sequential building of the upper beach. Upper beach changes were larger during years of mining. At the F. Clows site, less beach change corresponded to years with no mining and dune-line retreat was less following the years when no permits were granted and more sediment accumulated on the beach.

C) Impacts on Shoreline Stability by Other Factors

- *The natural supply of sediment to Poverty Beach was decreasing before 1955 when human activities increased along the Gaspereaux Shore.*

Between 1936 and 1955 when shoreline changes are attributed to natural processes, sediment supply to Poverty Beach was decreasing from updrift shores and the spit was beginning to derive sediment from itself. Rates of natural shoreline erosion between 1936 and 1955 varied from 2 m/a at Irvings Cape to 0.5 m/a or less along the shores farther north toward McClures Pond. Another study (LRIS, 1988), which examined shoreline changes over the period 1936 to 1987, suggested the longer term rate of recession for these shores was less than 0.5 m/a.

- *The construction of the Irvings Cape jetty accelerated the natural breakup of Poverty Beach.*

Construction of the jetty at Irvings Cape in 1955 had a profound impact on shoreline stability within 225 m of its location. Sediment rapidly accumulated along the northern side of the jetty, thereby reducing the volume of sediment moving southward alongshore. It was only after the updrift side of the solid jetty was infilled that sediment moved south of the structure. By 1968 sediment had accumulated to the south, within the wave shadow of the jetty forming a spit 130 m seaward of the 1955 shoreline. The physical consequences of sediment being trapped by the jetty increased farther south over time. Initially erosion was accelerated along the northern or proximal end of Poverty Beach where a series of buildings were relocated from the backshore. By 1969 Poverty spit was cut by a tidal inlet and by 1982 it was cut by two more inlets which subsequently merged as one. Once the inlets formed the transfer of sediment from Poverty Beach to the estuary was 9 times greater than the volume of sediment trapped on both sides of the jetty. The breaching and transfer of sediment into the estuary are part of a natural evolutionary sequence for barrier beaches or spits with a decreasing sediment supply. The volume of sediment accumulated around the jetty between 1955 and 1968 was equivalent to 5 years accumulation at the end of the spit, assuming a growth rate of 10 m/a.

- *Beach mining and storms compounded the negative impacts of the jetty on shoreline stability.*

During the early 1980s, as the jetty deteriorated and mining was less intense adjacent to the structure, sediment moved southward along-shore. By the late 1980s accelerated sediment excavation nearer the jetty resulted in a reduced transfer of sediment southward. Mapping of sequential shoreline changes shows significant acceleration of shoreline retreat between 1974 and 1980 which is attributed to both mining and natural processes. Storms and particularly storm surges in the fall and early winter were a major factor in eroding the shores and the release of increased sediment to replenish the losses caused by beach mining. Evidence of the storms included several wave washover features across the backshore, the breakup of Poverty spit and increased shoreline retreat.

- *Sea level rise and shoreline maintenance.*

It is anticipated that sea level rise will rise by 0.49 m by end of next century (Houghton et al., 1996; Shaw et al., 1998). To maintain their present position, beaches will have to build themselves higher to prevent wave overwash at higher sea levels. Beach elevation can be increased by dune growth or by the reorganisation and reshaping of the beach by wave overtopping and the transfer of sediment to the beach crest. Shoreline maintenance against rising sea level was not considered when previous approvals for sediment extraction were made. A crude estimate of the volume of sediment required to maintain a sand beach against the suggested rise in sea level would be ~ 2.1 to 3.6 m^3/m of beach. The length of shoreline between Cody Point and Irvings Cape is 2.5 km. Therefore something in the order of 5350 to 9000 m^3/a of sediment, in addition to the volume required to offset the losses from mining, would be required to maintain these shores. Assuming stable beaches and a longer term rate of recession of 0.71 m/a for cliffs and backshore scarps, the natural supply of sediment could be 5000 m^3/a, which is nearly sufficient to maintain the beaches but insufficient to offset the losses caused by commercial sediment mining.

D) Conclusion and Recommendations

It is concluded that the construction of Irvings Cape jetty artificially extended the adjacent shoreline seaward of its 1955 position and has kept it farther seaward for more than 40 years. The presence of the jetty also accelerated the natural breakup of Poverty Beach by trapping sediment updrift of the jetty and by forming a wave shadow immediately south of the jetty. Beach mining aggravated the situation by removing sediment from the updrift side of the jetty. Continued mining at three locations for more than 20 years has accelerated natural erosion of the adjacent shores by permanently removing sediment. Based on sequential changes in shoreline position observed on air photographs from the 1970s and 1980s and from surveys of mining sites in the late 1980s and 1990s, it is concluded that shoreline instability has accelerated. The shores between Cody Point and Poverty Beach cannot sustain continued sediment extraction at the volumes permitted in the late 1980s.

It is therefore recommended for the Gaspereaux Shore that:

- All commercial beach mining be stopped between Poverty Beach and Cody Point.

It is further recommended for the other beach mining sites in PEI that:

- To improve calculations of natural sediment replenishment at specific sites, when the total volume of sediment extracted from a site is reported to the regulatory agency, it should be broken down into the volume of sediment stockpiled in the backshore and the volume of sediment hauled away from the site. At present, only the sediment hauled away from the site is reported for each extraction permit. When subsequent permits are issued for the same site, the source of the sediment extracted should be reported; whether it is from a previous backshore stockpile or the intertidal zone.

- To maintain an ongoing assessment of the impacts of commercial sediment extraction on the stability of a particular shoreline, all sites should be surveyed before and after each extraction permit is issued. Furthermore, monitoring should be expanded to include sites farther alongshore, up -and down- drift of all active beach mining sites in PEI. The monitoring activities should be designed to document natural fluctuations in sediment abundance and any abnormal changes caused by commercial sediment extraction or other human activities along the coast. Consequently, more effort will be required in monitoring, analyzing field data, and maintaining accurate records of the volumes of sediment extracted than in the past. If beach mining is to continue in PEI, increased financial and human resources should be allocated to the Department of Technology and Environment to effectively monitor the impacts of mining on shoreline stability at all sites.

- Before any new intertidal mining sites are approved, it would be extremely useful to have a detailed map of the distribution and thickness of surficial deposits in the marine areas adjacent to the mining site. The information would provide a baseline for future assessments of changes in sediment availability offshore during the life of a mining operation. It would alleviate some of the problems encountered in the sediment budget calculations for the Gaspereaux Shore, where there was very little field information about the nearshore.

- New remote sensing technology, such as scanning airborne laser altimetry, should be tested in active beach mining areas to assess whether it is a more cost effective way of monitoring physical shoreline changes and impacts of mining than conventional ground surveys which are very time consuming.

ACKNOWLEDGMENTS

I wish to thank several people for their support with this project. In particular, I thank Paul White for assistance with the initial field work in 1991 and for his efforts in compiling the initial report on the impacts of beach mining as part of his undergraduate degree at Acadia University. The complexity of the problem of isolating the impacts of mining from other causes of shoreline change became obvious during the writing of his report. Special thanks are also extended to Bruce Raymond, PEI Department of Technology and Environment, who has supplied all the provincial government information on commercial sediment extraction, and the beach surveys and sediment volume compilations from specific mining sites along the Gaspereaux Shore. Bruce has been extremely supportive of this study in his efforts to objectively assess the impacts of sediment extraction in the intertidal zone. He has been assisted by Phil Ward, Greg Wilson, and Alan McLennan who completed the field surveys for the PEI Department of Technology and Environment. They also answered many questions about the surveys. Several local residents also provided support and encouragement during the project.

David Boyce of the Southeast Environmental Association has continually badgered me to complete the report and has along with Bob Miller, George MacLeod, and Eugene MacCarthy provided local knowledge about storms and shoreline changes.

Ken Hale (Geological Survey of Canada, Atlantic) was responsible for the final design and layout of this report.

Jacqueline Miller and Carol Rydinsky instigated the study and Clair Murphy made official requests on behalf of the PEI Department of Technology and Environment. Assistance is also acknowledged from M. Bell at the PEI Provincial Archives, Bob Nicholson at the PEI Forestry Branch, and Kerry Taylor at Public Works Canada. Ken Hale and Rhonda Sutherland of GSCA Electronic Publishing prepared the final diagrams. Andy Sherin and Pierre Gareau (Geological Survey of Canada, Atlantic) assisted with the rectification of maps and air photographs of Poverty Beach and Irvings Cape using GIS and computer imaging software.

Comments and discussions on parts of the report were provided by Greg Wilson and detailed reviews of the report by D. L. Forbes (Geological Survey of Canada, Atlantic) and Dave Boyce provided valuable comments on how to improve the manuscript.

INTRODUCTION

Background and Objectives

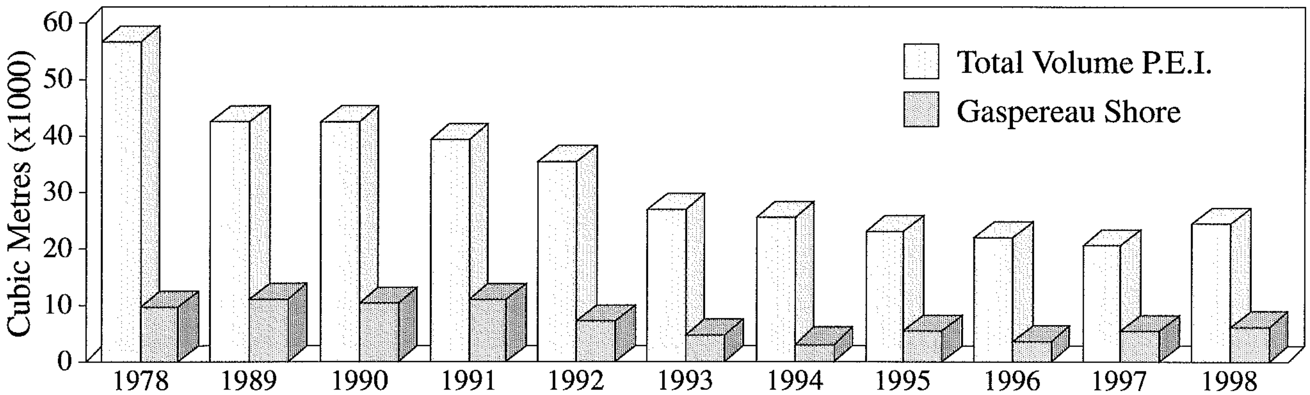
Sediment extraction from beaches on Prince Edward Island has been practised for many years. Commercial extraction has been regulated since 1975 by the issuance of permits by the provincial Department of Technology and Environment (formerly called the Department of Environment and Fisheries, Appendix 1). Beach sand has been used mainly in the concrete industry, however there is a provision in the provincial Environmental Protection Act (Appendix 1) which allows individuals without a permit to remove beach sediment if using a vehicle with a payload of less than 4 m^3 and if it is used for domestic purposes. Typical annual volumes of commercial beach sediment extraction on PEI are summarized in Figure 1, and listed in Appendix 2. Removal rates of beach sediment totalled more than 50,000 m^3/a during the 1970s until the 1990s when volumes decreased to less than 25,000 m^3/a (Fig. 1). In the late 1970s a review of beach mining activities in the province was completed by Woodward-Clyde Consultants (1980). A summary of this report was produced by Owens (1980). On the basis of this review, sediment extraction was recommended only for beach sites where there was a positive sediment budget, ie. more sediment was naturally supplied to a site than was extracted, and where extraction had a minimal impact on shoreline stability. It was at this time there was a switch from using the term beach extraction to intertidal extraction, probably because of the recommendation that sand be removed from the lower intertidal rather than the upper beach. In this report the term beach extraction and intertidal extraction are used synonymously. There are five primary areas of intertidal sediment extraction around the province (Fig. 2). The Gaspereaux Shore, along eastern PEI, is one of the five areas and it is the focus of this report.

In the early 1980s eight beach sites were approved for sediment extraction along the Gaspereaux Shore (Fig. 3). By 1997 there were only four commercial operations. As a percentage of the total sediment removed by commercial operators in PEI, sediment extracted from the Gaspereaux Shore increased from 9% in the mid 1970s to 27% in the early 1980s. More recently the percentage has varied from a low of 10% in 1994 to a high of 48% (Fig. 1, Appendix 2) in 1992, but this was an exceptional year because it included a one-time permit issued for the removal of 10,000 m^3 from the seabed off Murray Harbour (Fig. 3).

Dramatic morphological changes along the Gaspereaux Shore during the past few years have led many local residents to be concerned about the integrity of that shoreline. They have raised questions about present shoreline management practices and whether the mining of beach sediment can continue without adversely affecting the stability of the whole coastline from Murray Harbour to Panmure Island (Fig. 3). Other local residents contend that mining has been active along this coast for many years with little adverse affect on shoreline stability.

Since the review by Woodward-Clyde (1980) many things have changed along the Gaspereaux Shore, including the closure of five commercial extraction sites and the opening of a new beach site (W. Johnston) in 1987 and an offshore site in 1992 (Fig. 3). Also, annual extraction rates at some sites have exceeded rates recommended by the 1980 review (Appendix 2). One of the most significant changes was the removal of the jetty and wave breakwater at Irvings Cape between 1984 and 1987. Subsequent erosion and loss of sand along the adjacent shores have been attributed by some to the removal of the jetty, while others believe the beach mining is to blame. Changes resulting from natural processes have been largely ignored in the debate.

Figure 1. *Total volume of commercial sediment extracted each year from the intertidal zone of Prince Edward Island and specifically from the Gaspereaux Shore, which is the focus of this study. The volume of sediment extracted in 1978 and 1989 are representative of the amounts extracted during the 1970s and 1980s respectively. There has been a decline in sediment extraction since 1990 when 43,000 m^3 of sediment was mined. The sediment volumes used in this graph are listed in Appendix 2; they are derived from records kept by the PEI Department of Technology and Environment and from Woodward-Clyde Consultants (1980).*



This study has four objectives:

1) To assess the impacts of commercial sediment extraction at specific shore sites, in particular, Irvings Cape (Cody Point) and F. Clows (Fig. 3, 4), where operations began in the 1970s. Beach surveys have been completed at these sites since 1984 by the provincial Department of Technology and Environment as part of the permit review process. The surveys are used to document the physical impacts of mining. Beach changes at the W. Johnston mining site also are discussed, although surveys are only available since 1997.

2) To re-evaluate sediment as a renewable resource, its availability and its distribution, particularly between Cody Point and Poverty Beach (Fig.3) by documenting the physical characteristics of the Gaspereaux Shore and the changes that have occurred during the past 30 to 50 years.

3) To differentiate the impacts of intertidal mining on shoreline stability from other artificial and natural effects.

4) To assess whether these shores can sustain intertidal mining activities without reducing their stability.

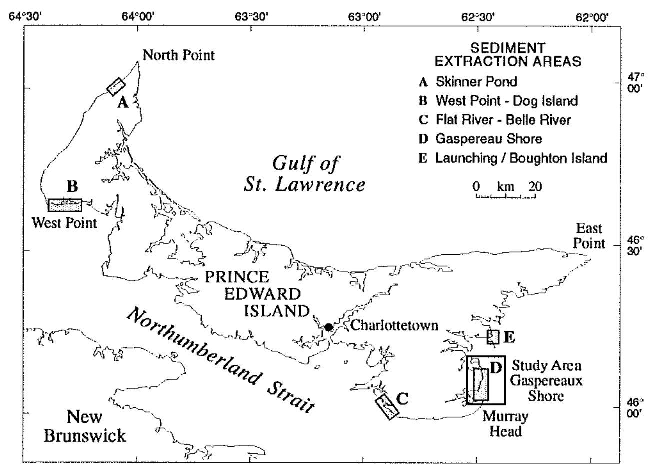
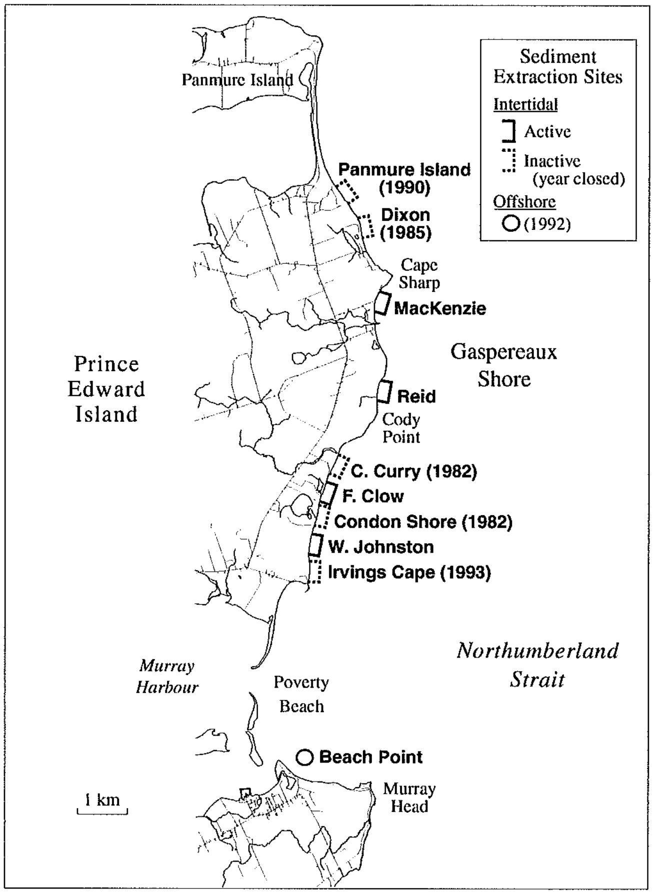


Figure 2. Location of the five primary areas of commercial sediment extraction from the intertidal zone of Prince Edward Island: A) Skinner Pond; B) West Point-Dog Island, C) Flat River-Belle River, D) the Gaspereaux Shore and E) Launching-Boughton Island.

Figure 3. Place names and location of intertidal sediment extraction sites along the Gaspereaux Shore, PEI. Since the last review of beach mining in 1980 by Woodward-Clyde Consultants (1980), several things have changed: five mining sites have become inactive, a new operation was begun at the W. Johnston site in 1987, and a permit was granted for sediment extraction offshore of Murray Harbour in 1992.



Physical Setting

The east coast of Prince Edward Island consists of long narrow or broad estuaries separated by low, cliffed headlands (Fig. 2, 4). Many of the estuaries are partially enclosed by low barrier beaches and spits (Geographical Branch, 1959; Owens, 1974, 1979). The complex coastal planform is the product of erosion along the geological fold axes which are aligned perpendicular to shore, and the subsequent drowning of the valleys. Longshore sediment transport is restricted by the irregular configuration of the coast and is confined within smaller coastal compartments.

Sediment composition at the coast includes three general stratigraphic units, at the base there is bedrock, which is overlain by glacial deposits and post glacial deposits. The presence or absence of one or more of the three sediment units will depend primarily on the coastal relief. The bedrock is a poorly indurated conglomeratic and lithic sandstone with varying amounts of siltstone and claystone (Frankel, 1966; Prest, 1973; van de Poll, 1983). At the coast the bedrock is covered by 2 to 5 m of unconsolidated glacial material (Fig. 5) deposited beneath the ice about 13000 radiocarbon years BP (13ka). In Murray Harbour glacial deposits include kames and eskers surrounded by outwash, and some ground moraine (Frankel, 1966; Prest, 1973). Post-glacial deposits include littoral sediment, as well as salt marsh peats and swamp muck, which have formed in the estuaries and low-lying backshore areas where the local drainage has been closed off by landward-migrating shore deposits (Fig. 4a).

The presence of submerged tree stumps (Fig. 6) and peat deposits at several places along the Gaspereaux Shore provide visual evidence of the transgressive nature of the shoreline and a rising sea level. Recent paleo-geographic reconstructions of the coastline of Prince Edward Island suggest that the east coast has been retreating since at least 9.0 ka (Gareau et al., 1998a,b) and in particular since 6.0 ka, when Northumberland Strait opened to the Gulf of St. Lawrence (J. Shaw, pers com., 1999). Field samples are not available to confirm the older rates of relative sea-level changes but there is information for the past 3000 years. On the basis of radiocarbon dated marsh microfossils Scott et al.(1981) suggested sea level has risen at 14 to 19 cm/century. Trees at 1.5 to 2.4 m below high tide level at Nicholas Point were dated at 915 ±90 yrs BP, which suggests a slightly higher submergence rate of 16 to 26 cm/century (I-GSC-23, Frankel and Crowl, 1961). Tide gauge records collected at Charlottetown between 1907 and 1988 indicated a rise in relative sea level of 31.2 cm /century (Shaw and Forbes, 1990).

Marine geological surveys are few. With the exception of the study by Bartlett (1975) all surveys have been completed seaward of the 10 m isobath (Kranck, 1971, Frobel, 1989; Pecore et al. 1993). Air photos and field observations show that the inner shoreface is dominated by an irregular rock platform 200 to 1000 m wide, discontinuously covered by thin, coarse lag deposits and mobile sand (Fig. 4b). Sediment accumulates within the embayments and estuaries. The largest accumulation of shoreface sediment in the study area exists seaward of Poverty Beach, where large sandy bedforms exist for several hundred metres offshore. Little is known about the sedimentary stratigraphy beneath Poverty Beach and the mouth of Murray Harbour. Bartlett (1975) suggested the tidal channel at south end of Poverty Beach was floored by bedrock 8 to10 m below normal lowest tide which provides a thickness of the distal spit deposits but it is not known if the spit deposits consist of only littoral sediment, or littoral deposits over glacial outwash material.

Farther offshore the surficial sediment has been mapped as Buctouche sand and gravel (a lag deposit formed during the post-glacial transgression of the sea), Egmont Sand (a well sorted, medium sand) and Pugwash mud (Fig. 4b; Kranck, 1971). The Buctouche sand and gravel is similar to the lag deposits formed as a result of wave erosion at the present shoreline. Pugwash muds blanket the seabed in water depths greater than 30 m. The volume of mud derived from eroding shorelines is unknown and no information is available on rates of offshore sedimentation.

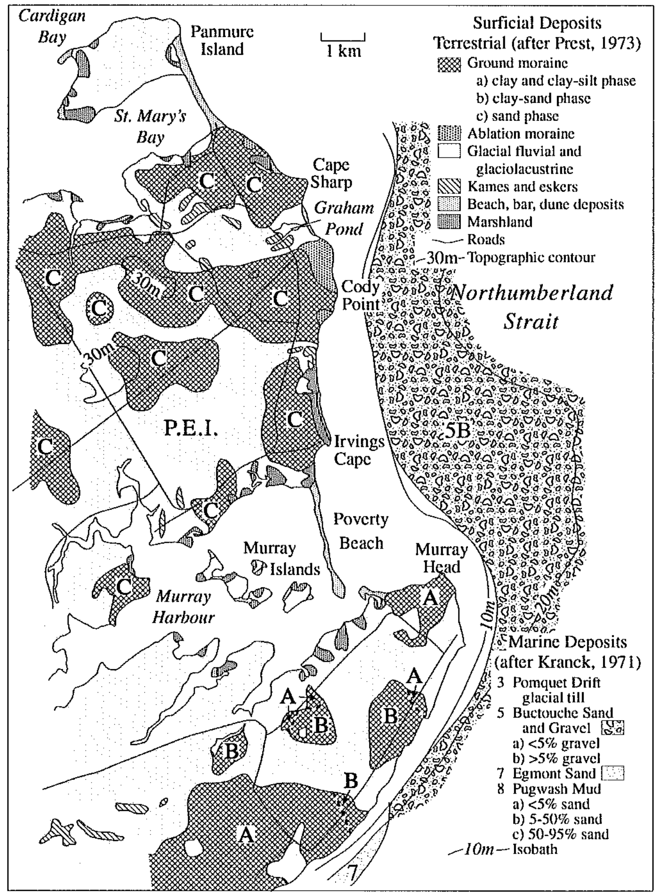
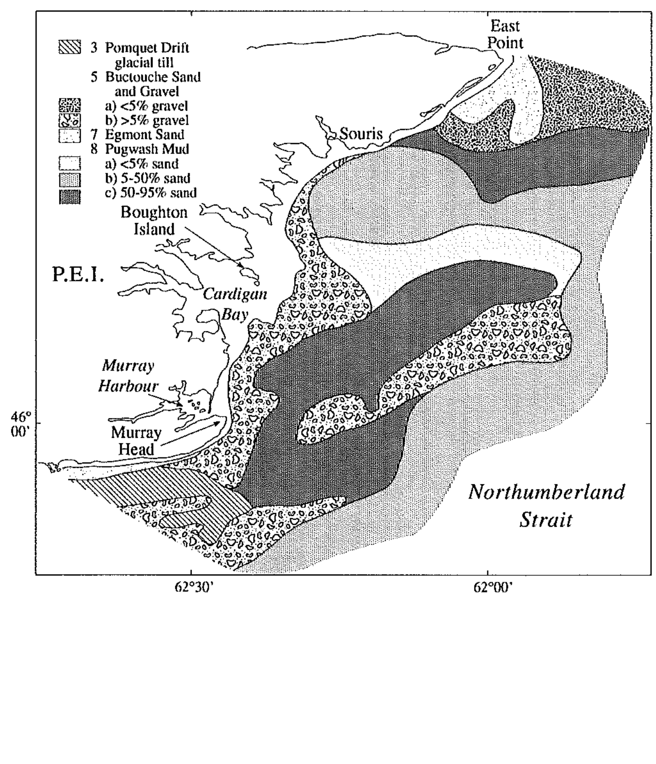


Figure 4. (A) Distribution of terrestial and nearshore surficial deposits, southeast PEI, (generalized after Frankel, 1966; Prest, 1973 and Kranck, 1971). These deposits are potential sources of sediment for beach building and the replenishment of sediment extracted by intertidal mining operations. (B) Map of surficial marine deposits in Northumberland Strait from Kranck, 1971.



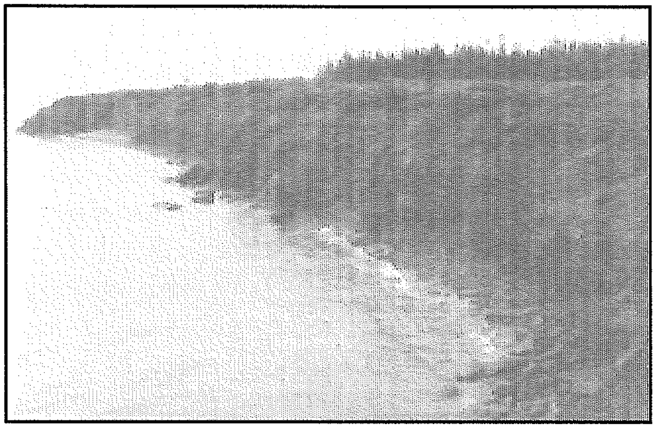


Figure 5. Shore cliffs of less than 12 m elevation form the headlands which separate the estuaries along East Prince Edward Island. The cliffs, such as those at Murray Head (view looking east) consist of 2 to 5 m of glacial material over top of poorly indurated conglomeratic and lithic sandstone bedrock. Cliff erosion is a major source of sediment for beach building.

The wave regime of eastern Prince Edward Island is controlled by three primary factors: the presence of sea ice from December to March or April; a limited fetch of 80 km; and a prevailing offshore wind direction from the W to WSW (Woodward -Clyde Consultants, 1980; Hill and Jenner, 1989).

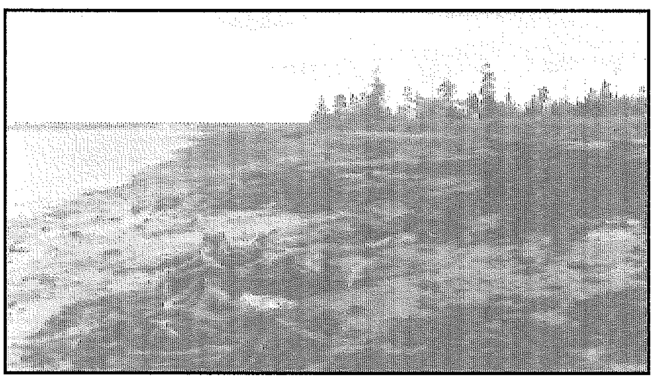


Figure 6. The presence of submerged tree stumps and peat deposits at the north end of Poverty Beach and several places along the Gaspereaux Shore provide visual evidence of the transgressive nature of the shoreline and a rising relative sea level

Owens (1980), using wave hindcasting techniques suggested the prevailing wave direction for east Prince Edward Island was from the south, and significant wave heights were less than 0.8 m. Although waves of relatively low energy persist for most of the year, storms during the fall and early winter, can produce significant wave heights of 2 to 3 m and wave periods of 6 to 7 seconds. Longer-period swells are generated by strong northeasterly gales that develop in the Gulf of St. Lawrence (Woodward-Clyde Consultants, 1980). These storms are often accompanied by extreme water levels with positive surges of up to 1 m, as in November 21-22, 1988 (Hill and Jenner, 1989) and October 29, 1991 (Parkes and Ketch, 1992). The impacts of the October 1991 storm were clearly visible in early November when the Gaspereaux Shore was visited. The beachface was combed down exposing a coarser substrate. Peat blocks, cut from the subtidal zone, also were scattered across the upper beach. The duneline was severely scarped and in many places overwashed by waves. Northumberland Strait is normally congested with sea ice in winter, but local residents (E. MacCarthy, pers. com., 1993.) can recall periods during the mid-1980s when northeasterlies coincided with ice-free conditions and waves severely impacted the shoreline.

Oceanographic and hydrological parameters from Murray Harbour have been tabulated by Gregory et al., (1993). The tides are mixed semi-diurnal with a mean range of 1.2 m and a spring range of 1.8 m.(CHS, 1990). Tidal volume flowing at mean tide is 20 x10 6 m^3. Mean tidal currents (over half a tidal cycle) are 0.95 m/s and peak currents are 1.5 m/s (3 knots) as confirmed by local fishermen (R. Miller, pers com.,1992). These are considerably stronger than those in Cardigan Bay to the north (Fig. 2) where currents are reported from less than 0.08 m/s (Gregory et al., 1993) to a maximum of 0.6 m/sec (Bartlett, 1977).

COMMERCIAL INTERTIDAL (BEACH) MINING SITES

Introduction

Each year local contractors apply to the PEI Department of Technology and Environment for a permit to extract a specific amount of sediment from a beach. Permits are issued by the provincial agency in the late spring and early fall allowing the contractors to take sediment from the lower foreshore and stockpile it on the backshore. Recommended procedures for sediment extraction are outlined to the operators in the permit regulations (Appendix 1). There is no person onsite to regulate the mining operations and to register the amount of sediment taken by each operator. However, under the permit regulations, the permit holder is required to report the volume of sediment extracted. In some cases the permit holder is the concrete industry and in other cases it is an individual hauler. If sediment extraction values are not reported to the provincial agency, future permits are denied until the reports are filed. Unfortunately, this regulation has not always been upheld in the past, reports were not always filed, particularly by the haulers and some sediment was stockpiled in the backshore for future use and not reported in the year it was extracted from the intertidal. The volume of sediment listed in the application permit does not always reflect the actual amount of sediment removed from a beach because of changing demands for the product. The sediment volume data provided by the PEI Department of Technology and Environment vary in quality. For example, the annual volumes tabulated for the 1980s (Appendix 2) are average values based on ten years of application permits. In contrast between 1975 and 1979 and after 1991, the volumes are based on annual reports of the sediment extracted at each of the sites. The sediment extraction data is now archived on computer and is easily accessed, but problems in obtaining reliable and consistent data for years prior to 1990 was a significant problem in the preparation of this review.

Field inspections are made at the extraction sites by the PEI Department of Technology and Environment as part of the review process. Beach surveys are completed where there are concerns about shoreline stability. The surveys, which were recommended in the earlier review by Woodward -Clyde Consultants, (1980), are also a method of checking the volume of sediment extracted by operators. Where there is evidence of inappropriate extraction practises or illegal extraction, charges have been made in the past. In principle, beach surveys should be completed at all sites in the spring and fall before permits are issued. Two surveys per year were completed initially and were resumed after 1993 however between 1984 and 1992 only one survey was completed each year. Furthermore, several sites were never surveyed because of the lack of field support and time to measure them. For the same reasons there was little ongoing monitoring of the surrounding shores and nearshore to assess sediment abundance and the impacts of mining.

Along the Gaspereaux Shore, routine beach surveys have been completed at three of the commercial mining sites: Irvings Cape (Cody Point) , F. Clows, and Mackenzies (Fig. 3). Beach surveys did not begin until 1997 at the W. Johnston site.

Beach Survey Methodology

Beach surveys of commercial sediment extraction sites include the establishment of a baseline along the backshore and a series of lines extending seaward across the beach from the baseline to water level (Fig. 7a). Where the shoreline retreats, the surveys are extended landward of the baseline. Sequential surveys at the same beach location provide critical information about the magnitude and location of physical changes as well as changes in the sediment volume at that location. It should be remembered that the differences in beach profile surveyed on one date when compared to another, represent the net changes during that time period. The long time interval between surveys and the lack of information about when and where sediment was extracted each year makes it more difficult to determine beach changes which occur between survey dates and to differentiate changes caused by natural processes versus mining activities.

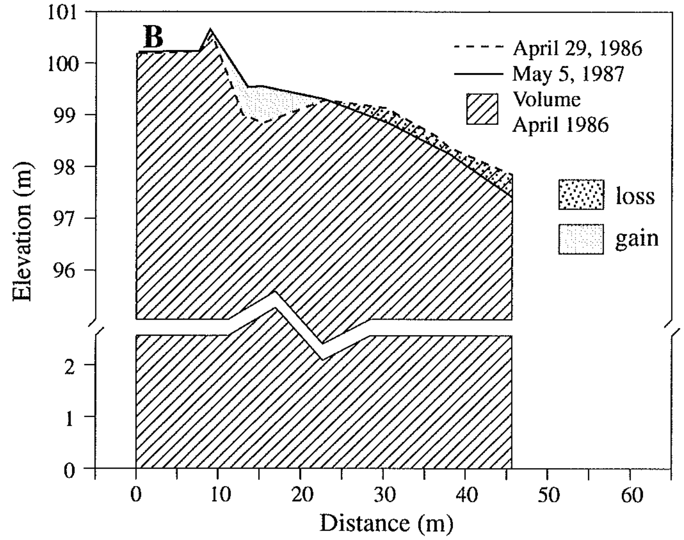
The volume of sediment at a beach site is calculated by measuring the area under the curve of each survey line to a base level, which in this case is set to zero (Fig. 7b). Each survey line is assumed to be representative of a specific section of shoreline. To calculate the sediment volume, the area under the curve is multiplied by the distance half way to the next survey line. The volume of sediment within each segment of beach is then added to calculate the total sediment volume for the site (Table 1). To translate these values to more realistic volumes for a site, a further step is taken. For each site the total volume of sediment from each year is compared and the year with the least sediment which is used as the base volume for the site, ie. 1989 in the case of Irvings Cape. Next, the base volume is subtracted from all other yearly volumes to calculate the relative change in sediment volume at a site (Table 1). The same results could have been achieved by measuring the changes in volume between subsequent surveys of each beach line. The same portion of the beach, 45.7 m seaward from the baseline, is used to calculate the sediment volume each year, even though in many cases the mining operations have expanded farther landward. The sediment volumes only reflect the relative changes for a specific portion of each site, not the entire beach. Hence, the changes in sediment volume listed in this report are less than the total changes.

