HAZARD SENSITIVITY IN NEWFOUNDLAND AND COASTAL COMMUNITIES - IMPACTS AND ADAPTATIONS TO CLIMATE CHANGE: A CASE STUDY OF CONCEPTION BAY SOUTH AND HOLYROOD, NEWFOUNDLAND

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A CASE STUDY OF CONCEPTION BAY SOUTH AND HOLYROOD, NEWFOUNDLAND

by

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Abstract

Impacts and adaptations to climate change on the coastal zone of the communities of Conception Bay South and Holyrood, Newfoundland were investigated. Based on the concept of geoindicators and unique shore-zone morphology, a coastal hazard sensitivity assessment was conducted to assess the present sensitivity of the Conception Bay South-Holyrood coastline to the impacts of flooding and erosion. As the most immediate effects of climate change will be felt along the coastline, the implications of future climate change and variability in Atlantic Canada on the Conception Bay South-Holyrood coastline were then considered.

Results of the hazard sensitivity assessment indicate that overall, the Conception Bay South-Holyrood coastline has a low to moderate sensitivity to coastal flooding and erosion. However, subsequent analysis reveals that these results mask important differences in sensitivity based on differences in morphology. Results of the flood hazard sensitivity assessment indicate that the most sensitive segments of coastline surround the numerous lagoons located in Conception Bay South. The majority of the "exposed straight" coastline has a low sensitivity to flooding. In the foreshore erosion hazard sensitivity assessment, sections of coastline classified as barrier beach are highly to extremely sensitive to foreshore erosion processes, while segments classified as fringing beach or bedrock dominated receive low to moderate sensitivity ratings. Results of the backshore erosion hazard sensitivity assessment indicate that the majority of the Conception Bay South-Holyrood coastline has a low sensitivity to backshore erosion, a reflection of the fact that a third of the coastline is composed of highly resistant, igneous bedrock. Sections of backshore classified as unlithified are highly to extremely sensitive to erosion and there are a number of segments actively eroding.

With portions of the Conception Bay South-Holyrood coastline currently sensitive to coastal flooding and erosion and anticipated changes in climatic conditions and accelerated rates of sea-level rise potentially increasing the risk, there are important implications for town management and planning decision-making processes that are capable of supporting sustainable community practices. A number of specific adaptation options, including hazard identification and monitoring; managed retreat or avoidance; accommodation; protection; coastal management and public education, have been recommended to enable current protection and in preparation of accelerated sea-level rise and climate variability in southern Conception Bay.

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Chapter 1
Introduction

1.1: Introduction

With increasing development pressure, many coastal regions are experiencing rapid alteration of their natural environment, leading to widespread impacts on natural systems (Lawrence, 1994) and increasing hazards for human populations. Newfoundland communities have been tied to the coastline since initial human settlement 7000 to 8000 years BP. On the Avalon Peninsula, home to approximately 50% of the province's population, no community is more than 30 km from the coast. However, assessment and management of the Newfoundland coastal zone have been hampered by a lack of understanding of the geomorphic environment and its responses to the variations in climate conditions unique to this region.

Coastlines are sensitive to environmental change and many aspects of the coastal environment can be clarified by study of coastal geology and geomorphology. Numerous examples of inappropriate coastal management decisions or failed engineering solutions can be explained by the failure to consider all relevant aspects of the coastal system. Coastal landforms can be used as indicators of the processes that shape the coastal zone (Forbes and Liverman, 1996), as critical observations of large and small scale coastal features and vegetation provide clues to the natural history, degree of erosion or accretion and potential risks of associated natural hazards for any particular location (Young et al., 1996).

Coastal processes such as sea-level rise, storm-surge flooding, wave attack, sea-ice impact, and shoreline erosion are important components of the climate-driven marine environment (Catto, in press). When human developments coincide with these physical processes, naturally occurring events can become geologic hazards. The effects of these coastal processes and their potentially devastating impacts need to be considered in managing any coastal segment. Critical observation of a series of environmental features - geoindicators - provides clues to the active physical processes within the coastal zone and their associated natural hazards and thus provides an indication of the level of risk associated with coastal development (Young et al., 1996).

With more and more people moving into the coastal environment, steps must be taken to ensure that people, property and infrastructure are not situated in environmentally vulnerable locations, now or in the future. This is particularly true when future environmental conditions are likely to change. Some the most immediate effects of climate change and variability on the physical environment and on social and economic activity will be felt along the coastline (Bijlsma, 1996; Forbes et al., 1997; Klein and Nicholls, 1998; Mclean et al., 2001).

Meteorological observations indicate that since the beginning of the twentieth century, global temperatures have risen by approximately 0.5 °C (Kemp, 1991). While significant changes in global temperatures are not a modern phenomenon, recent climate records for Canada indicate that there has been a substantial amount of temperature variation within the past 100 years. Canadian mean annual temperatures have risen by 1.1 °C (Gullett and Skinner, 1992), while temperatures in Atlantic Canada have only increased by 0.4 °C and are actually characterized by an overall decrease of 0.7 °C between the years 1948 and 1991 (Gullett and Skinner, 1992; Pocklington et al., 1994; Lewis, 1997). However, the most recent Environment Canada data (1948-2002) indicates that there is no noticeable temperature trend (0.0 °C) in Atlantic Canada (Environment Canada website).

A continuing increase in greenhouse gas emissions is expected to result in a changing and/or more varied climate, with the potential to cause large-scale alterations to both the natural environment and socio-economic systems (Kemp, 1991; Shaw, 1997b). Within the coastal zone, global climate change is predicted to cause an increase in global sea-level, as well as changes in atmospheric circulation patterns which may lead to increased storm intensity, and possible changes in storm tracks and frequency (Forbes et al., 1997; Mclean et al., 2001; Schneider et al., 2001). Increases in open-water fetch and wave energy during the winter months, due to higher sea-surface temperatures and an expected reduction in the extent and duration of winter sea-ice may also be expected to occur (Forbes et al., 1997; Mclean et al., 2001). Thus coastal stability, flood and storm hazards, and development within the coastal zone may all be affected (Forbes et al., 1997; Mclean et al., 2001).

1.2: Purpose and Objectives

The purpose of this study is to assess the impacts of specific geomorphic hazards – coastal erosion and coastal flooding - on the communities of Conception Bay South and Holyrood, Newfoundland, by considering their present sensitivity to these hazards and by considering the implications of future climate change in Atlantic Canada. It forms a component of a larger research project (CCAF Project #A-242) designed to develop an approach for providing objective information on climate change impacts and adaptation options to Newfoundland coastal communities.

Over 80% of the developed area within the Towns of Conception Bay South and Holyrood, lies within 2 km of the coastline (Taylor, 1994). Historically, much of the area fronting the coastline in these communities was devoted to agricultural and fishing activities, but recently these lands have been converted to residential and retail uses. These uses are much more significantly impacted economically by storm activities and changes in coastal processes. By studying how these impacts will affect existing and future activities and resources in these communities and how ongoing climate change and sensitivity could alter the risks associated with various coastal hazards, important implications for town management and planning can be recognized.

The main objectives of this study are:

- To systematically classify the Conception Bay South-Holyrood coastline using the concept of geoindicators and unique shore-zone morphology for use in developing a qualitative framework for evaluating coastal hazard sensitivity based on coastal morphology.

- To evaluate the sensitivity of specific coastal segments to the impacts of the geomorphic hazards of coastal erosion and flooding.

- To test the sensitiveness and accuracy of the coastal hazard sensitivity assessment methodology in rating coastal segments with known flooding or erosion problems.

- To qualitatively assess the impacts of anticipated climate change and variability on the Conception Bay South-Holyrood coastline, including the evolution of coarse clastic barrier beaches under rising sea levels.

- To develop a series of land use management recommendations to help the Towns of Conception Bay South and Holyrood to successfully adapt to coastal hazards under current and future climatic conditions.

Chapter 2
Previous Work

2.1: Coastal Classification

Early attempts at coastal classification were rather generic and based on simple differences in coastal morphology or processes, i.e. tide versus wave dominated coastlines (Johnson, 1940; Cotton, 1954; Putnam et al., 1960; Tanner, 1960a; Shepard, 1976; Klemdal, 1982). These were followed by procedures to classify and partition a coastline into units that exhibited similar attributes or characteristics (Cotton, 1951, 1952; Tanner, 1960b; Swan, 1968; McLaren, 1980; Hiscock, 1981; Owens et al., 1981; Hiscock and Maloney, 1983; Fricker and Forbes, 1988; Harper et al., 1991; Howes et al., 1994; Catto et al., 1999a, 1999b; Jennings and Shulmeister, 2002). Such approaches were purely descriptive, as they systematically recorded shore morphology, shore-zone substrate and wave exposure characteristics, leading to the subdivision of the shore-zone into distinct alongshore and across-shore components. Functional relationships were not included. The various shore units that were generated could then be characterized by one of a number of distinct standard shoreline types (Owens et al., 1981; Harper et al., 1991; Howes et al., 1994; Catto et al., 1999a, 1999b). However, these approaches suffered from the fact that seasonal and yearly variability hindered effective classification based on a single time of observation. Seasonal changes in texture and morphology for example, could lead to different classifications of the same coastal segment (Catto et al., 1999a, 1999b).

Since the late 1970s, there has been a substantial increase in the use and development of physical shoreline description and classification systems. Nowadays, coastal classifications are frequently associated with risk assessments and integrated coastal zone management plans and seek to assess the vulnerability of particular segments of a coastline to the impacts associated with various hydrodynamic, climatic or anthropogenic hazards (Cooper and McLaughlin, 1998). Recognition of the variability in coastal morphology, differing approaches to mitigation strategies and differing management objectives, highlights the need for identification of distinct types of coast. Coastal scientists and planners have recognized this and are demanding detailed coastal classifications that are applicable to their own unique coastlines (Weerakkody, 1993; Cooper and McLaughlin, 1998).

Several of the classification systems were specifically designed for assessing oilspill sensitivity (McLaren, 1980; Hiscock, 1981; Hiscock and Maloney, 1983; Jensen et al., 1990; Harper et al., 1991; Catto et al., 1999a, 1999b; Griffiths, 1999; Strickland, 2002). Other recent coastal classifications have been developed as coastal vulnerability indices that are capable of assessing the vulnerability or sensitivity of a coastline to such coastal threats as future sea-level rise, episodic storms, climate change and anthropogenic disturbance (Gornitz and Kanciruk, 1989; Gornitz, 1990, 1991; Daniels et al., 1992, 1998; Gornitz et al., 1993; Kay and Hay, 1993; Dal Cin and Simeoni, 1994; Sheppard, 1997; Zeidler, 1997; Bush et al., 1998, 1999; Shaw et al., 1998; Small et al., 2000; Forbes et al., 2001; McCulloch et al., 2002). Recent climate change hazard assessment studies have also sought to investigate adaptation options (Zeidler, 1997; Klein and Nicholls, 1998; Forbes et al., 2001; McCulloch et al., 2002; Robinson, in preparation; Solomon, in preparation). Coastal vulnerability or sensitivity indices have also been developed for application to specific coastal systems. Such classification schemes allow coastal managers to focus management strategies at specific locations, as both the potential vulnerability and the main source(s) of imposed change can be identified. For example, Williams *et al.* (1993) and García-Mora *et al.* (2001) developed coastal vulnerability indices for specific application to dune systems.

However, in a review of eighteen coastal classification procedures, Cooper and McLaughlin (1998) concluded that few indices adequately considered the physical basis for interaction between variables used in the classification procedure. In particular, while most indices recognize the need for socio-economic data, few were able to adequately incorporate such information. They found that the indices that considered the nature of the potential disturbance along with clearly defined issues of management concern were the most useful. Indices in which these were not considered or adequately defined were likely to be of use mainly as databases.

2.2: Coastal Hazard Assessment

There are two fundamental approaches to coastal evolution, change and hazard assessment: a qualitative approach that simply detects environmental change without providing a rigorous basis for prediction; and a quantitative approach that serves as a long-term historical record and provides rates of change suitable for forecasting future conditions (Morton, 1996). Both have their advantages and disadvantages.