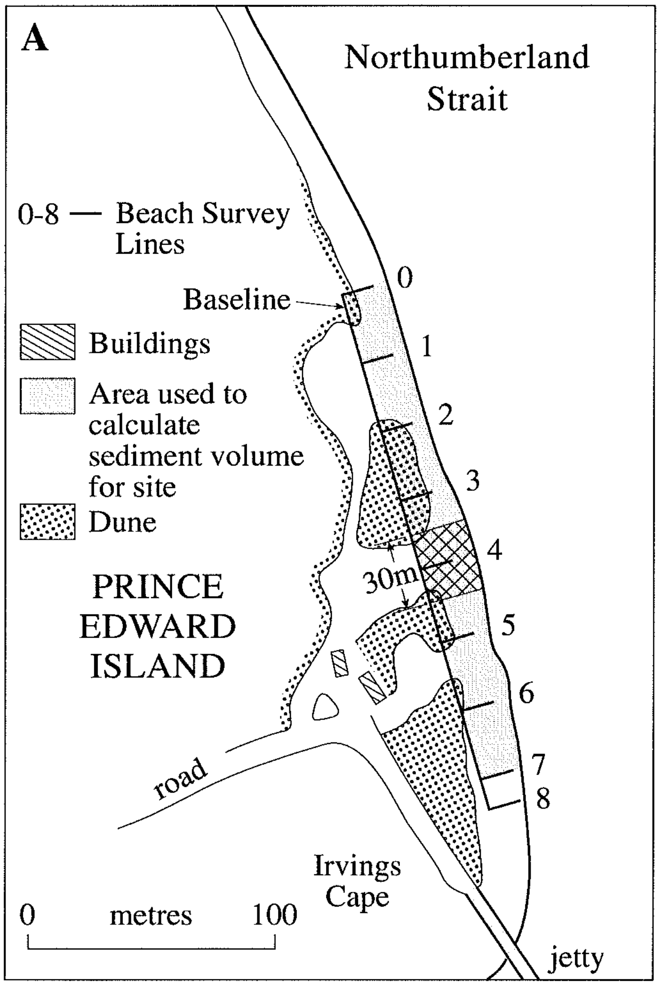
Table 1.Changes in total sediment volume (m^3), rates of sediment extraction and natural sediment supply from 1984 to1997 at Irvings Cape commercial beach mining site, east Prince Edward Island.

DATE OF BEACH SURVEY	TOTAL VOLUME	TOTAL VOL RELATIVE TO 1989	NET CHANGE IN VOLUME	ANNUAL COMMERCIAL EXTRACTION BETWEEN SURVEYS	NATURAL SEDIMENT SUPPLY	ANNUAL NET SUPPLY
Nov 29, 1984	1102260.33	2161.33				
May 15, 1985	1101990.40	1891.40	-269.93	0.00	-269.93	-269.93
April 29, 1986	1104480.49	4381.49	2490.08	4100.00	6590.08	6590.08
May 5, 1987	1103678.04	3579.04	-802.45	4100.00	3297.55	3297.55
June 7, 1988	1102201.90	2102.90	-1476.13	4100.00	2623.87	2623.87
May 31, 1989	1100099.00	**0.00**	-2102.90	4100.00	1997.10	1997.10
June 18, 1990	1101372.78	1273.78	1273.78	4100.00	5373.78	5373.78
May 21, 1991	1101776.85	1677.85	404.08	4100.00	4504.08	4504.08
May 22, 1992	1101336.29	1237.29	-440.56	3558.00	3117.44	3117.44
June 15, 1993	1102002.84	1903.84	666.56	396.00	1062.56	1062.56
SEPT 22 1993	1102421.58	2322.58	418.73		418.73	
APR 26 1994	1101534.46	1435.46	-887.11		-887.11	-468.38
AUG 30 1994	1102034.70	1935.70	500.24		500.24	
May 11, 1995	1102868.19	2769.19	833.49		833.49	1333.73
SEPT 13 1995	1104249.02	4150.02	1380.83		1380.83	
MAY 14 1996	1103367.20	3268.20	-881.82		-881.82	499.01
SEPT 6 1996	1103274.67	3175.67	-92.53		-92.53	
SEPT 12, 1997	1101708.80	1609.80	-1565.87		-1565.87	-1658.40

SUMMARY:	(m3)
TOTAL SEDIMENT EXTRACTED (1985 to 1992) =	28554
NET CHANGE IN SITE SEDIMENT VOLUME 1984 TO JUNE 1993 =	-257
NET CHANGE IN SITE SEDIMENT VOLUME 1984 TO SEPT.1997 =	-552
TOTAL NET SEDIMENT SUPPLY (m3) (1984-1993) =	28297
TOTAL NET SEDIMENT SUPPLY (m3) (1993-1997) =	-294
TOTAL NET SEDIMENT SUPPLY (m3) (1984-1997) =	28002
MEAN ANNUAL SEDIMENT SUPPLY (m3) (1984-1993) =	**3144**
MEAN ANNUAL SEDIMENT SUPPLY (m3) (1993-1997) =	**-74**

Figure 7. (A) Map of survey lines used to monitor changes in beach morphology and sediment volume at the Irvings Cape intertidal mining site. Total sediment volume at the site was calculated using the beach area seaward of the baseline between lines 0 and 7 (shaded area). The volume of sediment at a beach site is calculated by measuring the area under the curve of each survey line (B). Each survey line is assumed to be representative of a specific section of shoreline. To calculate the sediment volume, the area under the curve is multiplied by the distance half way to the next survey line. The volume of sediment within each segment of beach is then added to calculate the total sediment volume for the site.





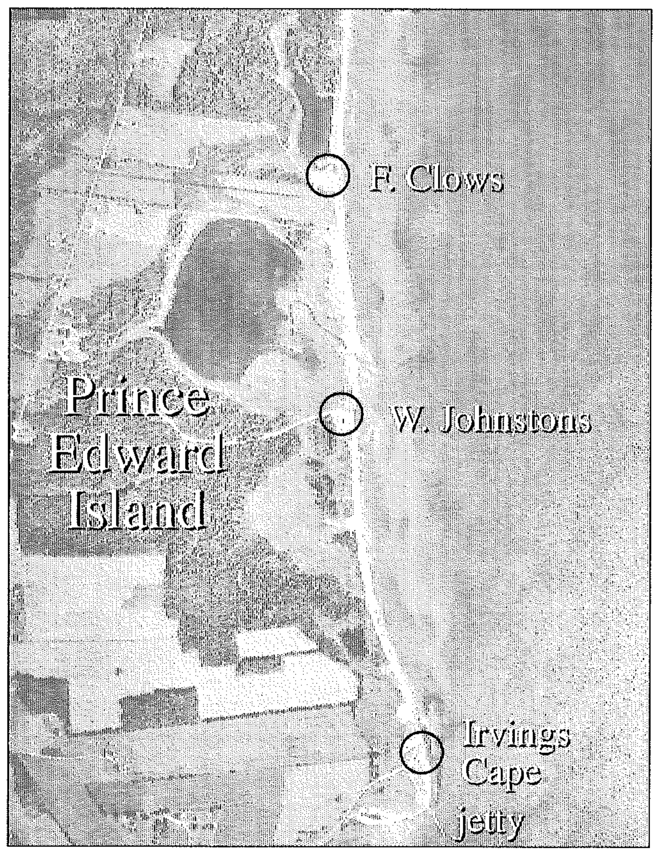


Figure 8. Aerial view taken in 1987 showing the physical character of the shoreline and nearshore bars in the vicinity of three sediment extraction sites: F. Clows, W. Johnston, and Irvings Cape (Photo 87228-31, 1:10,000, Courtesy of Land Registration and Information Service, Amherst, N.S.).

storms that struck the area.

The mid to lower beach was cut back and waves deposited sediment farther upslope forming a sand ramp against the higher beach areas or washing sediment onto low backshore areas. The building of the upper beach sand ramp facilitated the gradual spread of dune vegetation seaward from backshore at several lines.

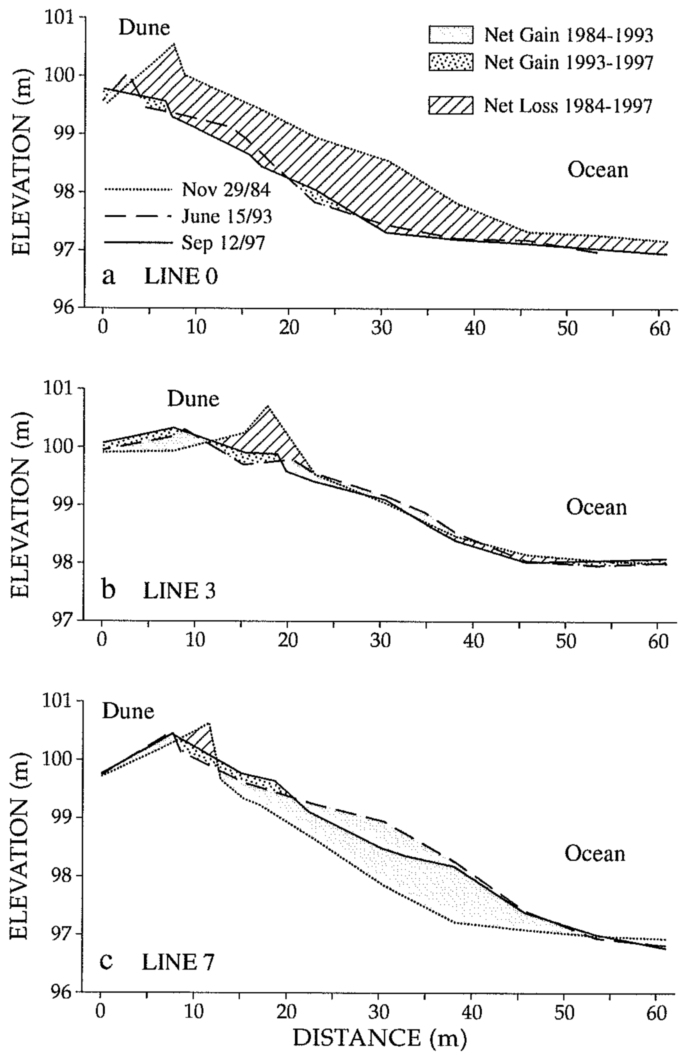


Figure 10. A comparison of net sediment gains at Irvings Cape mining site during periods of sediment extraction, 1984 to 1993, and non-extraction, 1993-1997. The surveys also illustrate differences in the net loss of sediment alongshore during the thirteen years. Lines 0, 3 and 7, represent changes at the north, middle and south parts of the mining site (lines are located on Fig. 7a).

Between May and September 1996 the mid to lower part of the northern beach was combed down by waves; however south of line 5, a substantial berm had built near high tide level. A survey was not completed in the spring of 1997 but by the fall of that year the mid to lower beach had been further combed down and a scarp had been cut along the upper beach. South of line 5 the beach had been combed down but there had also been buildup of material across the upper beach which suggests that the shore was impacted by more than one storm. Beach changes often differed north and south of line 5 which appears to be a nodal point for waves reworking the site.

The impacts of natural processes versus beach mining on the stability of this beach site are documented by comparing changes that occurred between 1984 and 1992 with those observed after 1992 (Fig. 10,12). Between 1987 and 1988 there was severe degradation of the backshore dunes and little beach recovery (Fig. 12a). In 1991, one year after deep cuts were observed across the upper beach, only minor infilling of the low areas was observed. In contrast, between September 1993 and 1997 the beach experienced a more natural cut and fill sequence across the mid to lower beach and there was a gradual building of the upper beach (Fig. 12b). During the period of mining, beach change was much more pronounced across the upper beach and dune, losses of sediment were larger and the cuts in the beach more irregular and deeper (Fig. 12a). Sweep profiles are a common method used to show the upper and lower limits of beach change over a specific time interval. Sweep profiles were compiled for lines 0 and 7 for the period of mining and the non-mining (Fig. 13). The sweep profile produced by natural processes is more confined than the one resulting from the period when both mining and natural processes occurred.

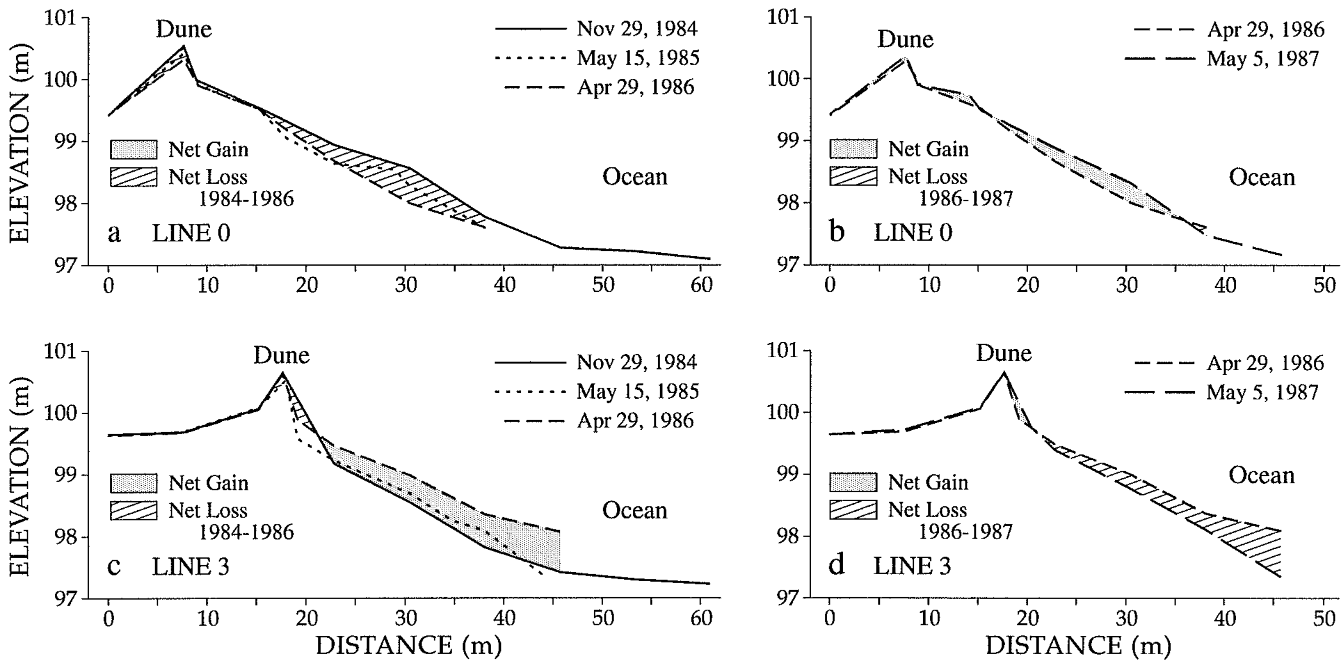


Figure 11. Variations in beach response alongshore at the Irvings Cape site are illustrated using a comparison of beach changes at lines 0 and 3 between 1984 and 1987. Line 0 represents beach changes at the north end of the site and line 3 represents the changes recorded along the rest of the site.

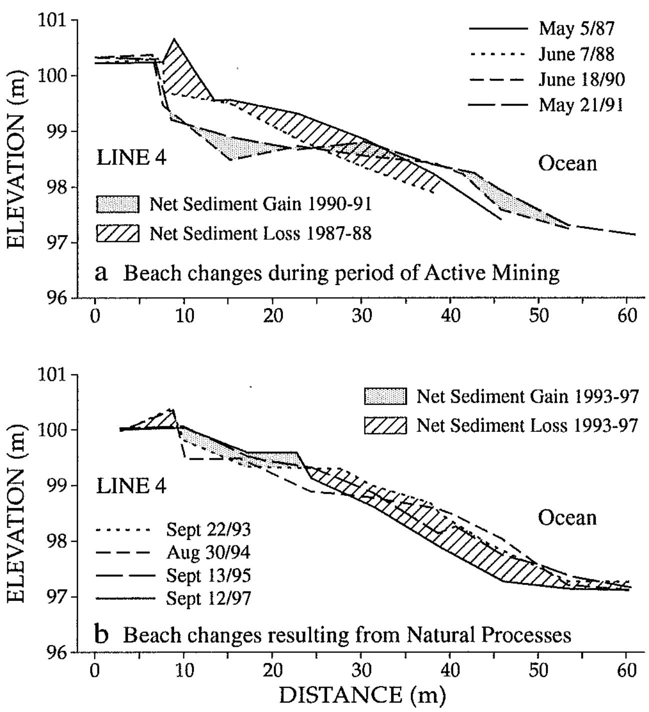


Figure 12. Comparison of beach changes at Line 4 observed during (A) fours years of sediment extraction and (B) four years of natural processes when upper beach was gradually rebuilt and net losses were greater across the lower beach.

The plots in figure 13 also show that sweep profiles can either shift upward or downward depending on local conditions. For example, at line 0 where there has been net beach retreat, the lower limit of the sweep zone continued to lower even after mining was stopped. In contrast, at line 7, the lower limit of the sweep profile moved higher because the short- term beach changes were less than the total sediment accumulation after 1984 (Fig. 13).

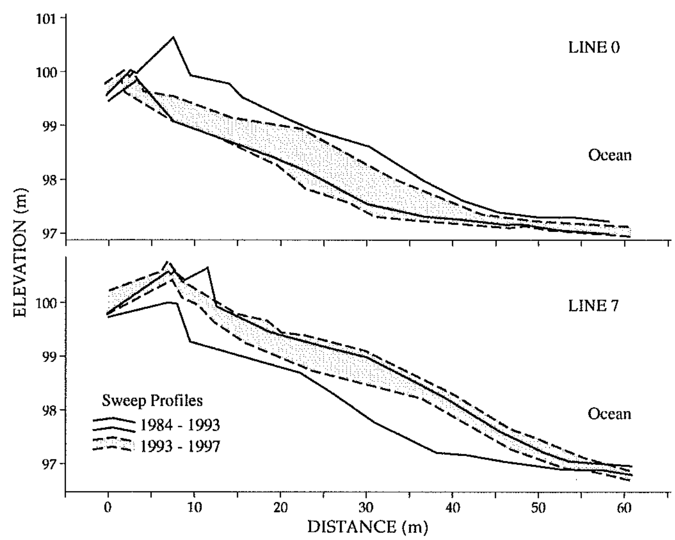


Figure 13. Sweep profiles of lines 0 and 7 showing the difference in the extreme limits of beach change between the period of mining (1984 to 1992) and after 1992 when mining had ceased. The sweep profiles are more confined for the non-mining period.

Dune Changes (1984-1997)

The duneline at Irvings Cape is relatively similar in elevation alongshore except for the three cuts which were dug to allow excavation equipment access to the beach (Fig. 7a, 9). The retreat of the duneline was very irregular and sporadic alongshore (Figs. 10 to 12, Table 2). For instance, the greatest retreat over the thirteen years was at line 3 where 10 m of dune was lost, and at lines 0, 5 and 8 where 7 m of dune was eroded (Table 2). The dune at lines 4 and 6 retreated the least, but it was lowered by 0.5 to 0.6 m. The timing of duneline erosion appears to reflect excavation activities rather than natural processes. For example lines 7 and 8 were severely cut back in 1984-85; line 5 between 1987 and 1988, line 3 between 1987 and 1989 and line 0 experienced its greatest retreat in 1988-89 (Table 2). Three years following the stoppage of mining the duneline became much more stable and the dune vegetation expanded seaward in response to the higher sand levels across the upper beach, particularly in 1995. The stability and growth of the dunes after 1992 reduced the occurrence of wave overwashing and flooding of the backshore. Continued growth of the dunes will protect the backshore during future storms and provide a source of sediment for beachface recovery. Mean duneline retreat between 1984 and 1992 was 0.65 m/a, whereas between 1992 and 1997 it decreased to 0.03 m/a. This sharp contrast between the periods of mining and non-mining demonstrates that dune instability is one of the negative impacts of mining activity.

Table 2 Changes in the seaward position of the duneline and rates of retreat between 1984 and 1997 at Irvings Cape beach mining site. Negative positions signify the duneline has retreated landward of the survey baseline. The information is based on beach surveys completed by the PEI Department of Technology and Environment.

YEAR	SEAWARD DUNELINE POSITION (metres from baseline)						
	LINE 0	LINE3	LINE 4	LINE 5	LINE 6	LINE 7	LINE 8
1984	7.62	17.67	9.14	13.41	9.14	11.58	12.80
1985	7.62	17.67	9.14	13.41	9.75	7.62	6.40
1986	7.62	17.67	9.14	13.10	10.05	*7.62*	6.09
1987	7.62	17.67	8.83	13.10	9.75	7.62	6.09
1988	7.62		7.62	7.62		7.62	6.09
1989	2.74	10.05	7.62	*7.62*		7.62	5.79
1990	2.74	10.36	6.40	7.62		7.62	5.48
1991	*2.74*	9.14	6.70	6.40	7.62	7.01	5.48
1992	2.74	8.83	6.70	6.40	7.62	7.01	5.48
1993	2.74	8.83	6.09	*6.40*	7.62	*7.01*	5.48
1994	1.82	8.83	6.70	6.10	7.62	6.70	5.18
1995	1.52	7.62	7.62	7.62	7.62	6.70	5.18
1996	1.52	7.62	7.62	7.62	7.62	7.01	5.18
1997	0.00	7.62	7.62	7.62	7.62	7.62	7.62
DUNELINE CHANGE (m)							
1984-92	-4.88	-8.84	-2.44	-7.01	-1.52	-4.57	-7.32
1992-97	-2.74	-1.21	0.92	1.22	0.00	0.61	2.14
1984-97	**-7.62**	**-10.05**	**-1.52**	**-5.79**	**-1.52**	**-3.96**	**-5.18**
RATE OF CHANGE(m/a)							
1984-92	-0.61	-1.11	-0.31	-0.88	-0.19	-0.57	-0.92
1992-97	-0.55	-0.24	0.18	0.24	0.00	0.12	0.43
1984-97	**-0.59**	**-0.77**	**-0.12**	**-0.45**	**-0.12**	**-0.30**	**-0.40**
MAX. TOTAL RETREAT	-7.62	-10.05	-2.44	-7.01	-1.52	-4.57	-7.32

Mean Change In Duneline Position At Irvings Cape
(1984-1992) Mining = -0.65 m/a
(1992-1995)Non-Mining = 0.03 m/a

Sediment Extraction, Supply and Net Changes in Volume

A beach is composed of sediment. To make an assessment of the impacts of commercial sediment extraction on this beach site, or elsewhere alongshore, it is important to document the amount of sediment accumulating, eroding or stored at a site. Annual net change in sediment volume at this site (between lines 0 and 7) is calculated from the differences between the annual beach surveys (Table 1). An estimate of the volume of sediment lost from the site is obtained from commercial extraction permits issued by the provincial government and subsequent operator haulage reports. The volume of sediment added to the site each year is estimated using the difference between the volume of sediment extracted and the net change in sediment volume at the site. Each of these aspects is examined next.

Estimates of the annual volume of sediment extracted from the site between 1984 and 1992 and the net difference in sediment volume at the Irvings Cape site are plotted in Figure 14 and listed in Table 1. Sediment volumes for the whole site are plotted relative to the lowest volume recorded in 1989 which has been set to zero.

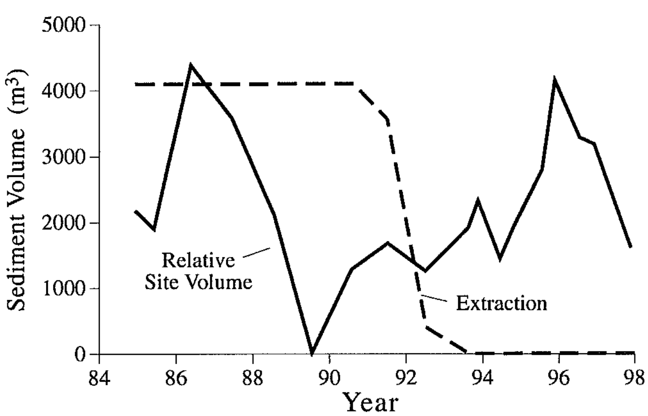


Figure 14. Changes in sediment volume and rates of sediment extraction at the Irvings Cape mining site, 1984 to 1997. Permits for sediment extraction were not issued after 1992 but surveys were continued to assess natural fluctuations in sediment volume at the site. The sediment volumes are listed in Table 1.

Following a sizeable accumulation of sediment in 1986 there was a net loss of sediment at the site until 1989 when sediment accretion again began to exceed sediment erosion (Fig. 14). The volume of sediment at the site did not recover to its initial (1984) level until late 1993 and it remained higher than 1984 volumes from late 1994 to 1997. Maximum sediment volume was attained at the site in the fall of 1995 and then it began to decrease again. Fluctuations in sediment volume after 1993 reflect natural seasonal beach changes.

The exact sequence of natural beach changes is dependent on the frequency and timing of major storms during a particular year. In some years maximum sediment was observed during the spring surveys, in others the summer or fall surveys, but the normal sequence is for the beach to build through the late spring and summer until the fall when maximum sediment levels are attained. The impact of beach mining is reflected in the differences in the net loss of sediment at line 4 between 1987-88 and 1993-94 (Fig. 12). There was 1.9 times more sediment lost during 1987-88 than during 93-94 (347 m^3 vs 174 m^3), when the beach was struck by several winter storms. A similar but slightly smaller difference was observed when comparing changes in sediment volume for the entire site (Table 1). The difference in the magnitude of storms that occurred during the two periods is not known, but the increased losses at Irvings Cape in 1987-88 are attributed to mining activity (Table 1: 1477 m^3 vs 887 m^3).

From the plot of changes in site sediment volume (Fig. 14) it would be natural to conclude that sediment supply cannot sustain sediment extraction over several consecutive years but it can supply sufficient sediment to rebuild the beach within four to six years after mining is stopped. One might even conclude mining has no long term negative impacts on beach stability. However a different trend in shoreline recovery is revealed when changes in sediment volume are examined at individual lines within the site and from surveys continued for a longer time. In Figure 15 the sediment volumes recorded at individual lines on five dates are plotted relative to the volume recorded at each line in 1984 (represented by zero). 1987 represents the year that the jetty was removed, 1989 represents the year of the lowest volume of sediment, 1995 the maximum volume (Table 1, Fig. 14), 1993 represents the first year after mining was stopped and 1997 represents the last survey completed at the site. Line 8 is excluded from the analysis so that the information is comparable to the sediment volume changes for the whole site which are calculated for the beach between lines 0 and 7.

The graph in Figure15 shows that by 1987 more sediment was accumulating at the south than the north end of the site and a net loss of sediment was only recorded at line 0. By 1989 all survey lines, particularly lines 2 and 3, suffered a net loss of sediment. By 1993 the beach south of line 3 had recovered more sediment than in 1984 and sediment continued to accumulate along that part of the site between 1993 and 1995.

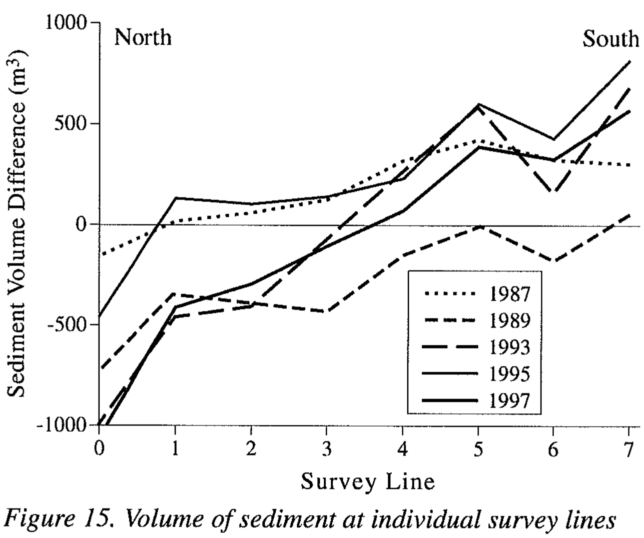


Figure 15. Volume of sediment at individual survey lines along Irvings Cape is plotted for five years 1987, 1989, 1993, 1995 and 1997. The volumes are plotted relative to the amount of sediment at each line in1984 which was set to zero. The graph shows that more sediment had accumulated in 1987 but volumes decreased dramatically by 1989. Lines 3 to 7 did not accumulate more sediment than 1984 until 1993, lines 1 and 2 recovered by 1995 and line 0 never did recover. It appears that the southern part of the beach is rebuilding, at least in part, using sediment from the north end of the site.

In contrast, the north end of the site continued to erode by 1993, had nearly recovered by 1995, and then suffered significant sediment loss by 1997. Although total sediment volumes for the site suggest that the site had recovered by 1993, one year after mining was stopped and by late 1995 it had accumulated nearly twice the sediment volume of 1984, the total volume had fallen again in 1997 to less than the 1984 volume (Table 1). It appears that new sediment reached the site after mining was stopped and the south end of the site was building with sediment eroded from the north end. Since mining has stopped, the site has experienced fluctuations in sediment volume but they were storm-driven rather than human-induced changes.

The changes in sediment volume at the Irvings Cape site reflect a combination of factors. The increased sediment volume in 1987 may be attributed to the residual left from the large accumulation of sediment in 1986. The dramatic loss of sediment between 1987 and 1989 may reflect the removal of the Irvings Cape jetty and the subsequent loss of sediment downdrift and/or the starting of mining at the Johnston site (Fig. 8) which would reduce longshore sediment inputs to Irvings Cape. However the latter is not likely a factor, since sediment supply increased after 1989. The increase after 1989 may reflect the restabilization of the beach following adjustments to the loss of most of the jetty. A comparison of beach width at the updrift (north) side of the concrete wall of Irvings Cape jetty in 1990 (air photo) and 1993 (field) suggests that the upper beach had prograded 10-20 m. Plots of seasonal changes in sediment volume at each line (Fig. 16) suggest that the north end of the site experienced greater change during the winter months whereas the south end builds more in the summer months. After 1993 sediment accumulation increased more at the north than the south end although 1995 appears to have been a particularly good year for beach building. (Fig. 15). The gradual decrease in the fluctuation of sediment volume at the south end of the site is attributed to the infill of sediment at the remaining jetty and the subsequent resumption of sediment bypassing.

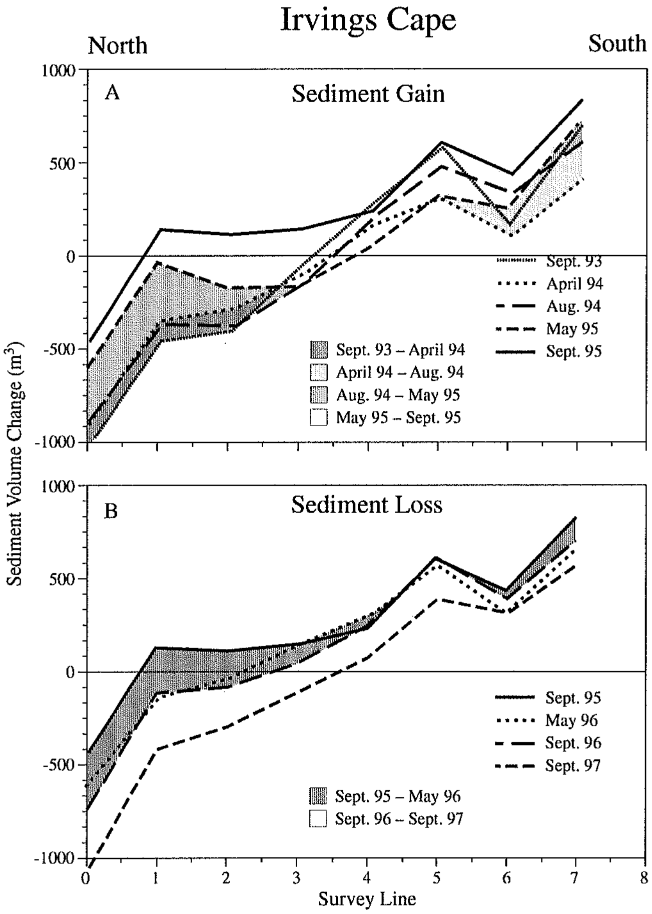


Figure 16. Changes in seasonal volumes of sediment at individual survey lines along Irvings Cape beach showing (A) the sediment gain between 1993 and 1995, and (B) the sediment loss between 1995-1997. Changes appear to be greater at the north end of the site between September and May and the gains are larger during the summer at the south end of the site.

It may be that as sediment accumulated against the Irvings Cape jetty, it trapped sediment farther updrift and beach width progressively increased northward with time, however a closer look at Figure 16 suggests that line 1 and 5 are locations of greater sediment accretion and beach stability which may be the result of natural wave patterns.

If the annual volume of extracted sediment is added to the changes in sediment volume at the site, it is possible to determine the amount of sediment naturally supplied to the site and to assess whether there is sufficient sediment to sustain extraction activities at their present level (Table 1, Fig. 17). A significant problem with this calculation is the uncertainty whether the annual permits for sediment extraction closely resemble the amount of sediment mined. We know that in some years more sediment is taken and in other years less sediment is extracted. However if we assume the extraction values listed in the permits are the best estimates, it provides a way to analyse the sediment supplied to the site versus losses caused by a) mining and b) natural processes. Sediment supplied annually to the Irvings Cape site during the years of sediment extraction (1984-1992) averaged 3144 m^3/a, a value more than 10 times higher than the average annual sediment supply after mining was stopped (Table 1). After 1992 the amount of sediment supplied varied from a net gain of 1380 m^3/a in 1995 to a net loss of 1565 m^3/a in 1997. One conclusion from this might be that less sediment is required to maintain a beach when there is no mining. An alternative interpretation might be that there was less sediment available after 1992 to supply the site, than was available before 1992. Both interpretations may be correct. Another factor to consider is the increased extraction farther to the north at the W. Johnston and F. Clows sites.

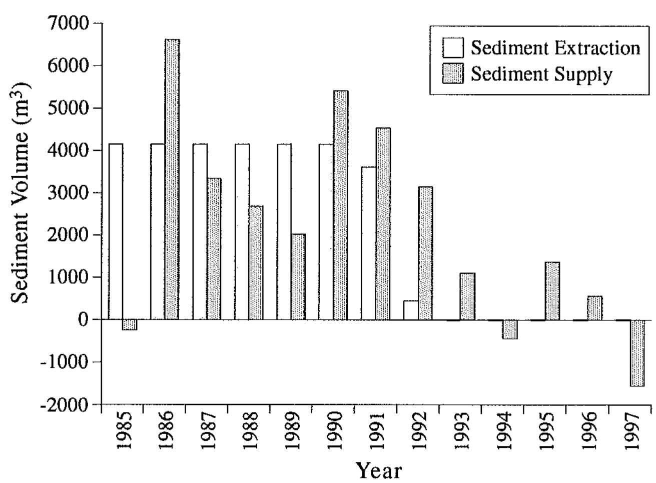


Figure 17. Volume of sediment artificially extracted and naturally supplied to the Irvings Cape site each year. The volume of sediment supplied is calculated by adding the volume of sediment extracted to the net change in sediment volume at the site. Sediment supply only exceeded the volume extracted in 4 of 8 years. Despite this imbalance, ten times the amount of sediment was supplied to Irvings Cape during years of active mining than after mining had ceased.

Between 1987 and 1991 it was the southern part of the site that exhibited the greatest changes. At line 0 the duneline was progressively cut back despite rebuilding of the lower beach slope each spring. The sediment which accumulated across the lower slope may have been derived from dune erosion. The natural recovery of sediment across the lower beach slope and the building of a berm at high tide was observed in each of 1988 and 1989 but it was not apparent in 1991(Fig. 21b). The till cliff north of the F. Clows site became more exposed to wave attack and retreat was accelerated. All that remained of the beach and wetland that fronted the till cliff was an exposure of peat representing the base of the former wetland.

Despite minor sediment accumulation across the upper beach in 1992, the dune and upper beach slope retreated landward as a result of storms during the winter of 1993-94 and the loss of sediment across the lower beach (Fig. 21c). Permits for sediment extraction were not issued in 1994 because of the dramatic changes to the shoreline by storms the previous winter. During 1994 there was a slight net increase in sediment at the site. By the fall of 1994 sediment had accumulated on the upper beach at the northern part of the site but a similar gain was not recorded at line 0 until the spring of 1995. An extraction permit was re-issued for 1995 and despite a slight gain in sediment by the fall of 1995 at some lines, the whole site suffered a net loss of sediment by the fall of 1996 (Table 4). No permits for sediment extraction were issued in 1996 and only a small net loss of sediment and minor changes in the beach morphology were observed in that year and early 1997. By the spring of 1998 the duneline had retreated 0.5 to 5.1 m landward and there was a further net decrease in sediment volume at the site. The accelerated change is attributed to the re-issuing of a permit, albeit small, in 1997. No permits were issued in 1998 and the beach showed signs of progradation at several lines, but the dune continued to retreat.