2.2.1: Quantitative Approaches

Quantitative approaches to future coastal change or hazard assessment provide the most precise and accurate results as they are based on detailed, long-term monitoring data and rely on statistical, geometric or numerical (deterministic) models to predict future conditions (Gibb, 1983; Morton, 1996; Young et al., 1996; Coyne et al., 1999). Statistical models are based on the principal of uniformitarianism, with the conditions that caused coastal change in the past causing future coastal change. As a result, they are easy to understand and apply (Morton, 1996). Future projections of coastal change are derived from calculations of average rates of observed shoreline movement (Coyne et al., 1999) or through simple equations (Gibb, 1983), such as the Bruun Rule (Bruun, 1962). However, if the physical causes of coastal modification change significantly, future predictions of shoreline movement will be inaccurate (Morton, 1996). Geometric models assume that coastal change is caused by submergence. It is assumed that the beach and offshore profile are smooth and unchanging. As a result, future shoreline positions can be easily determined from topographic maps and estimates of relative sea-level rise. The main disadvantage with using geometric models, however, is that because they assume coastal land loss only occurs as a result of submergence, shoreline retreat may be greatly under-estimated if other process, such as erosion, also occur (Morton, 1996). Numerical models are mathematically sophisticated models that attempt to explain shoreline retreat and coastal land loss through a series of equations that represent observed physical conditions and coastal processes. Sea level is assumed to be constant, with the beach and offshore profile smooth and unchanging. Although likely to simulate realistic conditions, the accuracy of numerical models depends on site specific knowledge of coastal behaviour and data for parameters that are generally unavailable (Morton, 1996).

While quantitative approaches to coastal evolution, change and hazard assessment are the most accurate, the detailed monitoring required is expensive, time consuming and requires a high level of expertise. Financial backing for long-term (i.e. decade-long) monitoring projects that are not producing immediate results is difficult to obtain. However, coastal managers, planners or scientists often need immediate information about the state of a particular shoreline (Young et al., 1996). As well, quantitative approaches to coastal hazard assessment are often regional in scale, relying on global databases that are incomplete, and are not suitable for site-specific evaluation of short reaches of coastline (Young et al., 1996; Small et al., 2000). In addition, incomplete understanding of complex coastal processes and the lack of an equilibrium beach profile limit the ability of geometric and numerical models to predict accurate shoreline movement positions (Morton, 1996).

2.2.2: Qualitative Approaches

In areas where quantitative data is lacking, a procedure for the quick and effective determination of coastal hazard areas is needed. Qualitative approaches to coastal evolution, change and hazard assessment are based on a general understanding of how nearshore environments respond to changing oceanic conditions. They are best suited to situations where financial resources are extremely limited, source data are unavailable or of questionable quality, and the primary coastal management objective is to provide a quick assessment of current conditions and possible future conditions (Morton et al., 1996; Young et al., 1996; Sheppard, 1997; Bush et al., 1998, 1999; Daniels et al., 1998). As a result, they fill a need for a scientifically valid, yet inexpensive, method of qualitative shoreline monitoring and assessment (Young et al., 1996). They are able to assess vulnerability to a wide range of coastal hazards including hurricanes, landslides, coastal erosion, earthquakes, tsunamis and flooding (Morton et al., 1996; Young et al., 1996; Sheppard, 1997; Bush et al., 1998, 1999; Daniels et al., 1998). However, qualitative approaches are limited in their application as they are of little use when it comes to knowing where and when changes will occur (Morton, 1996). The interpreted results can be misleading or incorrect as observations are site specific and reflect only the most recent geomorphic condition (Morton, 1996; Catto et al., 1999a, 1999b). As Catto *et al.* (1999a, 1999b) noted in a shoreline assessment of Placentia and Conception Bays, Newfoundland, seasonal and yearly variability hinders effective classification based in a single time of observation, as textural and morphological fluctuation can lead to different classifications of the same coastal segment. Only quantitative analyses of long-term historical trends are able to avoid the potential errors associated with qualitative descriptors of beach stability (Morton, 1996)

2.3: Conception Bay South

A substantial amount of research has been conducted within the Conception Bay region. The Geological Survey of Canada – Atlantic (GSCA) has investigated the area since the early 1980s (Forbes, 1984; Shaw and Forbes, 1987; Forbes and Taylor, 1994) and, in conjunction with the Geological Survey of Newfoundland and Labrador, have an ongoing coastal monitoring program in the Topsail Beach area (Liverman et al., 1994). Detailed geomorphic studies of the area have been ongoing since the early 1990s, particularly by Catto (1994, 1999, in press), Catto *et al.* (1999a) and students (Prentice, 1993; Sheppard, 1997; Pittman, 1999, in preparation).

Taylor (1994) conducted the first coastal land-use management study for the town of Conception Bay South. At the time of the study, there were no standards or regulations (federal, provincial or municipal) in place to govern development along the coastline and development was randomly dispersed throughout the community, reflecting land-use patterns inherited when nine separate communities amalgamated. The lack of integrated coastal management polices between municipal, provincial and federal levels of government resulted in confused jurisdiction, duplication and a general lack of communication (Taylor, 1994; Simms, 1997). When determining development or protection potential, sites were investigated independently from adjoining areas, ignoring the influence that development in one section of coastline would have on another (Taylor, 1994).

In 1999 and 2000, students in the Advanced Diploma in Coastal Zone Management program at the Marine Institute of Memorial University, in partnership with the Federal Department of Fisheries and Oceans, conducted two integrated coastal zone management projects for the town of Conception Bay South. Subsequently, in 2001, the Department of Fisheries and Oceans commissioned a general socio-economic study of Conception Bay, along with a detailed study of Conception Bay South (Canning and Pitt Associates, 2001a, 2001b). The local economic development board, the Capital Coast Development Alliance, undertook a detailed coastal resource inventory of the entire Conception Bay Region, including St. John's (Kerry Murray, personal communication).

The present study is based on a modification of the geoindicators approach to coastal hazard assessment developed by Young *et al.* (1996:Tables 1 and 2). The geoindictors approach is based on standard qualitative and quantitative methods for measuring geological processes and aims to provide an indication of the level of safety or risk a particular location has from natural hazards. This study seeks to build on previous work conducted within the Conception Bay South region, particularly studies by Taylor (1994) and Sheppard (1997), by integrating the results of a coastal hazard assessment with an understanding of both current and future land-use and climate conditions.

Chapter 3
Study Area

3.1: Location and Physical Setting of Study Area

The study area is located on the Avalon Peninsula, in the southeast part of the island of Newfoundland, between 47°23'25'' and 47°32'40'' N and between 52°55'00'' and 53°08'30'' W **(Figure 3.1)**. It consists of two communities, the Town of Conception Bay South and the Town of Holyrood, and approximately 35 km of coastline.

The town of Conception Bay South is located on the northeast side of the Avalon Peninsula, approximately 12 km from St. John's, the provincial capital. It is an amalgamation of nine formerly separate communities **(Figure 3.2)**: Topsail, Chamberlains, Manuels, Long Pond, Kelligrews and Upper Gullies amalgamated in 1971, while the communities of Foxtrap, Lawrence Pond and Seal Cove joined in 1986 (Taylor, 1994).

The town of Holyrood, southwest of Conception Bay South, is located approximately 48 km from St. John's at the head of Conception Bay. Most of the community is concentrated along the shore of the South Arm, although a few homes are found along the North Arm (Smallwood, 1984). This study covered only part of the Holyrood shoreline, from the Conception Bay South town boundary to two hundred metres north of the head of the South Arm to the wharf found near Mahoney's Beach. This location was chosen as the study area boundary as it formed the limit of Holyrood Beach.

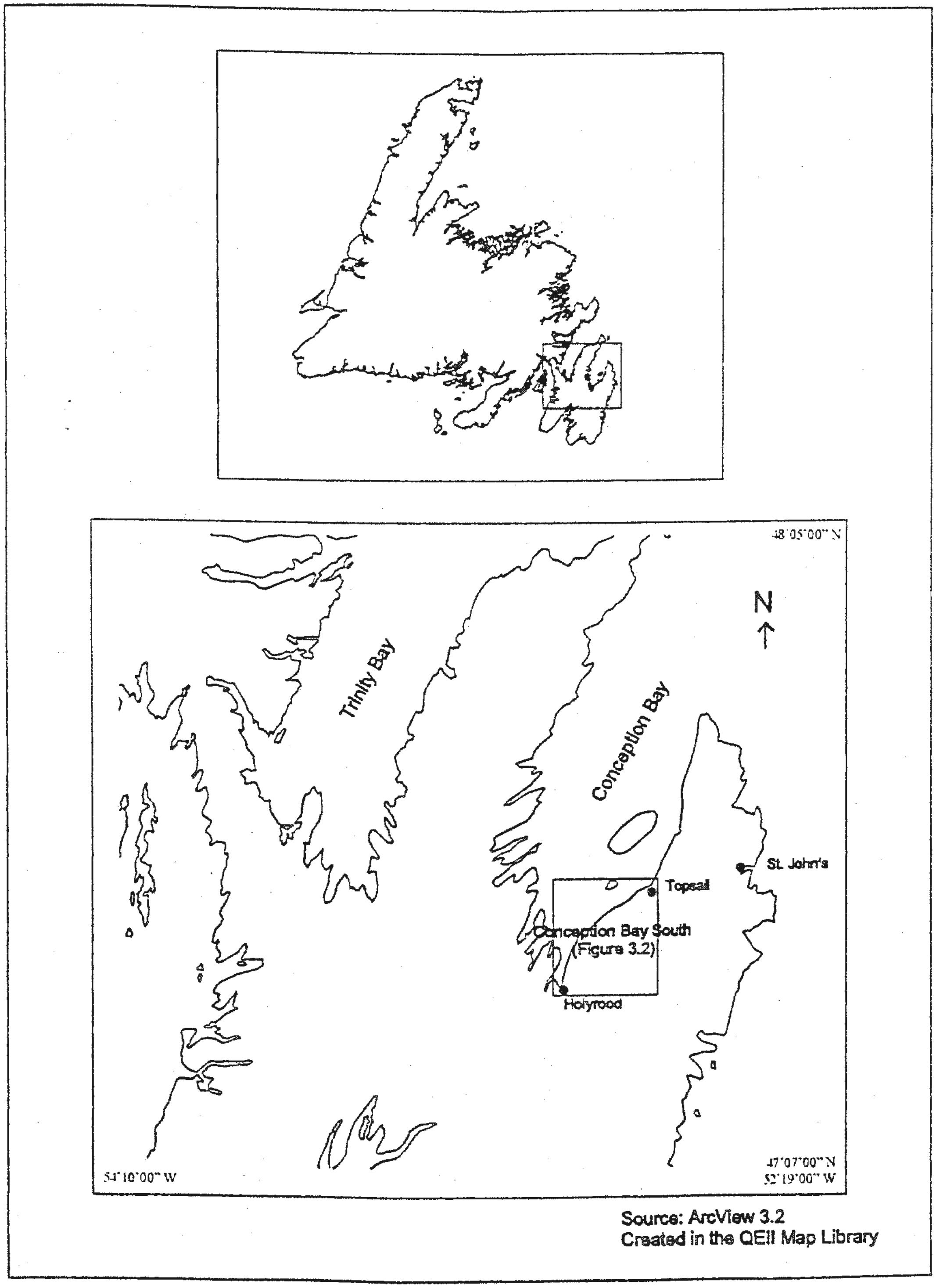

Figure 3.1: Location of the Conception Bay South and Holyrood, Newfoundland study area. Note location of Figure 3.2 in inset map. (scale approximately 1:1 000 000)