A comparison of beach morphology at lines 3, 4, 5 (Fig. 22) in May 1985, 1996 and 1998 illustrates both the landward displacement of the beach as well as a shift in the location of the largest beach changes. In 1985 the largest changes in beach morphology were recorded at and below high tide level, whereas by 1996 larger changes were observed across the whole profile (Fig. 22a). In 1996 there was also a lack of sediment accumulation across the lower slope, which may partly reflect local wave conditions just prior to the survey. Other evidence suggests that there was insufficient sediment supplied to the site by 1996 to build the same constructional features observed in 1985. The lack of lower beach recovery means that the upper slope is more vulnerable to wave attack as was observed by 1998 when the upper beach was eroded and the lower beach recovered slightly. It appears that over time, even though sediment excavation is restricted to the lower intertidal zone, the whole beach is impacted.

Dune Changes (1984-1998)

Between 1984 and 1998 the seaward duneline at the F. Clows site retreated 12.0 to 17.6 m landward (Fig. 23, Table 3). The duneline was scarped at line 0 as early as 1984 and at the other lines by 1987. A slight seaward progradation of the duneline was recorded between 1985 and 1986. The duneline appeared more stable between 1989 and 1992. However it was severely cut back between 1987 and 1988 and between 1993 and 1994, which were periods of increased storminess. D. Boyce (pers. com., 1995) reported that a major storm in the fall of 1993 had cut back the dunes. Another storm on December 30, 1993, produced a positive surge of 1.15 m at Charlottetown, (G. Parkes, Environment Canada, pers. com., 1997). This would have elevated wave attack in the study area. No permits were issued for sediment extraction at the F. Clows site in 1994 because of these storms. The larger loss of dune during these storms may also be attributed to the weakened condition of the beach because of the continued extraction of sediment and its inability to recover between the storms. The duneline was also fairly stable between 1994 and 1996, but retreat became accelerated after 1996. The duneline retreated 7.0 to 8.2 m at lines 4 and 5. It is not known if the increased retreat was due to mining or natural causes but a permit for extraction was re-issued in 1997 and the dune continued to retreat in 1998 when no permit was issued. Regardless of the causes, the duneline retreated in a more step-like progression than the dunes at Irvings Cape, where some dune recovery was observed after mining was stopped.

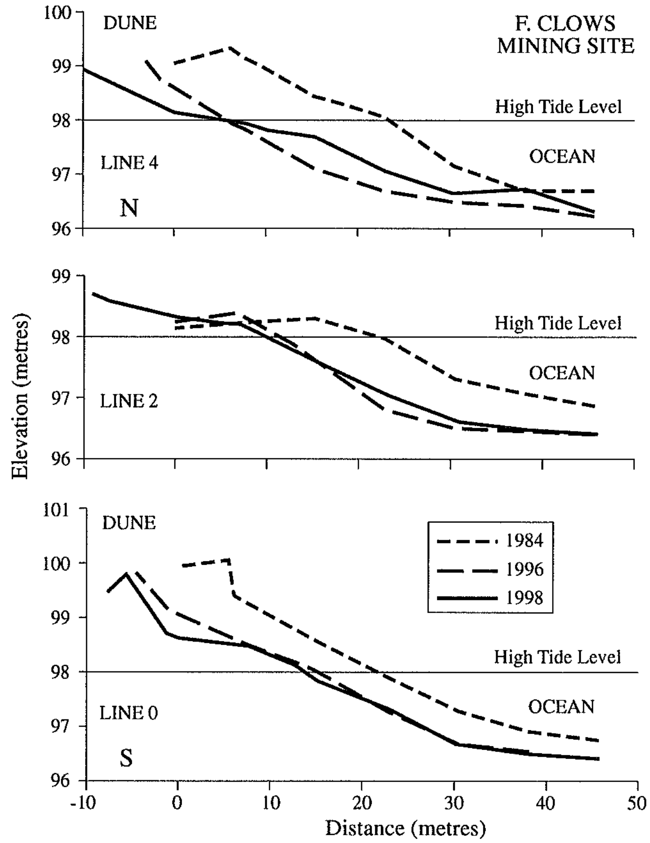


Figure 20. Beach profiles surveyed in 1984, 1996 and 1998 at lines 4, 2, 0, (Fig 18) illustrate the net loss of beach along the northern, middle and southern parts of the F. Clows extraction site. The beach retreated 15 to 19 m landward at the northern end and 10 m at the southern line (Table 3). After 1996 when extraction activities were significantly reduced, the intertidal zone experienced less net change, however the upper beach and dune continued to retreat.

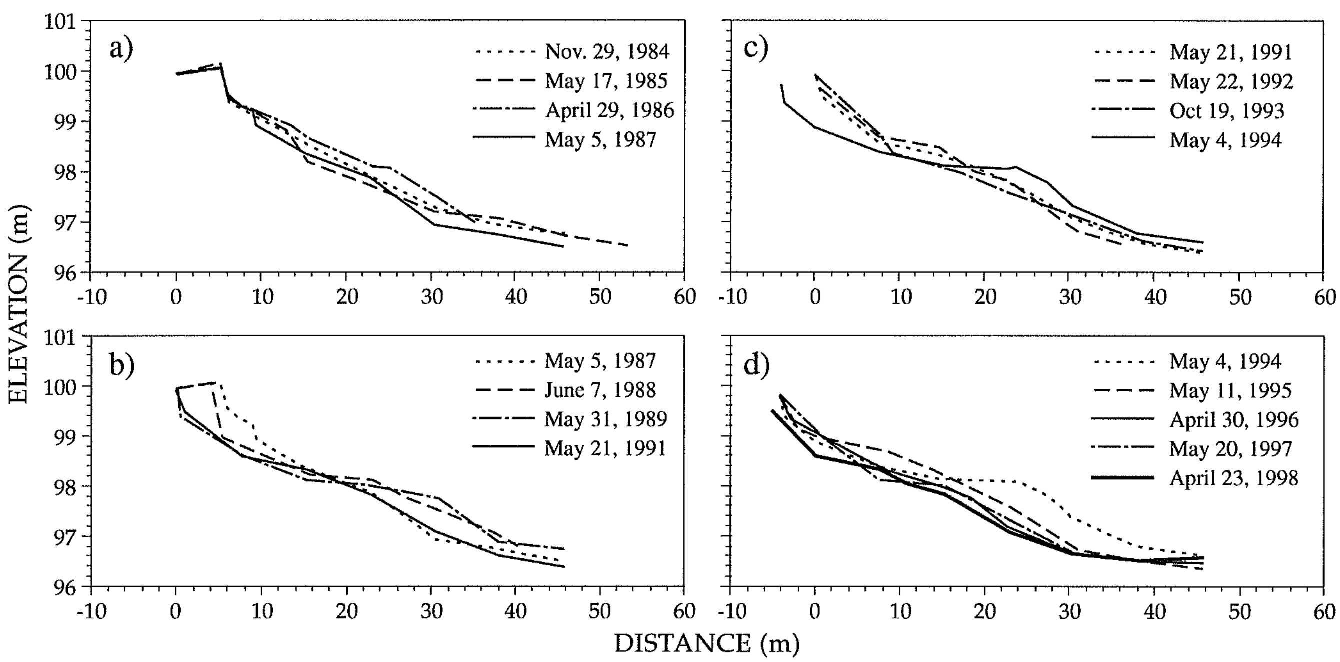


Figure 21. Sequential beach profile changes at the south end of the F. Clows site between 1984 and 1996 are illustrated using line 0 (Fig. 18). The backshore retreated most between 1987 and 1994 at this location.

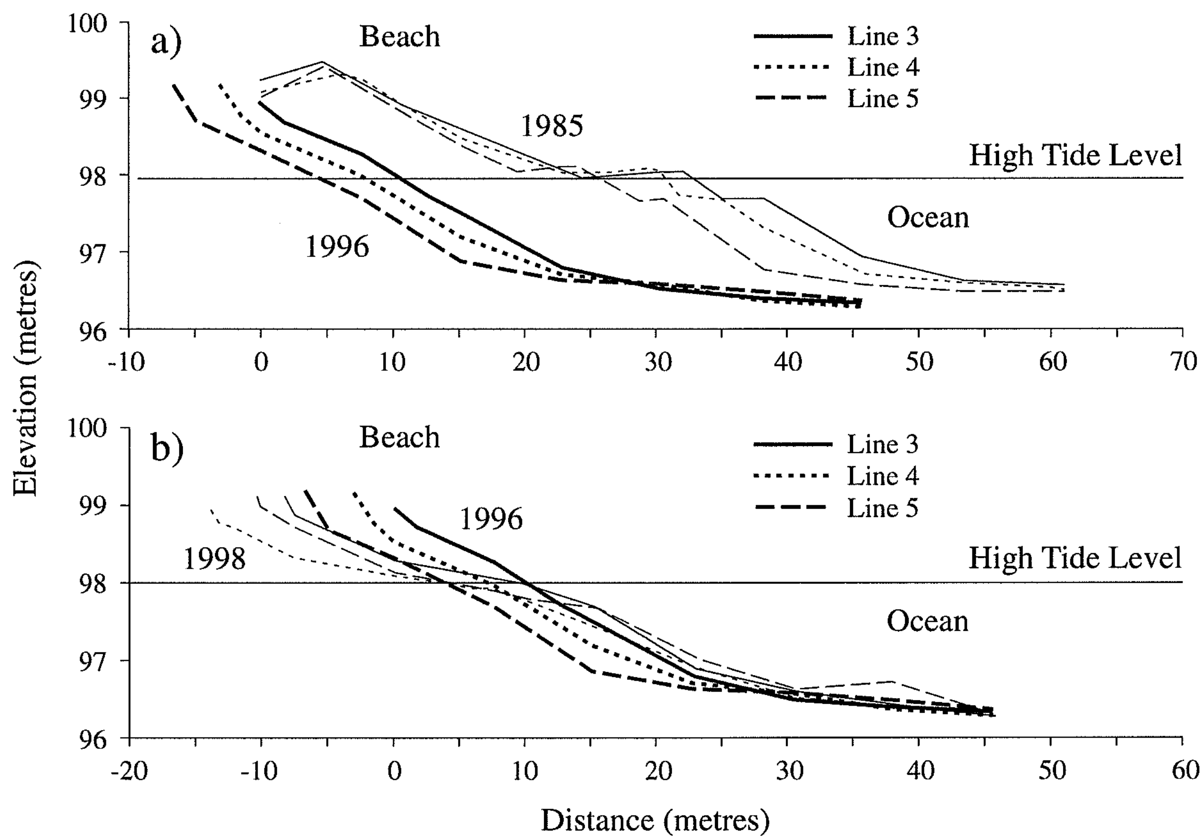


Figure 22. Temporal and longshore changes at F. Clows are illustrated by comparing three survey lines from (a) 1985 and 1996 (bold lines) and (b) 1996 (bold lines) and 1998. The graphs show that all of the lines retreated landward especially between 1985 and 1996. The more southern line, line 3, has maintained a more seaward position over time relative to the other two lines, and the changes across the upper beach have increased toward the north end of the site. In 1985 the largest difference between the three lines was below high tide level but by 1996 the differences were more consistent across the entire beach slope which is attributed to the absence of lower beach building. After 1996 (b) there was less of a shift in beach position as the lower beach appeared to gain sediment from the upper beach.

A comparison of Figures 23 and 24 suggests that increased dune stability correlates with periods of net increased sediment across the beach.

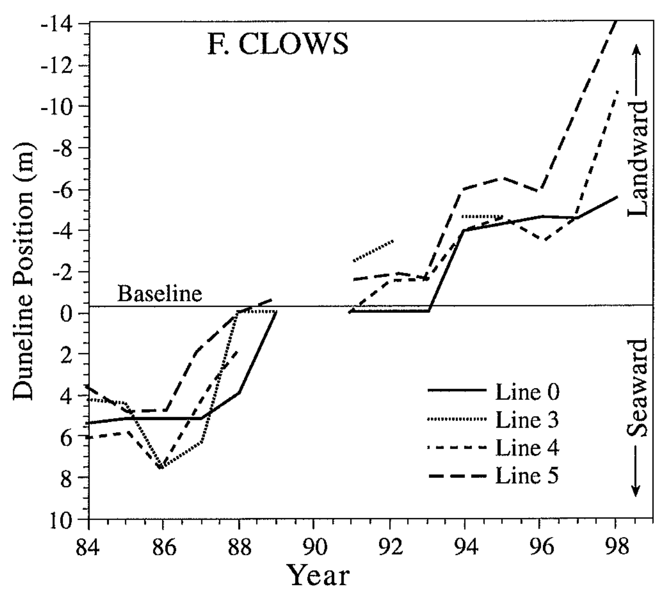


Figure 23. Changes in the seaward position of the duneline at four lines (Fig. 18) along the beach at F. Clows are plotted relative to the survey baseline. Despite some initial progradation seaward, the duneline has retreated an average of 15.4 m between 1984 and 1998. The largest retreat was recorded between 1987 & 1988, 1993 & 1994 and 1997 &1998 (Table 3). The first two set of years were periods of increased storminess.

Sediment Extraction, Supply and Net Changes in Volume

The volume of sediment stored, gained and lost at the F. Clows site (Table 4) was documented following the same procedures used at the Irvings Cape site. Apart from minor net sediment gains in 1985, 1988, 1994 and late 1997 there has been a steady decrease in sediment volume at the F. Clows site (Fig. 24, Table 4). The increase in sediment volume in 1994 reflects natural change since there was no mining in that year. The net loss of sediment at the site between November 1984 and September 1998 was 5950 m^3 (Table 4). The total volume of sediment extracted between 1984 and 1998 was 18814 m^3. This value is derived from permits issued between 1985 and 1992 by the PEI Department of Technology and Environment, and from volumes reported by haulers and concrete operators between 1992 and 1998. Annual sediment extraction rates averaged 2000 m^3 from 1984 to 1993, and have varied from zero to 1500 m^3 since 1993 (Table 4).

From the difference between the net change in sediment volume at the site and the total sediment extracted, it is estimated that at least 12,800 m^3 of sediment was supplied by natural processes to the site between 1984 and 1998 (Fig 25, Table 4). Therefore the average annual volume of sediment accumulating at the site is roughly 920 m^3 which is less than half the volume of sediment being mined. Net changes in sediment volume during non mining years (1994, 1996, 1998) varied from +780 m3 and -450 m3. These volumes are considerably less than the volumes of sediment supplied during the years of mining. The decrease in sediment supply may reflect the decreased demand for sediment to replace the extracted sediment at the site, or it may reflect a decreasing natural supply of sediment. Both may be correct. The Clows site suffered a major loss of sediment in 1995, the time when the Irvings Cape site was building which may reflect natural change due to storms from a specific direction.

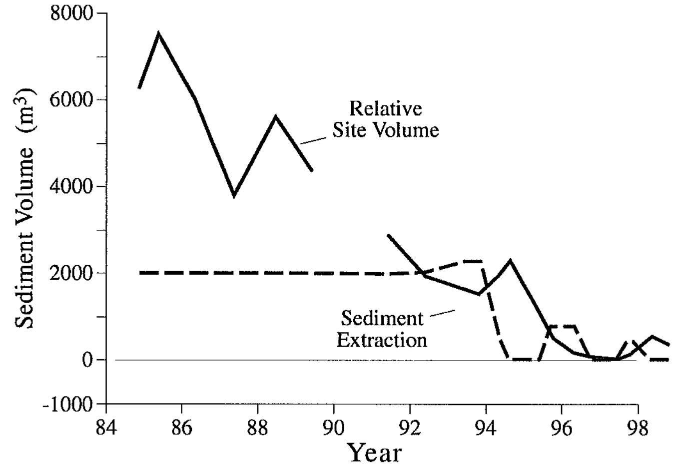


Figure 24. Changes in sediment volume at the F. Clows mining site are plotted from 1984 to1998 relative to a base level of zero set for May 1997 (Table 4). Despite four periods of sediment accumulation, the total volume of sediment has decreased since 1984. The volumes for extracted sediment are based on permits issued by the PEI Department of Technology and Environment, and the volume of sediment at the site is calculated from beach surveys completed by the same provincial agency.

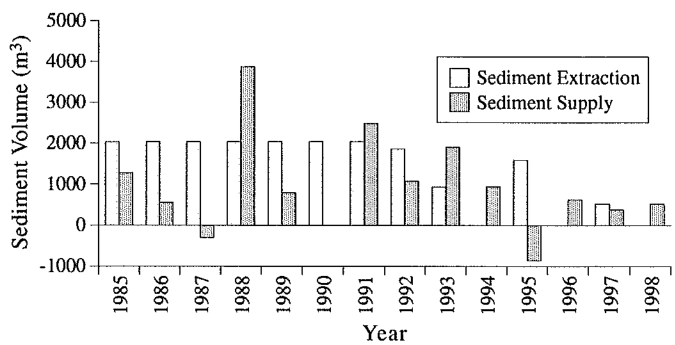


Figure 25. Volumes of sediment extracted and supplied to the F. Clows site each year between 1984 and 1998. Sediment supply exceeded sediment extraction only during three years 1988, 1991 and 1993. The difference between the volume of sediment extracted and the net change in sediment volume at the site provides a measure of the volume of natural sediment supply (Table 4).

Table 4. Changes in the total sediment volume (m^3), rates of sediment extraction and natural sediment supply between 1984 and 1998 at F.Clows commercial beach mining site, east PEI. Permits were not issued for excavation of beach sediment in 1994, 1996 and 1998.

DATE OF BEACH SURVEY	TOTAL VOLUME	VOLUME RELATIVE to May 1997	NET CHANGE IN VOLUME	VOLUME SEDIMENT EXTRACTION BETWEEN SURVEYS	NATURAL SEDIMENT SUPPLY	ANNUAL SEDIMENT SUPPLY
Nov 24,1984	818586.52	6276.22				
May 17, 1985	819849.97	7539.67	1263.45	0	1263.45	
April 29, 1986	818394.82	6084.52	-1455.15	2000	544.85	544.85
May 5, 1987	816111.49	3801.19	-2283.32	2000	-283.32	-283.32
June 7, 1988	817941.68	5631.38	1830.19	2000	3830.19	3830.19
May 31, 1989	816722.32	4412.02	-1219.36	2000	780.64	780.64
1990	no data	no data	no data	2000		
May 21, 1991	815170.02	2859.72	-1552.30	2000	2447.70	1223.85
May 22, 1992	814228.99	1918.69	-941.03	2000	1058.97	1058.97
OCT 19 1993	813788.93	1478.63	-440.06	2309	1868.94	
MAY 4 1994	814254.31	1944.01	465.39	455	920.39	2789.33
AUG 31 1994	814573.63	2263.33	319.31	0	319.31	
May 11, 1995	813397.08	1086.78	-1176.55	0	-1176.55	-857.24
Sept 7, 1995	812820.88	510.58	-576.19	775	198.81	
APRIL 30 1996	812456.70	146.40	-364.18	775	410.82	609.62
SEPT 5 1996	812374.43	64.13	-82.27	0	-82.27	
May 20 1997	812310.30	**0.00**	-64.13	0	-64.13	-146.40
Sept 11 1997	812390.88	80.58	80.58	500	580.58	
April 23 1998	812814.20	503.90	423.32	0	423.32	1003.90
Sept. 23 1998	812636.48	326.18	-177.72	0	-177.72	

VOLUME CHANGE:	NOV. 84 to OCT 93 =	-4797.60
	OCT 93- SEPT 98 =	-1152.45
TOTAL SEDIMENT MINED (1974-1998)= (24000+6843+4813 m3)		35656.00
NUMBER OF TRUCK LOADS (34246/9.9)=		3601.62

SUMMARY:	(m3)
TOTAL SEDIMENT EXTRACTED (1985-98) =	18814
NET CHANGE IN VOLUME AT SITE (1984-1998) =	-5950
TOTAL NET SEDIMENT SUPPLY (1984-98) =	12864
SEDIMENT SUPPLY (m3/a) (1984-1998) =	919

W. Johnston Mining Site

Introduction

W. Johnston's commercial mining site lies between the F. Clows and Irvings Cape sites (Fig. 3, 8). Commercial mining of the beach began in 1987; however, monitoring of the beach did not begin until the spring of 1997. A baseline and five cross-beach lines were established at the site in May 1997 and were surveyed three times by the fall of 1998 (Fig. 26). Each line was 30 m apart. There is only an intermittent duneline remaining along the mining site because most of the area has been cleared for the mining operation (Fig. 8, 27). A dune scarp only existed at lines 1 and 5 (Fig. 26). At line 4 the upper beach is frequently cut by a channel draining water from the backshore wetland.

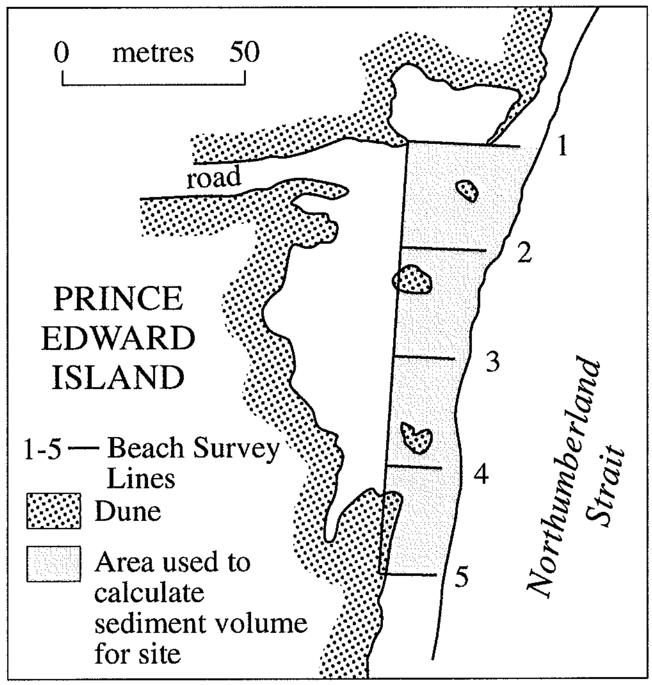


Figure 26. Location of the survey lines and baseline at the W. Johnston beach mining site. It is located north of Irvings Cape, along the Gaspereaux Shore (Fig 3, 8).

Beach and Dune Changes (1955-1998)

The only information about the magnitude of shoreline changes before commercial mining began is from air photographs since there were no surveys of the site prior to mining. The shoreline was fairly stable from 1936 to 1974 but between 1974 and 1982 duneline retreated nearly 18 m (Fig. 27). Although there was little change in the shoreline position by 1987 (Fig. 27) the duneline had been removed by mining operations and an area roughly 40 m wide was cleared for stockpiling sediment and vehicle access.Between 1987 and 1990 shoreline retreat again increased. There is no information available until 1997 when site monitoring began. Between 1997 and 1998 the magnitude of beach change was least at line 5 at the south end of the site (Fig. 28c). Line 5 also showed evidence of beach progradation and aggradation in contrast to the rest of the beach which retreated 2 to 7 m (Table 5).

Table 5 . Changes in the seaward position of the duneline and beach (at HTL) and rates of retreat between 1997 and 1998 at the W. Johnston commercial beach mining site. The information is based on beach surveys completed by the PEI Department of Technology and Environment.

YEAR	LINE 1 DUNE	LINE 1 BEACH	LINE 2 BEACH	LINE 3 BEACH	LINE 4 BEACH	LINE 5 DUNE	LINE 5 BEACH
1997	19.81	27.73	28.34	29.26	25.29	10.97	15.24
1998	15.24	30.48	22.86	22.86	18.28	10.05	15.24
NET CHANGE	**-4.57**	**2.75**	**-5.48**	**-6.4**	**-7.01**	**-0.92**	**0**
RATE (m/a)	**-3.52**	**2.12**	**-4.22**	**-4.92**	**-5.39**	**-0.71**	**0.00**

Mean Dune and Beach retreat and rate of retreat at the W. Johnston site.

mean dune retreat(m)=	**-2.75**	mean beach retreat (m)=	**-3.23**
mean dune retreat (m/a)=	**-2.11**	mean beach retreat (m/a)=	**-2.48**

A berm developed at lines 3 and 4 in May 1997 and at line 1 and 2 in April 1998 (Fig. 28a,b). The thickness of the berms was 0.5 to 1.1 m. The intermittent occurrence and large size of the berms suggests that they may result from the welding onshore of nearshore bars but there are no field observations to confirm this. Between the spring and fall there was a build up of sediment and infilling of depressions across the upper beach.

The longshore changes in beach buildup during 1997 and 1998 is attributed mainly to excavation activities, a reversal in sediment transport, or both but there may also be an important onshore-offshore transfer of sediment. The mean rate of beach change at high tide level was -2.48 m/a which was slightly higher than the rate of backshore retreat. The backshore scarp at line 1 retreated 4.5 m and the base of the dune at line 5 was cut back 0.9 m (Table 5).

Sediment Extraction, Supply and Net Changes in Volume

Since May 1997 the volume of sediment at this site has decreased by 1307 m^3 (Table 6, Fig. 29a). The total volume of sediment extracted, according to permits issued by the PEI Department of Technology and Environment, was 3600 m^3 which means that nearly 2300 m^3 of sediment has accumulated at the site during the past two years. Therefore average volume of sediment added each year was 1150 m^3 (Fig. 29b) which was slightly more than the volume of sediment supplied to the F. Clows site (Tables 4, 6). It appears that roughly half the sediment extracted is supplied to each of these beaches by natural processes.

Summary

1) **Sediment is naturally supplied to the beach mining sites.** "You dig the hole and nature will try to fill it"! Irvings Cape, and F. Clows were mined for at least 18 years and W. Johnston's was mined for 12 years. Total volume of sediment extracted since 1984 is estimated at 28,550 m^3 at Irvings Cape, 18,814 m^3 at F. Clows and 13,000 m^3 at W. Johnston's (Appendix 2). However the net changes in sediment volume at each of the sites is much smaller. For example by 1993 when mining was stopped at Irvings Cape there was only a negative balance of 250 m^3 (Table 1). By 1998 there was a net loss of just under 6000 m^3 at the F. Clows site and during 1997 and 1998 the W. Johnston site had a net loss of only 1300 m^3 when 3600 m^3 of sediment was mined (Tables 4, 6). The difference between the total volume extracted and the net sediment balance at these sites is made up by the natural supply of sediment (Tables 1, 4, 6).

2) **More sediment is supplied to the commercial extraction sites during years of mining than years of non-mining.** The mean volume of sediment supplied each year to the Irvings Cape site was 3140 m^3 between 1984 and 1993 whereas since mining stopped there has been a net average loss of 74 m^3/a. During the period of mining the annual net supply of sediment varied from 1000 to more than 6000 m^3 whereas after mining stopped the sediment gains were as much as 1300 m^3 but there were also losses of 1600 m^3/a. Sediment supply was also much higher during the years of mining at F. Clows (Table 4). Therefore, it appears that more sediment is required to offset the losses caused by excavation than the changes caused by natural processes. However, the problem is that the volumes of sediment supply are derived using values of sediment extraction. To more accurately determine the natural supply of sediment to these shores, a control site with no mining should have been surveyed but because this is a drift-aligned shore, mining will impact the whole shoreline and no control site was monitored. The best information on rates of natural supply come from Irvings Cape where beach surveys were continued after mining was halted. The problem is that the jetty artificially anchors the headland and affects the longshore transport of sediment. Between 1993 and the fall of 1995 there was a net increase of 2250 m^3 of sediment. During 1996 and 1997 the volume decreased and by the fall of 1997 the site, since 1984, had a net loss of 550 m^3 (Table 1). The differences in sediment volume that we observe after mining stopped at the Irvings Cape site may not reflect the difference between the impacts of natural processes and artificial extraction but rather a temporal change in sediment supply. The larger volume of sediment supplied to the beaches during years of mining raises the question of where the increased sediment came from. Was it available alongshore or offshore, or did the increased demand trigger increased rates of shoreline erosion? This question is addressed in the next part of the report.

3) **The rate of commercial sediment extraction exceeds the rate of sediment supply.** Between 1984 and 1993 when mining was most active, there were only three years at Irvings Cape and two years at F. Clows when sediment supply exceeded sediment extraction producing a net positive sediment balance. At Irvings Cape the volume of sediment supplied nearly equaled the volume of sediment extracted but at F. Clows and at W. Johnston mining sites only half the volume of extracted sediment was added to the site each year (Table 4, 6).

4) **Beach changes were more extreme and more irregular during periods of mining than non-mining.** Sweep profiles compiled at Irvings Cape during mining and non-mining times show that the range of beach change is greater during mining operations. Furthermore beach scouring was deeper and the occurrence of pits and dune erosion was more haphazard. During the period of mining the duneline retreated as much as 9 m

landward at Irvings Cape and 19 m landward at the F. Clows site. The mean duneline retreat of 0.65 m/a at Irvings Cape between 1984 and 1992 was 16 times higher than after the mining was stopped and 3 times higher than longer term rates of shoreline recession documented by LRIS (1988). Cut and fill sequences were more restricted to the lower beach. Dunes recover at a slower rate than the beach face. Once mining was stopped at Irvings Cape the upper beach began to build-up which provided conditions favourable to the spread of vegetation and dune recovery. In contrast, at F. Clows, the beach has continued to erode and retreat landward and there has been little or no recovery of the duneline. There was better dune stability when sediment volumes increased. Beach and dune retreat at W. Johnston mining site was 6 to 8 times higher than the average longer term recession rates quoted by LRIS (1988) however there is only two years of survey information from this site.

5) **The physical impacts of higher energy natural processes are not masked by mining.** During years where physical changes differed between beach sites or within the same site, the variations are attributed to local differences in beach condition, wave approach and local excavating practices. In other years such as 1985-86, 1988-89, and 1993-94 when similar morphological changes were observed at all sites, the changes are attributed to higher energy wave events. Similar beach changes were also observed at the Clows and Irvings Cape sites in 1995-96 and 1996-97 when the beaches were responding to the natural processes. On beaches where commercial mining is active, storms caused larger changes to the backshore, i.e. 1993-94 at F. Clows.

6) **The volume of extracted sediment represents the size of a significant beach.** If one translates the volume of extracted sediment since 1984 into beach dimensions the total volume of extracted sediment (60364 m^3) from these three sites could have built a beach 10 m thick by 50 m wide by 120 m long. If one includes all of the sediment mined since 1975 (131650 m^3) the beach could have been 10 m thick by 50 m wide by 263 m long.

7) **More resources are required to accurately monitor all of the beach sediment extraction sites in the province of PEI.** There has been a very conscientious effort by the staff at the Department of Technology and Environment to obtain as much field information on the mining sites as their financial and human resources allowed. Efforts were focused on several key sites where shoreline stability was in question and it was not possible to maintain surveys at all sites. It became obvious to the author when compiling the field and archival sediment extraction information that there were insufficient resources allocated to allow the department to effectively monitor the beach mining industry. The lack of resources meant there was little monitoring of the shores adjacent to the mining sites and it was more difficult to document the impacts of the mining or differentiate the impacts on shoreline stability caused by other factors such as natural processes or artificial shore structures.

SEDIMENT, THE RESOURCE

Introduction

In the first part of this report we have examined changes in the beach morphology and sediment volume at three specific beach sites. The next step is to examine the Gaspereaux Shore as a whole to assess the sources and abundance of sediment, its distribution, temporal changes and the impacts on shoreline stability.

In an earlier review of beach mining, Woodward-Clyde Consultants (1980) presented a sediment budget for the east coast of PEI. They concluded that the east coast is a catchment for a large volume of sediment derived from the erosion of local shore cliffs and sediment transported from the north shore around East Point and from the south shore around Murray Head (Fig. 30).

Owens (1980), the author of the Woodward-Clyde Consultants report, estimated in excess of 57000 m^3 (75000 yds^3) of sediment is supplied to the eastern shore of PEI each year. Of that total 26750 m^3 (35000 yds^3) or 46% was from local shoreline erosion.

For the shores south of Cardigan Bay, Owens estimated that 7530 m^3 (9850 yds^3) of sand is supplied each year from shore erosion. This total included 2905 m^3 of sand derived from the north shore of Panmure Island. This sediment would not contribute to the mining areas farther south (Fig. 3) because longshore sediment transport is mainly directed into Cardigan Bay (Fig. 30). Therefore only 4625 m^3 of sand was potentially supplied to the Gaspereaux Shore each year. The average volume of commercial sediment extraction along this shore in the late 1970s and 1980s was 8,000 to 9700 m^3/a and as high as 15200 m^3 in 1979, suggesting a severe negative imbalance in the sediment budget. If only the shoreline between Cape Sharp and Murray Head is included in the assessment, then the sediment imbalance is worse. The sediment supply was 2830 m^3/a and the sediment extraction averaged 8050 m^3/a (Woodward-Clyde Consultants, 1980; Appendix 2, Fig. 30).

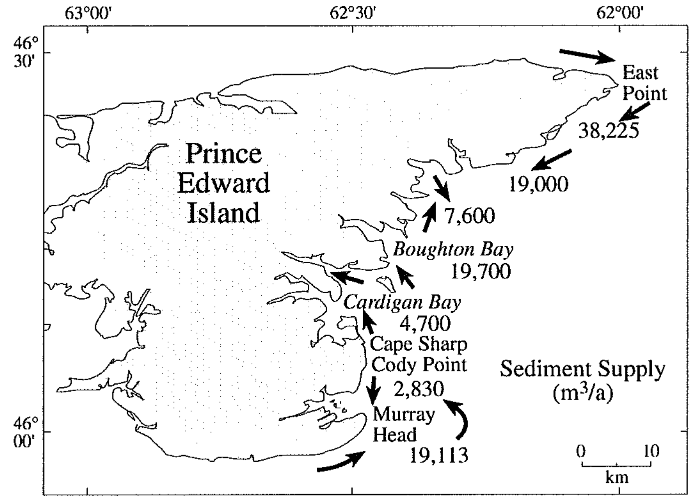


Figure 30. Map of eastern PEI showing an estimate of the volume of sediment supplied from local shoreline erosion and from around East Point and Murray Head from an earlier review of beach mining by Woodward-Clyde Consultants (1980), and Owens (1980). The sediment transport directions are inferred from coastal features.

There is also some scepticism about the amount of sediment Owens (1980) suggested was transported around East Point and Murray Head. Recent marine geology surveys of Milne Bank, off East Point (Frobel, 1989; Shaw et al., 1997) suggest that much of the sediment from the north shore of PEI may be carried offshore onto the bank. Only a small quantity is transported southward alongshore where it is trapped in a few embayments (J. Shaw, 1997, pers. com.) Other geology surveys in Northumberland Strait (Pecore et al., 1993) show that the sand deposit between Wood Island and Murray Head is less than 3 m thick and it appears to pinch out before reaching Murray Head (Fig. 4b). Also, there was little field evidence at Murray Head to support the idea that large amounts of sediment are transported around the base of the headland. Furthermore there is little morphological evidence of progradation along the Gaspereaux Shore at present. Instead, narrow beaches, small accretionary shore features, and landward retreating spits and barrier beaches are observed.

Sediment Supply

A) What are the major sources of sediment for beach building?

Primary sources of sediment for beach development include rivers, shore and seabed erosion, biogenic and artificial nourishment. However in this case the supply of sediment from rivers and streams is assumed to be negligible because most of the fluvial material accumulates within the estuaries (Bartlett, 1977). Also, there is no biogenic or artificial nourishment. Onshore and seabed erosion remain the primary sources of sediment. It is assumed in this study, as Owens (1980) did, that the primary source of beach sediment is from shore erosion. Little was known about the input of sediment from offshore in the previous review. Consequently an attempt is made to map the sediment bodies across the shoreface using aerial photography.

Shore Deposits: The Gaspereaux Shore like the rest of eastern PEI, consists of a series of embayments and headlands, which form coastal cells or compartments. On the basis of coastal morphology, and the potential sediment transport paths, three compartments are defined along the Gaspereaux Shore. The first extends from Murray Head to just north of Cody Point, the second includes the embayment south of Cape Sharp and the third extends northward from Cape Sharp toward Panmure Island and Cardigan Bay (Fig. 3). The last compartment was examined by Hill and Jenner (1989) and is not discussed in this report. Instead, our focus is on the first compartment where the three commercial mining sites, discussed earlier, are located. The small embayment just north of Cody Point is included within the first compartment; however it is treated as a separate subcompartment because it appears to be fed by sediment eroded from the adjacent headlands. The D. Reid commercial excavation operation exists within this small embayment. The second compartment is not examined in detail but it is included in the mapping and sediment budget calculations because of the presence of the MacKenzie sediment mining operation (Fig. 3).

Shore deposits were mapped from Murray Head (excluding inner shores of Murray Harbour) to Cape Sharp, a total of 13.7 km (Fig. 31). The mapping was completed using vertical, colour air photos taken in 1987, aerial oblique video collected in the fall of 1990 (Taylor and Frobel, 1992) and field observations in 1991 and 1993. The shoreline was divided into 43 segments (Fig. 32, Appendix 4) on the basis of morphological and sedimentological characteristics. Each segment represents a homogeneous section of shoreline, e.g. cliff, cliff with beach, barrier beach. Tidal channels and man-made structures, e.g. breakwalls, were also mapped as separate shore segments. Sediment sources were identified in each shore segment (Fig. 31, 32, Appendix 4). The length of each deposit was measured from vertical air photos, and its thickness was measured in the field or off the topographic maps (Appendix 4). Some difficulties were encountered in measuring the surface of bedrock in shore cliffs because it was often masked by overlying slope deposits.

Cliffs: Cliff face morphology varies depending upon its height, composition and the degree to which it is modified by slope versus marine processes. The coastal headlands are 9 to 12 m high (Fig. 5). The Geographical Branch (1959) when mapping the shore types of Northumberland Strait divided shore cliffs into eight categories based on morphology, composition and height. Two forms of rock cliff and two types of unconsolidated cliff were identified in the study area (Fig. 32) by the Geographic Branch (1959). The rock cliffs are capped by glacial deposits, have a steep face (Type 1) or are masked by talus (Type 5) (Fig. 5). At the headlands, e.g. Cape Sharp, the base of the rock cliffs consist of either wave-cut hollows (Type 2) and/or rock platforms (Type 4 and 6) with little debris (Fig. 33a). Beach width along the base of the cliffs increases toward the head of embayments and where surficial deposits are thicker (Fig. 33b,c). In many places the cliff face is masked by fallen trees, clumps of vegetation and slope deposits. Low (1 to 4 m high) erosional scarps, e.g. segment 31 (Fig. 32), of unconsolidated sediment (Types 7, 8) form the transition between the outer rock headlands and the beaches at the head of the embayments. (Fig. 33c).

Frankel (1966) and Prest (1973) described the deposits left by glacial ice as compact clayey to sandy tills; loose textured, more sandy ablation tills; and meltwater deposits composed of poorly to well sorted silt, sand and gravel. Frankel (1966) distinquished two types of ground moraine, a sand-rich phase north of Murray Harbour (>65% sand, <35% clay and silt) and a clay-rich phase (>35% silt and clay, <65% sand) covering Murray Head (Fig. 4). Prest (1973) subdivided the clay-rich phase into a clay and clay silt phase and a clay-sand phase (Fig 4; unit a,b). There is a close correlation between the bedrock lithology and the glacial deposits in the area because glaciers deposited the bulk of their material close to the site of derivation (Frankel, 1966). For this exercise it is important to note that glaciofluvial deposits are looser than the ground moraine. At Panmure Island, to the north of the study area, Hill and Jenner (1989) described the upper cliff deposits as a diamict with a sandy matrix and 20% silt and clay with scattered boulders up to 1 m diameter. Prest (1973) had mapped these as glaciofluvial (kame) deposits (Fig. 4).

Beaches: Beaches are most extensive within the embayments where sediment accumulates as a result of erosion of coastal headlands. Poverty Beach is the longest depositional feature in the study area (Fig. 4, 31c). Before 1969, Poverty Beach consisted of a single, 2.8 km long spit which has since broken into as many as four segments separated by tidal channels. At present, Poverty Beach consists of a 1.3 km long spit (Fig. 31c) at the north end, a barrier island in the middle with extensive intertidal sand flats, and a 0.6 km long spit at the south end. Growth of the spit at Beach Point is restricted by a man-made breakwall and tidal currents flowing through the inlet cut by the Murray River (Fig. 31d). Other beaches of significant length exist between Irvings Cape and MacLures Pond (Fig. 4, 31a,b) (Note: MacLures Pond refers to the pond on the outer coast north of Irvings Cape, not the MacLures Pond at the head of the Murray River) and to both sides of the harbour entrance to Grahams Pond (Fig. 31a).

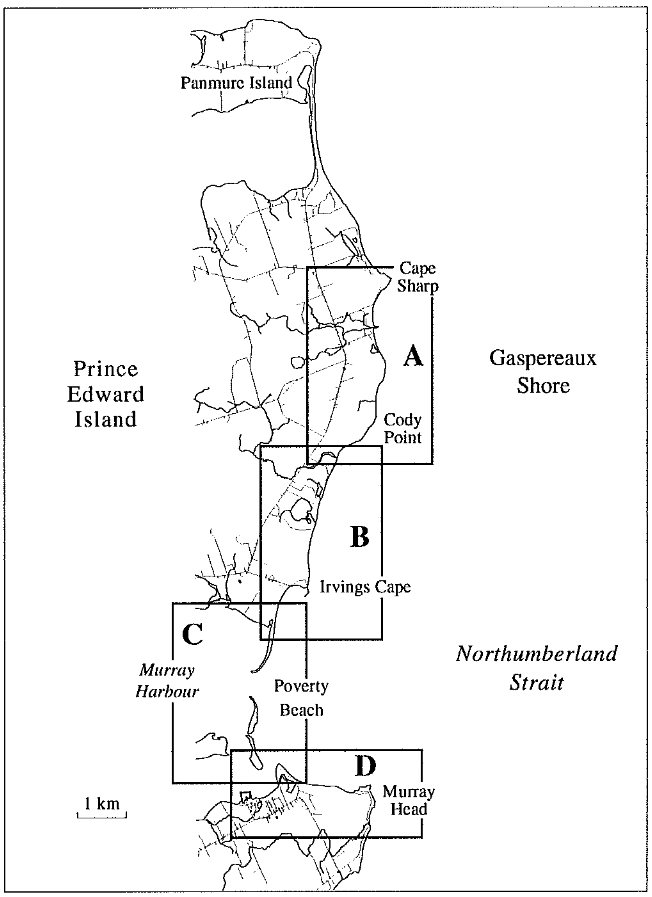
In cross-section the beaches are capped by a primary dune ridge commonly 2 to 3 m high and up to 3.9 m maximum elevation. At the mouth of Murray Harbour, multiple dune ridges exist on the barrier island which was once the distal end of Poverty Beach spit. There is also evidence of multiple ridges near Condons Pond (Fig. 31b). Upper intertidal beach slopes are 7-10° and in summer often consist of a well defined sand berm (Fig.11, 21, 28). Where beach mining operations occur or have taken place, the dunes are marked by scarps, blowouts and wave washover features (Fig. 34). Changes in beach profile have been documented in detail at the F. Clows and Irvings Cape mining sites. Aeolian transport is variable and difficult to quantify without detailed investigations using sand traps. Instead, the volume of sediment gained or lost to the backshore is estimated by measuring changes in the position of the seaward duneline. Duneline retreat signifies sediment input to the beach and duneline progradation signifies temporary sediment loss from the beach.

The proportion of sand supplied from the shore deposits was estimated using textural information from representative samples collected in the area. The sand content assigned to various deposits was as follows: 41.13% for glacial deposit (Appendix 5); 70% for bedrock (van de Poll, 1983) and 99.4 % for dunes (Owens, 1974). The input of sand from bedrock

Table 7. Rates of shoreline erosion (m/a) measured from vertical air photographs of the Gaspereaux Shore, PEI. In each study, shoreline change was monitored for different time periods between 1936 and 1987.

Source	No. of Sites	1936 -1959 (Mean) (m)	1936 -1959 (Max.) (m)	1955 -1987 (Mean) (m)	1955 -1987 (Max) (m)	1968 -1987 (Mean) (m)	1968 -1987 (Max) (m)	1936 -1980/ 87 (Mean) (m)	1936 -1980/ 87 (Max) (m)	Avg Width Land Loss (m)
Geographical Branch (1959)	8	0.8	1.8	----	----	----	----	----	----	18
LRIS (1988)	10	----	----	----	----	----	----	0.2	0.5	8 to 10
Present Study	12	----	----	1.0	1.5	0.4	1.3	----	----	32 & 8

would vary with locality but this value was based on observations by van de Poll (1983) who observed sandstone in the study area consisted of 70% clastic framework (predominantly sand) and 30% silt-clay matrix.



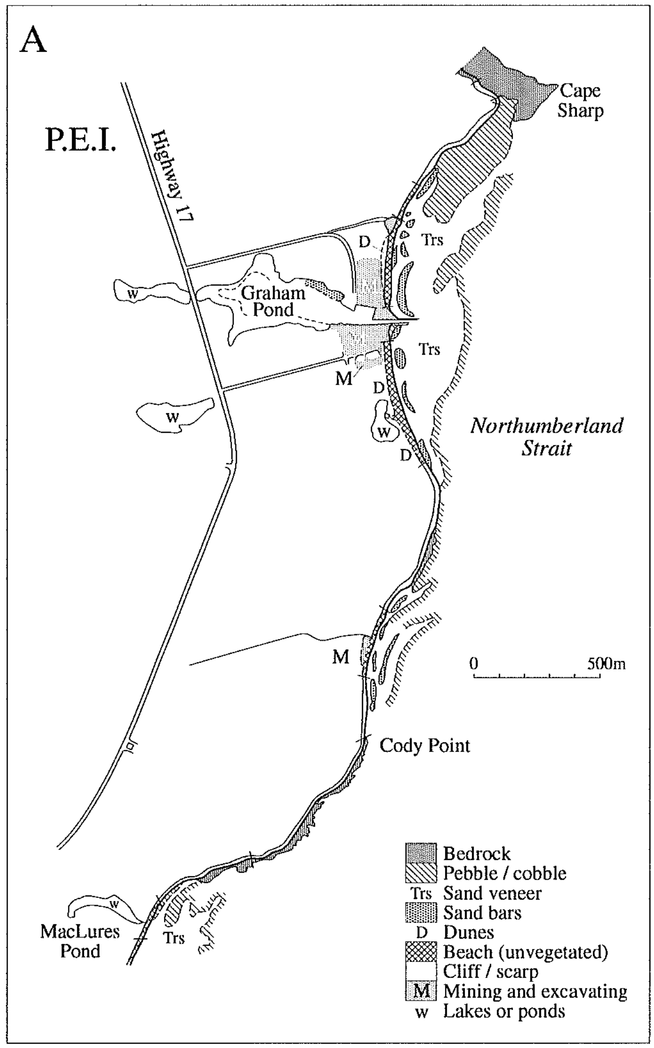
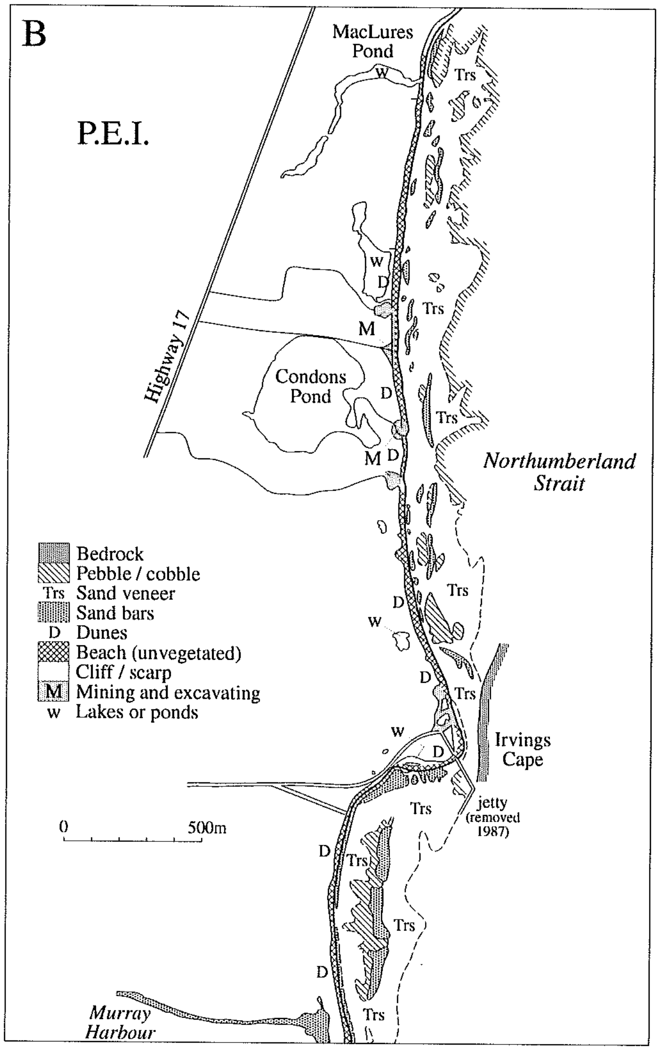
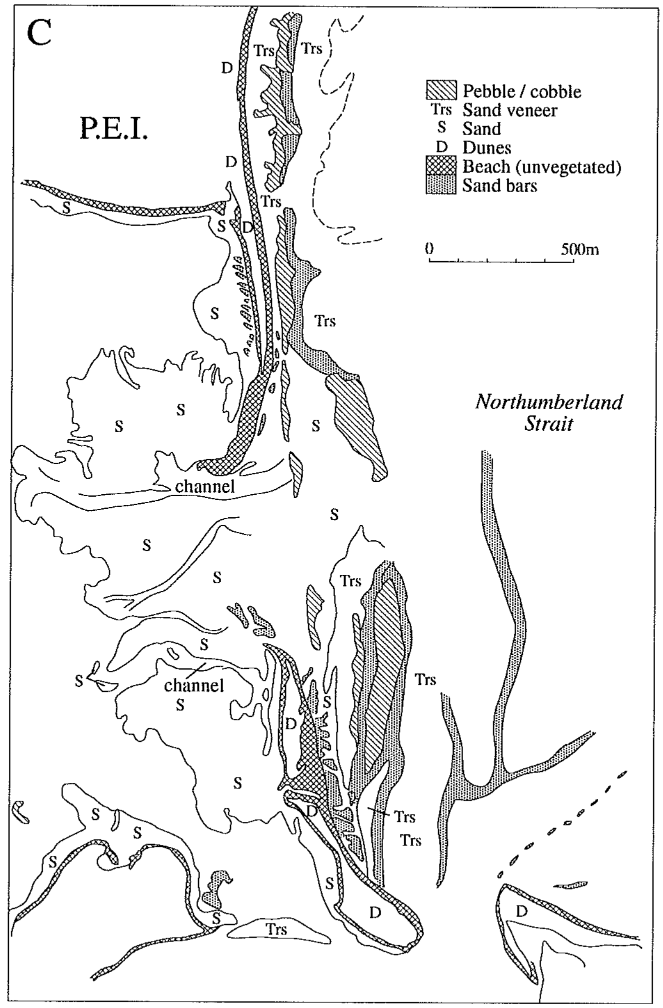
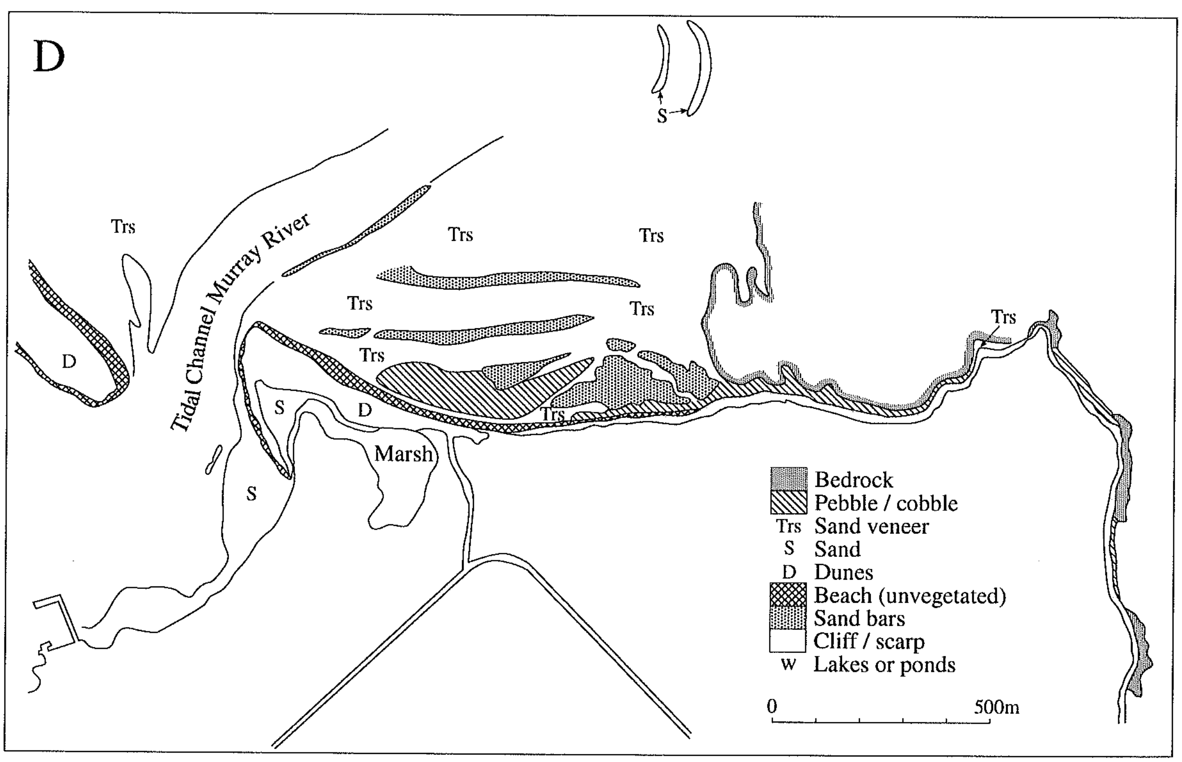


Figure 31. Coastal geomorphology of the Gaspereaux Shore (A) from Cape Sharp to MacLures Pond; (B) MacLures Pond to Poverty Beach; (C) Poverty Beach and (D) Murray Harbour to Murray Head. Maps were prepared using the 1987 vertical air photography (1:10,000 flight line 87228 (Courtesy of Land Registration and Information Service, Amherst N.S.).

The composition of unconsolidated cliff deposits was determined from a large bulk sample collected from the upper 1.5 m of a shore cliff just south of Cape Sharp (Fig. 33c). The largest clast sampled was 190 x 165 x 85 mm. The sample consisted of 36.5% gravel, 41.1% sand


B
MacLures Pond
P.E.I.
Highway 17
Condons Pond
Northumberland Strait
Irvings Cape
jetty (removed 1987)
Murray Harbour
Bedrock
Pebble / cobble
Trs Sand veneer
Sand bars
D Dunes
Beach (unvegetated)
Cliff / scarp
M Mining and excavating
w Lakes or ponds
0 500m


C
P.E.I.
Pebble / cobble
Trs Sand veneer
S Sand
D Dunes
Beach (unvegetated)
Sand bars
0 500m
Northumberland Strait
channel
channel


D
Tidal Channel Murray River
Marsh
Bedrock
Pebble / cobble
Trs Sand veneer
S Sand
D Dunes
Beach (unvegetated)
Sand bars
Cliff / scarp
w Lakes or ponds
0 500m

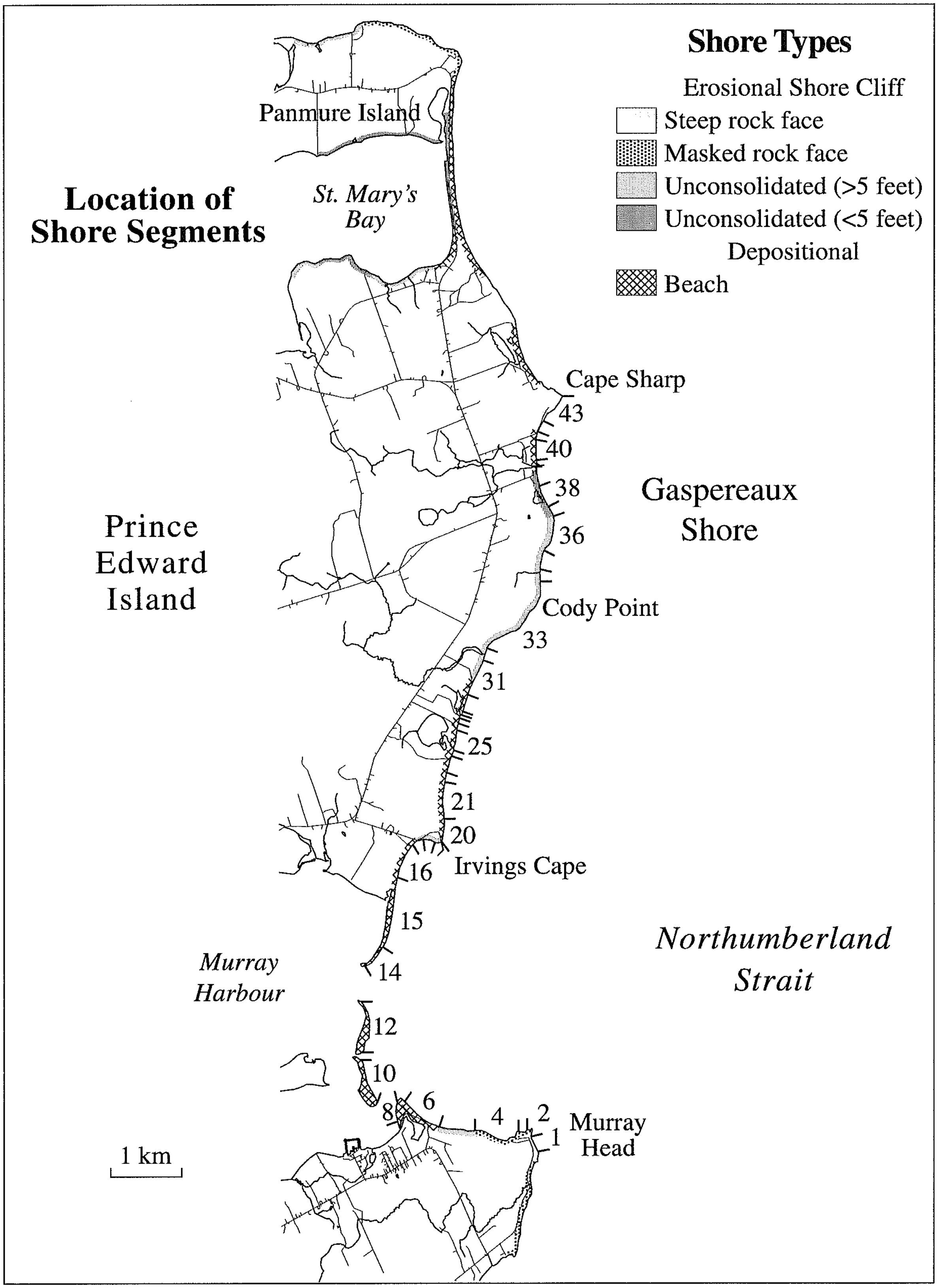


Figure 32. In an earlier mapping exercise the Geographical Branch (1959) identified five shore types along the Gaspereaux Shore. They included two types of rock cliff, two types of unconsolidated cliff and beaches. In the present mapping exercise the shoreline was divided into 43 relatively homogeneous segments based on morphology. The volume of sediment supplied to the littoral zone from each segment was calculated to develop a sediment budget for this coastal area. (refer to Appendix 4).

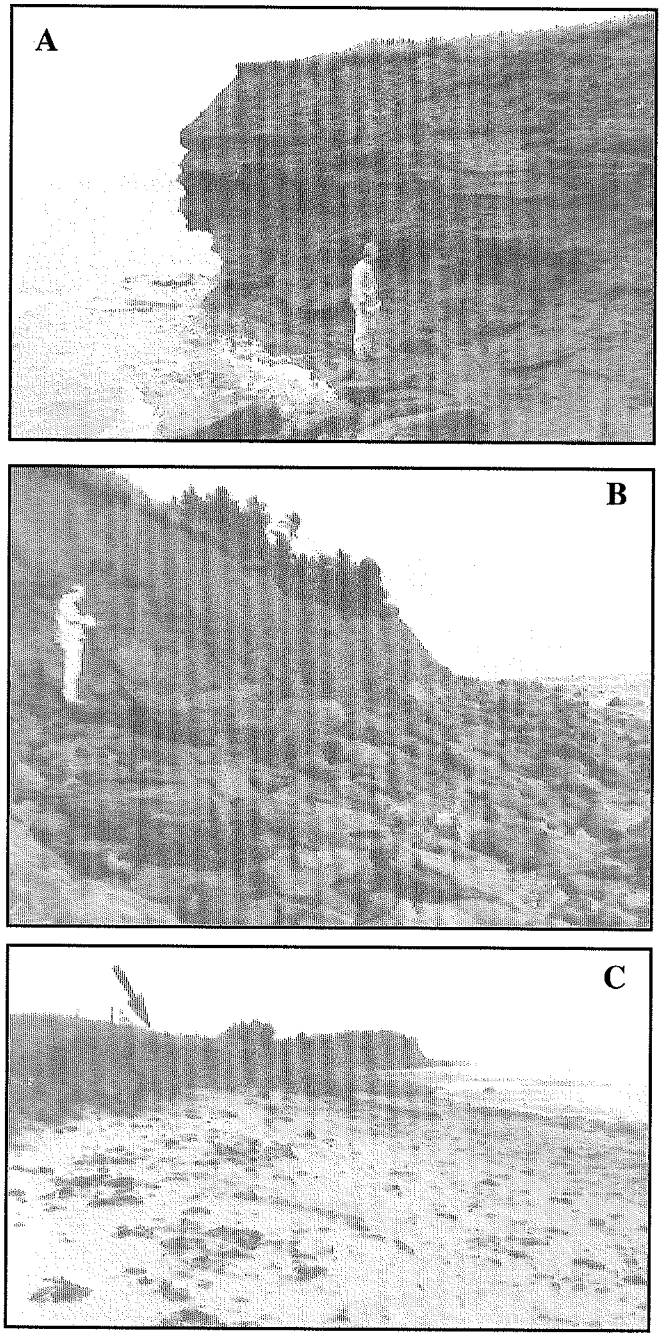


Figure 33. The presence of sand increases alongshore from the headlands as illustrated in these views from (A) the north side of Cape Sharp where the cliff is fringed by a 4-6m wide intertidal rock platform; (B) approx 150 m south from Cape Sharp where the cliff is fringed by a cobble-boulder frame and (C) at the north end of Graham Pond where a wider sand beach, intersects with the unconsolidated shore cliff. The arrow marks the location where the till was sampled for grain size analysis (Appendix 5).

and 22.4% mud (Appendix 5). The sample is thought to represent the sand-rich till mapped by Prest (1973).

Sediment samples were not collected from the beaches during this study. Instead textural information was taken from Owens (1974) who sampled a number of beach sites in the area. His samples consisted of 0.28-0.68 mm sand with gravel concentrated at the seaward base of the dunes, the storm swash limit, and in the troughs between the intertidal ridges and subtidal bars.

Figure 34. Aerial view of the shoreline at the W. Johnston sediment extraction site (location on Fig. 3) showing the disturbance to the natural setting. Coarse lag deposits (dark coloured areas) in the nearshore suggest that the sand deposits are thin (photo by D. Boyce, 1995).

<u>Shoreface Deposits</u>: Little is known about the distribution of surficial deposits and features which exist within the 10 m water depth. Some information comes from nearshore surveys by Bartlett (1975), sediment sampling at Irvings Cape jetty by PWC (1954, 1955) and from aerial photography. The areal extent of surficial deposits mainly sand, gravel or 'broken' bottom and bedrock was mapped from vertical air photos taken in 1987 and 1990 (Fig. 31, 35, 36). The largest sand deposits were observed off Poverty Beach where a complex pattern of bedforms exist. Elsewhere two sets of sand bars more commonly fringe the beaches - a discontinuous intertidal bar and a more continuous crescentic outer bar in water depths of less than 2 m below mean high tide (CHS, 1981,1985). The inner bars can become welded onshore. The sand deposits

were observed up to 200 m (3 m below MHTL) from shore (Figs. 31, 35, 36).

The thickness of sand at present is estimated to be less than 1 m. Bartlett (1975) observed cobble-boulder clasts and traces of sand <0.1 m thick within bedrock ridges off Irvings Cape; local residents described the seabed as "broken bottom" with little sand north of Irvings Cape; and in August 1992 we observed only a thin cover of sand over cobble and frequent exposures of peat in the nearshore north of Irvings Cape. Test borings drilled into the seabed in 1954 for the new jetty off Irvings Cape, showed there was less than 2 m of packed sand, gravel and clay over friable sandstone. In many places the friable sandstone extended to the seabed (PWC, 1954, 1955).

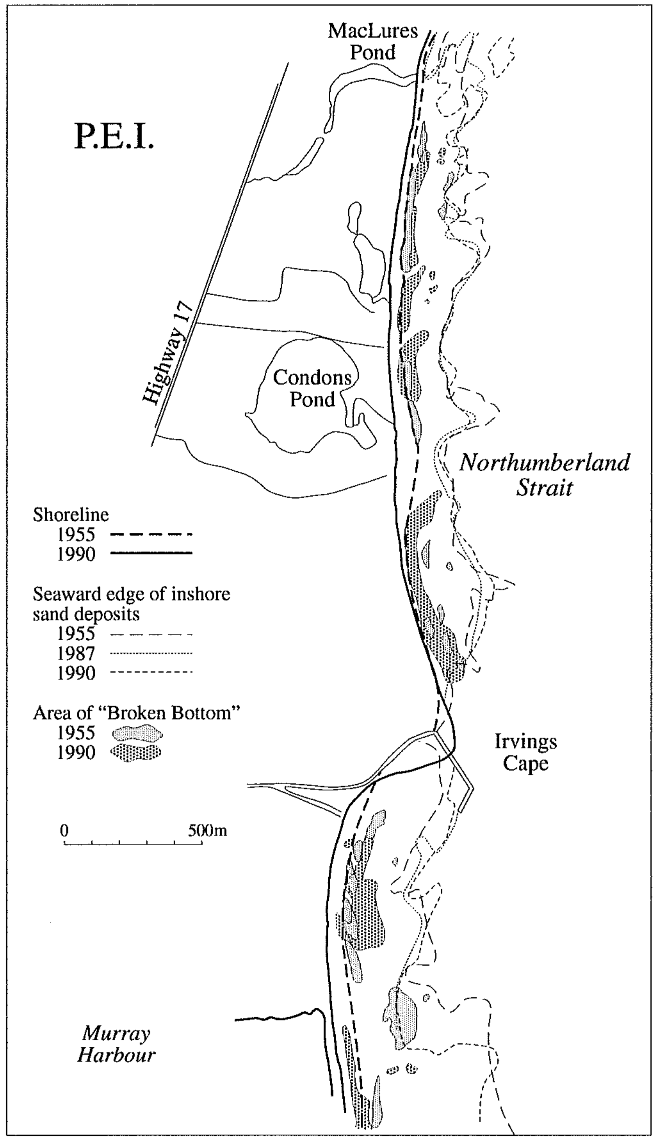


Figure 35. Distribution of nearshore sediment from MacClures Pond to Poverty Beach using air photos taken in 1955, 1987 and 1990.

B) What is the annual rate of sediment supplied from the shore and shoreface?

One method of estimating the volume of sediment supplied to the littoral system each year from onshore is to multiply the length of specific shore deposits by their mean rate of recession. The most common method of measuring changes in shoreline position is by comparing sequential vertical air photographs (Appendix 4, 6). A similar approach of using sequential air photos was taken in mapping changes in the distribution of sediment across the nearshore.

When comparing two shoreline positions on two air photos, the average retreat measurement error Ex over a specific time (T) is given by

$$E_x = \frac{\sqrt{(m_1)^2 + m_2)}}{T}$$

where m_1 and m_2 are the measurement errors of each photo. Using photos of 1:10,000, it was estimated that the accuracy of measuring shoreline change was ± 5 m. The accuracy of the measurements may have been better than this, but there are several other factors, such as aircraft flying height, that were not taken into account, so this is a reasonable error. The average retreat measurement error (Ex) will decrease when photos, of similar scale, with longer separation in time are used. For example, when measuring change from photos taken 30 years apart Ex would be 0.23 m/a, whereas using photos separated by ten years, Ex would be 0.7 m/a. Therefore to determine the most realistic volume of sediment supplied, shoreline recession was measured over the longest time period wherever possible. However, it is also known that rates of shoreline change can increase or decrease over short time intervals; consequently

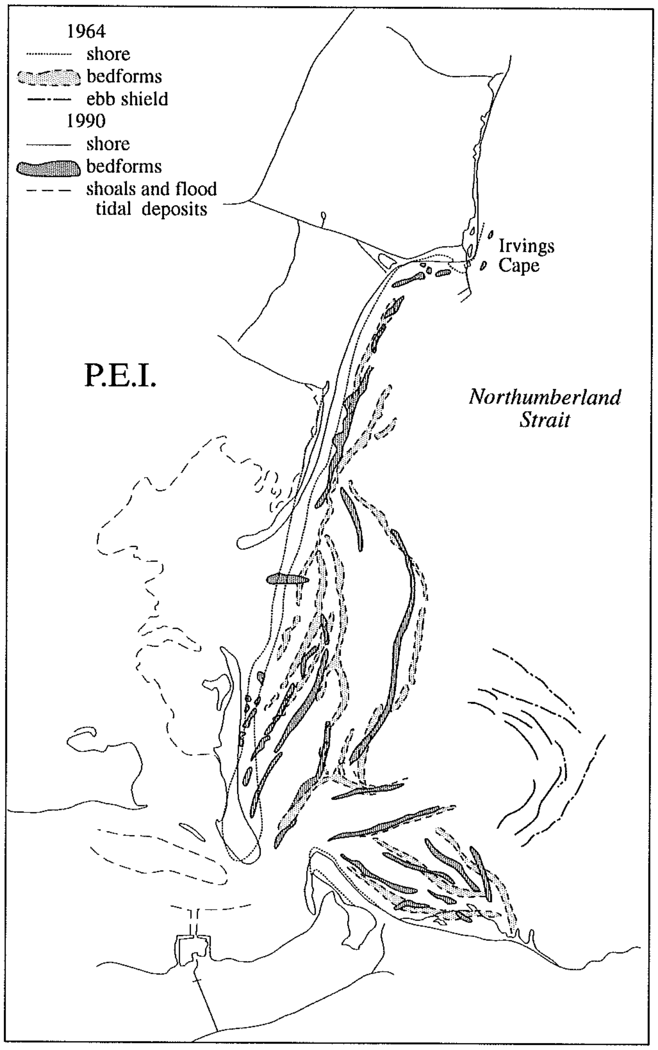


Figure 36. Comparison of nearshore bedforms in the vicinity of Poverty Beach and Irvings Cape in 1964 and 1990. Information was derived from air photos A18453-187 (1964) and 90402-31, -82 (1990).

longer term averages also provide conservative estimates of sediment supply.