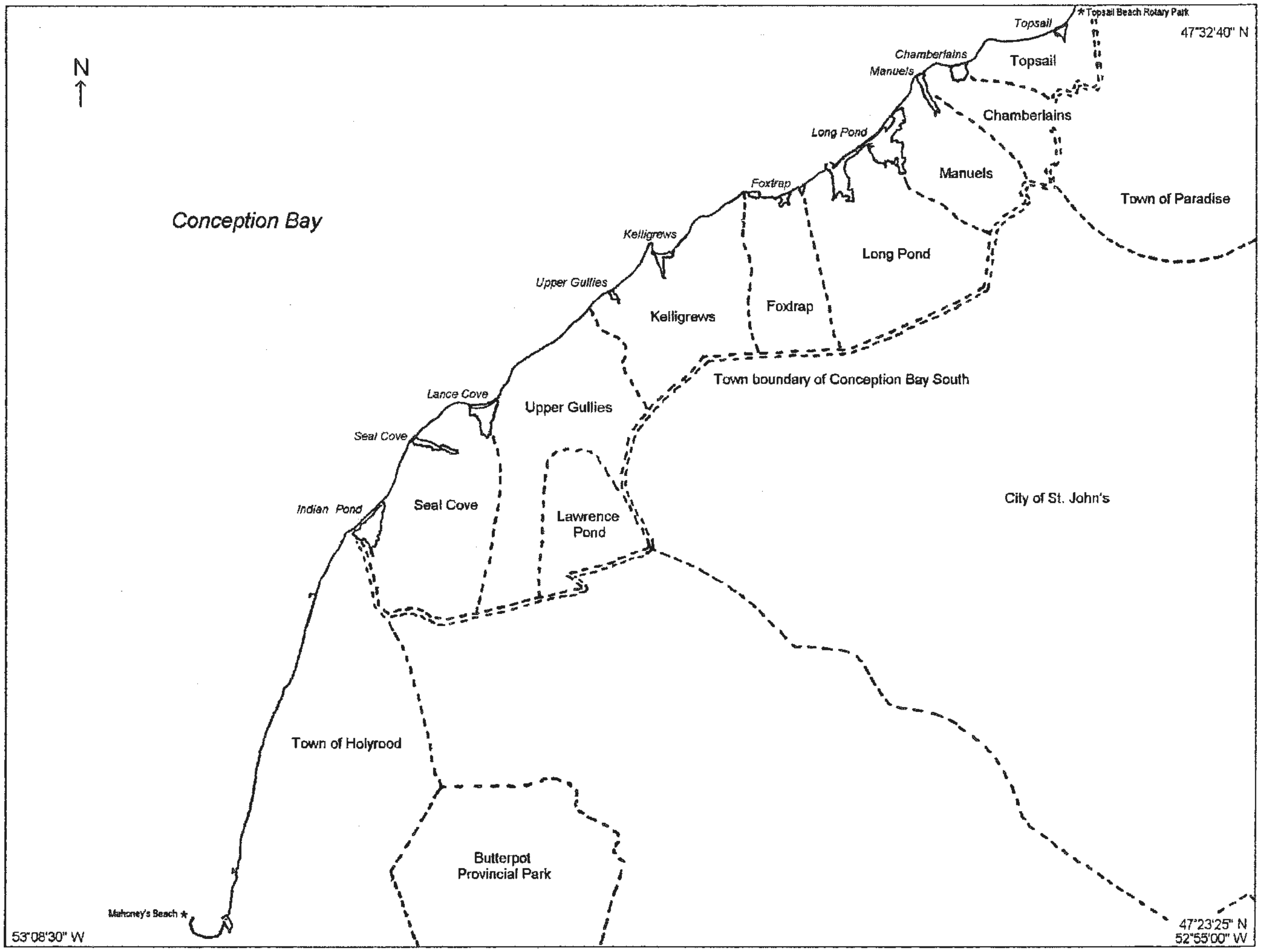

Figure 3.2: Location of the nine original Conception Bay South Communities. Lagoon names are italicized. (scale approximately 1:130 000)

The Avalon Peninsula is part of the Atlantic uplands of Newfoundland, a part of Appalachia which lies between 180 and 300 m elevation (Bostock, 1970). In a few places the upland is rocky and rugged, but mostly it is a rolling plain of low relief (Heringa, 1981). It is the lower part of an ancient peneplain that slopes in a southeasterly direction, the surface of which is preglacial and has only been slightly modified by glaciation (Bostock, 1970; Heringa, 1981). Bedrock geology is dominated by Late Proterozoic sedimentary, metasedimentary and volcaniclastic rocks of varying resistance and the strata are cut by northeast-southwest trending faults and joints and are locally folded (Brückner, 1969; King, 1988). The coastline of the study area is characterized by steep rocky headlands and cliffs, with gravel-dominated pocket beaches and baymouth barriers, locally called barachoix or barasways (Catto, 1994).

Maximum relief in the area surrounding Conception Bay is approximately 270 m, with coastal cliffs 30 m high. Three islands, the largest being Bell Island, are located approximately 7.5 km northwest of the study area. Conception Bay itself has a maximum depth of 280 m.

3.2: General Climate Setting

The climate of Newfoundland is classified as mid-boreal (Köppen-Geiger Dfb), marked by cool winters and summers and seasonally consistent precipitation (Banfield, 1981, 1983; Catto, 1994, 1999). The Avalon Peninsula is located within Climatic Zone 1 of Newfoundland (south and south-east coasts and immediate hinterlands), characterized by Banfield as having the:

> "[g]reatest maritime influences. Annual precipitation 1500-2000 mm, with heaviest falls during southerly airstreams, especially over hills inland. Winters relatively mild with less than half [the] precipitation falling as snow; snow cover intermittent. Freezing rain frequent [in] late winter. Summers cool with frequent sea fog" (Banfield, 1981:129).

The northeastern part of the Avalon Peninsula, which includes the study area, is further characterized by "less mild winters with more frequent snowfalls, especially with northeasterly airflow. Warmer and sunnier summers ...after late spring" (Banfield, 1981:129).

Daily mean temperatures in St. John's are approximately -5°C in January and 12-17°C in July (Catto, 1994, 1999), with annual extremes of approximately -23°C and 31°C (Hiscock, 1981). July mean temperatures vary with aspect, with northerly areas and those consistently exposed to northeast winds being cooler. Freeze-thaw cycles are numerous from mid-December to early April (low sea surface temperatures and frequent northerly and easterly airflow delay the rise of mean daily temperature above freezing till early April) and frost events may occur at any time from early September to June (Banfield, 1981, 1983, 1993). Complete freeze-over of lakes and rivers occurs two to four weeks following the decrease in mean daily temperature to below 0°C, approximately the third to last week in December, and complete thaw ranges from the third to fourth week in April (Banfield, 1981, 1983).

On the Avalon Peninsula, there is 1050-1600 mm of annual precipitation (Banfield, 1993). Annual average precipitation in December is 152.6 mm and 77.8 mm in July (Griffiths, 2001). Snow cover is often discontinuous in time and variable in depth throughout the winter. On average, approximately 200 cm of snow falls on the Avalon Peninsula (Banfield, 1981, 1983, 1993). During the time of this study, a 121 year snowfall record for St. John's was broken, as 648.4 cm of snow fell between November 2000 and April 2001, with another higher than average snowfall the following winter: 393.2 cm (Bruce Whiffen, Environment Canada, personal communication). Coastal areas receive less snowfall and more freezing rain and drizzle: up to 80 hours per year (Catto, 1999).

Fog is common in areas heavily influenced by southwest winds, particularly open coastlines (Catto, 1999): the mean monthly percentage of time with fog is 31.2% at St. John's in May and 41.0% in Argentia in July (Hiscock, 1981), Conception Bay tends to have less summer sea fog due to a general excess of offshore over onshore winds (Banfield, 1993).

Wind patterns vary seasonally, and local topographic effects can be significant (Catto, 1999). Prevailing winds are from the west and southwest, as both have an average annual occurrence of >20%, although winds may originate from any compass direction (Banfield, 1981, 1983, 1993; Griffith, 2001). Southwesterly winds bring warm, moist air to the region from the warmer surface waters south of Newfoundland and are associated with many of the major storms and hurricanes during the summer and early autumn (Catto, 1999). Northeasterly winds, associated with autumn gales, are responsible for much of the storm modification of the coastline in Conception Bay (Catto, 1994, 1999, in press). Diurnal onshore and offshore winds are also common in most embayments (Catto, 1994).

3.2.1: Tides, Waves and Currents

Conception Bay (mixed, mainly semi-diurnal tide) occupies a microtidal setting, with a mean range of approximately 1.3 m (Canadian Tide and Current Tables, 2000, 2001). The coastline is storm wave dominated, characterized by sharp seasonal differences in wind, waves, and ice conditions. Wave energy is 5 to 6 times greater in December than in July (Farmer, 1981; Prentice, 1993). Coastal dynamics within Conception Bay are dominated by local storm waves generated by extra-tropical cyclonic activity during the autumn and winter (Khandekar and Swail, 1995). Wave activity is partially or totally responsible for the majority of sedimentary landforms and contributes substantially to coastal erosion of unlithified cliffs (Catto, in press). Reflective wave behaviour is dominant over dissipative conditions in most segments (Catto, 1994). Long period swells generated by strong winds offshore make only a small contribution to total wave energy, thus emphasising the importance of locally generated wind-driven or storm waves in the region (Farmer, 1981). The incident wave front is predominantly northwest, but is occasionally northeast (Prentice, 1993), reflecting dominant storm wind directions. Annual wave statistics from Transport Canada show that significant wave heights of >7m are most common from the west and southwest, although monthly wave statistics for the months of September, October, and November show a shift in significant wave height occurrence originating from the north. Off the open Atlantic shoreline, modal significant deep-water wave heights are 7-8 m (Neu, 1982). In the western Atlantic Ocean, storm wave heights are at a maximum east of Newfoundland. The 10-year significant wave height is estimated as 11 m and the 100-year height as 12-15 m in the vicinity of Conception Bay (Neu, 1982; Khandekar and Swail, 1995). The 100-year maximum wave height is estimated as 23 m (Khandekar and Swail, 1995).

Currents in nearshore areas are weak, but generally follow a counter-clockwise circulation pattern, moving southward from Baccalieu Island to Holyrood and northeastward to Cape St. Francis, with longshore drift of sediment following this general southwest to northeast pattern (deYoung and Sanderson, 1995; Griffiths, 2001). However, considerable local variation exists, especially within embayments. Open beach areas are influenced by shore-parallel and shore-normal transport, with onshore-offshore sediment movement essentially normal to the beach dominating. Alternating shore-parallel and shore-normal transport is common, due to variations in wind direction and strength, surf and swell action, and shore-normal and edge wave activity. Along all beaches and in many coves, current patterns shift in response to changes in wind direction and to storms (Catto, 1999, in press).

3.2.2: Sea Ice

Sea ice in this area of the province is provided by the southward advection of floe ice on the Labrador Current (Markham, 1981; Farmer, 1981) and in severe years can extend south of 45°N latitude (Farmer, 1981). The maximum ice limit reaches the Avalon Peninsula and Conception Bay by mid-January, with the median ice limit located at the Baie Verte Peninsula and western Notre Dame Bay at this time. The median ice limit does not reach Conception Bay at any point, but the maximum extent reaches Cape St. Francis by the end of February (Seaconsult Limited, 1985; Cote, 1989; Canadian Ice Service, 2001).

The development of landfast and pack ice in Conception Bay occurs in 16-20 out of 25 years, with maximum persistence generally greater than 11 weeks from January through to May (Seaconsult Limited, 1985; Hill and Clark, 1999). Sea ice formation starts about the beginning of February and increases to about 30 cm thickness as the season progresses. It begins retreating by late March and is typically gone by the first week in April. However, in severe ice years there is a return of sea ice in late April or early May. This ice tends to be thicker (50-120 cm), having drifted from arctic or near-arctic locations, and is often mixed with bergy bits, growlers and icebergs. This ice remains until middle or late May (Hill and Clarke, 1999). Onshore winds can also divert pack ice into the bays along the east coast of the province, narrowing the open water lead considerably and creating an ice hazard for navigation (Farmer, 1981; Canadian Ice

Service, 2001). A persistent open lead occurs along the northwest coast of Conception Bay (Seaconsult Limited, 1985).

The southerly extent of persistent ice foot development coincides with the position of the -0.5°C February sea surface temperature isotherm, confining the phenomenon to the northern and central parts of the Avalon Peninsula coastline. Formation begins in late December and remains until late March (Catto, 1999, in press). Ice foot development is common along the shorelines of Conception and Trinity Bays and is a major factor in the geomorphic development of beaches as it precludes winter erosion of beach sediments. It does occur on beaches in southern Conception Bay, but is less extensive, pervasive and persistent than in Trinity Bay (Catto, 1994, 1999, in press).

Icebergs occur within Conception Bay from the end of March and last till the end of June, although they can occur any time between late December and early August. Typically, their arrival at the end of March or early April coincides with the initial retreat of sea ice and is dependent on wind and current conditions (Clarke and Hill, 1999; Griffiths, 2001). Over 300 icebergs have entered Conception Bay since 1961 and are of various sizes, with iceberg heights of 50-60 m possible (Hill and Clarke, 1999). General ice data for Conception Bay are summarised in **Table 3.1**.

Table 3.1: Ice data for Conception Bay from 1961-2001.

Ice Data for Conception Bay from 1961-2001	
Total number of years:	41
Number of years with no ice:	2
Number of years with no sea ice:	9
Number of years with no bergs:	12
Number of years with very light sea ice and few bergs:	3
Number of years with no or minimal ice conditions:	15 (37%)
Number of years with heavy sea ice conditions:	19 (46%)
Number of years with heavy sea ice and bergs present:	11 (27%)
(Hill and Clarke, 1999:6; field observations, 1999-2001)	

3.3: Vegetation

The study area is classified within the Maritime Barrens Ecoregion, and is characterized by extensive barren areas consisting mainly of dwarf shrub heaths, bogs and shallow fens (Hiscock, 1981; Damman, 1983; Meades, 1990). Forests are most common in valleys, although they can be found on hilltops and slopes (Damman, 1983). Most of the forest cover was gradually eliminated by the combined effect of frequent fires after European settlement, poor regeneration after fires, marginal climatic conditions, and strong competition from ericaceous dwarf shrubs. The majority of the region is now covered with *Kalmia* barrens and shallow bogs and fens. Remaining patches of forest are generally of poor quality (Damman, 1983). Heathland vegetation is composed mainly of *Kalmia angustifolia*, *Rhododendron canadense*, *Vaccinium angustifolium* and *V. vitis-idaea*. *Cladonia* species dominate the moss layer and *V. vitis-idaea* and *Empetrum nigrum* are dominant on exposed sites. Balsam fir (*Abies balsama*) is the most common tree species, with black spruce (*Picea mariana*) and eastern larch

(*Larix glauca*) colonizing the wetter sites (Hiscock, 1981). Peatland in the study region is characterized by slope bog vegetation assemblages: *Kalmio-Sphagnetum fusci*, *Vaccinio-Cladonietum boryi*, *Calamagrostio-Sphagnetum fusci*, *Scirpo-Sphagnetum magellanici*, and *Scirpo-Sphagnetum tenelli* (Wells and Pollett, 1983). Sea rocket (*Cakile edentula* var. *edentula*) and beach pea (*Lathyrus maritimus*) are common colonizers of cobble beaches (Rodman, 1986; Barimah-Asare and Bal, 1994), while purple loosestrife (*Lythrum salicaria*) is dominant in shallow water mashes (Thompson et al., 1987), particularly in the Foxtrap region (Karyn Butler, personal communication). Coltsfoot (*Tussilago farfara L.*) can also be encountered on cobble beaches and is a primary colonizer of failing slopes (Hendrickson, 1999).

3.4: Bedrock Geology

Bedrock within the study area is dominated by Palaeozoic sedimentary units and late Proterozoic and early Cambrian intrusive igneous rocks (King, 1988). The oldest Precambrian rocks outcropping in the area belong to the Harbour Main Group, a sequence of mainly basic and acidic volcanic rocks consisting of resistant green to purple basaltic flows, pyroclastic rocks, felsic volcanic rocks, clastic sedimentary rocks, and gabbro (King, 1988). The Harbour Main Group constitutes the steeply cliffed shoreline from Topsail northwards and is also found in the Holyrood area (McCartney, 1969; King, 1988). These rocks were subsequently deformed and intruded by the Holyrood plutonic series, which is dominantly composed of medium-grained, massive, pink to grey granite with minor amounts of aplite. The Holyrood Intrusive Suite is exposed south of Indian Pond (Brückner, 1969; King, 1988).

Within the study area, the Harbour Main and Holyrood rocks are unconformably overlain by the sedimentary strata of the Black Hill sequence. This unit consists of fine-grained clastic marine sediments, including siltstone and sandstone and is exposed in Holyrood (Brückner, 1969; McCartney, 1969; Catto and St. Croix, 1998).

Along the southeast coast of Conception Bay, between Indian Pond and Topsail, the volcanic Precambrian rocks are overlain by sedimentary rocks of Cambrian age. The Adeyton Group (90 m thick) is exposed further inland and extends northward to the Topsail Highlands (Brückner, 1969). These consist of red, greenish, and grey, silty mudstone, with some minor limestone nodules, and in the Topsail/Manuels area as much as 6 m of basal conglomerate (King, 1988). The Harcourt Group overlies the Adeyton Group (120-150 m thick) and are composed of grey, green to black, thinly laminated micaeous shale (King, 1988)

The study area contains two approximately north-south (NNE-SSW) trending major fault zones. The Topsail fault zone roughly follows the eastern shore of Conception Bay, continuing southward from Topsail inland for a considerable distance. The Holyrood-Brigus fault zone roughly follows the western coast of Conception Bay and extends southward inland from Holyrood Bay (Brückner, 1969).

3.5: Quaternary Geomorphology

An extensive till blanket characterizes the Topsail to Foxtrap region of Conception Bay South, while glaciofluvial outwash sediments are dominant along the coastline from Kelligrews southwestward to Indian Pond. The glaciofluvial sediments form a series of kames and kame deltas, developed as meltwater flowed northward to the retreating ice margin at the mouth of Conception Bay (Catto and St. Croix, 1998; Catto and Taylor, 1998; Batterson, 2000). Typical sequences in these deposits contain two major sedimentary assemblages: a basal assemblage dominated by stratified and imbricated pebble and cobble gravel and an overlying second assemblage dominated by cross-stratified and horizontally stratified sand and gravel (Catto and St. Croix, 1998:455). The glaciofluvial deposits reach a maximum thickness of 25 m and they are locally capped by peat veneers and blankets, as in Upper Gullies and Seal Cove (Catto and St. Croix, 1998). Tills are coarse-textured, with silt concentrations of <2-30% and large clasts (pebbles, cobbles and boulders) forming 30-55% of the deposit (Catto and St. Croix, 1998; Catto, in press). A narrow foreshore strip of modern beach and barrier deposits, dominantly composed of pebbles and cobbles, extends from Topsail through to Foxtrap. Along the Kelligrews River, Lower Gullies River and Seal Cove River there is a thick sequence of modern stream deposits of sand, silt and gravel (Henderson, 1974; Taylor, 1994; Catto and Taylor, 1998). Colluvium deposits characterize the east side of Topsail Beach Pond and the Holyrood coastline from the Ultramar storage facility site eastwards (Catto and Taylor, 1998; Batterson, 2000).

The presence of the highly permeable and porous glaciofluvial sediments along the Conception Bay coastline has contributed to the susceptibility of this area to coastal erosion and to the development of gravel-dominated barrier beaches (Catto and St. Croix, 1998). Fringing barricades of glacially transported boulders that have remained after marine waters have removed finer-grained clasts, flank much of the shorelines (Catto, in press). As significant amounts of sea and landfast ice are not common in southern Conception Bay, the mechanism of ice-push is eliminated as the mode of formation for these nearshore boulder deposits. They are not boulder barricades. Boulders are not formed into a rampart and ice-push of individual clasts only occurs in association with strong northeast winds. Observations by Pittman (in preparation) indicate that ice push is limited and confined to finer-grained sediments.

3.6: Holocene Sea-level History

Sea levels along the coast of the Avalon Peninsula have undergone a series of changes since deglaciation, approximately 12 000 years BP, through a combination of sea-level rise and crustal response, following the "Type C" model proposed by Quinlan and Beaumont (1981) and modified by Liverman (1994) **(Figure 3.3)**. The northeastern part of the peninsula, around St. John's and Cape St. Francis, shows the least amount of fluctuation, while the northwestern part, at the head of Placentia Bay, exhibits the greatest (Catto, 1994). In general, all of coastal Newfoundland, excluding the Northern Peninsula, is experiencing submergence (Shaw et al., 2002), although at various rates.

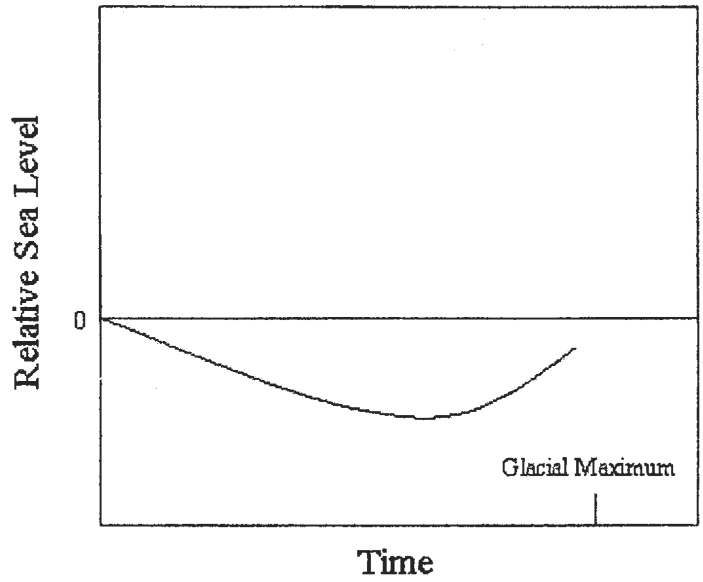

Figure 3.3: 'Type C' sea-level curve due to migration of peripheral forebulge (Quinlan and Beaumont, 1981; Liverman, 1994).

Along Placentia Bay, submerged estuarine and deltaic sediments indicate that sea-level was eight to twenty metres lower than present (Catto, 1994; Forbes et al., 1995; Shaw and Forbes, 1995; Catto et al., 2000). At Biscay Bay Brook, east of Trepassey, a spruce stump rooted in forest peat below the modern high tide line dated at 750±90 years BP (GSC-5414), indicating a rise in relative sea-level. Radiocarbon analysis of a spruce stump found at Mobile also suggests a rise in relative sea-level: at 40 to 65 cm/century, it is more than double the rates assumed for Conception Bay (20 to 30 cm/century at Port de Grave Harbour) (Catto et al., 2000). Archaeological excavations at Ferryland and Placentia suggest that sea-level may have been up to three metres lower than present in the early 1600s (Catto, 1994, 1999; Catto et al., 2000).

Along Conception and Trinity Bays, marine sediments and erosional features are noted at elevations between five and twenty metres above present sea-level (Brückner, 1969). However, raised marine features have not been recognized along the open Atlantic coastline south of Cape St. Francis, approximately 15-30 km east of Conception Bay. Cores taken from St. John's Harbour indicate the presence of a freshwater lake around 11 000 years BP, suggesting that sea-level was at least 14 m lower than present, as this is the elevation of a controlling sill at the entrance to the harbour. Marine foraminifera dated at 9900 years BP record the transgression of marine waters into the harbour (Lewis et al., 1987): an approximate sea-level rise of 12.7 cm/century.

Offshore of the Conception Bay coast, submerged shoreline features have not been located, although extrapolation from data for Placentia and Trinity Bays suggests that sea levels fell to between ten and twenty metres below present during the early Holocene (Grant, 1989; Shaw and Forbes, 1995; Liverman, 1994; Catto et al., 2000)

3.7: Coastal Geomorphology

The coastline of the study area is characterized by steep, nearly continuously linked, fringing and barrier beaches primarily composed of pebble to cobble-sized clasts and backed by 20 to 30 m high bluffs of unlithified, Quaternary glaciogenic sediments **(Plate 3.1)**.

Plate 3.1: Typical coarse clastic barrier beach encountered in Conception Bay South.

Gravel barriers are distinctive coastal landforms in glacially influenced regions. Their development and behavioural controls can only be understood with a knowledge of coastal morphodynamics, the combined adjustment of topography and fluid motion through sediment transport (Cowell and Thom, 1994), and sedimentation (Orford et al., 1991). It is important to understand these processes to fully understand the implications of climate change and variability on barrier beach evolution.

3.7.1: Morphological Development Controls

Short-term barrier beach stability is highly dependent upon a range of pre-existing conditions that determine morphodynamic status and vulnerability to rapid change or breakdown. Long-term stability is governed by strong morphology and sedimentary memory and feedback interactions, in addition to such crucial external controls as sea-level change, wave climate and sediment supply (Carter et al., 1987; Orford et al., 1991, 1995a, 1996; Forbes et al., 1995). In general, gravel barrier beach processes are strongly affected by two factors: the appearance of long-period swells in the nearshore and the inheritance of large-scale sedimentary structures from storm events (i.e. beach cusps) (Carter and Orford, 1984). Their morphology is extremely sensitive to wave run-up height and volume, which are functions of breaking wave structure, sediment roughness and beach permeability (Orford et al., 1995b).

On microtidal, wave-dominated beaches, such as those in southern Conception Bay, morphological change is primarily induced by variations in the incident-wave climate (Masselink and Pattiaratchi, 1998a). Beach cusps are uniformly spaced, scalloped-shaped, shoreline features formed by swash action and are characterized by steep-gradient, seaward-pointing horns and gentle-gradient, seaward-pointing embayments **(Plate 3.2)** (Inman and Guza, 1982; Miller et al. 1989; Werner and Fink, 1993; Masselink et al., 1997; Masselink and Pattiaratchi, 1998b, Masselink, 1999). Cuspate structures are common from Topsail through to Long Pond and are occasionally encountered at Lance Cove. Stacked sequences are commonly encountered on Topsail Beach and may remain unaltered for several years **(Plate 3.3)**.