Two studies are known to have documented shoreline changes within the study area. The first was by the Geographical Branch (1959) which documented rates of shoreline change from 1936 to 1959. The second was by the Land Registration and Information Service (LRIS, 1988) which measured shoreline change between 1935 and either 1980 or 1987, depending on the availability of photos (Table 7, Fig. 37). A comparison of the results of the two studies suggests that the mean rate of shoreline recession was more than 3 times faster between 1936 and 1959 than between 1936 and 1987. The lower values of shoreline recession obtained from the LRIS (1988) study however may reflect the longer time interval investigated and the methodology of averaging recession rates for 1 km lengths of shore.

Since shoreline change had not been measured at all of the shore segments defined in the present study, new measurements were compiled for the period 1955 to 1987 (shore segments 1-32, Fig. 32) and 1968 to 1987 (shore segments 33- 43, Fig. 32). The time interval depended upon the availability of air photos. The mean rate of shoreline retreat measured in this study varied from 0.4 to 1.0 m/a, Table 7). In contrast to the previous studies of shoreline change, short-term beach progradation, i.e.where the edge of the dune grass expanded seaward, was observed along beach segments 18 to 20, 38, and 40 (Fig. 32). The mean rate of dune progradation at all sites was 1.20 m/a but this value was skewed upward by higher rates of 0.9 and 2.87 m/a recorded adjacent to the Irvings Cape jetty. In all three studies the largest fluctuations in shoreline position (>1 m/a) occurred between Irvings Cape and Poverty Beach (Fig. 37, Table 7).

The total annual sediment supply (Q) from shore deposits is the sum of all the sediment supplied (qi) from each of the 43 shore segments in the study area, ie.

$$Q = q_i + q_i \ldots q_n \quad \text{where } q_i = (tlr)_i$$

$$Q_s = q_{is} + q_{is} \ldots q_n \text{ where } q_{is} = (tlr)(s)_{is}$$

where **t** is the thickness of a deposit (metres); **l** is the length of the deposit (metres); and **r** is the shoreline recession (metres/year). The supply of sand, $\mathbf{Q_s}$, is obtained by applying the percent sand **s** contained in a particular deposit.

This is a very simplistic approach to quantifying sediment supply but it provides the best estimate of the maximum total volume of sediment that could be supplied annually from shoreline erosion. This methodology assumes that the

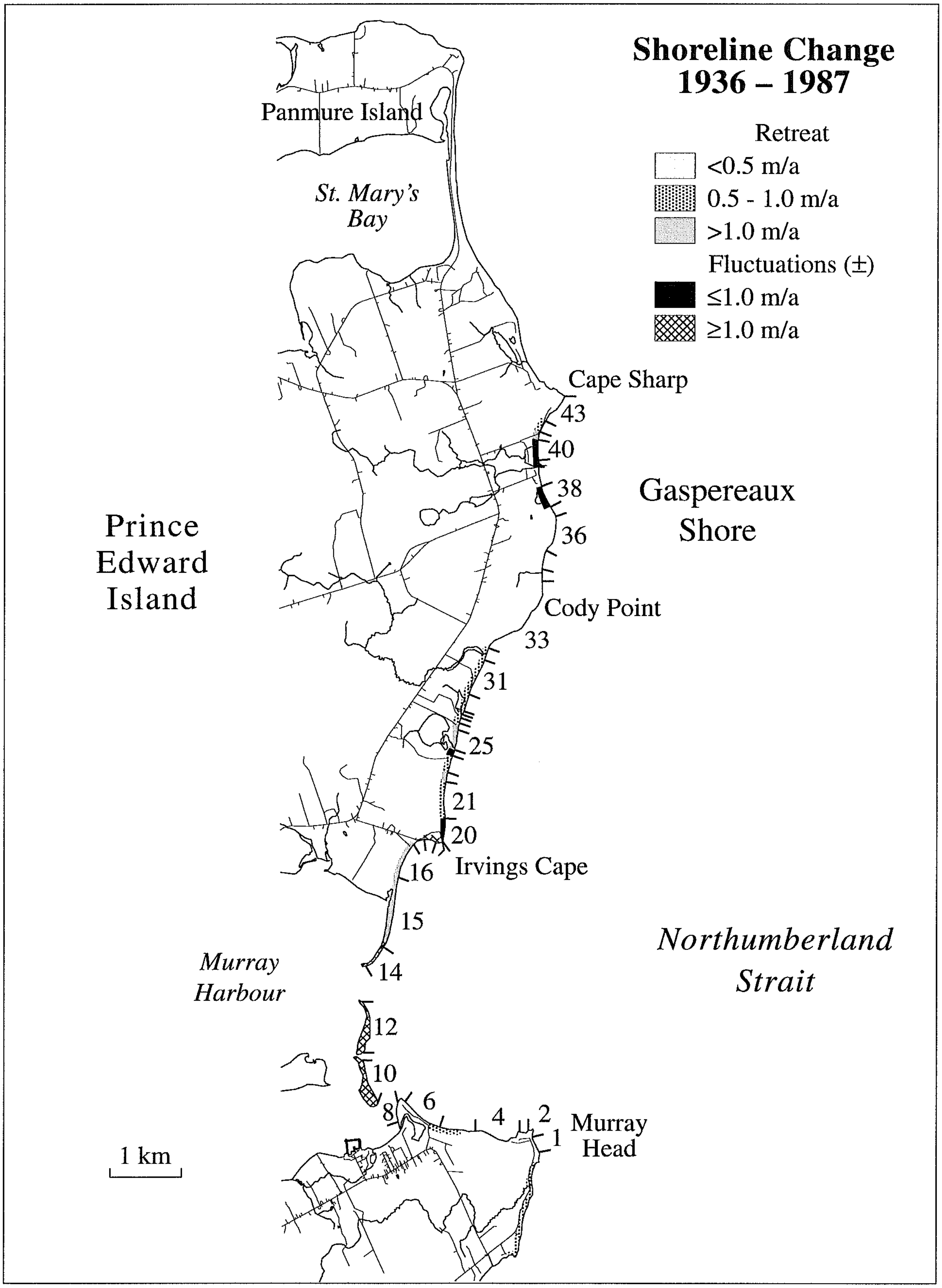


Figure 37. Rates of shoreline recession were compiled from two previous studies Geographical Branch (1959) and LRIS (1988) and the present study. Measurements were based on comparisons of shoreline position using sequential aerial photography from different time periods between 1936 and 1987 (Appendix 4, 6, Table 7).

shore cliff or bank erodes landward at a uniform rate, i.e. bedrock and unconsolidated deposits retreat at same rate, and that the cliff maintains a similar profile. In reality material eroded from the top edge of a high cliff often resides on the middle to lower cliff face for some time before being transported alongshore, therefore the implication of this assumption is that maximum sediment supply values are derived.

It is known that the porosity of deposits varies, e.g. sandstone (15%, Bell, 1983) is less than glacial deposits (20%, Kovacs and Holtz and, 1981) and beach/dune deposits (30%) but porosity was not applied directly in the equation of sediment input because it is partially factored in by using a similar recession rate for the whole cliff face. It is assumed that porosity also was not factored in the volumes provided for mined beach sediment.

Rates of change in sediment distribution across the shoreface are not as easily determined because much of the surface sediment is in motion. The approach taken was to map the areal extent of sand, gravel or 'broken' bottom, and bedrock using air photos taken in 1955, 1987 and 1990 (Fig. 31,35). The area of shoreface mapped extended 0.5 km offshore and 4.5 km alongshore between Cody Point and Poverty Beach (Fig 35). Differences in the distribution and character of the bedforms off Poverty Beach were also examined using smaller scale aerial photography taken in 1964 and 1990 (Fig. 36).

During the 35 years the seaward edge of the sand migrated an estimated 50-150 m shoreward at several places including off MacLures Pond, Condons Pond and the proximal end of Poverty Beach (Fig. 35). The sand deposits were also more patchy by the late 1980s and did not extend as far northward along the front of the shore cliffs. The only place where the sand deposit expanded seaward was just south of the former Irvings Cape jetty (Fig. 35). Between 1955 and 1990 there was a net decrease in sand cover north of Irvings Cape and a net increase south of the Cape. The total area of sand cover increased, but only by 5000 m^2. The shift in its location to south of Irvings Cape may reflect the removal of the Irvings Cape jetty. The most significant change observed in the surficial deposits was the increase in "broken" or gravel bottom cover from an area of 91600 m^2 to 218000 m^2. The gravel deposits remained in much the same position, at or just seaward of the 1955 shoreline, however they had become more continuous and wider by 1990 (Fig. 35). The increase in 'broken' bottom cover, combined with other field observations suggest that the sand cover within the inner shoreface has decreased during the past 35 years.

Between 1964 and 1990 the position of the larger bedforms off Poverty Beach remained essentially the same, however the continuity of the sand bars was less by 1990 because of the formation and influence of several new tidal inlets since the early 1980s (Fig. 36). The sand bars have been replaced by larger ebb tidal deposits. South of Beach Point, the area of sand exposed at low tide has increased. The implication is that there has been a net accumulation of material there between 1964 and 1990.

C) What is the total annual supply of sediment to the Gaspereaux Shore?

The total volume of sediment, and volume of sand supplied from erosion within each shore segment between Murray Head and Cape Sharp is tabulated in Appendix 4 and summarized in table 8. Sediment supply is broken down by shoreline compartment and by shore type. Sediment supplied as a result of changes at Poverty Beach is not included in Table 8 because most of the sediment is redistributed locally within the Poverty Beach-Murray Harbour estuary. Temporal changes in Poverty Beach and its implications to the sediment budget of the Gaspereaux Shore are discussed later.

Using the longer term shoreline erosion rates, the annual volume of sediment that could be supplied to shore compartments 1 and 2 from cliffs and scarps is estimated to be 14285 m^3/a of which 8715 m^3/a is sand (Table 8, Appendix 4). An additional 2454 m^3/a of sediment is derived from the erosion of backshore dunes. Not all of this sediment is available to the littoral system in any given year; there will be years when larger or smaller inputs of sediment will occur. For comparison, Woodward-Clyde Consultants (1980) estimated that the net supply of sand from the same shore area was just less than 3000 m^3/a.

What is the contribution of sediment from the shoreface? In the absence of field surveys and sampling, it is not easy to determine how much of the sediment across the shoreface is derived from onshore versus seabed erosion. It was assumed for this exercise that most sediment comes from onshore erosion and the submarine bars provide an important pathway for sediment transport alongshore and onshore-offshore. During storms, sediment tends to be transported offshore from the beaches, whereas during periods of lower wave energy or longer period waves, sediment is carried back onshore. Therefore the shoreface deposits can be thought of as either a sediment sink or source for beach development. It was assumed that sediment in water depths of less than three metres moves back and forth within the littoral zone. The shoreface deposits were considered a potential input or source of sediment if their area decreased over time, and they were considered a sink or sediment loss, if their area increased. If features such as nearshore bars became better defined but decreased in areal extent, it was assumed that the thickness of the deposit increased.

A crude estimate of sand supply from the shoreface was calculated but only for the 4.5 km stretch of shoreline between Irvings Cape and Cody Point where commercial sediment extraction is concentrated. It was assumed that the average thickness for the sand cover was 0.5 m, the area of broken bottom increased at an average rate of 3611 m^2/a, and the area of sand increased by 143 m^2/a during the 35 years. Therefore the annual volume of mobile sand removed from the 'broken bottom' area would be (3611 x 0.5)=1806 m^3/a and the volume of sand added to other parts of the shoreface was (143 x 0.5) =71.5 m^3/a. Therefore the potential supply of sediment to the shoreline from the shoreface is estimated to be (1806-71.5) =1735 m^3/a. However, it should be remembered that much of this sediment may not be new but rather only remobilised sand from relict beach and shore cliff deposits.

Table 8. Summary (from appendix 4) of annual supply and loss of sand along the two southern shore compartments of the Gaspereaux Shore, east Prince Edward Island. Natural losses include dunes and tidal inlets; artificial losses include commercial excavation (mean for 1975-1998). The shore segments are located on Figure 32.

Compartments (Segments)	**Sand Inputs (m3/a)**			**Sand Losses (m3/a)**	
	Cliffs	Dunes	Shoreface	Natural	Artificial
1* (1 to9)	1699	298	—	97	----
(16-33)	2265	2139	1735	688	5725
(34-36)	849	17	—	—	1105
Subtotal	4813	2454	1735	785	6830
2 (37-43)	1447	—	—	521	941
Totals	**6260**	**2454**	**1735**	**1306**	**7772**

BALANCE *Compartment 1 = 9002-7615 = + 1387 m3/a
Compartment 2 = 1447-1462 = - 15 m3/a
* Total Compartment 1 and 2 = 10,449- 9078 = + 1371 m3/a

* Compartment 1 and Totals exclude Poverty Beach (segments 10-15)

Sediment Loss

A) How much of the annual sediment supply is temporarily stored on the backshore, or within tidal inlets?

The shoreline is only a narrow part of the coastal zone which in this report is considered to extend seaward to wave base and landward into any water body, e.g. lagoons, bays and estuaries, that is linked to the littoral system. Sediment is constantly redistributed between different parts of the coastal zone in response to changing environmental conditions and over the longer term as sea level changes. Sand and gravel is used to maintain the shoreline against storms and rising sea level and for building new features within the estuaries or subtidal. Muds which represent 22-35% of the local till deposits onshore are carried offshore into deeper basins, or landward into lagoons, estuaries and marshes.

To quantify the total volume of sediment transported away from the littoral zone at any one time is very difficult because many of the losses are temporary. New technology such as airborne laser altimetry will provide digital elevation maps of coastal areas which if repeated over the same areas will allow quick assessments of changes in coastal morphology. Unfortunately this technology was not available for this study. Instead, an estimate of sediment accumulation across the nearshore and backshore was made by measuring changes in the size and shape of specific coastal features using sequential air photos. For example between 1936 and 1955 Poverty Beach lost 66600 m^2 along its seaward side and one third was transported across the backshore as wave overwash deposits and two thirds was transported and deposited at the distal end of the spit. Temporal changes in Poverty Beach will be examined in more detail later in this report.

Backshore: During the compilation of recent shoreline changes along the Gaspereaux Shore, minor duneline progradation was observed along seven shore segments (Appendix 4). The estimated temporary capture of sand by dunes was 1306 m^3/a (Table 8, Appendix 4). Furthermore, several of the spits and barrier beaches of Poverty Beach aggraded, inlets were closed off and the flood and ebb tidal deposits expanded (see next section). Sediment that is transported into lagoons, lakes or wetlands by wind and wave overwash are acknowledged but can not be quantified at this time.

Tidal Inlets: Sediment transported through tidal inlets accumulates as the water velocity decreases at both ends of the inlet. Flood deltas form at the lagoon side of an inlet and ebb deltas form at the seaward end of the inlets. Measurements from sequential vertical air photos provide an estimate of the sediment gains and losses in the flood and ebb tidal deltas which changed as inlets opened and closed along Poverty Beach. The total surface area of flood delta nearly doubled from 325594 m^2 in 1974 to 720541 m^2 in 1987. No field measurements of thickness were available for these deltaic deposits. An estimate of the sediment thickness was calculated using hydrographic charts and the area of delta surface above or below low tide (Appendix 7, Table 9). The total estimated volume of flood tidal deposits increased rapidly between 1969 and 1974, then slowed until 1981, then nearly doubled by 1987 (Table 9, Appendix 7, Fig. 38).

Ebb tidal deposits at inlets B and C (Fig. 38) also were measured for the same time period (Table 9). These deposits are derived from beach erosion, landward migrating sand bodies and sediment transported seaward through the tidal inlets. They represent a potential supply of new sediment to the beaches. The size of the ebb deltas between 1974 and 1987 fluctuated between a low of 35109 m^2 in 1980 and a high of 308446 m^2 in 1987 (Table 9). The decrease in1980 reflects the gradual closure of inlet B and the incorporation of ebb tidal deposits onshore (Table 10). An estimated 2500 m^2 of beach was gained at inlet B. The increase in area of ebb

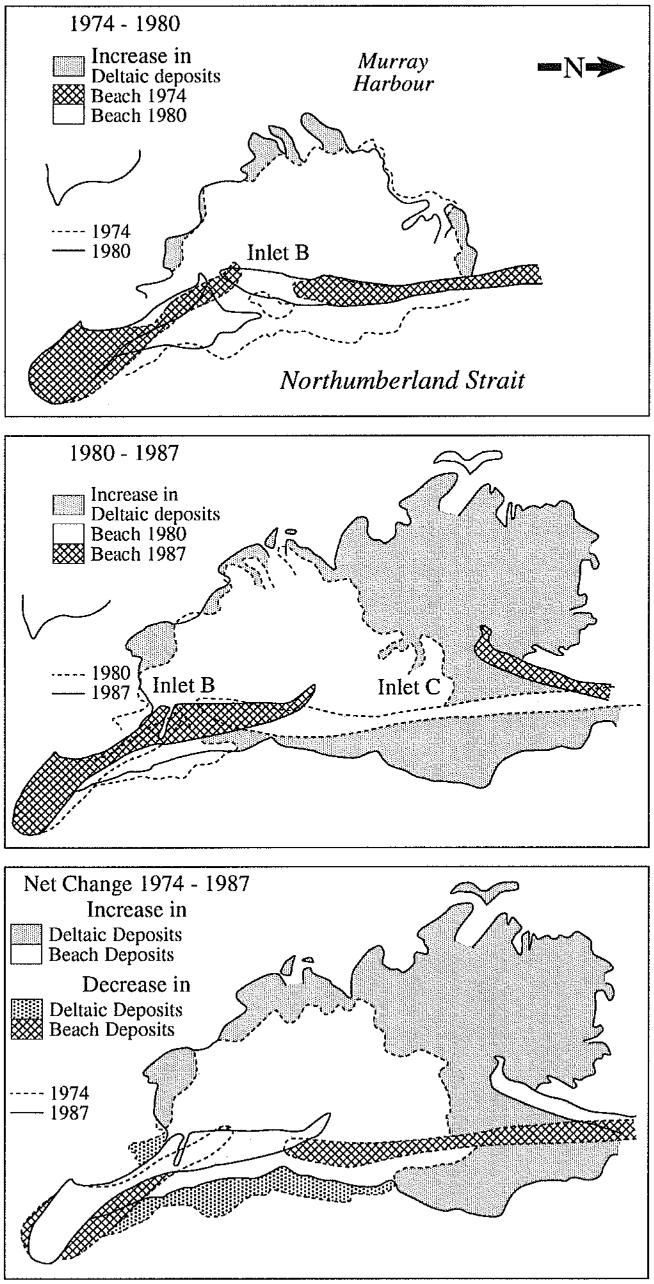


Figure 38. Sequential changes in the tidal inlets and distribution of flood delta and beach deposits on Poverty Beach (A) 1974 to 1980, (B) 1980 to 1987 and (C) the net change 1974 to 1987. Names of tidal inlets and their development and closure are shown in Figure 43

tidal deposits by 1987 reflects the opening of inlets C1 and C2 and the growth of new tidal deposits.

Temporal changes in the size of the barrier beach, compared with changes in the inlet deposits, provides an indication of the volumes of sediment gained or lost from the system. For example, between 1968 and 1974 when inlet B formed, the loss of sediment where the breach occurred (35000 m^2) was similar to the gain of sediment at the distal end of the beaches flanking the breach (37700 m^2). Therefore the net gain of sediment at the tidal inlet must have come from offshore, farther alongshore, or both. In contrast between 1980 and 1987 the distal part of Poverty Beach grew by 9000 m^2 but the proximal end lost an estimated 111427 m^2 of beach where inlets C1 and C2 developed. Since the net increase in sediment across the deltas at C1 and C2 was similar to the loss from the proximal end of Poverty Beach it suggests that very little new sediment was being added from farther alongshore or offshore. However the growth of the distal end of Poverty Beach does suggest that some sediment is being transferred to the distal parts of the barrier along the nearshore bedforms (Fig 36, 38).

It therefore appears that between 1969, when the first inlet formed, and 1974, sediment accumulating at the tidal deltas was supplied from farther away or offshore. By 1987, the beach itself was feeding the tidal inlet deposits because the sediment that used to be transported alongshore or from offshore was no longer available. A significant portion of that sediment was being removed by commercial beach mining farther up the coast.

B) What volume of the annual sediment supply is permanently lost from the coastal zone?

Mechanical extraction differs from sediment loss by natural processes because it is a permanent loss of material. The sediment is trucked away from the coastal zone whereas sediment accumulating in natural features can be recycled back onto the shores or become new shores. In this study sediment trapped as flood and ebb tidal deposits on an annual time scale is considered a loss even though some of the material may be redistributed within the inlet or alongshore. In the longer term, as Poverty Beach migrates landward, or the inlet position shifts laterally, the

Table 9. Changes in the surface area and estimated sediment volume of the flood and ebb tidal deltas associated with the inlets at Poverty Beach, Prince Edward Island. The changes are illustrated in Figure 38.

Date	Area (m2) of Poverty Beach	Area (m2) of Flood Delta	Area (m2) of Ebb Delta	Volume (m3) of Flood Delta	Volume (m3) of Ebb Delta
1974	242,714	325,594	112,547	97,678	33,764
1980	245,198	368,362	35,109	142,739	14,044
1987	142,783	720,541	308,446	274,701	99,307

Table 10. Changes in the dimensions of Poverty Beach and its associated tidal inlets between 1936 and 1990 based on measurements from vertical aerial photographs.

Year	Beach Segments No.	Beach Segments Length (m)	Beach Segments Width (m)	Beach Total Area (m2)	Inlets Name	Inlets Total Width (m)	Ratio Beach/ Inlet
1936	1	2875	83-121	291,375	A	A = 446	6.4
1955	1	2774	49-99 distal = 197	281,925	A	A = 330	8.4
1968	1	2776	19-95 distal = 266	227,543	A	A = 278	10
1974	2	prox.=1727 distal = 979	prox.= 60-131 distal = 237	242,714	A B	A = 267 B = 220	5.5
1980	2	prox.= 2109 distal= 795	prox.= 37-95 distal = 68-196	245,198	A B	A = 286 B = 53	8.6
1982	4	prox.=1013 2 = 200 3 = 708 dista l= 742	prox.=18-76 2 = <18 3 = 75-118 distal = 54-163		A B C1 C2	A = 290 B = 42 C1 = 58 C2 = 129	5.1
1984	3	prox.= 1060 3 = 700 distal = 745	prox = < 25-80 3 = 30-110 distal =15-150		A B C	A = 275 B = 20 C = 525	3.1
1987	3	prox = 1130 3 = 540 distal = 745	prox = 35-60 3 = 30-130 distal=15-150	142,783	A B C	A = 275 B = 15-20 C = 650	2.6
1990	2	prox = 1248 distal = 1257	prox = 26-35 distal = 26-150	149,135	A C	A = 273 C = 563	3

inlet deposits become a source of sediment for beach building or become the foundation for the retreating beach.

Sediment removed during commercial extraction operations is tabulated using reports filed with the PEI Department of Technology and Environment. The number of sediment extraction sites and the volume of sediment removed varies each year. South of Cape Sharp there have been a maximum of 5 sites and a minimum of 2 sites operating in any one year (Appendix 2). The largest number of sites were operating in 1981 and between 1988 and 1992. The total volume of sediment extracted by commercial operators from the shores south of Cape Sharp between

1975 and 1998 was 178757 m^3. The mean annual rate of extraction was 7772 m^3. For the shores south of Cody Point to Irvings Cape (segments 16-33) the total volume of sediment extracted under permit was 131649 m^3 or 5725 m^3/a. These values do not include the 10000 m^3 of sand pumped from offshore of Beach Point in 1992. Assuming the normal dump truck hauls 17 metric tonnes of sand which equates to 9.9 m^3, roughly 18056 truck loads of sediment have been removed from the shores south of Cape Sharp since 1975. The total volume of sediment extracted from the shores south of Cody Point (131600 m^3) could build a beach 263 m long, 50 m wide and 10 m thick. Or, to express it another way, the volume represents roughly 20 years of sediment accretion (6400 m3/a) recorded before 1936 at the distal end of Poverty Beach.

Sediment Balance/ Budget

A) What is the present sediment balance along the Gaspereaux Shore?

The total input or supply of sand from cliffs and dunes along shore compartments 1 and 2 of the Gaspereaux Shore is estimated to be 8715 m^3/a. The total loss of sediment through dune aggradation / progradation and commercial sediment extraction is 9078 m^3/a (Table 8). If estimates of sand supplied from the shoreface are added from compartment 1, then the net balance becomes +1371 m^3/a .

If the two shore compartments are examined separately, compartment 1 has a positive balance and compartment 2 has a slight negative balance, although the offshore supply was not calculated for the second compartment (Table 8). Compartment 1 has a positive balance of 1387 m^3/a but 1900 m^3/a of that sediment is derived from shore erosion between Murray Head and Beach Point. Since not much of this sediment would likely reach the primary commercial sediment extraction sites north of Irvings Cape, the net balance in the mining area decreases to roughly -500 m^3/a. Furthermore about one half of the sediment derived from dunes in segments 16-33 comes from segment 16 (Fig. 32) which may or may not reach the mining sites because of the presence of the Irvings Cape jetty. Nevertheless it is included as a source of sediment. It should also be remembered that much of the sediment derived from offshore is only remobilized sand from beach and shore cliff deposits so the net supply of new sediment to these shores is even less. Woodward-Clyde Consultants (1980, p. 3-33), who included sediment supply from the shores as far north as Boughton Bay calculated a net balance of only 389 m^3 (490 cu yds) and they commented that "the present removal rates were close to the maximum that can be sustained without exceeding replenishment rates" (Woodward Clyde Consultants, 1980, p. 4-38). It is obvious that the supply of sediment calculated in this study is more than Woodward-Clyde predicted; however, the annual net input of new sediment is less.

B) How do the present rates of annual sediment supply and loss apply to the primary commercial sediment extraction area?

Sediment can oscillate back and forth alongshore or onshore and offshore depending on local wave conditions. However, if we assume that most of the sediment derived from erosion of shore segments 33 to 14 (Fig. 32) is transported southward and the rate of shoreline erosion is known, an estimate of the maximum supply of sediment to the mining sites can be made. Several scenerios are presented (Fig. 39): Case 1 and 2 use the longer term (1955-1987) rate of shore erosion calculated for each shore segment (Appendix 4). Cases 3 and 4 use erosion rates calculated from air photos for the period 1982 to 1990 (Appendix 4a).

Case 1: Late 1980s. (Fig. 39a). An estimated 2450 m^3 of sand can be potentially supplied each year by wave erosion of shore segments 33 to 29 (Fig. 32). For simplicity, we assume all of the sand moves southward in one season and none is trapped alongshore between coarser clasts or bedrock crevices, and none is carried offshore. At segment 28, erosion of the duneline contributed 27 m^3 and an average of 2000 m^3 of sand was excavated each year (F. Clows mining site). That leaves 450 m^3 of sand that could accumulate at the mining site or move farther downdrift. An additional 50 m^3/a of sand is supplied from backshore erosion at shore segments 28 and 27, and 705 m^3/a of sand is derived from dune erosion of segments 26 to 23. At segment 26 an average of 1353 m^3/a of sediment was extracted by a commercial operation (Condons Shore) until 1982. It is not included in this senerio but the loss of sediment may have caused the higher rate of erosion along segments 25 and 26. Instead the average volume of sediment, ie. 1000 m^3/a., extracted at the W. Johnston site (segment 22) after 1987 is included. The net sediment balance at this location would be -217 m^3. If the excess sediment at F. Clows also travels this far south, then the balance could be +233 m^3 but for now we will assume a slight deficit. An additional 140 m^3 of sand is derived from the dunes of segments 22 and 21. At segment 20 sediment was accumulating at an estimated average of 400 m^3/a because of Irvings Cape jetty. Also an average of 4100 m^3/a of sand was removed by the two commercial mining operations in the late 1980s. The net sediment balance would be close to -4577 m^3/a. The net loss of sediment suggests that little or no sediment is transported farther south. As a consequence, there is little or no beach building farther south.

Segment 16 (Fig 32, 39a) eroded and contributed an estimated 1250 m^3 of sand which was transported southward to Poverty Beach or northward into the wave shadow of the Irvings Cape jetty.

Site surveys at F. Clows beach suggest that half the volume of sediment extracted, ie.1000 m^3, is replaced each year and the south end of the Irvings Cape mining site was building at

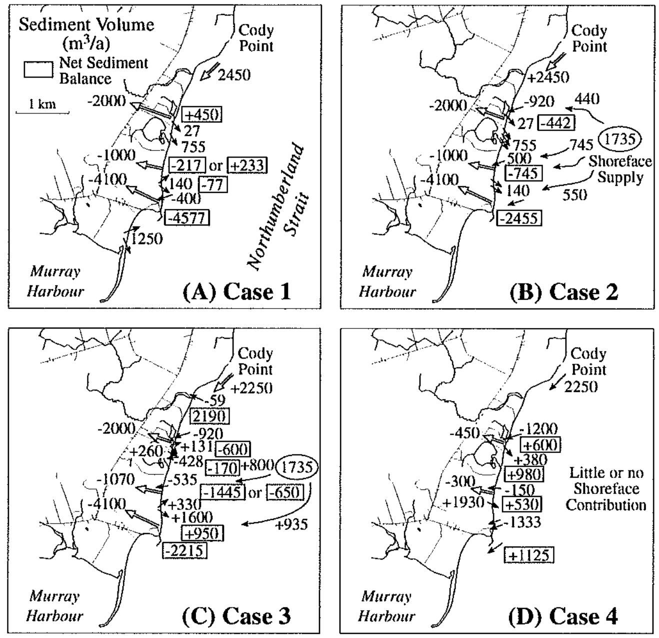


Figure 39: Maps of sediment inputs, losses and balances alongshore between Cody Point and Irvings Cape: A) assuming sediment supply only from onshore and sediment extraction rates from late 1980s; B) using sediment supplied from alongshore and the shoreface and C) using sediment supplied by accelerated shore erosion and the shoreface and D) with reduced sediment extraction rates from mid 1990's.

different times before and after 1989; net changes in sediment volume at the Irvings Cape site were less than +/- 2500 m^3/a and there was beach building south of the jetty in the mid to late 1980s. How could these positive changes have occurred given the lack of sediment observed in case 1?

Case 2: Late 1980s (add sediment supply from offshore, Fig. 39b). We assume the same volume of sand (2450 m^3) is supplied from shore erosion north of F. Clows (segment 28). There is an additional input 27 m^3 from dune erosion at F. Clows which may or may not remain at the mining site. Sediment extraction at segment 28 was 2000 m^3/a resulting in a positive balance of 477 m^3. However field surveys suggest that the beach at F. Clows gained as much as 1830 m^3 in 1988 and lost 2283 m^3 in 1987 or on average a replenishment of 920 m^3/a occurred each year. Therefore if it is assumed that the shores balanced their sediment volume, approximately

440 m^3/a (i.e. 920-477) of sediment must be derived from some other source. In this case it is assumed from offshore (Fig. 39).

Farther south from segments 27 to 23, shore erosion contributes 755 m^3/a. Volumes of sediment extracted from the W. Johnston site were roughly 1000 m^3/a and field surveys in the late 1990s suggested half that volume is replenished each year. There are no surveys in the late 1980s to confirm this observation. Assuming it is correct, the difference in sediment volume would be (1500-755) = -745 m^3. The sediment is not available from onshore to balance the deficit so it must be derived from elsewhere, assumed from offshore. At Irvings Cape the net annual change in sediment volume in the late 1980s varied from a net loss of 802 m^3 to a net gain of 2500 m^3 each year which means that if you have an average extraction rate of 4100 m^3/a, the average volume of sediment supply would range from 2000 to 6600 m^3/a. For this example an average volume of 3144 m^3/a was used as the figure for supply. Only 550 m^3/a would be available from offshore and 140 m^3/a from alongshore therefore a deficit of 2455 m^3 of sediment results. However, in 1986 the site actually increased in volume by nearly +2500 m^3 (Table 1). It is possible that either the supply of shore sediment is too small, especially from offshore, or the values of sediment extracted provided by the province are too high. However, assuming everything is correct, where does the additional sediment come from which replenishes the Irvings Cape extraction site? Increased shore erosion?

<u>Case 3</u>: (Shore recession 1980s; Fig. 39c). We know from field observations and from erosion values published by the Geographical Branch (1959) and LRIS (1988) that rates of shoreline erosion can differ substantially from year to year or between different periods of time. One could assume that the increased volumes of sediment supplied to the mining sites are the consequence of accelerated shore erosion. Shoreline retreat was measured from rectified air photos taken between 1982 and 1990 when mining was near its peak at three sites. Surprisingly, erosion was observed to be slightly less with some gains along the northern shores including the old Condons Shore mining site. Backshore erosion was observed to be higher between the W. Johnston and Irvings Cape extraction sites.

For the period 1982 to 1990 the estimated volume of sediment supplied from segments 33 to 29 was 2250 m^3/a (Fig 39c). However 59 m^3/a was deposited by wave overwash along the backshore of segment 30. Records show that 2000 m^3 of sediment was extracted at F. Clows mining site, therefore 190 m^3/a of sediment is available to replenish the mining site. However shore surveys suggest that on average 920 m^3/a is supplied to the site. Therefore 730 m^3/a of sand would be required from offshore or from farther alongshore to replenish these shores. In this case we will assume there is no input from offshore but there is 11 m^3/a from dune recession adjacent the F. Clows site. Shore erosion had increased south of F. Clows. It is assumed that some of the sediment moved northward, e.g. 120 m^3/a and was added to the F. Clows site; the remainder e.g. 260 m^3/a was transported south alongshore to segments 25 and 26. Therefore, with the supply of 131 m^3, F. Clows site would have a net deficit of roughly 600 m^3 of sediment which is in the range of the net changes observed in the late 1980s (Table 4). At the former Condons Shore mining site there was evidence of dune building. An estimated 430 m^3 of sediment accumulated there. The net sediment balance is now -170 m^3. The average volume of sediment extracted from the W. Johnston mining site in the late 1980s was 1070 m^3/a. Half of that volume is naturally replenished. The total deficit would be 1070 + 535 + 170 = -1775 m^3/a. Shoreline erosion supplied 1930 m3/a of sediment south of W. Johnstons. We assume a small amount, lets say 330 m^3 moved northward to supply the mining site. The net deficit would be 1775 - 330 = -1445 m^3. During the late 1990s the normal sediment balance at the W. Johnston site was +/- 650 m^3/a. Therefore roughly 800 m^3 sediment must be contributed from offshore to make up the difference. The net sediment balance could be as high as -1445 m^3 but it is assumed that it is closer to -650 m^3 Adding the 1600 m^3/a of sand supplied from shore erosion between the W. Johnston mining site and Irvings Cape, the sediment balance is now +950 m^3/a. If the volume of sediment extraction at Irvings Cape was 4100 m^3/a then there would be a net deficit of -3150 m^3/a. According to our estimates of sediment contributed from offshore, there could be as much as 935 m^3/a. contributed to this site which would still result in a deficit of -2215 m^3. This is very close to the figure of net sediment change for 1989. However after 1989 the Irvings Cape site began building again until 1995. Where does the increased supply of sediment originate in the 1990s? In the early 1990s measurements at the shore monitoring site suggest erosion had increased by 0.1 m/a and dune recession had increased at the F.Clows site and was high at the Johnston site in the late 1990s? Unfortunately there are no air photos or shoreline measurements elsewhere alongshore to substantiate these higher erosion rates. At the same time the rate of sediment extraction was severely reduced because of the impacts of several storms on shoreline stability in the early 1990s. It is suggested that it was these same storms that caused the increased erosion and increase in sediment supply to the downdrift shores.

Case 4: (Reduced sediment extraction -mid 1990s, Fig. 39d) If we use the reduced sediment extraction values from 1994 and assume the same volume of sediment input and erosion rates as Case 3, a much improved sediment budget is calculated for Irvings Cape. By 1994 sediment was no longer extracted from Irvings Cape and the volume of sediment extracted at the other two sites was reduced to a total of 750 m^3/a. In this case 2250 m^3/a of sediment is transported southward from shore segments 33 to 29; 450 m^3 of sediment was extracted from Clows and 1200 m^3 of sediment (according to surveys) was naturally supplied to the site. That means there was 600 m^3 of sediment available to move southward alongshore if none was lost as wave overwash deposits or trapped offshore. If we assume that 380 m^3 is derived from backshore erosion between F. Clows and W. Johnston mining sites, and none is trapped onshore or offshore, there is potentially 980 m^3 of sediment available for transport. At W. Johnstons site 300 m^3 of sediment was extracted and we assume 150 m^3 of sediment was supplied to the site. That means there is roughly +530 m^3 of sediment that could move southward alongshore to augment the +1930 m^3 of sediment from shore erosion of segments 20 and 21. There was no mining at Irvings Cape and site surveys suggested a net gain of 500 m^3 by mid 1994 and an additional gain of 833 m^3 by the spring of 1995. Our calculations would suggest a net gain of +2460 m^3. If all is correct the surplus sediment (1125 m^3) must have bypassed the jetty and supplied the shores farther south. An alternative is that the volume of sediment reaching Irvings Cape was smaller than we predicted because the storms of the mid 1990s had transported a significant volume of sediment offshore to replenish to gradual reduction of sediment observed across the shoreface in the 1980s. Regardless, it is apparent that this shoreline can better sustain itself at reduced rates of sediment extraction. Also, there is still the problem of sediment depletion farther south at Poverty Beach and the weakened state of this shoreline because of more than 20 years of continuous extraction north of Irvings Cape.

In the above examples several assumptions were made and potential rates of sediment supply and loss were computed with the best available information, but the whole exercise is a shell game where numbers can be juggled by proponents and opponents of beach mining to promote their cause. Many of the uncertainties could have been eliminated if repetitive airborne laser altimetry surveys had been available for the region but this technology is not yet widely available. The importance of this exercise is to illustrate that there is not an unlimited supply of sediment. If you remove sediment from the natural system through extraction it is gone forever and it can only be replaced by increasing the amount of sediment eroded from alongshore or offshore. The other important point to remember when assessing the impact of sediment extraction is that a new supply of sediment from onshore or offshore is required to replenish the lost sediment.

Summary

Sediment is supplied to the beaches primarily from shore erosion and possibly redistributed between the beach and shoreface by nearshore bars. Sediment is only a renewable resource if there is increased or continued coastal erosion. Within shore compartment 1, Murray Head to Cody Point, the total sediment supply exceeds the suggested losses, including commercial sediment extraction, by1387 m^3/a. However roughly 1900 m^3 is supplied from south of Poverty Beach and would not reach the shores where the commercial mining operations are taking place. Furthermore, these estimates of sediment supply are maximum values. In reality not all of the sediment eroded from onshore is immediately supplied to the downdrift shores. It takes time as sediment moves both north and south alongshore under varying wave conditions. However, if one assumes a net southerly transport of sediment between Cody Point and Irvings Cape and calculate a sediment budget for that shore, there is some agreement between the proposed sediment budget especially in Case 3 and the changes recorded by field surveys at the mining sites. However, there are several unknowns, particularly about sediment movement within the nearshore, and the rates of shoreline erosion in the 1990s which make quantitative conclusions very imprecise. What is obvious is that sediment depletion (mainly mining) was greater in the 1980s and early 1990s than sediment supply within the area of mining. Sediment accumulated at all of the mining sites but the only place where there was a net buildup in the upper beach was adjacent to the Irvings Cape jetty. It is concluded that these shores can not sustain continued sediment extraction at the volumes permitted in the early 1990s. A very limited extraction operation could be sustained at Irvings Cape, if the jetty remains intact. The problem with allowing a small extraction operation is that the downdrift shores including Poverty Beach would suffer from continued sediment depletion and the presence of the jetty.

the seaward edge of vegetation were offset by its distance from high tide line in 1936 (Fig. 41). Air photos were not available for all years at transects 9 and 10 and no photos were available after 1990. Shoreline changes are discussed for three time periods: historical to 1954 (pre- jetty), 1954 to1974 (jetty) and 1975 to1998 (mining and partial jetty).

Natural Historical Shoreline Changes

A wealth of historical maps exist for the shores of Prince Edward Island. A comparison of present topographic maps with maps from circa 1780 (Archive no. 0,318, PEI Archives) and 1843 (Bayfield, 1843) show that the outer shores have receded landward, the headlands have been trimmed back, and the embayments, such as Murray Harbour and Grahams Pond (Herring Bay) have become nearly closed off from Northumberland Strait by beach deposits. Between 1843 (Bayfield, 1843) and 1936, when the first air photos were taken, (Fig. 42) the shoreline between Irvings Cape and Cody Point retreated landward by as much as 150 m, Irvings Cape retreated by 100 m, and the north end of Poverty Beach by 80-90 m.

In 1843 the shores between Irvings Cape and Cody Point were depicted on the maps as low lying wetland or lagoon (Bayfield, 1843) which became at least partially infilled by landward moving beaches. Much of the sediment derived from shore erosion is assumed to have been transported southward to the distal end of Poverty Beach where the spit grew 12 to14 m/a during the period 1780 to1843 and as much as 16 m/a from the mid-1800s until 1936.

Between 1936 and 1955, physical changes in the shoreline continued to be dominated by natural processes. There were no artificial structures extending offshore, nor government approved commercial beach mining operations. In 1936 Poverty Beach varied from 80 to120 m in width and it extended 2.8 km across Murray Harbour (Table10, Fig. 42b, 43a). A single dune ridge extended along the backshore. In 1936 there was evidence that sediment was being supplied to the spit. For example, the distal end of the spit continued to grow, at least one of the large washovers was being infilled and an increased number of buildings were being constructed along the northern end of Poverty Beach (Fig. 42b) which implied better beach stability. However, there was also evidence that the evolution of Poverty Beach was changing by 1936 and sediment supply was decreasing. Until the 1930s the spit had continued to extend southwestward as a linear shore feature but after the 1930s it began to curl seaward at its southern end. Its growth had been halted by currents flowing through the tidal inlet from Murray Harbour. By 1936 the continuity of the duneline was broken by two large wave washover channels (Fig. 42b, 43a). During the next twenty years sediment partially infilled and stabilized the northern washover (WO1, Fig 43a) but the beach retreated 75 m landward at the southern washover (Fig. 43a, WO2) and two new washover channels had developed north and south of WO2. An estimated 66200 m^2 of beach was eroded, one third of the material was transferred through the low washover channels into Murray Harbour and two thirds was added to the distal end of the spit where it curled and prograded seaward as a series of well defined beach ridges and swales.

In 1948 an attempt was made by fishermen to dredge a channel through the north end of Poverty Beach. The objective was to reduce the travel time to Northumberland Strait from Clows wharf located farther up Murray Harbour. The 100 ft wide channel kept infilling during the dredging operation and a free flow of water was never achieved. Failure to dredge the channel confirms the dominance of longshore sediment transport. After the failure of the channel, plans were made to build a landing wharf at Irvings Cape. Construction began in 1954 and the initial stages of construction are visible on 1955 air photographs.

From 1936 -55 a net retreat was measured at all of the cross-shore transects but number 6 where the shoreline was stable (Fig. 40). The largest retreat of 30 to 36 m was recorded at lines 4 and 5 (Appendix 8, Fig. 40, 41) and the least change was north of transect 5. The shoreline fronting Condons Pond consisted of a series of beach and dune ridges suggesting it had been an area of natural sediment accumulation.

Impacts of Constructing the Irvings Cape Jetty and Wave Breakwater (1954-1974)

Following the construction of the jetty and wave breakwall at Irvings Cape in 1954-55 and its extension in the early 1960s (Appendix 3) shoreline changes accelerated between transects 1 and 6 until at least 1968 (Fig. 9, 44). Farther north beyond the influence of the new jetty the shores were fairly stable with only minor retreat observed at some transects (Appendix 8). Sediment rapidly accumulated along the northern side of the new jetty. By 1968 the shoreline had built 130 m seaward adjacent to the jetty (Fig. 9, 44) and 65 m seaward at transect 5. An estimated 14400 m^3 of sediment accumulated north of the jetty between 1955 and 1968. South of the jetty sediment was already accumulating by 1964 (Fig. 45). The expansion of the intertidal flats within the wave shadow of the jetty facilitated the growth of a spit southward from the jetty. By 1968 the spit had become a barrier enclosing a wetland/lagoon behind (Fig. 44). The barrier beach was fed by sediment from both the south and north and a small foreland developed where the transport paths met. The resultant shoreline was 130 m seaward of its 1955 position (Fig. 44). It is estimated that just over 16000 m^3 of sediment accumulated south of the jetty. Farther south alongshore, beyond the wave shadow of the jetty, the backshore retreated 11 to 15 m and the beachface at transect 2 migrated an estimated 39 m landward. Several buildings which existed along this part of the beach in 1955 were less than 5m from the eroding beach face in the late 1950s (Geographical Branch, 1959) and had to be moved before the next aerial photography was taken in 1968. It was also about 1968 that a seawall was constructed to protect the road leading to Irvings Cape jetty (E. MacCarthy, local resident, pers. com., 1993).

Poverty Beach spit continued to build seaward at its distal end but other parts of the spit retreated landward particularly near the northern of the two 1936 washovers (Fig. 43a,b). At one location the spit was only 19 m wide and wave washover features were increasing in number.

By September 1969, Poverty Beach spit had broken into two segments (PEI, 1970; Bartlett 1975). The breach occurred where the spit had experienced its greatest retreat and bending during the previous 30 years. Over the next 5 years the beaches on both sides of the new inlet were forced landward. The south barrier moved an estimated 100 m landward and sediment from the breach was added to the beaches on both sides of the new inlet and to the newly developed flood tidal delta (Fig. 38a, Inlet B). After 1968 changes in the shoreline became more variable alongshore. By the early 1970s, the wharf at Irvings Cape had deteriorated to a point where it was no longer used. South of the jetty, at transect 3, the foreland which was building in 1968, was erased by 1974 and the beach had migrated 40 m landward.

From1968 to 1974 was one of the few times when the shore built seaward at transect 2 (Appendix 8). The zone of beach building was short-lived. Closer to Poverty Beach the shores retreated 8 to 12 m during those six years (Fig. 41). North of the jetty the beach at transect 5 also had begun retreating by 1974 but the duneline had migrated slightly seaward. There was very little mobile sediment observed offshore of Irvings Cape in 1974, only bedrock or broken bottom was visible on the air photos.

Farther north shoreline change was still minor; there were areas of net sediment accumulation, e.g. transect 6, and net erosion at transects 7 and 8. The first evidence of beach mining was observed on the 1968 photos near transect 9 (approx location of the C. Curry extraction operation in the 1980s).

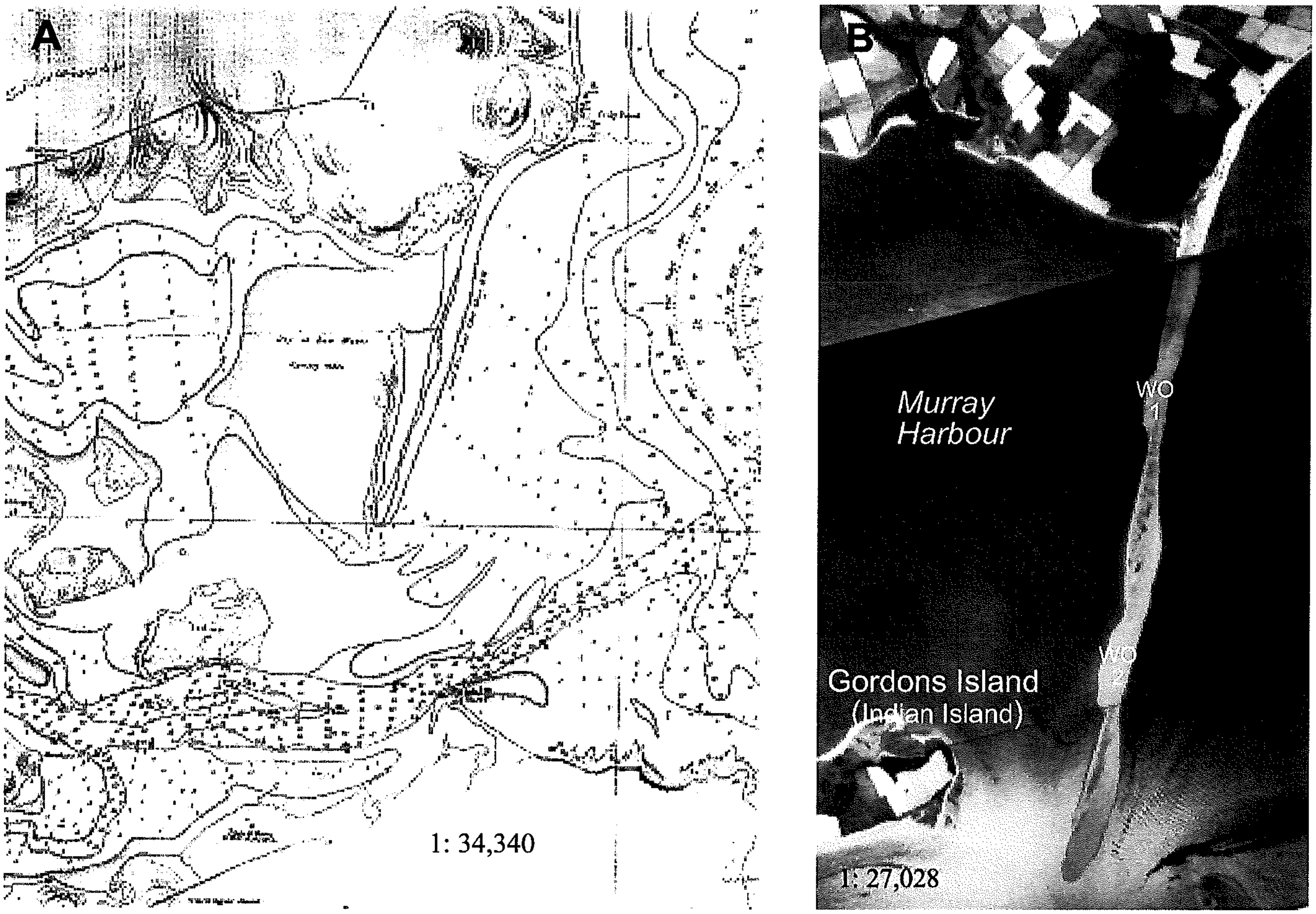


Figure 42. A comparison between the Bayfield 1843 map(A) and the first air photos(B, photos A5346-7,9) of Poverty Beach in 1936 illustrate the dramatic growth of the spit and closure of the inlet into Murray harbour. The occurrence of two large wave washover channels (marked by WO1, WO2) cut across Poverty Beach by 1936 may also signal a decrease in beach stability.

Impacts of Commercial Sediment Extraction in the Intertidal Zone (1975-1998)

By the mid 1970s permits for commercial beach mining were issued for three sites: Irvings Cape, Condons Shore and F. Clows which lay between transect lines 5 and 8 (Fig. 3, 40) and evidence of some digging was visible near transect 9 but it may have been relict scars from the late 1960s operations. Air photos revealed extensive sediment removal across the dunes at and to the north of Irvings Cape, and at Condons Shore. Many of the dune cuts observed in the mid to late 1970s were the result of mining activities but there was also evidence that the duneline had been trimmed landward by waves. Sediment accumulation at the mouth of Condons Pond had decreased by1968 and the adjacent shores had started to retreat by 1974.

The late 1970s and early 1980s were a pivotal time in the evolution of the shoreline near Irvings Cape: volumes of sediment extraction were increasing (Appendix 2), less sediment was moving southward past the jetty, and the shoreline was struck by one or more severe storms. Evidence of the storms included: the breaking apart of Poverty Beach, high rates of shoreline recession between 1974 and 1982

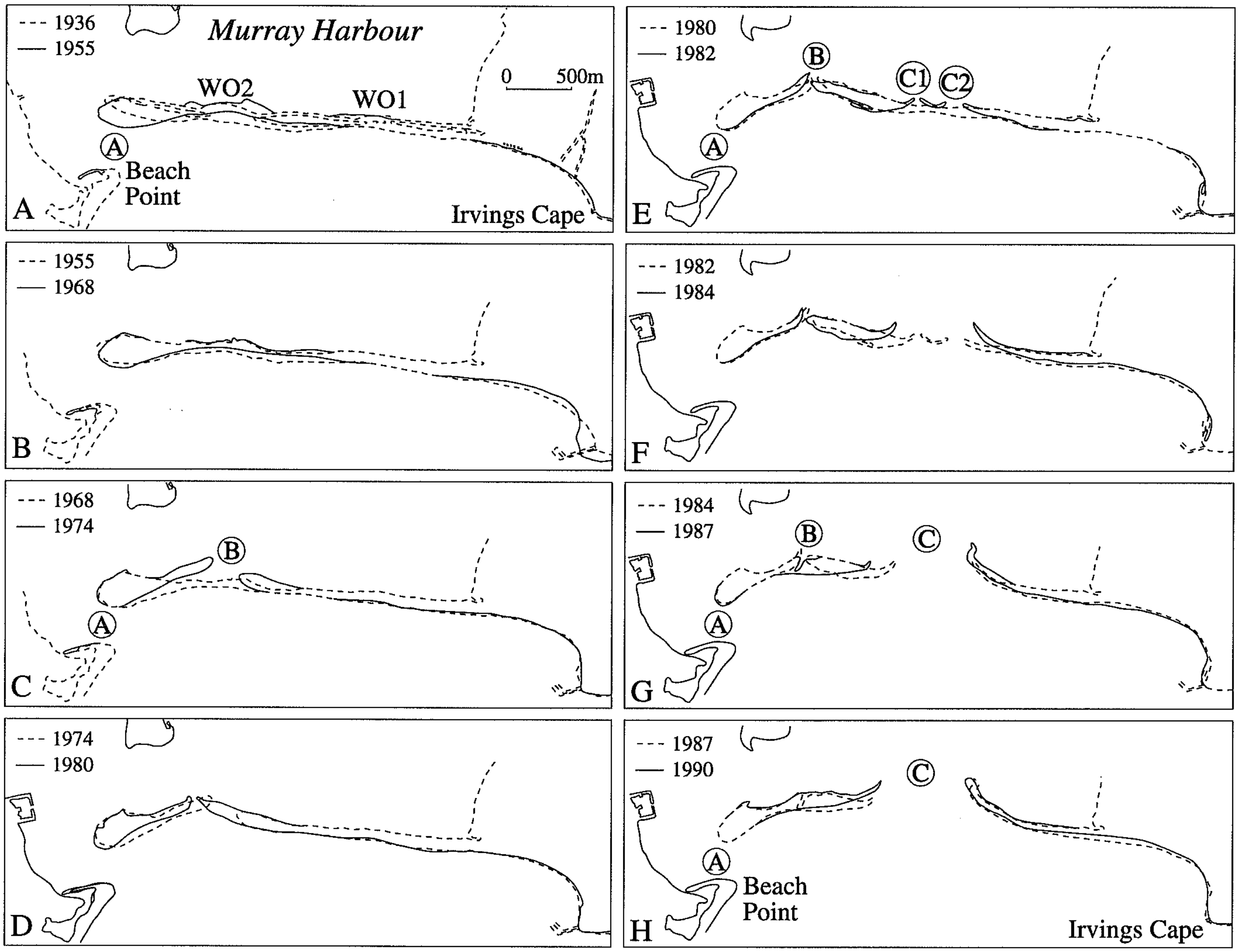


Figure 43. Sketches of shoreline changes at Poverty Beach (a) 1936 to 1955; (b) 1955 to 1968; (c) 1968 to 1974; (d) 1974 to 1980; (e) 1980 to 1982; (f) 1982 to 1984; (g) 1984 to 1987 and (h) 1987 to 1990. The information is taken from aerial photographs listed in Appendix 6.

(Appendix 8) and the occurrence by 1980 of several very long wave washover features north of Irvings Cape. One washover lobe near transect 6 (Fig. 40) extended 143 m inland. It took 7-10 years before it was recolonized by vegetation. Wave washover features of this magnitude had not reoccurred by 1990 but there was evidence of older washover scars in the same vicinity on the 1936 air photos.

By 1980 the beach had built seaward to the northern end of the jetty and during the early 1980s, sediment transport increased southward past the jetty. By 1982 the mid-section of the Irvings Cape wave breakwall was gone which may have also facilitated downdrift sediment transport. As a consequence, a spit began extending south of the jetty as it had during the late 1960s. North of Irvings Cape an increase in shoreline retreat, (>2 m/a) was recorded between 1974 and 1982 (Appendix 8, Fig. 9) this could be attributed to the mining but was probably triggered by storms in the late 1970s.

Poverty Beach continued to break apart between the mid 1970s and mid 1980s. Inlet B which formed in 1969, was gradually closed off and two new inlets C1 and C2 (Fig. 43 e, f ;) developed farther north along the spit. As the 1969 inlet was closed, the inlets C1 and C2 coalesced into one inlet C, approximately 500 m wide (Fig. 45). At the north side of the new inlet, mining operations morphological changes appear to be subtle at first but with time there are larger changes in shoreline morphology. The increased change is either caused by accelerated mining where less sediment is replenished, or by storm activity along shores that are sediment deficient. The latter or a combination of both factors appear to have occurred along the Gaspereaux Shore in the late 1970s and mid 1990s. Subtle changes followed by dramatic changes in shoreline stability have been reported from several beach mining sites in Nova Scotia (Bowen et al., 1975; Taylor, 1982). Shore instabilities caused by mining can persist for more than 20 years after the mining has ceased, e.g. Silver Sands beach NS (Taylor et al., 1996).

QUESTIONS OF SHORELINE RECOVERY, STABILITY AND COMMERCIAL SEDIMENT EXTRACTION

Introduction

A number of questions have been raised during this investigation about commercial beach sediment mining, whether it should continue, and what the consequences are of permitting mining to continue? In this section a number of the most common questions are addressed.

Shoreline Recovery

A) Can these shores recover from commercial sediment extraction operations?

On the basis of field surveys completed by the provincial government between 1984 and 1998, the answer would be Yes for Irvings Cape and No for the W. Johnston and F. Clows sites. To understand the conflicting answer it is important to examine the local shore conditions at these sites. The Gaspereaux Shore south of Cody Point is drift aligned which means that the dominant direction of sediment transport is alongshore, rather than onshore-offshore. Increased changes at the north end of all three mining sites suggest that the dominant direction of sediment movement is from north to south. At Irvings Cape the solid inner portion of the jetty has provided an artificial anchor and trap for sediment moving alongshore since the mid-1950s. There is no such structure at the Clows and Johnston sites so it is much more difficult for large quantities of sediment to accumulate and build seaward. Having said that, the shore at the W. Johnston site appears to have been a possible accretionary node in the past, so (given sufficient sediment), it is possible it could rebuild if beach mining ceased.

Since 1984 there have been annual oscillations of ±1500 m^3 of sediment at the Irvings Cape site. More erosion occurred along the northern than southern part of the site. The net change in sediment volume for the site from 1984 to 1997 was minor. Since mining stopped in late 1992, sediment has gradually moved upslope allowing the upper beach and backshore dunes to rebuild and become revegetated. As the beach rebuilt and infilled against the jetty, sediment transport increased southward alongshore. This site is artificially controlled by the jetty which was one of the main reasons for allowing mining in the first place. The same can not be said for the other two mining sites. At the F. Clows and W. Johnstons sites extracted sediment is replaced by material derived from the adjacent shores and shoreface. It was found that only half the excavated sediment was replenished at these sites in any one year. As a result, beach buildup was less and the backshore dunes became more vulnerable to wave attack. The backshore also retreated in response to the increased demand for sediment within the intertidal zone. Before mining began, the dunes had built higher over time which reduced wave overwash and in some cases there was some beach progradation, as at Condons Pond. As sediment extraction increased, erosion of the dunes and backshore scarps increased to satisfy increased demands for sediment across the intertidal zone. Even if mining was stopped it would be a slow process to rebuild the upper beach and dunes. There is little information available from the W. Johnston site. Although this shore has built in the past, it is anticipated that it would retreat and erode in a similar manner to the shore at F. Clows because the proximity of the two mining sites severely reduces the availability of sediment for their recovery. Also, the continued reduction of sediment just offshore reduces the chance of sediment supply from that source. Hence the negative answer for a quick recovery at the F. Clows and W. Johnston sites.

B) Why was there more sediment supplied to the beaches during mining operations than after the mining was stopped?

A specific quantity of sediment exists in any given area. It is assumed that new sediment may be added each year. Over time sediment can accumulate in an area. As sediment is removed from the natural system by mining, the material is either quickly replaced by sediment from nearby sources, thus protecting the backshore or the backshore comes under attack by waves, it retreats and sediment is moved to the beach or transported farther inland. For a period of time natural processes are able to redistribute sediment and little change is detected in the mining areas. If wave directions change, increased quantities of sediment can be shifted back and forth into a site, as we observed. As the sediment extraction activities continue there is increased pressure on the natural system to replenish the sediment extracted. Beach and backshore erosion must increase to offset the sediment supplied to the intertidal zone. Sediment would also be derived from the shoreface, water depths would change, altering the location where waves break, and altering bar morphology and the existence of bars. The potential for bars welding onshore and rebuilding the intertidal zone would decrease. Decreased sediment accumulation across the intertidal and lower supratidal results in increased erosion of the backshore. Destruction or lowering of the beach and dune crest results in more wave overwashing and a temporary loss of sediment into the low lying backshore and wetlands. Changes to the coast are subtle at first and fluctuations in sediment supply and loss may be higher because of the larger availability of sediment. But as increased quantities of sediment are extracted and removed from the littoral system, physical changes in the coast increase, and can become accelerated during storms. Such was the case at a number of mining sites monitored along the Nova Scotian coast (Bowen et al., 1975; Taylor, 1982).

A local natural analogy is currently occurring at Poverty Beach. We observed subtle changes in the physical character of the spit between the 1930s and 1950s as sediment supply gradually decreased. The opening of the first inlet resulted in losses of sediment into Murray Harbour estuary (Fig. 43). Larger physical changes were observed along the adjacent spit and shoreface. Additional breaches in the spit were triggered by storms in the early 1980s because of the weakened condition of the spit. After the formation of the larger inlets, increased volumes of sediment were sucked into the estuary resulting in dramatic changes to Poverty Beach. Sequential beach surveys at F. Clows show how beach retreat switched from mostly across the lower beach in the mid-1980s to the whole profile by 1996 (Fig. 22). Retreat continued after 1996 despite a reduction in mining. There is not enough sediment supplied each year to offset the physical changes observed alongshore and offshore which are attributed to the mining.

Shoreline Stability

A) Can these shores sustain commercial sediment extraction and maintain their present position?

No. Except where the solid portion of the Irvings Cape jetty artificially anchors the shoreline, the remainder of the shores will erode or retreat. Different shores have a better ability to sustain beach development. For example, assuming a maximum sediment supply each year and the rates of commercial sediment extraction from the early 1990s, the sediment budget computed for compartments 1 and 2 of the Gaspereaux Shore suggests a positive balance of nearly 1400 m^3/a (Table 8); therefore, theses shores should be able to sustain themselves. For example given an average sand supply of 8700 m^3/a from shore erosion over 23 years an estimated 200,400 m^3 of sediment could be supplied and 178,700 m^3 was extracted from the two compartments over the same period. However when one restricts the sediment budget analysis to the shores south of

Cody Point, the sediment supply to the mining areas is less than the volumes extracted in the early 1990s but higher than the decreased volumes extracted in the late 1990s. When mining was at its maximum production, the increased demand for sediment was supplied by increased shore erosion and a depletion of sediment reserves offshore.

In reality the quantity of sediment that moves alongshore is less than the volume calculated because not all of the sediment leaves the source, e.g. cliff, or is moved alongshore in one year: some of it moves back and forth alongshore, some is trapped in the backshore, or offshore. A portion of the sediment is used to infill the voids between larger clasts covering the intertidal and subtidal zones or against bedrock ridges, as it moves away from the source areas. Although there have been a few years when a net sediment surplus was registered at all sites, only Irvings Cape because of the jetty structure, prograded and was capable of trapping sediment. Even there, sediment accumulation was limited to the south end of the site and the reserve of sediment accumulating decreased between 1968 and 1990 (Fig. 44). More importantly, sediment trapped at Irvings Cape or extracted by mining depletes the supply of sediment to the downdrift shores which find it more difficult to maintain their position. Consequently beach erosion or retreat has resulted. The problem of maintaining their position is compounded by the natural loss of sediment through the tidal inlets at Poverty Beach. Irvings Cape site has a better potential for shoreline recovery in the vicinity of the jetty. However, if mining were continued the loss of sediment would have significant impacts on Poverty Beach, a provincial natural area.

B) How much sediment would be required to maintain these shores in their present position given an accelerated sea level rise of 50 cm in the next century?

Projected eustatic sea-level rise by the year 2100 resulting from climate change, varies from a minimum of 15 cm to a maximum of 95 cm depending on the emission and climate scenerio applied. The best estimate is a rise of 49 cm by end of next century (Houghton et al., 1996; Shaw et al. 1998). Researchers in the United States, using a model known as the Bruun Rule, have estimated the volume of sediment that would be required to maintain a sandy shore if sea level rose (NRC, 1987). The Bruun Rule assumes an equilibrium profile where the nearshore depths are maintained during a rising sea level by deriving equal amounts of sediment from the adjacent beaches. Using an annual average shoreline retreat rate (R1) due to natural causes of 0.5m/a. With a present sea level rise (S_1= 30cm/century) and a projected rate of sea level change (S_2) the projected shoreline retreat rate (R_2) is

$$R_2 = R_1 (S_2 / S_1),$$

and the annual volume of sediment required to maintain and stabilize a shoreline (V) is

$$V = R_2 h,$$

where h is the limiting depth of changes observed on the shoreface. Adopting average retreat rates of 0.5m/a, present sea level rise of 30 cm/century and h= 9 m, these researchers predicted that low sandy shores in Florida could retreat 117 m in the next century given a sea level rise of 0.7 m/century and as much as 200 m if sea level rise reaches 1.2 m/century (NRC, 1987).

The Bruun Rule may not apply as well to the mixed sediment beaches of eastern PEI. However for this exercise if we assume it did apply, how much sediment would be required to maintain the shores in their present position given a sea level rise of 0.5 cm/century?

If we assume an average shoreline retreat of 0.5 m/a, a present sea level rise of 35 cm/century in east PEI (Shaw et al. 1998), the projected shoreline retreat rate would be 0.71 m/a.

Using a smaller value for h = 3 or 5 m for the Gaspereaux Shore, the estimated average annual volume of sediment required to maintain the shores at a projected sea level rise of 0.5 m/a, would be 2.1 to 3.6 m^3/m of beach. The length of shoreline between the cliffs at Cody Point and Irvings Cape is 2.5 km, therefore an estimated 5350 m^3/a to nearly 9000 m^3/a of sediment would be required to maintain that shoreline. The mining sites are roughly 150 m long consequently they would require 150 x 2.14 = 321 m^3/a just to maintain themselves. If we assume only the shore cliffs and backshore scarps erode and the beaches are stable, the net input of sand for the area between Cody Point and Irvings Cape, using the same projected rate of shore erosion of 0.71 m/a, would be just over 5000 m^3/a. If all of this sediment was transported southward, it would approximate the volume of sediment required to maintain these shores against the projected rise in sea level, but it would be insufficient to replenish the losses caused by continued commercial sediment excavation.

Commercial Sediment Extraction

A) What are the implications of continuing or stopping mining on the Gaspereaux Shore?

If mining is continued at rates of 1500 to 2300 m^3/a at the F. Clows and W. Johnston sites, the following changes are predicted based on the information gathered in this study:

- Backshore retreat at the mining sites will continue at higher than average rates, especially at the northern end of the sites.
- The barrier beach may become overwashed by waves.
- Erosion of the adjacent shores will continue to be higher than the long term average and the rate may increase farther alongshore.
- The abundance of sand will continue to decrease across the shoreface and area of broken bottom will increase but the changes will not be as large as the changes observed since the 1950s because there is less sediment stored across the shoreface than in the 1950s.

Changes at the Irvings Cape site are dependent on the presence of the jetty. However, if sediment extraction is continued at the two mining sites farther updrift, the availability of sediment for Irvings Cape will gradually decrease. A net reduction in sediment supply will result in renewed retreat at the northern end of the site. The duneline may continue to stabilize but as the lower beach retreats because of less sediment supply, the upper beach and backshore will begin to retreat again.

Longshore sediment supply will continue to be minimal at Poverty Beach resulting in major adjustments in the beach plan form as a consequence of sediment transfer into the tidal inlets. Erosion will continue at higher than average amounts just north of the spit but increased amounts of sediment bypassing Irvings Cape will gradually build up the shoreface sand just south of the cape.

If mining is continued at present extraction rates but only at the Irvings Cape site, the following changes might be expected:

- The backshore and beach would continue to retreat at above average values at the F. Clows and W. Johnston sites for a few years, but as sediment accumulates across the upper beach, the rate of shoreline retreat will decrease to longer term values.
- The lower backshore areas will be gradually raised by sediment deposited during wave overwashing and wave overtopping.
- Retreat and destruction of the upper beach and backshore dune will increase at Irvings Cape mining site and the northern end of the site will experience increased retreat to offset changes along the rest of the site.
- As the jetty structure becomes more exposed to wave and sea ice attack because of the loss of beach sediment, it will corrode faster, decreasing its ability to anchor the cape and trap sediment moving alongshore.
- Continued mining will reduce the availability of sediment to Poverty Beach which will cause continued retreat at the northern end of the beach.

If mining is stopped at all mining sites, i.e. F. Clows, W. Johnston and Irvings Cape, the following changes might be expected:

- Little change from what is happening at present at the F. Clows and W. Johnston sites is anticipated for the first few years but given increased sediment availability and less change on the lower beach, the backshore and upper beach may begin to recover and dune vegetation would begin to spread because of increased sediment supply.
- Over the long term these beaches will continue to retreat but at slower rates, similar to the longer term rate.
- The shoreface bar features will begin to replenish their supply of sediment, rebuild and resume their role of transferring sediment onshore.
- Annual berm development would improve which would have positive implications for the upper beach and dunes.

Little change would be expected at the south end of Irvings Cape beach because its stability is more controlled by the jetty but it is anticipated that the upper beach and dune would continue to restabilise unless impacted by a major storm. As the beach builds against the jetty, increased sediment would bypass it and contribute to the shores and shoreface farther south. Not much change other than a new recurved spit south of the jetty is anticipated in the first few years but with time sediment accumulation across the shoreface would increase. This sediment would then be available for moving on and offshore which would enhance beach recovery and resume the natural cut and fill sequence. The stoppage of mining may not have much impact on the closing of the inlet at Poverty Beach but it might enhance beach ridge building at the distal end of the present spit. It would take a large pulse of sediment to close off the inlet and resume building the Poverty Beach spit as it did prior to 1936. The only source of a large influx of sediment would be from Irvings Cape. If the solid portion of the jetty were completely removed, the shoreline would be quickly eroded and return to its 1955 position.

Lastly, there would be no more income from the sale of sediment and the issuing of extraction permits and material for the concrete industry would have to be derived from elsewhere. However, beach recovery could result in increased income for the region from eco-tourism and recreational activities.

Recommendations

A) Should intertidal beach mining be continued?

It is strongly recommended that all intertidal sediment mining between Cody Point and Poverty Beach be stopped because of the low natural sediment supply and the accelerated negative impacts of mining on shoreline stability. Continued intertidal beach mining at the W. Johnston and F. Clows sites will result in accelerated erosion and retreat at the two sites, the adjacent shores and the shoreface. Furthermore, Poverty Beach will be adversely impacted because of the reduction in sediment supply. The dunes, a significant environmental feature of Poverty Beach, will continue to erode and Poverty Beach will have less chance to re-establish as a continuous spit.