Plate 3.2: Example of a beach cusp, Topsail Beach.

Plate 3.3: Series of beach cusps along Topsail Beach.

Cusps have important implications to the form and scale of nearshore circulation patterns and/or wave dynamics (Miller et al., 1989). They act as a template for directing and concentrating run-up, potentially leading to crest breaching and overwashing and the introduction of beachface material onto the backbarrier (Carter and Orford, 1984; Orford et al., 1991). Their development and persistence can result in the direction and control of subsequent overwash and washover spacing (Carter and Orford, 1984).

In addition to waves, sediment texture and supply characteristics exert considerable control on barrier morphology and dynamics (Carter et al., 1987; Klein and Menezes, 2001). Most coarse clastic barriers are composed of varying mixtures of gravel and sand, along-shore, across-shore, and at depth (Forbes et al., 1995) and shore forms of sediment organization (Orford et al., 1991). Sorting of clasts by size, shape and composition can induce significant effects on the rate of barrier change. According to Carter *et al.,* (1987:1788), "lateral variation in barrier facies will lead to modification of barrier slopes, which in turn will affect the structure of breaking waves and the morphodynamic status of the beach-nearshore zone."

Although "sediment supply is regarded...as the main control on barrier morphological variation...this control is regulated by the bathymetric terrestrial basement geometry over, and onto, which the coastal sediment is transported" (Orford et al., 1996:590). The nature of geologic basement is crucial for both barrier progradation and recession, as it controls long-term sediment transport and incident waveform (Orford et al., 1996). For example, as a barrier migrates landward, it may encounter basement irregularities that can result in disruptions to the sediment supply, causing accretion updrift and erosion downdrift, and can lead to the development of new wave refraction patterns and gradients, leading to locally-enhanced sediment mobility (Orford et al., 1991). Headlands also exert a considerable influence over barrier development, as they serve as hinge or anchor points from which barriers form. Their emergence and spacing alters the incident wave field, affecting wave refraction and diffraction. They may also act as local sediment sources and control the rate and pattern of coastal sediment transport (Carter et al., 1987).

The integrity of coarse clastic barrier beaches also depends on their ability to maintain cross-shore drainage. In some cases, drainage is through channels, which may or may not allow tidal exchange (Carter et al., 1987; Orford et al., 1991). Over longer timeframes, the development of drainage-related features; such as lagoons, channels and inlets; will have a profound effect on barrier evolution, as they influence the mechanisms promoting sediment stability and transport direction (Orford et al., 1991). For example, incised channels may be deflected by longshore drift, resulting in the reworking of the barrier during migration (Carter and Orford, 1984).

3.8: Communities of Conception Bay South and Holyrood

Since the end of Second World War, the towns of Conception Bay South and Holyrood have become dormitory suburbs of St. John's (Hyde, 1973; Smallwood, 1981, 1984; Brown, 1988; Veitch, 1989; Poole, 1991, 1993, 1994). Improved transportation networks (construction of the Manuels Access Road, the Conception Bay South Bypass Road [Route 2] and the Outer Ring Road within St. John's, have greatly improved accessibility) have supported the growth and development of the towns. Conception Bay South was designated as a sub-regional centre [an area for residential development supported by a commercial sector to serve local needs (Canning and Pitt Associates, 2001a)] in the St. John's Urban Regional Plan adopted in 1976, and is meant to be "supportive and complementary to the regional centre of St. John's and Mount Pearl" (Canning and Pitt Associates, 2000a:6). With their proximity to the provincial capital, unique mix of urban and rural characteristics, and accessible coastline and industrial port facilities, both communities have become desirable locations in which to live and work (Taylor, 1994; Canning and Pitt Associates, 2000a; Marine Institute, 2000; Canning and Pitt Associates, 2001a).

3.8.1: Population Characteristics

Over the past fifty years the population growth rate in Conception Bay South has exceeded that of the province. Historical data indicate that town's population has almost doubled every twenty years **(Figure 3.4)** (Canning and Pitt Associates, 2001a). By 1988, Conception Bay South was the third largest municipality and largest town in the province (Hochwald and Smith, 1988). Statistics from the 1991 census determined the population to be 17 590 (Statistics Canada, 1992). By 1996, the population had increased to 19 265 inhabitants (Statistics Canada, 1999). The most recent census figures, for 2001, indicate a 2.6% increase in population to 19 772 (Statistics Canada, 2002). Newfoundland and Labrador's fastest growing community for two decades; with a 20.8% population increase between 1996 and 2001, the Town of Paradise is currently the fastest growing community; the population of Conception Bay South is projected to reach 22 200 by

2006, necessitating the construction of 90 to 130 residential units annually (Canning and Pitt Associates, 2000a; Marine Institute, 2000).

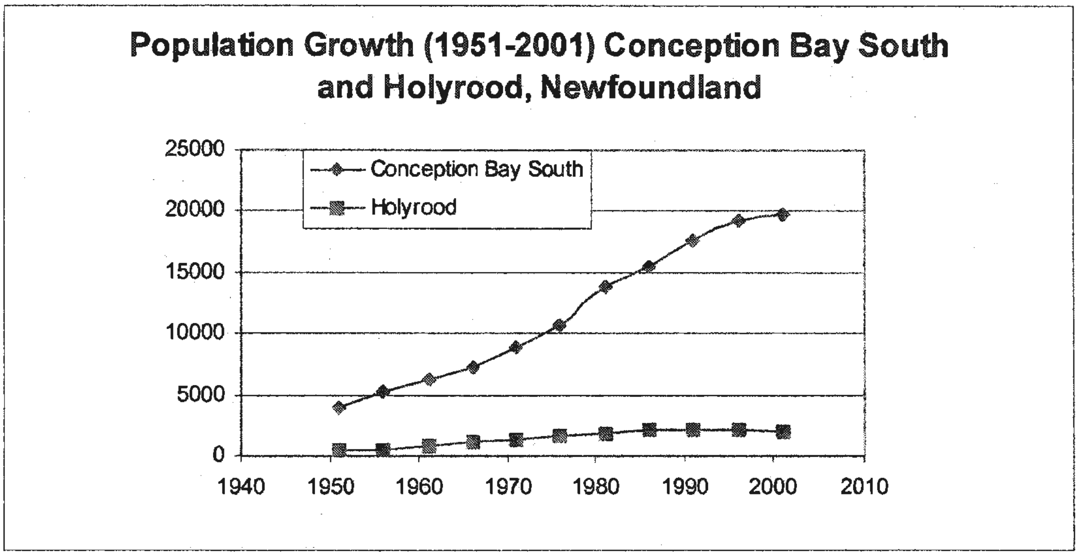

Figure 3.4: Population growth (1951-2001) Conception Bay South and Holyrood, Newfoundland. (Statistics Canada, 1973, 1982, 1992, 1999, 2002; Taylor, 1994).

While many communities within Newfoundland and Labrador are losing young people and families through out-migration, with the provincial population decreasing 7% between 1996 and 2001 (Statistics Canada, 2002), Conception Bay South has continued to attract young families. 52.5% of Conception Bay South's current residents are children under 15 years of age and adults between the ages of 25 and 44. People over the age of 55 are also an important component of the population, constituting 18.1% (Statistics Canada, 2002). The proportion of the population over the age of 40 is expected to increase significantly over the next decade, as the population ages and more people over the age of 55 move into the community (Canning and Pitt Associates, 2000a).

Although Holyrood has an area nearly twice that of Conception Bay South, its population has historically been considerably smaller and continues to be **(Figure 4.1)**. Statistics from the latest federal census of 2001 indicate that Holyrood has a population of 1906, down from 2087 in 1996. Interestingly, the population grew slightly between the previous census years, as the population was 2075 in 1991. However, this is still below the high of 2118 inhabitants in 1986 (Statistics Canada, 1992, 1999, 2002). Holyrood has also tended to attract families. Of the current population, 40.1% are children under 15 and adults between 25 and 44 years of age **(Table 4.2)**. People over the age of 55 constituted 26.5% of the population (Statistics Canada, 2002).

3.8.2: Land Use

With consistent population growth and demand for new housing, as well as an improved provincial and regional economy, Conception Bay South has continued in its development as a sub-regional centre (Canning and Pitt Associates, 2001a). Taylor (1994) indicated that over 80% of the developed area in Conception Bay South lies within 2 km of the coastline. Over the past decade, rapid urbanization, recreation and tourism have become significant economic activities within the community (Canning and Pitt Associates, 2001a). The situation is similar in Holyrood, with a number of residential and commercial developments situated along the coast **(Plate 3.4)**. Historically, much of the area fronting the coastline in these communities was devoted to agricultural and fishing activities **(Plate 3.5)**, but in the recent past, these lands have been converted to residential and commercial uses: uses that are much more significantly impacted by storm activities and changes in coastal processes.

Plate 3.4: The backshore of Holyrood Beach today contains numerous residential and commercial buildings, often constructed very close to the shoreline.

Plate 3.5: Holyrood Beach around the turn of the 20^{th} century: the backshore is dominated by agricultural and pastoral activities.
(photograph courtesy Provincial Archives of Newfoundland and Labrador – PANL VA 9-73)

Chapter 4
Climate Change and Variability

4.1: Climate Change and Variability

Since the end of the last ice age, 10 000 years ago, Canada has experienced both warmer and colder climates, although average temperatures have only varied by 1 to 2 °C (Folland et al., 1990; Gullett and Skinner, 1992). Some 6000 years before present, average global temperatures were approximately 1 °C warmer than at the beginning of the twentieth century and year round precipitation was probably lower (Gullett and Skinner, 1992; Phillips, 1993). In the arctic, summer temperatures may have been as much as 3 °C higher than present values (Gullett and Skinner, 1992). A second warming period occurred between 700 and 1300 AD, when average temperatures were 0.5 to 1 °C higher than present. During this period, known as the "Little Climatic Optimum" or the "Medieval Warming," sea ice cover extent was reduced, the tree line extended further north and the Viking occupation of northern Newfoundland occurred (Gullett and Skinner, 1992; Phillips, 1993; Catto, in press). Beginning in the fifteenth century, a significant cooling began as temperatures dropped 0.5 °C below present values. During this interval, known as the "Neoglacial" or "Little Ice Age," alpine glaciers advanced to the furthest positions since the previous ice age. Along the northern North Atlantic, mean temperatures were 1 to 3 °C cooler than those during the preceding warm period and precipitation values increased (Francis and Hengveld, 1998; Catto, in press). The years between 1810 and 1820 were the coldest on record, with 1818 the coldest year on Newfoundland's Avalon Peninsula (Catto, in press).

With regards to recent climate trends, analysis of Canadian mean annual temperature departures from 1895 to 1991 indicates a statistically significant increase of 1.1 °C. However, this increase was not steady as there was a substantial amount of temperature variation within the past 100 years (Gullett and Skinner, 1992). Temperatures increased throughout the country from the late 1800s to the mid-1940s, after which a gradual cooling was evident. Temperatures began rising again in the late 1970s and approached values not experienced since the Medieval Warming period (Gullett and Skinner, 1992). Environment Canada national temperature departure statistics indicate that seven of the ten warmest years on record have occurred since 1980, four since 1998. Based on annual national temperature departures for the period 1948-2002, the warmest ten years in Canada have been: 1998, 1981, 2001, 1999, 1987, 1953, 1952, 2000, 1977 and 1998. The warmest year, 1998, was 2.5 °C above normal (Climate Trends and Variation Bulletin, Environment Canada). However, climate records for Atlantic Canada indicate that its pattern of temperature change does not follow the general trend seen in the interior of North America, particularly over the last forty years (Pocklington et al., 1994; Jacobs and Banfield, 1996; Morgan and Pocklington, 1997). The ten warmest years in Atlantic Canada for the period 1948-2002 have been 1999, 1953, 1951, 1998, 1981, 1952, 1979, 1960, 2001, 1983 (Climate Trends and Variations Bulletin, Environment Canada). Pocklington *et al.* (1994), in a detailed analysis of mean surface air temperatures of the region, show that although a warming trend is evident in the region starting in 1895, it peaked in the mid-1950s, nearly a decade later than the rest of Canada, and was followed by a cooling trend which is still evident. Analysis of records for St. John's, Newfoundland show a similar pattern, with a general rise during the first half of the twentieth century, a peak near 1950, followed by a general decline in temperature (Pocklington et al., 1994).