B) Is there effective monitoring and accounting of sediment extracted from the intertidal mining sites and continual assessments of the impacts of mining on shoreline stability.

To maintain an ongoing assessment of sediment removal and the impacts of commercial sediment extraction on the stability of a particular shoreline it is strongly recommended that all sites be surveyed before and after each extraction permit is issued. Furthermore, it is recommended that monitoring be expanded to include sites farther alongshore, up -and down- drift, of all active beach mining sites in PEI. The monitoring activities should be designed to document natural fluctuations in sediment abundance and any abnormal changes caused by commercial sediment extraction or other human activities along the coast. To improve the documentation of natural sediment replenishment at specific sites, it is recommended that the total volume of sediment extracted from the intertidal zone be reported to the regulatory agency including the volume of sediment stockpiled in the backshore. At present, only the sediment hauled away from the site is reported for each extraction permit. When subsequent permits are issued for the same site, the source of the sediment taken from a site should be reported, i.e. from backshore stockpile or intertidal zone.

Sediment extraction information is now archived on computer and easily accessed but much of the earlier data was poorly documented and not all sites were routinely surveyed and assessed. More effort will be required if all sites and adjacent shores are monitored, for the analysis of field data, and maintenance of records. It is recommended that if intertidal mining activities continue in PEI that more financial and human resources be allocated to or within the Department of Technology and Environment to effectively document the impacts of this commercial activity on the physical environment.

In the preparation of this report, one of the largest knowledge gaps was information about the nearshore environment and the distribution and thickness of mobile sediment. Before any new intertidal mining sites are approved, it would be extremely useful to have a detailed map of the distribution and thickness of surficial deposits in the marine areas adjacent to the mining site. The information would provide a baseline for future assessments of changes in sediment availability offshore during the life of a mining site.

C) Is there a better way of monitoring coastal changes at and adjacent to other beach mining sites of PEI?

Conventional cross-shore surveys take an enormous amount of time and effort and the information is site specific providing very little information about broader coastal changes away from the excavation sites.

A technology that would be extremely useful for monitoring the impacts of sediment extraction would be scanning airborne laser altimetry, particularly the systems that have the capability of measuring shallow bathymetry. The airborne scanning lasers provide digital elevations. A comparison of repetitive airborne laser surveys would provide net changes in surface elevations on and offshore which could be used to prepare accurate assessments of excavated material as well as to document the impacts of mining over a larger coastal area. It is recommended that testing of this new technology at active mining sites in the province be undertaken to see whether it is a more cost effective way of monitoring physical shoreline changes than conventional ground surveys which are very time consuming.

SUMMARY

1) There is not an unlimited sediment supply, the most important sources of sediment are from onshore and across the shoreface. Sediment is supplied to shores and the beach mining areas in the study area but it is at the expense of sediment losses from the adjacent beaches, cliffs and shoreface. The only evidence of significant shoreline progradation was at Poverty Beach before1955, Irvings Cape after 1955 and along a few short sections of beach before the 1970s. There has never been an abundance of sediment along this shore to support large scale commercial beach mining. Even the earlier report by Woodward-Clyde Consultants (1980) suggested that removal rates were close to their maximum. The scarcity of sediment is illustrated by the breakup of Poverty Beach before the mining began. The only site where an excessive accumulation of sediment occurred was at Irvings Cape, where sediment accumulation was artificially induced because of the construction of the jetty and breakwater. The shoreline adjacent to the jetty is still 10 to 20 m seaward of its 1955 position.

2) The rapid shoreline response to the construction of the Irving Cape jetty and the infilling of the channel dredged across Poverty Beach confirms the dominance of longshore transport. Sediment transport is mainly within the beach zone except off Poverty Beach where sediment is transported to the distal end of the spit along the shoreface bars.

3) Natural replenishment of sediment to beach mining sites was much higher during years of active extraction than non-mining years. The difference is attributed to a reduction in the abundance of sediment stored in the shores and shoreface after many years of continual mining. Initially shores with sediment stored in backshore dunes and shoreface bars can compensate for losses caused by commercial extraction or depletion by storms. Continuous mining or frequently occurring storms place added stress on the shores to recover and backshore erosion increases in response to the demand for more sediment. Even before mining began there were temporal variations in erosion and accretion of sediment along these shores but the loss in one area was gained by another. With beach mining the losses can only be replenished by increased erosion of or depletion of sediment from adjacent shores and shoreface. It takes a supply of new sediment to offset the losses by commercial sediment extraction because the sediment is removed from the coastal system. Sediment removed during storms is redistributed within the coastal system and potentially can be returned to the eroded shores.

4) Shoreline changes in response to beach mining are subtle at first, then increase and become more dramatic over time, as observed at the F. Clows mining site. Dune retreat occurs whether you mine the upper or lower beach if there is a scarcity of sediment. The advantage of only mining the intertidal zone instead of the upper beach and dune is that this delays the loss of sediment from the upper beach and the occurrence of wave overwash and flooding. Waves will naturally infill or smooth out any depressions across the intertidal zone where sediment is extracted but waves can only replenish sediment if it is available. Along shores where sediment only accumulates close to shore, the availability of sediment for repairing the mined areas is more restricted and the effects become more exaggerated alongshore.

5) Rates of backshore retreat at the beach mining sites were greater than the published longer term retreat rates for this shoreline. Shoreline instability has been accelerated within and adjacent to some beach mining sites. Many of the most significant morphological changes observed along the Gaspereaux Shore were caused by storms but the impacts would not have been as great if the shores had not been in a weakened state caused by the reduction in sediment. The

reduction in sediment supplied to Poverty Beach had begun before the jetty was built. Construction of the jetty further depleted the sediment supply and the mining aggravated the situation by removing sediment and decreasing the transfer of sediment past the jetty.

6) The tidal inlets cut through Poverty Beach accelerated changes in the spit and barrier beaches and accelerated the transfer of sediment into Murray Harbour. These were natural changes.

7) Sediment derived from shore erosion is insufficient to account for all sediment supplied to the mining sites, the evidence suggests that sediment is supplied from a broader area including the nearshore.

8) Rates of beach change during natural storms are comparable to changes caused by commercial extraction but sediment eroded during storms can return to the beach, mined sediment can not. Beach changes are more exaggerated during mining than non-mining periods, especially across the upper beach where cut and fill by waves is more irregular because of mining practices.

9) Summary statistics:
a) Loss of beach along Poverty spit 1955 to 1990 was 132790 m^2. Assuming a 2 m thickness, the loss was 265600m^3.

b) Areal increase of flood tidal deltas at Poverty Beach 1969 to 1987 was 720500 m^2. Accumulation of sediment within the flood tidal deltas by 1987 was 274700 m^3 (Table 9).

c) Sediment accumulated at Irvings Cape as a result of jetty construction between 1955 and 1968 was estimated to be 30,500 m^3. The volume of sediment extracted between 1975 and 1992 was 72226 m^3.

d) Total volume of sediment extracted between 1975 and 1998 between Irvings Cape and Cody Point was 131600 m^3. For shores between Irvings Cape and Cape Sharp, the total sediment extracted by commercial operations was 168700 m3 (+10,000 from offshore).

10) Sea- level rise is predicted to continue for at least the next century. These shores will require additional sediment to maintain their position against these rising sea levels. If we assume an increase in shore cliff erosion, there may be sufficient sediment naturally supplied to maintain these shores, but any sediment extraction would aggravate the situation and negatively impact shoreline stability.

11) It is recommended that:
- All commercial beach mining be stopped along the Gaspereaux Shore between Cody Point and Poverty Beach.

Further if sediment extraction continues at other intertidal sites on PEI:
- Annual reporting of volumes of sediment extracted at beach sites to the Department of Technology and Environment needs to be better defined. It would be very useful, when the total volume of sediment extracted from the intertidal zone is reported for a given permit, if it was broken down into the volume of sediment stockpiled on the backshore and the volume hauled away from a site. When subsequent permits are issued for the same site, the source of the sediment extracted, ie. whether from a previous stockpile or the intertidal zone, should be reported. This information would assist in documenting the natural replenishment of sediment at a site.

- To maintain an ongoing assessment of the impacts of commercial sediment extraction on the stability of a particular shoreline it is strongly recommended that all sites be surveyed before and after each extraction permit is issued. Furthermore, it is recommended that monitoring be expanded to include sites farther alongshore, up -and down-drift of all active beach mining sites in PEI.

The monitoring activities should be designed to document natural fluctuations in sediment abundance and any abnormal changes caused by commercial sediment extraction or other human activities along the coast. Consequently, more effort will be required in monitoring, analyzing field data, and maintaining accurate records of the volumes of sediment extracted than in the past. If beach mining is to continue in PEI, increased financial and human resources should be allocated within or to the Department of Technology and Environment to effectively monitor the impacts of mining on shoreline stability at all sites.

- Before any new intertidal mining sites are approved, it would be extremely useful to have a detailed map of the distribution and thickness of surficial deposits in the marine areas adjacent to the mining site. The information would provide a baseline for future assessments of changes in sediment availability offshore during the life of a mining operation. It would alleviate some of the problems encountered in the sediment budget calculations for the Gaspereaux Shore, where there was very little field information about the nearshore environment.

- New remote sensing technology, such as scanning airborne laser altimetry, should be tested in active beach mining areas to assess whether it is a more cost effective way of monitoring physical shoreline changes and impacts of mining than conventional ground surveys which are very time consuming.

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Appendix 1

Environmental Protection Act (1990) of PEI
and
Application Form for Sediment Extraction
in the Intertidal Zone.

LAWS OF PRINCE EDWARD ISLAND

No. EC323/90

ENVIRONMENTAL PROTECTION ACT

SAND REMOVAL FROM BEACHES REGULATIONS

(Approved by His Honour the Lieutenant Governor in Council dated 24 May 1990).

Pursuant to section 25 of the *Environmental Protection Act* R.S.P.E.I. 1988, Cap. E-9, Council made the following regulations:

Definitions

1. In these regulations

beach

(a) "beach" means that portion of land between the ordinary or mean high water mark and the water's edge and includes a distance of three miles seaward of the mean high water mark and may contain sand, gravel, rock, clay or other earthen material;

concrete manufacturer

(b) "concrete manufacturer" means a person who receives a permit pursuant to subsection 2(4);

designated hauler

(c) "designated hauler" means the person designated on an application as the person who is to remove and transfer sand from a beach;

domestic use

(d) "domestic use" means the use of sand for the purpose of making improvements to one's residential, farm or business property;

permit

(e) "permit" means a regular or special sand removal permit;

regular sand removal permit

(f) "regular sand removal permit" means a permit issued by the Minister for the purpose of removal of sand from a beach to be used for the sole purpose of manufacturing concrete or concrete products;

special sand removal permit

(g) "special sand removal permit" means a permit issued by the Minister for the purpose of removal of sand from a beach for any purpose other than for the manufacturing of concrete and concrete products;

sand

(h) "sand" means sand, rock, gravel, shale, clay or other types of earthen material;

sand dune

(i) "sand dune" means a wind or wave deposited formation of vegetated or drifting wind-blown sand that lies generally parallel to and landward of the beach and between the upland limit of the beach and the foot of the most inland dune slope; and

Minister

(j) "Minister" means the Minister of the Environment.

Permit required

2. (1) No person shall remove or cause to be removed sand from a beach or sand dune for any purpose unless he has first obtained a permit from the Minister authorizing the removal.

Conditions

(2) No person shall remove or cause to be removed sand from a beach except in accordance with the conditions of a permit.

Charlottetown
Gordon Babineau, Queen's Printer

Removal without permit, conditions for

(3) Notwithstanding subsection (1), a person may, without a permit, remove sand from a beach if

(a) (i) the vehicle used to transport the sand from the beach to the point of use has a payload capacity of less than four cubic metres, and

(ii) the sand is transported directly from the beach to the point of use and is used for domestic purposes; or

(b) the person is the designated hauler on a permit obtained pursuant to subsections (4) or (6).

Application, concrete manufacture

(4) A person who seeks to remove or cause to be removed sand from a beach for the purpose of manufacturing concrete shall, on a form approved by the Minister, make application to the Minister for a regular sand removal permit.

Permit

(5) A permit issued pursuant to subsection (4) shall be issued to the person who is to manufacture concrete.

Application

(6) A person who seeks to remove or cause to be removed sand from a beach for purposes other than

(a) the manufacture of concrete;

(b) domestic purposes in accordance with clause (3)(a); or

(c) the transfer of sand as designated hauler

shall, on a form approved by the Minister, make application to the Minister for a special sand removal permit.

Sand from other locations

3. No concrete manufacturer shall cause or permit to be deposited upon his property sand that has been removed from a beach other than the one specified on his permit.

Location

4. (1) Where an application for a permit is made under these regulations, if in the opinion of the Minister the beach from which it is proposed to remove sand is unsuitable for that purpose, he may refuse to issue a permit or may issue a permit to remove sand from a beach that he considers to be more suitable.

Terms

(2) A permit issued under these regulations shall

(a) be valid only for the use, location, quantity and time period specified in the permit;

(b) be subject to any conditions indicated on the permit.

Obligations of permit holder

5. A person to whom a permit is issued under these regulations

(a) shall maintain inventory records regarding all sand removed from a beach or received by him and shall make such records available for inspection upon request by any person authorized by the Minister to make an inspection; and

(b) shall within two weeks following the expiration date of the permit forward to the Minister a cheque, money order or other bill of exchange, payable to the Minister of Finance in an amount equal to fifty cents for each cubic metre of sand removed under the permit.

6. The Minister may at any time revoke a permit where, in his opinion — Revocation of permit

(a) any of these regulations or conditions of the permit have been violated by the person to whom the permit was issued, his servant or agent, or the designated hauler named in the permit; or

(b) the continued removal of sand from the location specified in the permit will or may result in permanent or irreparable damage to the beach.

7. The Sand Removal in a Protected Area Regulations (EC341/76) made under the *Recreation Development Act* are revoked. — Revocation

8. These regulations come into force on June 2, 1990. — Commencement

Certified a true copy,

DIANE I. BLANCHARD
Clerk of the Executive Council

APPLICATION NO:______________

DATE APPLICATION RECEIVED:______________

PROVINCE OF PRINCE EDWARD ISLAND
ENVIRONMENTAL PROTECTION ACT
APPLICATION FOR SAND REMOVAL PERMIT

1.Send application to: Water Resources Division
Department of the Environment
P.O.Box 2000
Charlottetown, P.E.I. C1A 7N8

2. Application submitted by: ______________

Name of Dept./Company/Other: ______________

Applicants Address: ______________

______________ Postal Code

Applicants Phone #: Home   Work

3. Type of business for which sand or other material to be removed will be used:

4. Type of material to be removed:
__ Sand __Stone or Rock __Gravel __Earth

5. Numbers of Cubic Meters of Material To be Removed:

6. Site from which it is desired to remove material:

7. Owner of adjacent property(s):

8. Desired removal period:
______________ to ______________
Day/Month/Year   Day/Month/Year

9. Method of Transportation:
___Truck ___Other(specify)

10. Name of Person or Firm to transport material:

Address:

11. Make of Truck	Size	License Number(s)

12. Declaration of applicant:

As applicant, I hereby request a permit to commence, make or carry out removal of sand or other material from a beach as described on this application form. It is understood that by submitting this application it does not allow the applicant to commence the removal described herein.

It is understood that the issuance of a permit does not exempt the applicant from the provisions of any Act of the Legislature of P.E.I. or the Parliament of Canada or any due process of law. It is acknowledged that the issuance of the permit does not serve to deprive any person of his or her rights either under statute or common law to claim damages for loss or injury caused to his or her property by reason of the removal of beach material. It is understood that the issuance of a permit places no liability upon the Minister or the Department of the Environment and its employees.

If issued a permit, it is agreed that only such removal of beach material as approved by the permit shall be carried out and all such work shall be done according to the permit and within the designated time allotted so as to cause a minimum of disturbance to the beach and surrounding area.

It is further understood that within two weeks following the expiration date of the permit, payment will be made to the Minister of Finance in an amount equal to fifty cents for each cubic meter of sand removed under permit if no such payment has already been made.

I, the applicant have read and agree to abide by the above declaration.

DATE______________

SIGNATURE OF APPLICANT______________

F93

Appendix 2

Annual Volumes of Sediment
Extracted from Intertidal Mining Sites
Along the Gaspereaux Shore and the Province of PEI
1974 to 1998.

APPENDIX 2. ANNUAL VOLUMES OF SEDIMENT EXTRACTED FROM THE INTERIDAL ZONE OF SPECIFIC SITES ALONG THE GASPEREAUX SHORE AND THE TOTAL VOLUMES FROM ALL SITES ON PRINCE EDWARD ISLAND.

A) 1975 to 1979

			SEDIMENT EXTRACTION (m3) BY YEAR					
							RECOMMENDED	
MINING SITES	**1975#**	**1976#**	**1977#**	**1978#**	**1979#**	**1975-1979**	ANNUAL	TOTALS
COMPARTMENT 1						**AVG**	EXTRACTION#	
IRVINGS CAPE	2294	3937	4511	5772	6116	4526	5700	22630
CONDONS SHORE	688	191	612	765	4511	1353	1520	6767
F. CLOWS	841	0	1529	1682	2791	1368	1520	6843
SUBTOTAL	3823	4128	6652	8219	13418			**36240**
COMPARTMENT 2								
MACKENZIE	459	650	1223	765	917	803	760	4014
SUBTOTAL	459	650	1223	765	917			**4014**
COMPARTMENT 3								
DIXON	459	0	0	382	0		760	841
STEELE	1147	1147	1109	0	917		760	4320
SUBTOTAL	1606	1147	1109	382	917			**5161**
TOTAL GASPEREAU SHORE	**5888**	**5925**	**8984**	**9366**	**15252**	**9083**		**45415**
TOTAL P.E.I. ##, *	63229	56577	71104	55965	NO DATA			
GASPEREAU % OF TOTAL	**9.31**	**10.47**	**12.64**	**16.74**	**NO DATA**			

COMPARTMENT 1 is Murray Head to Cody Point, subcompartment 1a is small embayment just north of Cody Point.
COMPARTMENT 2 is Embayment south of Cape Sharp
COMPARTMENT 3 is Cape Sharp to Panmure island

APPENDIX 2.con't												
B) 1980 to 1990					SEDIMENT EXTRACTION (m3) BY YEAR							
				(AVG VOLUMES BASED ON YEARS OF USE ONLY)								
MINING SITES	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**TOTALS**
COMPARTMENT 1												
IRVINGS CAPE	4100	4100	4100	4100	4100	4100	4100	4100	4100	4100	4100	45100
W. JOHNSTON								1000	1000	1000	1000	4000
CONDONS SHORE	1750	1750										3500
F. CLOWS	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	22000
C. CURRY		500										500
SUBTOTAL	7850	8350	6100	6100	6100	6100	6100	7100	7100	7100	7100	**75100**
SUBCOMPARTMENT 1a												
D. REID	1500	1500				1500	1500	1500	1500	1500	1500	12000
SUBTOTAL	1500	1500				1500	1500	1500	1500	1500	1500	12000
COMPARTMENT 2												
MACKENZIE	1250				1250		1250	1250	1250	1250	1250	8750
SUBTOTAL	1250				1250		1250	1250	1250	1250	1250	8750
COMPARTMENT 3												
DIXON	160	160	160	160	160							800
PANMURE IS. (STEELES)	800	800	800	800		800	800	800	800	800		7200
SUBTOTAL	960	960	960	960	160	800	800	800	800	800		**8000**
TOTAL GASPEREAU SHORE	11560	10810	7060	7060	7510	8400	9650	10650	10650	10650	9850	**103850**
TOTAL P.E.I. ##, *	42000	42000	42000	42000	42000	42000	42000	42000	42000	42000	42000	**462000**
GASPEREAU	**27.52**	**25.74**	**16.81**	**16.81**	**17.88**	**20.00**	**22.98**	**25.36**	**25.36**	**25.36**	**23.45**	
% OF TOTAL												

APPENDIX 2.con't

C) 1991 to 1996 — SEDIMENT EXTRACTION (m3) BY YEAR

MINING SITES	1991*	1992*	1993*	1994*	1995*	1996*	1997*	1998*	TOTALS
COMPARTMENT 1									
IRVINGS CAPE	4100	396	0	0	0	0	0	0	4496
W. JOHNSTON	1500	1000	300	300	800	1500	1800	1800	9000
F. CLOWS	2000	1854	910	0	1549	0	500	0	6813
SUBTOTAL	7600	3250	1210	300	2349	1500	2300	1800	**20309**
SUB COMPARTMENT 1a									
D. REID	2000	2000	1975	1326	1529	1115	1749	1765	13459
SUBTOTAL	2000	2000	1975	1326	1529	1115	1749	1765	13459
COMPARTMENT 2									
MACKENZIE	1000	1499	909	936	960	763	818	2000	8885
SUBTOTAL	1000	1499	909	936	960	763	818	2000	8885
OFFSHORE	0	10000	0	0	0	0	0	0	
TOTAL GASPEREAU SHORE	10600	16749	4094	2562	4838	3378	4867	5565	42653
TOTAL P.E.I. ##, *	39000	35000	26409	25000	22646	21444	20082	24130	**213711**
GASPEREAU % OF TOTAL	**27.18**	**47.85**	**15.50**	**10.25**	**21.36**	**15.75**	**24.24**	**23.06**	

DATA SOURCES
WOODWARD -CLYDE (1980)
OWENS (1980)
* PEI DEPARTMENT OF TECHNOLOGY AND ENVIRONMENT

Appendix 3

History of Construction and Changes at
the Jetty And Wave Breakwater,
Irvings Cape, PEI.

APPENDIX 3.

IRVINGS CAPE LANDING WHARF AND BREAKWATER
A History of Construction and Dismantling

The following is a summary of activities associated with the construction and repairs of the wharf and wave breakwater structures at Irvings Cape between 1954 and 1990. The information is derived from the files at Public Works of Canada and from air photographs.

1952: marine soundings and first plans for the landing wharf and breakwater. The plans included access road of 80 feet (24.4m) wide from the main road at the Johnston Brothers Cannery to the new wharf. The wharf was to be "L" shaped, 14 ft wide (4.3 m) and it included an approach from just above HWST for 500 ft (152 m) to approx LWST, a 450 ft (137 m) section and then bend and extend an additional 350 ft (106 m). It would extend to water depths of 6.3 feet (1.9 m) below LWST.

1954: A series of 8 borings were drilled into the seabed along the projected length of the wharf stucture. Most commonly, there was 6 to 7 ft of packed sand, gravel and clay over friable sandstone. In places the friable sandstone extended to the seabed. Approval for construction of the wharf came in October 1954. The final plans show slightly different dimensions for the wharf sections than were on the 1952 plans. A wave breakwater structure was to be built along the seaward side of the wharf. The breakwater extended from LWST for 453 ft (138 m) offshore, then bend and extend an additional 351 ft (107 m). The landing wharf had piles at 12 ft (3.6 m) spacing and the breakwater at 6 ft (1.8 m) spacing. Only the approach to the landing wharf was completely infilled by gravel over sand for a distance of 500 ft to LWST.

1955: Air photographs show that the access road from the cannery is under construction and a coffer dam extends approx. 30 m from shore which is assumed to represent the initial part of the "approach" section.

1962: New plans show that the mid section of the landing wharf was to be extended by 12 ft and 3 new borings of the seabed where the extension was to be located showed 6 ft of packed sand, gravel and clay over a soft sandstone. Local residents and fishermen call this type of seabed "broken bottom".

1968: Air photos in 1964 and 1968 show that the wharf was in heavy use by fishermen. By 1968 there was roughly 130 m of beach progradation and only 18-20 m of the approach section of the wharf was exposed suggesting infill of sediment on both sides of the structure.

1971: Plans were drawn up for repairs to the landing wharf, but local residents report that moneys were never allocated for repairs and the structure was abandoned by the fishermen around 1970.

1974: Beach mining is now active north (updrift) of the landing wharf but there is no activity at

the wharf itself. Erosion on the updrift side of the wharf is observed since 1968. An estimated 15 m offset of the HTL beach line between the updrift and downdrift side of structure, suggests increased erosion due to mining on updrift side.

1980: Landing wharf and breakwater still intact but were abandoned; beach mining still occurring farther updrift. The seaward edge of the approach is still an estimated 15 m from HTL as was observed in 1974. Evidence of increased transport of sediment south alongshore past the structure.

1982: The beach has prograded by an estimated 15-20 m and the approach to the landing wharf incorporated by the beach. The mid section of the breakwater is now gone allowing waves to strike the outer part of the landing wharf.

1984: Only a few small sections of the inner wave breakwater remain, the outer section is gone. The landing wharf continues to deteriorate and the extension added in 1962 had been removed or broken away. An estimated 15 m of the approach was exposed seaward of LWST suggesting renewed erosion of the shoreline and its retreat to the same position as observed in 1980. Beach surveys also suggest low beach levels.

1985: Plans approved for the removal of all parts of breakwater structure to ground level amd its disposal; remaining 40 piles closest inshore were to be removed in 1987.

1987: plans approved to remove all but the approach section of the landing wharf and disposed of. Air photos suggest that the mid section of the wharf and a segment of the approach were broken down or removed and there had been an estimated 15 m of shoreline recession since 1982 on the updrift side of the wharf, slightly less on the downdrift side. Mining activities are active in 1987. There is no evidence of the outer breakwater structure.

1990: An estimated 35 m of the approach portion of the landing wharf is exposed seaward of HTL.which suggests erosion since 1987. Mining is active on the north side of the jetty and the beach has retreated an estimated 25 m in three years, lessalong the downdrift shores.

1993: The length of the structure measured by tape; it extended a total distance of 63 m from the landward edge of the pavement and 30 m seaward of HTL. On north side of structure the concrete was 0.8 m above sand level at HTL and 1.5 m above sand at seaward end of structure.

REFERENCES

Public Works of Canada 1948. Poverty Beach, Kings Co. P.E.I., General map and soundings of proximal end of Poverty Beach spit and cut made by fishermen in May 1948; (Scale 1"=200 ft) 1 sheet.
Public Works of Canada 1952. Poverty Beach, Kings Co., P.E.I.; General map, soundings and Sections (Scale 1"=200 ft) 1 sheet.
Public Works of Canada 1954. Poverty beach, Kings County, PEI, Borings of proposed breakwater, Plan 1852, Test Boring Division, (Scale 1"=200 ft) 1 sheet.

Public Works of Canada 1955. Poverty beach (Murray harbour North) Kings county, PEI; Breakwater and landing facilities, Plan A385, 3 sheets

Public Works of Canada 1962. Poverty Beach, Kings Co., P.E.I., Extension of Landing, 1 sheet.

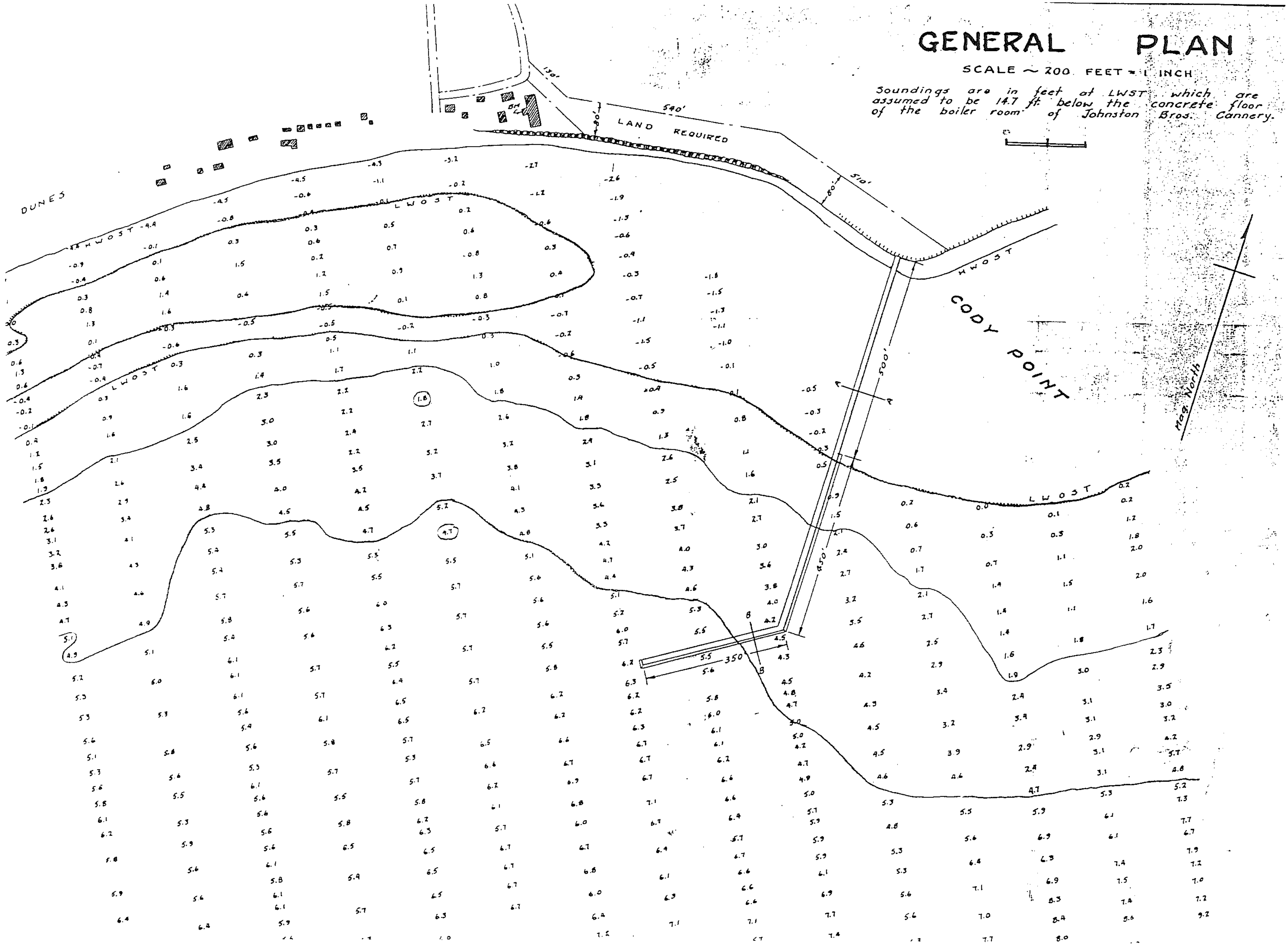
Public Works of Canada 1971. Repairs, Poverty Beach (Murray hrb North) Kings Co., P.E.I.; Project 14003-072, 1 sheet.

Public Works of Canada 1985.Breakwater removal, Poverty Beach, Kings Co., P.E.I. Location map and sections, Project 065858-062, 1 sheet.

Public Works of Canada 1987. Wharf removal, Poverty Beach, Kings Co. P.E.I.; Layout and Details, Project 770252, 1 sheet.

Figure 1. Map of nearshore soundings and general plan of the proposed jetty and access road to be constructed at Cody Point (Irvings Cape) (Public Works Canada, 1952).

Figure 2 Aerial photograph of Irvings Cape taken in April 1968 superimposed with the position of the high tide shoreline in 1936, 1955, 1987 and 1990 based on rectified aerial photographs using PCI WORKS computer software.


GENERAL PLAN
SCALE ~ 200 FEET = 1 INCH
Soundings are in feet at LWST which are assumed to be 14.7 ft. below the concrete floor of the boiler room of Johnston Bros. Cannery.
Mag. North
CODY POINT
LAND REQUIRED
540'
510'
130'
500'
450'
350'
HWOST
LWOST
DUNES

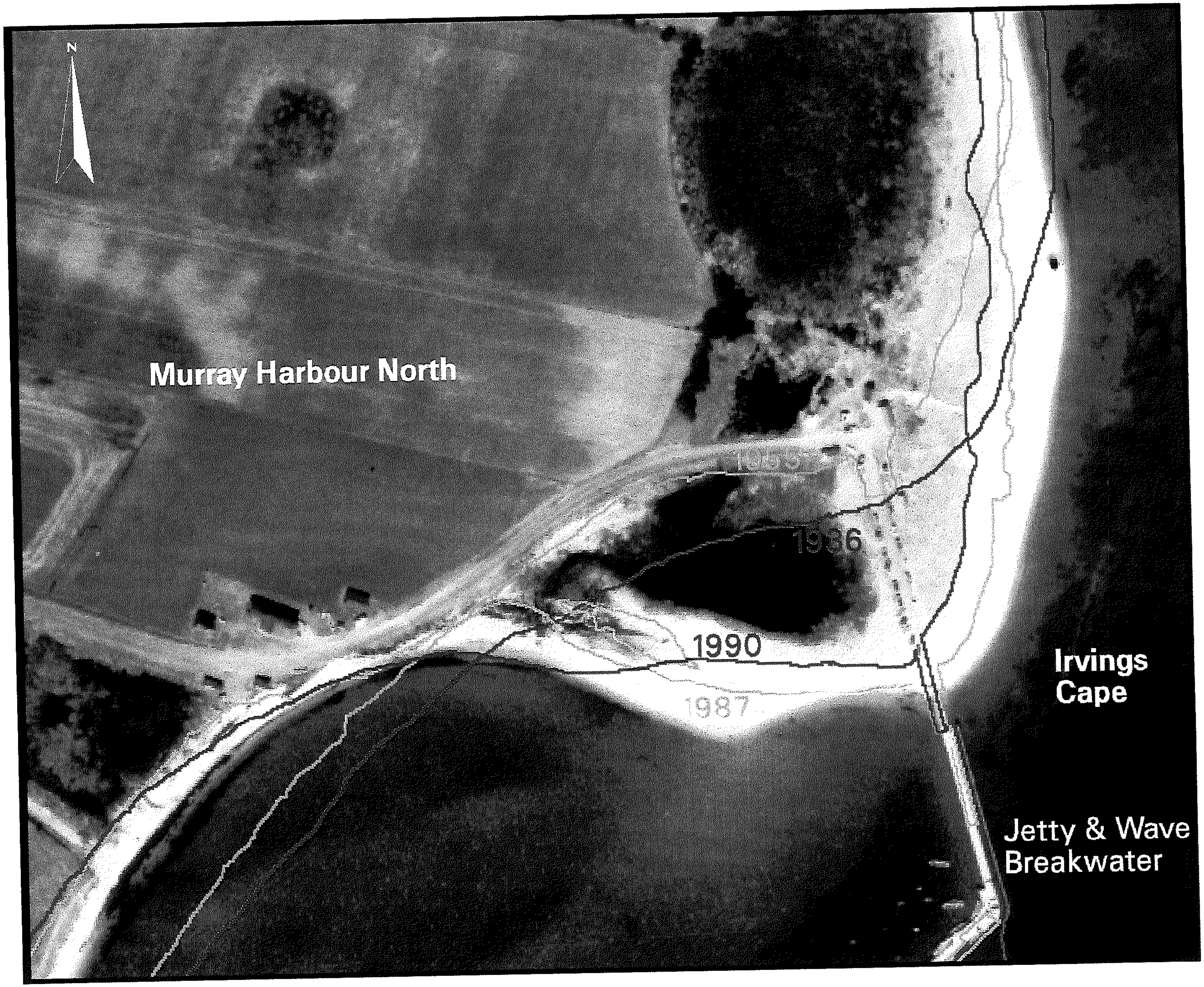

N
Murray Harbour North
1990
1987
Irvings
Cape
Jetty & Wave
Breakwater

Figure 2

Color
Fig 2

Appendix 4

Sediment Sources, Rates of Recession and Sediment Supply
From Specific Shoreline Segments
Of the Gaspereaux Shore

APPENDIX 4 Shoreline Description, potential sediment sources, rates of shoreline retreat and annual volumes of sediment supply from each shore segment.

See Figure 32 for location of segments.

PLACE NAMES	SHORE SEG.	SHORE DESCRIPTION	LENGTH (M)	HEIGHT (m ABOVE HTL)	COMPOSITION	THICKNESS (m)	PERCENT SAND	SHORELINE CHANGE (m/a)	SURVEY PERIOD (REFERENCE)	SAND INPUT FROM CLIFF AND SCARP (m3/a)	SEDIMENT INPUT FROM CLIFF AND SCARP (m3/a)	SAND INPUT FROM DUNELINE (m3/a)	SAND LOSS TO DUNELINE (m3/a)
	1	CLIFF	250	11.00	GLACIAL DEPOSITS	5.00	41.13	-0.21	1936-1987	-107.97	-262.50		
		WITH BEACH/ROCK			BEDROCK	6.00	70.00	-0.21	(LRIS,1988)	-220.50	-315.00		
					SAND(P,C)	<2.0							
MURRAY	2	CLIFF	200	11.00	GLACIAL DEPOSITS	5.00	41.13	-0.15	1936-1987	-61.70	-150.00		
HEAD		WITH ROCK PLATFORM			BEDROCK	6.00	70.00	-0.15	(LRIS,1988)	-126.00	-180.00		
					BOULDER/ROCK	2.00	70.00	-0.15					
	3	CLIFF	90	9 TO 10	GLACIAL DEPOSITS	6.00	41.13	-0.15	1936-1987	-33.32	-81.00		
		WITH BEACH/ROCK			BEDROCK	3.00	70.00	-0.15	(LRIS,1988)	-28.35	-40.50		
					SAND (P,C)	<2.0							
	4	CLIFF	700	12.00	GLACIAL DEPOSITS	6.00	41.13	-0.15	1936-1987	-259.12	-630.00		
		WITH BEACH (1-3M) /ROCK			BEDROCK	6.00	70.00	-0.15	(LRIS,1988)	-441.00	-630.00		
					SAND (P,C)	<1.0							
	5	SCARP	270	10.00	GLACIAL DEPOSITS	10.00	41.13	-0.24	1936-1987	-266.52	-648.00		
		WITH BEACH&FLATS	180	~5	GLACIAL DEPOSITS	5.00	41.13	-0.24	(LRIS,1988)	-88.84	-216.00		
			80	~2	GLACIAL DEPOSITS	2.00	41.13	-1.00	1936-1959	-65.81	-160.00		
		TOTAL LENGTH=530	530		SAND(P)	2.00			(Geog. Br. 1959)				
	6	BARRIER SPIT / DUNE	600	2.0 TO 2.5	SAND (P)	>4.0	99.40						
		&SUB TIDAL BARS			SAND	2.50	99.40	-0.20	1955-1974			-298.2	
BEACH	7	BREAKWALL	20		WOOD/CONCRETE								
POINT		WITH BEACH											
	8	BARRIER SPIT	390		SAND (P)	>2.0							
		WITH DUNES & FLATS		0.50	SAND	3.00	99.40	8.15	1936-1959				97.21
		SUBTIDAL BARS		(~4 m wide)	SAND (P)				(Geog Br. 1959)				
								2.44	1955-1987				
	9	TIDAL CHANNEL	260										
									SUBTOTAL	**-1699.12**	**-3313.00**	**-298.20**	**97.21**
POVERTY	10	BARRIER ISLAND	600		SAND	>4.0							
BEACH		WITH DUNES		2.0 TO 3.0	SAND		99.40						
		SUBTIDAL BARS			SAND	1.0TO 2.0							
	11	TIDAL CHANNEL	100	<2.0	SAND								
		WITH BEACH			SAND								
	12	BARRIER ISLAND	520	2.0TO3.0	SAND (P)	>4.0	99.40	(-199862/13)	1974-1987			-15282.00	
		WITH DUNES			SAND (P)								
		SUBTIDAL BARS/DELTA DEPOSITS											
	13	TIDAL CHANNEL (FLOOD DELTA)	640		SAND (P)		99.40	(242566/13)	1974-1987				18546.00
		BARS &EBB DELTA DEPOSITS											

PLACE NAMES	SHORE SEG.	SHORE DESCRIPTION	LENGTH (M)	HEIGHT (m ABOVE HTL)	COMPOSITION	THICKNESS (m)	PERCENT SAND	SHORELINE CHANGE (m/a)	SURVEY PERIOD (REFERENCE)	SAND INPUT FROM CLIFF AND SCARP (m3/a)	SEDIMENT INPUT FROM CLIFF AND SCARP (m3/a)	SAND INPUT FROM DUNELINE (m3/a)	SAND LOSS TO DUNELINE (m3/a)
	14	BARRIER SPIT	450		SAND	>4.0	99.40						
		WITH DUNES		0.5 TO 2.0	SAND (P)	1.00							
		SUBTIDAL BARS &DELTA DEPOSITS											
	15	BARRIER SPIT	880		SAND (P, O)	3.50	99.40	-1.27	1955-1987				
		WITH DUNES		1.0 TO 3.0									
		SUBTIDAL BARS				<2.0							
NOTE: SEDIMENT VOLUME CHANGES FOR ALL OF POVERTY BEACH HAVE BEEN SUMMARIZED IN SEGMENT 12 AND THE CHANGES IN SEDIMENT VOLUME FOR ALL TIDAL DEPOSITS HAVE BEEN SUMMARIZED IN SEGMENT 13													
	16	FRINGING BEACH	600		SAND, PEAT (P,O)	1.50	99.40	-1.82	1936-1959				
		WITH WETLAND/DUNE		1.5 TO 2.0	SAND,MUD, PEAT	1.50	99.40	-1.39	1955-1987			-1243.49	
		SUBTIDAL FLATS,											
	17	RETAINING WALL/RIPRAP	130	2.0 TO 3.0	WOOD,BOULDER	2.00							
		SUBTIDAL FLATS			SAND (P)								
	18	FRINGING BEACH / SPIT	200	0.5 TO1.0	SAND(P)	0.50	99.40	**2.87**	1955-1987				**285.28**
		SUBTIDAL FLATS											
									SUBTOTALS			**-1243.49**	**285.28**
IRVINGS CAPE	19	CONCRETE JETTY	30	0.80	CONCRETE, S,G								
	20	MINED BEACH (Cody Point)	300	1.0 TO 2.0	SAND(P)	1.50	99.40	0.90	1955-1987				402.57
		WITH DUNE/			S,P,C,R	<1.0							
		SUBTIDAL FLATS/ROCK											
	21	FRINGING BEACH	700	1.0 TO 2.5	SAND (P)	1.50	99.40	-1.16	1936-1959				
		WITH DUNE/WETLAND			SAND	1.50	99.40	-0.40	1955-1987			**104.37**	
		SUBTIDAL BARS											
	22	MINED BEACH (W. Johnstons)	20	<2.0	SAND(P)	1.50	99.40	-1.15	1955-1987			**-34.29**	
		WITH SUBTIDAL BARS											
	23	FRINGING BEACH	100	1.0-2.5	SAND (P)	1.50	99.40	-0.96	1955-1987			**-143.14**	
		WITH DUNE											
		SUBTIDAL BARS			SAND/PEBBLE								
	24	STREAM OUTLET	50										
	25	FRINGING BEACH	200	1.0-2.5	SAND (P)	1.50	99.40	-1.50	1955-1987			**-447.30**	
		WITH DUNE/WETLAND											
		SUBTIDAL BARS											
	26	MINED BEACH (Condons shore)	90	1.0-2.0	SAND	1.00	99.40	-1.28	1955-1987			**-114.51**	
		WITH SUBTIDAL BARS											
	27	SCARP WITH BEACH	90	1.0-2.0?	GLACIAL DEPOSITS	1.50	41.13	-0.90	1955-1987	**-49.97**	**-121.50**		
		WITH SUBTIDAL BARS											

PLACE NAMES	SHORE SEG.	SHORE DESCRIPTION	LENGTH (M)	HEIGHT (m ABOVE HTL)	COMPOSITION	THICKNESS (m)	PERCENT SAND	SHORELINE CHANGE (m/a)	SURVEY PERIOD (REFERENCE)	SAND INPUT FROM CLIFF AND SCARP (m3/a)	SEDIMENT INPUT FROM CLIFF AND SCARP (m3/a)	SAND INPUT FROM DUNELINE (m3/a)	SAND LOSS TO DUNELINE (m3/a)
	28	MINED BEACH (F. Clows)	20	0.5 TO 2.0	SAND (P)	1.50	99.40	-0.90	1955-1987			**-26.84**	
		WITH SUBTIDAL BARS											
	29	STREAM OUTLET	10										
	30	BARRIER BEACH	200	1.0-2.0	SAND (P)	1.00	99.40	-0.56	1955-1987			**-111.33**	
		WITH DUNES AND POND											
		SUBTIDAL BARS											
	31	SCARP WITH BEACH	520	1.4 TO 6.0	GLACIAL DEPOSITS	2.00	41.13	-0.72	1955-1987	-307.98	-748.80		
		SUBTIDAL BARS			SAND (P)	2.00							
	32	BARRIER BEACH	190	1.0-1.5	SAND (P)	1.00	99.40	-0.65	1955-1987			**-122.76**	
		WITH DUNE /POND-OUTLET											
CODY	33	CLIFF	1300	6.0-9.0	GLACIAL DEPOSITS	3.00	41.13	-0.27	1968-1987	-433.10	-1053.00		
POINT		WITH ROCK PLATFORM			ROCK	6.00	70.00	-0.27	1968-1987	-1474.20	-2106.00		
								-0.06 to -0.70	1955-1987				
									SUBTOTALS	**-2265.25**	**-4029.30**	**-895.79**	**402.57**
	34	MINED BEACH (D. REIDS)	210	1.0 TO 3.0	GLACIAL DEPOSITS	2.00	41.13	-0.10	1968-1987	-17.27	-42.00	-17.27	
		WITH LOW SCARP/DUNE											
		SUBTIDAL BARS											
	35	SCARP WITH BEACH	110	1 TO 3.0	GLACIAL DEPOSITS	2.00	41.13	-0.10	1968-1987	-9.05	-22.00		
					SAND (P)								
	36	CLIFF	180	6.00	GLACIAL DEPOSITS	2.00	41.13	-0.30	1968-1987	-44.42	-108.00		
		WITH ROCK PLATFORM	280	10.00	GLACIAL DEPOSITS	4.00	41.13	-0.30		-138.20	-336.00		
			40	6.00	GLACIAL DEPOSITS	2.00	41.13	-0.30		-9.87	-24.00		
		TOTAL LENGTH=500	500		ROCK (C,B)	6.00	70.00	-0.30		-630.00	-900.00		
									SUBTOTALS	**-848.81**	**-1432.00**	**-17.27**	
									total compartment 1	**-4813.18**	**-8774.30**	**-2454.76**	**785.06**

PLACE NAMES	SHORE SEG.	SHORE DESCRIPTION	LENGTH (M)	HEIGHT (m ABOVE HTL)	COMPOSITION	THICKNESS (m)	PERCENT SAND	SHORELINE CHANGE (m/a)	SURVEY PERIOD (REFERENCE)	SAND INPUT FROM CLIFF AND SCARP (m3/a)	SEDIMENT INPUT FROM CLIFF AND SCARP (m3/a)	SAND INPUT FROM DUNELINE (m3/a)	SAND LOSS TO DUNELINE (m3/a)
	37	SCARP WITH BEACH			SAND (P,C)			-0.36	1936-1959				
									(Geog Br. 1959)				
		TOTAL LENGTH=100	80	6.00	GLACIAL DEPOSITS	6.00	41.13	-0.10	1968-1987	-19.74	-48.00		
			20	3.00	GLACIAL DEPOSITS	3.00	41.13	-0.10		-2.47	-6.00		
	38	BARRIER BEACH	440		SAND (P)	<4.0							
		WITH DUNE/POND-OUTLET		0.5 TO 1.5		1.00	99.40	0.80	1968-1987				349.89
		SUBTIDAL BARS											
	39	ARTIFICIAL FILL, BREAKWALLS	220	3 to 4.0	METAL,BOULDERS,WOOD								
		HARBOUR ENTRANCE			CONCRETE SLABS								
	40	FRINGING BEACH	300		SAND (P)								
		WITH DUNE/WETLAND		1.0 TO 2.5	SAND	2.50	99.40	0.23	1968-1987				171.47
		SUBTIDAL BARS											
	41	MINED BEACH AND SCARP	70	2.5 TO 2.8	GLACIAL DEPOSITS	2.50	41.13	-1.26	1968-1987	-90.69	-220.50		
		(MACKENZIES)											
	42	SCARP WITH BEACH	200	3.8 TO 4.0	GLACIAL DEPOSITS	4.00	41.13	-1.00	1968-1987	-329.04	-800.00		
		SUBTIDAL BARS			SAND(P)								
	43	CLIFF	550	9.7 TO 11.7	GLACIAL DEPOSITS	8.00	41.13	-0.30	1968-1987	-542.92	-1320.00		
		ROCK (B)			ROCK	2.00	70.00	-0.30		-231.00	-330.00		
CAPE		WITH ROCK PLATFORM			ROCK	2.00	70.00	-0.30		-231.00	-330.00		
									SUBTOTALS	**-1446.86**	**-3054.50**	**0.00**	**521.35**
									Compartment 2				
TOTALS			**13680**						**TOTALS**	**-6260.04**	**-11828.80**	**-2454.76**	**1306.41**
									INPUTS			**LOSS**	
									SAND=	**-8714.80**		SAND=	**1306.41**
									SEDIMENT=	**-14283.56**			

Appendix 4a

Sediment Sources, Rates of Recession and Sediment Supply
1982 to 1990 from Shoreline Segments
Of the Gaspereaux Shore

APPENDIX 4a. Shoreline Description, potential sediment sources, rates of shoreline retreat and annual volumes of sediment supply from shore segment 16 to 33 for the years 1982 to 1990. See Figure 32 for location of segments.

PLACE NAMES	SHORE SEG.	SHORE DESCRIPTION	LENGTH (M)	HEIGHT (m ABOVE HTL)	COMPOSITION	THICKNESS (m)	PERCENT SAND	SHORELINE CHANGE (m/a)	SURVEY PERIOD (REFERENCE)	SAND INPUT FROM CLIFF AND SCARP	SEDIMENT INPUT FROM CLIFF AND SCARP	SAND INPUT FROM DUNELINE	SAND LOSS TO DUNELINE
	16	FRINGING BEACH	600		SAND, PEAT (P,O)	1.50	99.40	-1.82	1936-1959				
		WITH WETLAND/DUNE		1.5 TO 2.0	SAND,MUD, PEAT	1.50	99.40	-2.37	82-87			-2120.20	
		SUBTIDAL FLATS,											
	17	RETAINING WALL/RIPRAP	130	2.0 TO 3.0	WOOD,BOULDER	2.00							
		SUBTIDAL FLATS			SAND (P)								
	18	FRINGING BEACH / SPIT	200	0.5 TO1.0	SAND(P)	0.50	99.40	3.75	82-90				372.75
		SUBTIDAL FLATS											
									SUBTOTALS			-2120.20	372.75
IRVINGS CAPE	19	CONCRETE JETTY	30	0.80	CONCRETE, S,G								
	20	MINED BEACH (Cody Point)	300	1.0 TO 2.0	SAND(P)	1.50	99.40	-1.12	82-90			-500.98	
		WITH DUNE/			S,P,C,R	<1.0							
		SUBTIDAL FLATS/ROCK											
	21	FRINGING BEACH	700	1.0 TO 2.5	SAND (P)	1.50	99.40	-1.16	1936-1959				
		WITH DUNE/WETLAND			SAND	1.50	99.40	-1.37	82-90			-1429.87	
		SUBTIDAL BARS											
	22	MINED BEACH (W. Johnstons)	20	<2.0	SAND(P)	1.50	99.40	-1.62	82-90			-48.31	
		WITH SUBTIDAL BARS											
	23	FRINGING BEACH	100	1.0-2.5	SAND (P)	1.50	99.40	-2.00	82-90			-298.20	
		WITH DUNE											
		SUBTIDAL BARS			SAND/PEBBLE								
	24	STREAM OUTLET	50										
	25	FRINGING BEACH	200	1.0-2.5	SAND (P)	1.50	99.40	1.25	82-90				372.75
		WITH DUNE/WETLAND											
		SUBTIDAL BARS											
	26	MINED BEACH (Condons shore)	90	1.0-2.0	SAND	1.00	99.40	0.63	82-90				56.36
		WITH SUBTIDAL BARS											
	27	SCARP WITH BEACH	90	1.0-2.0?	GLACIAL DEPOSITS	1.50	41.13	-0.63	82-90	-34.98	-85.05		
		WITH SUBTIDAL BARS											
	28	MINED BEACH (F. Clows)	20	0.5 TO 2.0	SAND (P)	1.50	99.40	-0.38	82-90			-11.33	
		WITH SUBTIDAL BARS											
	29	STREAM OUTLET	10										
	30	BARRIER BEACH	200	1.0-2.0	SAND (P)	1.00	99.40	0.30	87-90				59.64
		WITH DUNES AND POND											
		SUBTIDAL BARS											

Appendix 4a

PLACE NAMES	SHORE SEG.	SHORE DESCRIPTION	LENGTH (M)	HEIGHT (m ABOVE HTL)	COMPOSITION	THICKNESS (m)	PERCENT SAND	SHORELINE CHANGE (m/a)	SURVEY PERIOD (REFERENCE)	SAND INPUT FROM CLIFF AND SCARP	SEDIMENT INPUT FROM CLIFF AND SCARP	SAND INPUT FROM DUNELINE	SAND LOSS TO DUNELINE
	31	SCARP WITH BEACH	520	1.4 TO 6.0	GLACIAL DEPOSITS	2.00	41.13	**-0.66**	87-90	**-282.32**	**-686.40**		
		SUBTIDAL BARS			SAND (P)	2.00							
	32	BARRIER BEACH	190	1.0-1.5	SAND (P)	1.00	99.40	**-0.30**	87-90			**-56.66**	
CODY	33	CLIFF	1300	6.0-9.0	GLACIAL DEPOSITS	3.00	41.13	-0.27	1968-1987	-433.10	-1053.00		
POINT		WITH ROCK PLATFORM			ROCK	6.00	70.00	-0.27	1968-1987	-1474.20	-2106.00		
								-0.06 to -0.70	1955-1987				
									SUBTOTALS	**-2224.60**	**-3930.45**	**-2345.34**	**488.75**
									INPUTS			**LOSS**	
									SAND=	**-4569.94**		SAND=	**488.75**
									SEDIMENT=	**-6275.79**			
									Total sand =	**-4081.19**			

Appendix 5

Textural Characteristics of a Glacial Deposit
Sampled from the Gaspereaux Shore.

APPENDIX 5.

TEXTURAL CHARACTERISTICS OF A SAMPLE OF THE GLACIAL DEPOSITS OVERLYING THE SHORE CLIFFS OF SOUTHEAST P.E.I.

A 1.47 kg bulk sample of material was collected from the upper 1.5 m of a shore cliff just south of Cape Sharp (Fig 3, 33c). The sediment was separated into gravel, sand and mud units using the 2.0 mm and 0.063 mm sieves. Dry sieving was prohibited because of the poorly indurated nature of the sandstone clasts which easily disintegrated. The largest clast sampled was 190 X 165 X 85 mm. All of the clasts sampled were sandstone in various stages of weathering. Although we believe that the sandstone clasts, derived from the bedrock cliffs, would be quickly reduced to sand particles once they are exposed to waves, the length of time required for this to happen is not known. Therefore, only the portion of the sample that fell between 2 mm and 0.063 mm is used in the estimate of sand input to the shore zone from the cliffs. The textural composition of the total sample was 36.5 % gravel, 41.1 % sand and 22.4 % mud. (46°06 05 N, 61°27 10W).

SEDIMENT TEXTURAL INFORMATION

Sieve Size (mm)	Texture	Weight (gm)	Total Sample Weight (%)
> 2.0	gravel	5377.5	36.50
>0.63	sand	6058.9	41.13
<0.63	mud	3294.5	22.36

Appendix 6

List of Vertical Air Photographs (1936 to 1990)
Used in this Study.

APPENDIX 6

Vertical air photos used in the study of shoreline changes from 1936 to 1990 along the Gaspereaux Shore, P.E.I.

Date	Time	Film Roll	Frames	Scale (Given)	Scale (Calculated)	Film
06 Oct. 1936	12:26-12:40	A5346	6 to 11	1:15,000	1:15,130	B&W
04 Sept. 1955	08:15-08:19 08:29-08:31 08:42-08:46 08:55-08:59 09:05-09:12 09:24-09:28	A14994	22 to 25 46 to 49 73 to 75 101 to 103 132 to 134 162, 163	1:7600	1: 7,600	B&W
28 July 1964	11:05-11:10	A18453	187 to 189	1:36,000	1:36,610	B&W
30 Apr. 1968	17:25-17:35 17:55 15:24 15:42	A20361 A20363	38 to 43 113, 114 94 to 97 156, 157	1:12,400	1:12,681	B&W
12 Aug. 1974	13:30 13:52 14:03 14:12	74105 74106	200, 201 48 to 50 78 to 80 117	1:10,000	1:10,106	Colour
01 Aug. 1980	11:52 12:03 12:36 12:44	80400 80404	194 to 196 245, 246 94, 95 104 to 106	1:10,000	1:10,625	B&W
26 May 1982	17:40 18:09 18:20	82019	74,75, 115-117 144,145	1:18,000	1:18,150	B&W
11 May 1984	17:44-17:47	84202	76a to 85	1:10,000	1:10,000	Colour
16 Sept. 1987	15:02-15:10	87228	23 to 39	1:10,000	1:10,017	Colour
04 Aug. 1990	17:41 17:58 18:14 18:45	90402	31, 32 59 to 61 81 to 84 133, 134	1:17,500	1:17,590	B&W

Appendix 7

Calculations of Temporal Changes in Area and Sediment Volume at the Tidal Inlets of Poverty Beach, PEI

APPENDIX 7
Volumes of Intertidal Deltaic Deposits of Poverty Beach

<u>Airphotos and Scales used</u>:

1974	**74106-79**	**1 cm = 101.06 m**
1980	**80400-195,245**	**1cm = 106.25 m**
1987	**87228-27,28**	**1 cm = 100.17 m**

<u>Areas:</u> Flood Deltas

1974 delta= 325,594 m^2
1980 old delta= 322,302 m^2 new delta = 46,060 m^2 Total = 368,362 m^2
1987 old delta= 292,692 m^2 new delta= 427,849 m^2 Total = 720,541 m^2

Ebb Deltas

1974 (A, B) delta=112,547 m^2
1980 (A, B) delta =35,109 m^2
1987 (A,B,C2) old delta = 67,730 m^2 new delta = 240,716 m^2 Total = 308,446 m^2

<u>Volumes:</u>

<u>1974</u>
The old seabed in the esturay lies at 4.4 feet below mean water level (MWL); by 1974 the surface of the flood delta lies at or just below lower low tide level (LLTL) therefore the water depth is 3.4 to 3.0 feet deep which means an increase in sediment of 1 to 1.4 feet (0.3 to 0.4 metres).
Volume
Flood delta = 0.3 m X 325,594 m^2 = 97,678 m^3

Ebb delta: (inlets A, B) = 0.3 m X 112,547 m^2 = 33,764 m^3

<u>1980</u>

Flood Delta: By 1980 more of the delta is exposed above LLTL therefore assume a further increase in sediment of less than 0.5 ft and more increase in area of delta surface. Therefore use 0.4 m thickness for the old delta and 0.3 m thickness for the new delta

old flood delta = 0.4 X 322,302 m^2 = 128,921 m^3
new flood delta = 0.3 X 46,060 m^2 = 13,818 m^3
Total flood delta= 142,739 m^3
Ebb delta: (inlets A and B) = 0.4 m X 35,109 m^2 = 14,044 m^3

Appendix 7 con't

Volumes:

1987

Flood Delta: The old delta is more or less shut off from inlet B but there is an increase so set sediment thickness to 0.5 m. The new delta formed and parts that infilled over the old delta are water depth of 3.4 ft (to water level) or an increase of 1.0 to 1.3 ft (0.3 to 0.5 m).
Volume
New flood delta = 0.3 X 427,849m^2 = 128,355 m^3
Old flood delta = 0.5 X 292,692 m^2 = 146,346 m^3
Total flood delta volume = 274,701 m^3

Ebb Delta: (inlets A, B, C_2) old ebb delta= 0.4 m X 67,730 m^2= 27,092 m^3
new ebb delta = 0.3 X 240,716 =72,215 m^3
Total volume ebb deltas = 99,307 m^3

Comparison of Changes on Poverty Beach versus the tidal inlet deposits

Between 1980 and 1987 if we assume a loss of 111,427 m^2 of the proximal end of the beach times a 2 m thickness=222,854 m^3 of sediment loss from the beach . If we add the volume of sediment added to the flood delta (131,962 m^3) and the ebb delta (85,263 m^3) the total is 222,225 m^3. Therefore the beach is feeding the inlet deposits.

Appendix 8

Changes in Shoreline Position (1936 to 1990)
At 10 Cross-shore Transects along the Gaspereaux Shore

Appendix 8 Changes in Shoreline Position Measured from Sequential Air Photographs 1936 to 1990. See Figure 40 for Location of shore transects.

PEI MINING	YEAR	CHANGES IN VEGETATION LINE EASTING	NORTHING	DIST BTWN	RATE OF CHANGE	CUM CHANGE	PROFILE DIST
TRANSECT1	1936	740397.94	266466.608			0.00	-15.00
	1955	740377.94	266466.358	-20.00	-1.05	-20.00	-35.00
	1968	740362.57	266466.358	-15.38	-1.18	-35.38	-50.38
	1974	740351.07	266466.983	-11.52	-1.92	-46.89	-61.90
	1982	740339.32	266466.983	-11.75	-1.47	-58.64	-73.65
	1987	740334.44	266466.858	-4.88	-0.98	-63.52	-78.52
	1990	NO DATA					
TRANSECT 2							
	1936	740561.69	266857.608			0.00	-33.79
	1955	740544.25	266871.92	-22.56	-1.19	-22.56	-56.35
	1968	740539.32	266881.983	-11.21	-0.86	-33.77	-67.56
	1974	740542.57	266882.733	3.34	0.56	-30.43	-64.22
	1982	740529.85	266893.733	-16.82	-2.10	-47.25	-81.04
	1987	740527.25	266897.17	-4.30	-0.86	-51.55	-85.34
	1990	740518.07	266899.483	-9.47	-3.16	-61.03	-94.82
TRANSECT 3	1936	740870.44	267074.358			0.00	-24.01
	1955	740870.44	267087.858	-13.50	-0.71	-13.50	-37.51
	1968	740870.44	267001.983	85.88	6.61	72.38	48.37
	1974	740870.94	266995.858	6.15	1.02	78.52	54.52
	1982	740870.94	267036.983	-41.13	-5.14	37.40	13.39
	1987	740870.94	266993.858	43.13	8.63	80.52	56.52
	1990	740870.94	266991.983	1.88	0.63	82.40	58.39
TRANSECT 4	1936	740963.44	267083.358			0.00	-8.56
	1955	740957.82	267113.233	-30.40	-1.60	-30.40	-38.96
	1968	740984.44	267019.858	97.10	7.47	66.70	58.14
	1974	740982.44	267020.358	-2.06	-0.34	64.64	56.08
	1982	740980.44	267019.358	-2.24	-0.28	62.40	53.84
	1987	740976.44	267014.858	-6.02	-1.20	56.38	47.82
	1990	740976.07	267040.985	-26.13	-8.71	30.25	21.69
TRANSECT 5	1936	741001.94	267140.608			0.00	-11.00
	1955	740969.57	267140.223	-32.38	-1.70	-32.38	-43.38
	1968	741004.94	267140.858	35.38	2.72	3.00	-8.00
	1974	741006.94	267140.858	2.00	0.33	5.00	-6.00
	1982	740994.32	267140.483	-12.63	-1.58	-7.63	-18.63
	1987	740988.94	267140.858	-5.39	-1.08	-13.02	-24.02
	1990	740982.44	267134.358	-9.19	-3.06	-22.21	-33.21

	YEAR	CHANGES IN HTL POSITION EASTING	NORTHING	DIST BTWN	RATE OF CHANGE	CUM CHANGE
TRANSECT 1	1936	740412.9	266466.36			0.00
	1955	740398.4	266466.36	-14.50	-0.76	-14.50
	1968	740379.9	266466.36	-18.50	-1.42	-33.00
	1974	740371.4	266466.36	-8.50	-1.42	-41.50
	1982	740349.1	266466.36	-22.38	-2.80	-63.88
	1987	740348.9	266466.36	-0.13	-0.03	-64.00
	1990	NO DATA	266466.36		0.00	
TRANSECT 2	1936	740590.4	266839.86			0.00
	1955	740580.4	266854.86	-18.03	-0.95	-18.03
	1968	740551.9	266882.36	-39.60	-3.05	-57.63
	1974	740556.9	266877.86	6.73	1.12	-50.91
	1982	740537.3	266891.05	-23.70	-2.96	-74.60
	1987	740534.4	266893.36	-3.64	-0.73	-78.24
	1990	740532.9	266894.36	-1.80	-0.60	-80.05
TRANSECT 3	1936	740870.9	267050.36			0.00
	1955	740870.9	267082.86	-32.50	-1.71	-32.50
	1968	740870.9	266952.86	130.00	10.00	97.50
	1974	740870.9	266993.36	-40.50	-6.75	57.00
	1982	740870.9	266970.48	22.88	2.86	79.88
	1987	740870.9	266972.36	-1.88	-0.38	78.00
	1990	740870.9	266988.36	-16.00	-5.33	62.00
N SIDE JETTY	1936	740962.4	267074.86			0.00
	1955	740957.9	267105.86	-31.32	-1.65	-31.32
	1968	740984.3	266977.73	130.81	10.06	99.49
	1974	740982.1	266988.23	-10.74	-1.79	88.75
	1982	740985.1	266971.73	16.77	2.10	105.52
	1987	740982.3	266986.98	-15.50	-3.10	90.02
	1990	740976.6	267012.23	-25.90	-8.63	64.13
TRANSECT 5	1936	741012.9	267140.86			0.00
	1955	740976.9	267140.86	-36.00	-1.89	-36.00
	1968	741041.9	267140.86	65.00	5.00	29.00
	1974	741028.4	267140.86	-13.50	-2.25	15.50
	1982	741019.7	267140.86	-8.75	-1.09	6.75
	1987	741016.9	267140.86	-2.75	-0.55	4.00
	1990	740999.4	267140.86	-17.50	-5.83	-13.50

Appendix 8 con't

PEI MINING	YEAR	CHANGES IN VEGETATION LINE EASTING	NORTHING	DIST BTWN	RATE OF CHANGE	CUM CHANGE	PROFILE DIST
TRANSECT 6	1936	740985.44	267440.36			0.00	-34.00
	1955	740985.94	267440.36	0.50	0.03	0.50	-33.50
	1968	740978.44	267440.36	-7.50	-0.58	-7.00	-41.00
	1974	740982.44	267440.36	4.00	0.67	-3.00	-37.00
	1982	740979.44	267440.36	-3.00	-0.38	-6.00	-40.00
	1987	740978.32	267440.36	-1.13	-0.23	-7.13	-41.13
	1990	740969.82	267440.23	-8.50	-2.83	-15.63	-49.63
TRANSECT 7	1936	741116.69	268000.86			0.00	-13.38
JOHNSTONS	1955	741106.94	268000.86	-9.75	-0.51	-9.75	-23.13
	1968	741096.44	268000.86	-10.50	-0.81	-20.25	-33.63
	1974	741093.94	268000.86	-2.50	-0.42	-22.75	-36.13
	1982	741076.32	268000.73	-17.63	-2.20	-40.38	-53.75
EXCAVATED	1987	741035.32	268000.48	-41.00	-8.20	-81.38	-94.76
DUNE	1990	741020.44	268000.73	-14.88	-4.96	-96.25	-109.63
TRANSECT 8	1936	NO DATA				0.00	
F. CLOWS	1955	741248.44	268625.61		0.00		-14.50
	1968	741243.69	268625.61	-4.75	-0.37	0.00	-19.25
	1974	741242.69	268625.61	-1.00	-0.17	-1.00	-20.25
	1982	741221.07	268626.23	-21.63	-2.70	-22.63	-41.89
	1987	741221.32	268625.36	-0.91	-0.18	-23.54	-42.80
artificial	1990	741223.44	268625.36	2.13	0.71		
real	1990	741202.94	268625.36	-18.38	-6.13	-29.67	-61.17
TRANSECT 9	1936	NO DATA					
	1955	741374.57	268950.23			0.00	-12.00
	1968	741373.94	268950.86	-0.88	-0.07	-0.88	-12.88
	1974	NO DATA					
68-82	1982	741352.44	268950.86	-21.50	-1.54	-22.38	
68-87	1987	741349.44	268950.36	-24.51	-1.29	-46.89	-37.39
	1990	741353.94	268950.36	4.50	1.13	-42.39	-32.89
TRANSECT 10	1936	NO DATA					
	1955	741553.82	269294.73		0.00		-4.01
	1968	741546.32	269294.98	-7.50	-0.58	-7.50	-11.51
	1974	NO DATA					
	1982	NO DATA					
68-87	1987	741529.82	269294.23	-16.52	-0.87	-24.02	-28.03
	1990	741528.82	269294.23	-1.00	-0.33	-25.02	-29.03

	YEAR	CHANGES IN HTL POSITION EASTING	NORTHING	DIST BTWN	RATE OF CHANGE	CUM CHANGE
TRANSECT 6	1936	741019.4	267440.36			0.00
	1955	741008.4	267440.36	-11.00	-0.58	-11.00
	1968	741002.9	267440.36	-5.50	-0.42	-16.50
	1974	741006.4	267440.36	3.50	0.58	-13.00
	1982	740993.9	267440.86	-12.51	-1.56	-25.51
	1987	740994.9	267440.36	1.12	0.22	-24.39
	1990	740985.9	267440.36	-9.00	-3.00	-33.39
TRANSECT 7	1936	741130.1	268000.36			0.00
JOHNSTONS	1955	741128.6	268000.36	-1.50	-0.08	-1.50
	1968	741124.6	268000.36	-4.00	-0.31	-5.50
	1974	741118.1	268000.36	-6.50	-1.08	-12.00
	1982	741089.6	268000.48	-28.50	-3.56	-40.50
	1987	741089.6	268000.36	-0.13	-0.03	-40.62
	1990	741070.6	268000.36	-19.00	-6.33	-59.62
TRANSECT 8	1936	NO DATA				
CLOWS	1955	741262.9	268625.36		0.00	0.00
	1968	741259.1	268625.61	-3.88	-0.30	-3.88
	1974	741261.9	268625.86	2.89	0.48	-1.00
	1982	741237.4	268625.86	-24.50	-3.06	-25.50
	1987	741239.4	268625.86	2.00	0.40	-23.50
	1990	741237.4	268625.86	-2.00	-0.67	-25.50
TRANSECT 9	1936	NO DATA				
	1955	741386.6	268950.23		0.00	
	1968	741385.4	268950.36	-1.13	-0.09	-1.13
	1974	NO DATA				
68-82	1982	741360.1	268950.86	-25.38	-1.81	-26.51
68-87	1987	741357.9	268950.86	-27.50	-1.45	-28.64
	1990	741364.9	268950.36	7.02	2.34	-21.62
TRANSECT 10	1936	NO DATA				
	1955	741557.8	269294.48		0.00	
	1968	741557.3	269294.23	-0.56	-0.04	-0.56
	1974	NO DATA				
	1982	NO DATA				
68-87	1987	741540.4	269294.73	-16.88	-0.89	-17.44
	1990	741535.9	269294.23	-4.53	-1.51	-21.97