The greatest increase of warming within Canada between 1895 and 1991 occurred in a broad band extending from the Mackenzie River Valley (a warming of 1.3 °C over the last century) through the Prairie Provinces (an overall warming of 0.9 °C) (Gullett and Skinner, 1992; Lewis, 1997). In contrast, Atlantic Canada temperatures only increased by 0.4 °C during the same time period and were characterized by an overall cooling of 0.7 °C between the years 1948 and 1991 (Gullett and Skinner, 1992; Pocklington et al., 1994; Lewis, 1997). On a seasonal basis, summers became slightly warmer (+0.5 °C mean), autumns cooler (-0.8 °C mean) and winters substantially colder (-2.2 °C mean) (Lewis, 1997). Sea surface temperature trends in Atlantic Canada followed a similar pattern as the general surface air temperature patterns and data from coastal stations around the northern North Atlantic (Greenland, Ireland, Great Britain) lend further support to this cooling trend, indicating that the cooling experienced in Atlantic Canada is not a localized phenomenon (Pocklington et al., 1994; Morgan and Pocklington, 1997). As Gullett and Skinner's (1992) analysis of Canadian temperature trends shows, temperature changes are not temporally or spatially uniform and it is crucial to remember that this future climate change will not be evenly distributed geographically and some regions may in fact experience a seemingly contradictory cooling. The possibility of continued regional cooling in Atlantic Canada under general conditions of global warming exists (Jacobs and Banfield, 1996). Although global warming will not affect all areas of the earth, the effects will, and evidence from the Climatic Optimum suggests that the greatest impact of any change will be felt in the mid to high latitudes of the Northern Hemisphere (Kemp, 1991).

4.2: Variable Storminess and Extreme Events

Although most studies on climate change have focused on the changes in average climatic conditions, global climate change is also likely to cause changes in climate variability and extreme events, those events that are rare both in their intensity and frequency of occurrence (Bijlsma et al., 1996; Hengeveld, 2000; Schneider et al., 2001). Temporal variations in storminess, including possible increases in storm frequency or intensity, wind climatology, and wave patterns can be expected to have significant effects on rates of coastal erosion and risks of storm surge flooding (Forbes et al., 1997; Mclean et al., 2001). Omitting changes in extreme events and/or climate variability will likely underestimate climate change impacts and vulnerability (Schneider et al., 2001).

In Atlantic Canada, the main types of extreme events are major storms such as extratropical cyclones (nor'easters), tropical cyclones (hurricanes), or severe weather, and their associated phenomena such as storm surges and extreme waves (Abraham, 1997).

Recent modelling experiments suggest that cyclone frequencies could change with climate warming, although there appears to be little change in storm tracks (Lambert, 1995, 1996; Canavan, 1997). For example, the Canadian Climate Centre's general climate model (GCM) indicates that under a doubled CO_2 atmosphere, there will be an overall decrease in the number of cyclone events, but an increase in the number of extreme events (Lambert, 1995; also work by Bengtsson et al., 1996). With subsequent research indicating that climate warming would result in increases to both storm frequency and magnitude (Lambert, 1996).

4.2.1: Nor'easters

The main type of extratropical cyclonic storm to affect Atlantic Canada is the nor'easter, named after the direction from which the wind blows during these events along the U.S. Eastern Seaboard (Davis and Dolan, 1993). They form off the eastern United States and track in a northeasterly direction through the Gulf of St. Lawrence, directly over the Island of Newfoundland or over the Grand Banks. Others form in the lee of the Rocky Mountains in Alberta and track over northern Newfoundland and Labrador. Occurring at any time of the year, nor'easters are most frequent in late autumn/early winter (Davis and Dolan, 1993; Griffiths, 2001).

Studies on extratropical storm frequency and variability in the Atlantic have generally indicated that there is a notable degree of interannual and interdecadal variability (Dolan et al., 1988; Abraham, 1997; Forbes et al., 1997; Mclean et al., 2001). Davis and Dolan

(1993) indicate that the occurrence of nor'easters between 1942 and the mid-1960's declined by approximately 22%. Since then, their occurrence has been erratic and below pre-1965 levels, although the number of very powerful nor'easters has increased. Seven of the eight most extreme storms that developed between 1942 and 1992 occurred after 1968. These findings are supported by Lambert (1996), who analyzed intense extratropical northern hemisphere winter cyclone events from 1899 to 1991 and also found that the number of intense cyclones increased dramatically after 1970. Lambert also found that between 1961 and 1991, there was an increase in intense cyclonic activity over Davis Strait, off Labrador and over the Island of Newfoundland.

Nor'easters are responsible for much of the storm modification of beaches along Conception Bay (Catto, 1999, in press). A strong nor'easter in late September - early October 1992, led to significant modification of beach systems in Conception Bay South and resulted in substantial cliff erosion behind the Topsail United Church (Liverman et al., 1994). Further modification and erosion resulted from weaker, although significant, storms in the fall of 1994 (Catto, 1999, in press).

4.2.2: Hurricanes

Hurricanes form west of the African continent, intensify as they move westwards towards the Caribbean and then tract northwestward towards the U.S. East Coast before weakening over the colder waters of the North Atlantic. The typical hurricane season extends from June through November, with the greatest probability of occurrence in

September. On average, ten tropical storms form each year in the Atlantic Ocean, of which, five reach hurricane strength. However, only one or two storms a year pass through Canadian waters **(Table 4.1)** (Griffiths, 2001).

The record of tropical storms in the western North Atlantic extends back to 1871, and shows a considerable variation in the annual frequency, and in the frequency of storms travelling through Atlantic Canada (Manson and Parks, 2001). For example, in general, between the years of 1931 and 1985, there was a 30% decrease in cyclone frequency in the Canadian Maritimes and New England States (Canavan, 1997). During the 1950s and 1960s overall hurricane frequency was quite high, while between 1970 and 1987 there was a relative decrease in overall hurricane activity. In 1988 and 1989 hurricane activity again increased (Goldenberg et al., 1997). However, the following years of 1991 to 1994 experienced the quietest tropical cyclone activity on record in terms of frequency of tropical storms, hurricanes, and intense hurricanes (Landsea et al., 1996). This was followed by the 1995 and 1996 hurricane seasons, which saw an increase in the average number of storms (Landsea et al., 1996; Francis and Hengeveld, 1998). In fact, 1995 was considered one of the busiest hurricane seasons of the previous 50 years (Landsea et al., 1996). Despite 1995's unusual amount of activity, it capped a five decade downward trend in the frequency of intense hurricanes and maximum wind speeds and a 25 year decline in overall hurricane frequency (Landsea et al., 1996; Francis and Hengeveld, 1998). In 1997, no hurricanes struck Atlantic Canada and the subsequent years of 1998-

Table 4.1: Significant hurricanes, tropical storms, nor'easters and winter storms (1989 - 2001) to impact eastern Newfoundland.

Storm Name	Type	Dates	Date(s) over Newfoundland	Maximum Wind Speed	Date Attained	Impacts
Dean	H	July 31 - Aug. 9, 1989	Aug. 9	169 km/h	Aug. 7	Newfoundland not impacted.
Hugo	H	Sept. 10 - 25, 1989	N/A	217 km/h	Sept. 15	Maritime Provinces received strong winds. Beaches modified along Cape Shore and Burin Peninsula.
Lili	H	Oct. 6 - 15, 1990	Oct. 15	120.5 km/h	Oct. 11 - 13	Caused strong winds in Nova Scotia and Newfoundland. Made landfall as an extratropical storm near Lamaline and Argentia.
Bob	H	Aug. 16 -29, 1991	Aug. 21	185 km/h	Aug. 19	Strong winds felt in Atlantic Canada. Storm modified beaches along Cape Shore, South Coast and Trepassey Bay.
Perfect or Hallowe'en Storm	H	Oct. 28 - Nov. 2, 1991	N/A	120 km/h	Nov. 1	Caused widespread damage from Florida to Newfoundland. Many boats, wharves and coastal properties were flooded or damaged. The highest waves ever recorded on the Scotian Shelf (30.5 m+) were reported during the storm. Beaches along the South Coast, Cape Shore and Conception Bays modified.
October Nor'easter	N	Oct. 2 -7, 1992	Oct. 2 - 7	74 km/h	Oct. 7	Beaches in Conception and Trinity Bays and on Southern Shore affected. Barrier beach in Long Pond breached causing significant damage to the Royal Newfoundland Yacht Club. Severe erosion noted in Chamberlains and Topsail, Conception Bay South.
October Nor'easter	N	Oct. 12-14, 1994	Oct. 12-14	65 km/h	Oct. 13	Beaches in Conception and Trinity Bays and on Southern Shore modified.
Felix	H	Aug. 8 - 25, 1995	Aug. 22	222 km/h	Aug. 12	Passed just south of the Avalon Peninsula on August 22. Southeastern Newfoundland received 15-40 mm of rain. Maximum wave heights of 15-25 m reported. Beaches along South Coast, Cape Shore and St. Mary's Bay modified.

Storm Name	Type	Dates	Date(s) over Newfoundland	Maximum Wind Speed	Date Attained	Impacts
Luis	H	Aug. 26 - Sept. 12, 1995	Sept. 11	222 km/h (92-130 km/h over eastern Newfoundland)	Sept. 3 - 5	Early on September 11, Luis crossed the Avalon Peninsula dumping 60-120 mm of rain. Severe damage to property resulted on the Burin and Bonavista Peninsulas. Maximum wave heights of 30 m reported by the Queen Elizabeth II luxury liner and Canadian NOMAD buoy 44141. Beaches in St. Mary's Bay and along the South Coast modified.
Opal	H	Sept. 27 - Oct. 6, 1995	N/A	241 km/h	Oct. 4	Beaches in St. Mary's and Trepassy Bays and along the South Coast modified October 4 to 6.
Saros	W	Dec. 10, 1995	Dec. 10	81 km/h	Dec.10	Beaches along South Coast and St. Mary's Bay modified.
Hortense	H	Sept. 3 - 16, 1996	Sept. 16	222 km/h	Sept. 13	Beaches along South Coast modified. Winds reached 120 km/h in Atlantic Canada.
Bill	H	July 11 - 13, 1997	July 13	120 km/h	July 12	Gale and storm warnings were issued by both the Maritime and Newfoundland Weather Centres for southern marine waters.
Bonnie	H	Aug. 19 - 20, 1998	Aug. 30	185 km/h	Aug. 24	A maximum windspeed of 74 km/h with gusts of 100 km/h was recorded on the southwestern Grand Banks. Maximum significant wave heights of 14.4 m were recorded.
Danielle	H	Aug. 24 - Sept. 4, 1998	Sept. 3 - 4	165 km/h	Aug. 27	A maximum windspeed of 85 km/h with gusts of 115 km/h was recorded on the southwestern Grand Banks. A wind speed of 93 km/h was recorded at the Hibernia drilling site. A rainfall advisory was issued by the Newfoundland Weather Centre for both the Avalon and Burin Peninsulas.
April Storm	W	1999	N/A	N/A	N/A	Beaches in Conception Bay modified.
Cindy	T	Aug. 19 - 31, 1999	N/A	115 km/h	Aug. 28	Over the southern Grand Banks, peak winds of 115 km/h and maximum wave heights of 16.7 m were reported. No significant effects were felt over land.

Storm Name	Type	Dates	Date(s) over Newfoundland	Maximum Wind Speed	Date Attained	Impacts
Floyd	H/T	Sept. 7 - 17, 1999	Sept. 19	83 km/h	Sept. 13	Maximum seas of 8 - 9 m reported. Beaches along Cape Shore and Conception Bay modified.
Gert	H	Sept. 11 - 23, 1999	Sept. 23	125 km/h	Sept. 16	High waves (approximately 24 m) and surf caused more than $1.5 million of damage and property losses, particularly at St. Brides, Placentia Bay. Beaches along the southern Cape Shore modified.
Harvey	T	Sept. 21 - 23, 1999	Sept. 23	93 km/h	Sept. 21	
Irene	H	Oct. 13 - 19, 1999	Oct. 19 - 20	98 km/h	Oct. 18	Maximum winds were near 98 km/h with gusts of 117 km/h measured along the east coast of Newfoundland. Rainfall amounts for eastern Newfoundland were between 40 and 70 mm. Maximum waves of 14.8 m were reported. Beaches along southern Cape Shore and Burin Peninsula modified.
January Storm	W	January 21 - 23, 2000	N/A	N/A	N/A	Beaches on South Coast and Burin Peninsula modified.
Leslie	T	Oct. 4 - 8, 2000	Oct. 9	65 km/h	Oct. 6	Rainfall amounts over eastern NFLD averaged 20 - 30 mm.
Michael	H	Oct. 15 - 19, 2000	Oct. 19	128 - 150 km/h	Oct. 19	Hurricane Michael made landfall near Harbour Breton, Newfoundland during the evening of October 19. It was the first hurricane to make landfall in the province since Luis in 1995. A peak gust of wind of 170 km/h was reported at St. Lawrence on the Burin Peninsula. Rainfall amounts of 20-75 mm were recorded. Significant wave heights of 7-8 m, with a peak wave height to 16.9 m, were recorded at buoy 44139. There were numerous reports of damages, mainly due to high winds.
Dean	T	Aug. 22 - 28, 2001	Aug. 27 - 28	102 km/h	Aug. 27	Bonavista reported 107 mm of rain between August 27 and 28.

Storm Name	Type	Dates	Date(s) over Newfoundland	Maximum Wind Speed	Date Attained	Impacts
Erin	H	Sept. 1 - 15, 2001	Sept. 14	194 km/h	Sept. 10	Maximum wind speeds were estimated at 130 km/h with significant wave heights of 9.3 m. The maximum recorded wave height, at buoy 44251, was 14.4 m. Heavy rains reported across Newfoundland.
Gabrielle	T	Sept. 11 - 19, 2001	Sept. 18	~100 km/h	Sept. 17	Rainfall records were recorded with between 100 and 175 mm of rain falling over the Avalon Peninsula, most of which fell over a six hour period. Wind gusts in excess of 130 km/h were recorded at Cape Race. Significant wave heights reached 11 m. There were major flooding problems and road washouts in St. John's. Declared as "the worst storm in 100 years," the mayor of St. John's activated the city's Emergency Preparedness Program.

H - Hurricane
T - Tropical Storm
N - Nor'easter
W - Winter Storm
N/A - Storm track did not pass directly over the Island of Newfoundland

(Catto, 2000; Canadian Hurricane Centre, Environment Canada, 2002; National Hurricane Centre, National Oceanic and Atmospheric Administration, 2002)

2001 were characterized by average conditions. Although hurricanes seldom reach Newfoundland because of the cold waters of the North Atlantic, on average, approximately three tropical storms a year threaten Atlantic Canada (Hickey, 1996).

Hurricane activity in the Newfoundland region has been relatively moderate, with similar shoreline morphology patterns over the past twenty years. However, in 1995, the enhanced frequency of hurricanes (Hurricanes Felix, Luis, and Opal affected significant portions of the southern Avalon Peninsula) caused southwesterly winds to be particularly effective in modifying the coastline (Catto, 1999, in press). Strong southwesterly winds frequently generate northeast counterwinds at sea-level, resulting in high waves and beach modifications. They are particularly effective agents of coastline change if they arrive prior to the formation of sea and landfast ice (Catto, in press). The absence of hurricanes in 1997, for the first time since 1961, precluded substantial coastal modification (Catto, 1999; in press). The most recent tropical cyclones to significantly affect the Avalon Peninsula include Felix (1995), Luis (1995), Opal (1995), Hortense (1996), Floyd (1999), Gert-Harvey (1999), Irene (1999), and Michael (2000). Hurricane Michael marked the first time since 1996, although the third time since 1995, that a hurricane made landfall in Atlantic Canada (hitting near Harbour Breton, Newfoundland) (Canadian Hurricane Centre, Environment Canada). In 2001, Tropical Storm Gabrielle caused considerable damages in the St. John's region.

Chapter 5
Methodology

Geomorphological mapping is an important tool in hazard assessment and in planning cost-effective, efficient and environmentally sensitive infrastructure improvements (Petley, 1998). It represents a proven method for collecting data on the location and nature of geomorphological hazards, as it identifies those areas where natural hazards have previously occurred and/or are likely to occur in the future. Thus, geomorphological hazard mapping serves two important purposes. First, it allows the location of the most hazardous areas to be ascertained, thus permitting better land use decision-making. Second, it allows the nature of any geomorphological hazards to be considered when construction is planned (Petley, 1998).

5.1: Geoindicator-Based Shoreline Mapping

Geoindicators are observable landscape responses and indicators of rapid environmental change at timescales of less than 100 years. They provide convenient and effective tools for assessing changes in the landscape resulting from natural processes or human actions (Berger, 1997, 1998). The geoindicator approach is based on standard methods (both qualitative and quantitative) for measuring geochemical, geophysical, and geomorphological processes. It aims to synthesize for any particular area, all the contemporary geological changes that might be significant for environmental assessments (Berger, 1997, 1998).

A major geoindicator in the coastal zone is shoreline position **(Figure 5.1)** (Morton, 1996). This varies over a broad range of time scales in response to sediment erosion and deposition, changes in water level, and land uplift and subsidence. Changes in shoreline position affect transportation routes, coastal infrastructure, communities and natural ecosystems. A number of geomorphological features provide clues to the active physical processes of a shoreline, its natural history and associated natural hazards. The detailed shape and sedimentary character of a beach (e.g. beach slope, cusp dimensions, bar position and morphology, barrier crest and berm elevation, sediment size and shape) are highly sensitive to oceanographic forcing, such as deep-water wave energy, nearshore wave transformation, wave setup, storm surge, tides and, nearshore circulation patterns (U.S. Global Change Research Information Office website). As a result, they are supplementary indicators of shoreline movement (Morton, 1996).

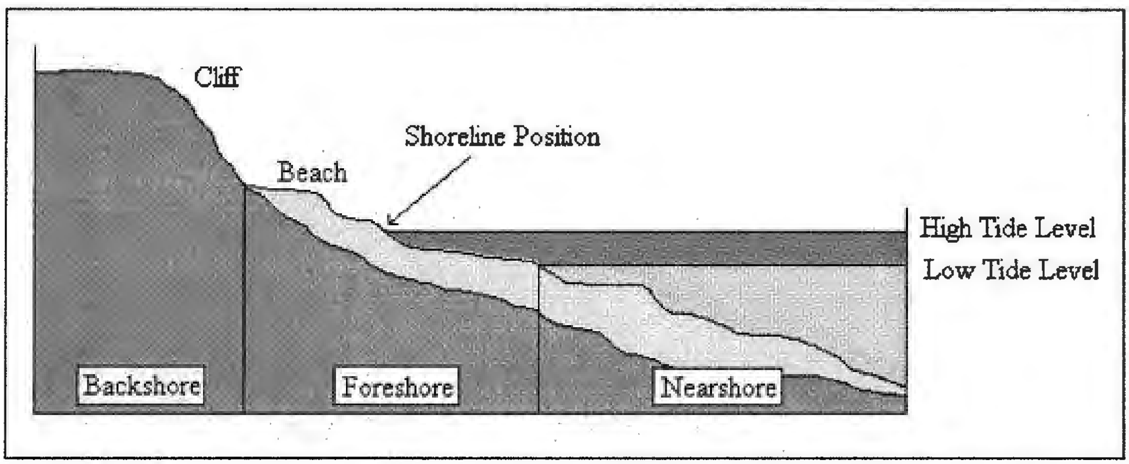

Figure 5.1: Illustration of the shoreline position geoindicator. For this study, the backshore was considered to be the area that extended landward from the cliff-line and active beach interface. Foreshore was the area that extended from the cliff-line to the low tide level. Nearshore (offshore) was the area that extend seaward from the low tide level.

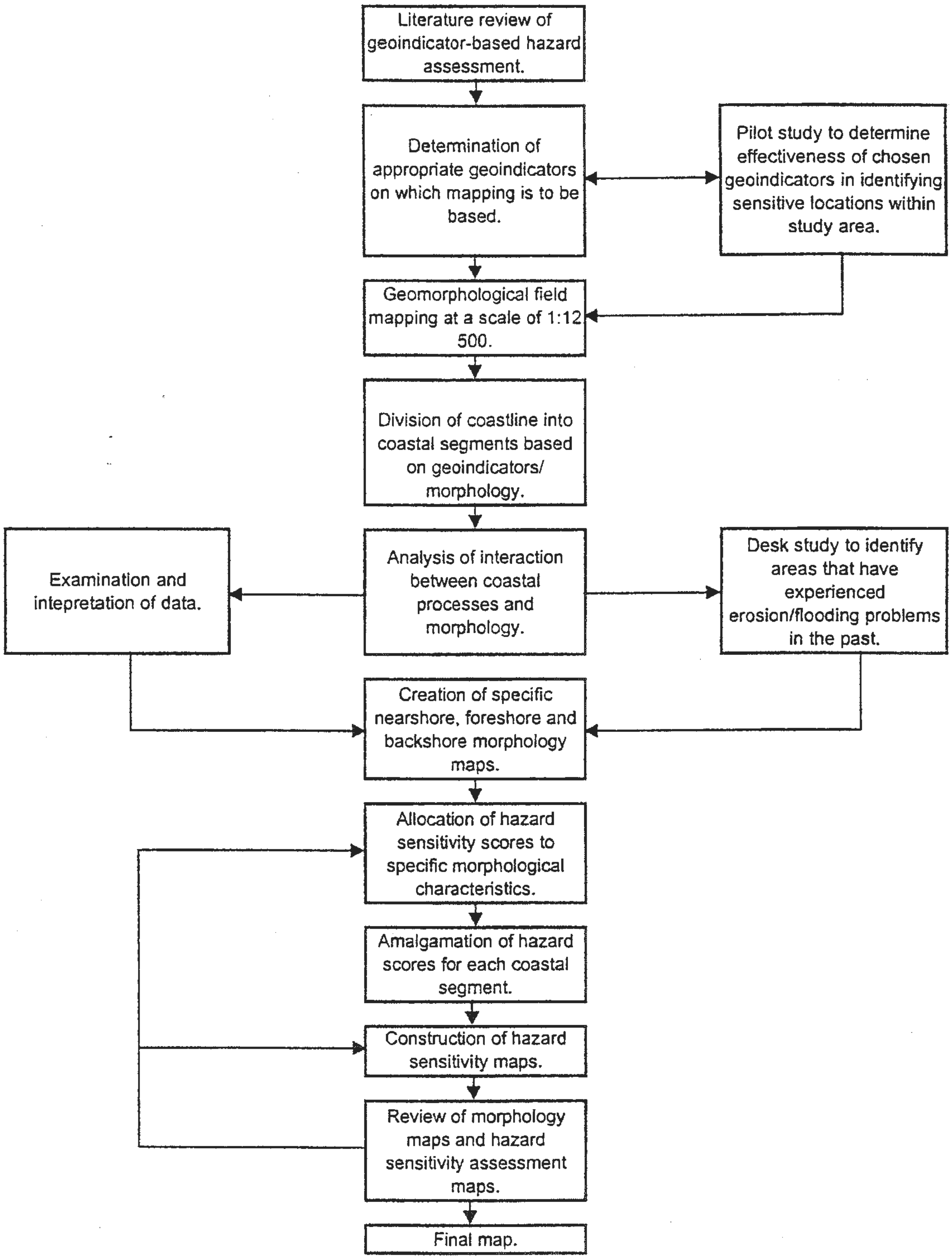

Figure 5.2: Flow diagram illustrating the procedure for the production of a geoindicator-based hazard assessment map (modified from Petley, 1998:192).

Critical observation of these features can help assess the relative intensity of various processes that have acted in the past and can therefore provide an indication of the level of safety or risk a particular location has (Young et al., 1996). For example, site elevation is a key indicator of susceptibility to inundation (Young et al., 1996), while barrier crest height on gravel-dominated systems is directly related to wave run-up, overtopping and overwashing processes (Forbes and Liverman, 1996). Beaches that form features such as spits or baymouth barriers (barachoix), with open water on both sides of the landform, are potentially susceptible to overwash, flooding or erosion. Inlets are often unstable and liable to migrate, posing a risk of erosion on nearby shores (Young et al., 1996). Vegetated washover fans suggest a stable shoreline, and thus a lower-risk area, although they could have a future risk of overwash. Vegetated hillslopes reduce surface flow rates during storms and also lower erosion potential (Young et al., 1996).

Detailed evaluation of the Conception Bay South – Holyrood coastline for the purposes of creating coastal hazard sensitivity maps was based on the geoindicators approach **(Figure 5.2)**. Field mapping was undertaken using a modification of the geoindicator-based assessment of shoreline change developed by Young *et al.* (1996:Tables 1 and 2) **(Tables 5.1 and 5.2)**. They developed a checklist of geoindicators to be used for the qualitative assessment of shoreline erosion or accretion, for qualitative shoreline monitoring and for the evaluation of other potential coastal hazards. Their system allows sites to be evaluated quickly and effectively, particularly where quantitative data are absent. Shoreline change is evaluated using a visually-assessed checklist based on specific geomorphic and vegetation indicators, thus providing solid documentation of when, where and to what degree change is occurring (Young et al., 1996). The checklist is biased towards eroding, storm-impacted systems such as barrier islands and unconsolidated shorelines and as such is ideally suited to the Conception Bay South-Holyrood coastline. Initial field assessments were conducted between September 30 and October 16, 2000. Additional fieldwork was conducted in November 2000, June and July 2001.

Table 5.1: Conception Bay South coastal hazard assessment site evaluation form.

Parameter	High Risk	Moderate Risk	Low Risk
Site elevation	1-5m	6-15m	>15m
Beach width and slope	1-5m: narrow and flat	6-10m: wide and flat or narrow and steep	>10m: wide with well developed berm
Beach material type and size	unlithified sand to cobble	Unlithified cobble to boulder	lithified
Beach thickness	backshore vegetation exposed on beach	-	-
Overwash	overwash apron (frequent overwash)	overwash fans (occassional overwash)	no overwash
Cliff configuration	bare face, recent or no talus ramp (severe to slow erosion)	Vegetated face and well-developed ramp (stable)	bluffs vegetated with vegetated ramp at toe (accreting)
Infrastructure	lots and close to beach *man-made structures now on beach or offshore	some and more removed from beach or on middle ground	little to none or on high ground
Vegetation on site	little vegetation or toppled vegetation, overwash fans unvegetated	well-established shrubs and grasses, none toppled; herbaceous vegetation on overwash fans	mature vegetation, forested, no evidence of erosion; overwash fans well vegetated
Distance to waterbodies	very close (flood potential)	within sight	distant
Area landward of site	lagoon, marsh or swamp	floodplain, low elevation terrace	upland
Drainage	poor	moderate	good
Coastal shape	concave or embayed	straight	convex
Natural offshore protection	none, open water	offshore boulders	limited fetch, offshore boulders
Offshore shelf	wide and shallow	moderate	steep and narrow

Table 5.2: Modifications made to the geoindicator-based assessment of shoreline change developed by Young *et al.*(1996: Tables 1 and 2).

Parameter	Modification
Site evaluation	Values were changed to more accurately reflect vulnerable elevations in Eastern Newfoundland.
Shoreline change rating from Table 1	This parameter was omitted as the checklist incorporated geoindicators for dune coastlines. Dunes are not present along the southern Conception Bay coastline. Geoindicators that were applicable were combined into the coastal hazard assessment site evaluation.
Beach width, slope and thickness	This parameter was divided into two categories, beach width and slope and beach thickness. The beach thickness description was changed from "mud, peat or stumps exposed" to "backshore vegetation exposed on beach."
Overwash	No change.
Site position relative to inlet or river mouth	Changed to "distance to waterbody."
Dune configuration	Omitted as dunes are not present along the southern Conception Bay coastline.
Bluff configuration	Low risk descriptor changed from "low angle (large ramp), mature cover of vegetation" to "bluffs vegetated with vegetated ramp at toe."
Coastal shape	Omitted due to small size of study area and uniform coastal shape.
Vegetation on site	No change.
Drainage	No change.
Area landward of site	No change.
Natural offshore protection	Moderate risk descriptor changed from "frequent bars offshore" to "offshore boulders present." Low risk descriptor changed from "submerged reef, limited fetch" to "limited fetch, offshore boulders."
Offshore shelf	Omitted.
Beach material type and size	Parameter added to coastal hazard assessment site evaluation form.
Infrastructure	Parameter added to coastal hazard assessment site evaluation form.

5.2: Description of Geoindicators

Geoindicators selected for field evaluation of the Conception Bay South-Holyrood coastline were chosen based on their applicability for assessing coastal hazards; specifically those that influence or are influenced by natural coastal processes. For example, site elevation is directly related to susceptibility to innudation, as low-lying areas are subject to destructive wave attack, overwash, and storm-surge flooding. Higher elevations protect coastal areas from the direct impacts of waves and sea ice (Young et al., 1996; Sheppard, 1997).

Distance to lagoon, in conjunction with site elevation, is related to flooding potential as the barrier beach in front of the lagoon is often low in elevation and likely to be overwashed, flooded or eroded. As well, if a lagoon outlet is blocked, flooding potential in the back-barrier area increases.

Bathymetric slope influences wave and sea ice climate. Relatively steep bathymetry allows higher waves to impact the coastline and also allows sea ice to reach the shore, potentially causing flooding (due to ice jams) and physical damage to infrastructure. Low slopes cause waves to dissipate further offshore, thus reducing their direct impact on the coastline, as well as preventing ice from reaching the shore (Sheppard, 1997).

Beach material type and size are important as bedrock coastlines are more resistant to erosion than unlithified sediments. Clast size of unlithified sediments is also important, as smaller clasts (sand and pebbles) are easily eroded and transported by wave action. Higher wave energy is required to move larger sediments.

Wide beach areas *(beach width)* absorb the majority of wave energy and can prevent the movement of ice to back-beach areas. Overwash fans or aprons along the backside of a barrier indicate overtopping by storm waves, with aprons indicating more frequent overtopping events.

Unlithified cliffs may be undercut by waves, resulting in cliff edge retreat *(cliff status)*. Cliff failures produce talus cones at the base of the cliff, slowing down wave attack. However, as the cone is eroded, stability is reduced and cliff failure is repeated. Unvegetated talus cones on the beach indicate active backshore erosion processes. Vegetated talus cones suggest current stability, but indicate past instability.

The *presence of vegetation* is an indicator of coastal stability and lower hazard potential, as well-developed grasses, shrubs and trees on the backshore suggests little erosion has occurred. Leaning or toppled vegetation indicates active erosion processes, while sparsely vegetated back-barrier fans are indicative of active overwash processes. Vegetation also reduces surface flow rates during storms, further reducing erosion. Therefore *site drainage* is an important parameter, with good drainage suggesting lower risk. The *presence of backshore vegetation* exposed on the beach face is directly related to active foreshore erosion as it means that the land-water interface has migrated landwards over the former backshore (terrestrial) environment. At the time that the vegetation initially developed, the foreshore was seaward of its current position **(Figure 5.3)**.

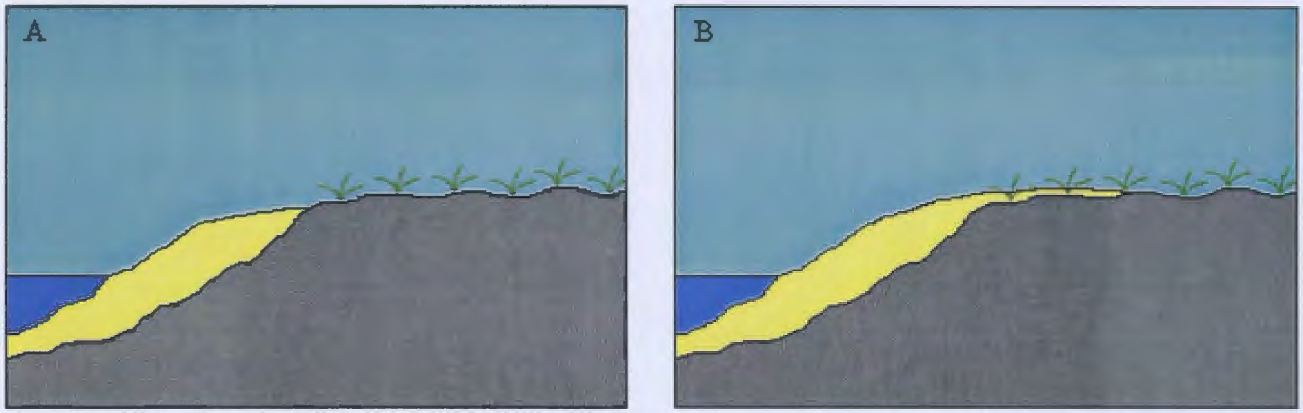

Figure 5.3: Illustration of *beach thickness* geoindicator. (A) Stable foreshore and backshore environment, with abundant backshore vegetation. (B) Landward migration of beach sediments over the backshore environment burying vegetation. Continued migration results in the exposure of former backshore vegetation in the foreshore environment.

The *amount of infrastructure* along a coastline increases the impact of coastal hazards, particularly if they are located close to the land-water interface. Flooding, erosion, waves and sea ice can have a direct impact on infrastructure.

In terms of natural protection, *offshore boulders* afford protection against erosion processes through dissipation of incoming wave energy. Wave action is the primary process controlling coastal morphology, sediment redistribution and biota in the shore zone.

Fetch distance determines the size of waves that can strike a coastline. Greater fetch distances result in higher wave energy and thus larger waves, which have a more pronounced effect on the shoreline in terms of increased erosion potential and damage to infrastructure. Therefore, shorter fetch distances provide a degree of protection from significant wave damage. Wind direction (frequency) and strength, along with an extensive fetch distance, may enhance the effects of waves and ice on the coastline.

5.3: Evaluation of Geoindicators

Site Slope

Site elevation was based on numerical slope gradients (measured in degrees) derived from contour interval data using simple trigonometric calculations made on 1:2500 topographic map sheets. Tan angles were calculated for a series of transects constructed normal to the shoreline. Transects were spaced approximately 12 to 25 m apart depending on continuity of coastal morphology. The landward extent of transects varied depending on location, but usually ended at the 10 m contour interval. On barriers, transects extended to the highest contour interval. Along coastal bluffs transects extended to the break in slope at the top of the bluff or to the T'railway (a province-wide recreational trail system that follows the former Newfoundland Railway line) where it bordered the coastline. Similar successive values were averaged together for simplicity. Individual transect values that were significantly different from the values of adjacent transects were not included in the average and were mapped as separate data points.

Bathymetric slope

Bathymetric slope angles were calculated from transects constructed normal to the shoreline on 1:15 000 and 1:60 000 hydrographic charts the same way they were calculated for site slope. On the 1:15 000 hydrograph charts (Foxtrap and Holyrood

Marinas and wharf at the Holyrood Generating Station), transect were spaced every 50 m and extended to the –2 m bathymetric depth interval. On the 1:60 000 hydrographic charts, transects were spaced every 450 m and extended to the –5 m depth interval. However, steeper nearshore bathymetry resulted in exceptions at the Holyrood Generating Station (to –10 m depth interval), from the Holyrood Generating Station to the Ultramar storage facility (to –20 m depth interval) and from the Ultramar storage facility to the end of the study area (to –10 m depth interval).

Beach width

Beach width was based on values obtained from beach profiles constructed using the Emery pole surveying methodology (Emery, 1961).

Beach material type and size

Beach material type and size was categorized as either lithified or unlithified. Unlithified segments were classified according to a field estimation of clast size, (sand, pebble, cobble, boulder) based on the Udden-Wentworth grain size classification scheme (Wentworth, 1922), and distribution.

Beach thickness

Beach thickness was visually noted in the field as the presence or absence of backshore vegetation (turfed ground) exposed on the beach face. As no measurements were made from an established datum, absolute values of beach thickness were not derived.

Overwash

Overwash was visually noted in the field as either present or absent. If present, a further distinction was made between washover fans and aprons (amalgamated washover fans). Presence of vegetation on overwash fans and aprons was also noted.

Area landward of site

Backshore areas were classified as lagoon, marsh, low elevation plain or upland for the purposes of defining unique coastal segments.

Cliff configuration

Composition of cliffs/upland areas was noted as being either lithified or unlithified. Unlithified cliffs were evaluated as having bare faces with cliff sediments present on the beach (presence of a talus cone), or vegetated faces with either a non-vegetated or vegetated talus cone on the beach.

Vegetation on site

Vegetation on site was visually assessed in the field by presence or absence, type (herbaceous versus arboreal), and status (well established or toppled). Specific plant species were not noted.

Drainage

Site drainage was visually assessed in the field as good, moderate, or poor. Classification was based on lagoons having or not having an outlet, whether these outlets were open, presence of standing water, and the status of watercourses and marshes.

Distance to waterbodies

Distance to waterbodies was a qualitative measure of site proximity to a lagoon, marsh or watercourse, used for the purposes of defining unique coastal segments. It allowed coastal segments with laterally extensive morphologic continuity to be subdivided into smaller segments. It was insignificant in differentiating hazard sensitivity and was therefore not included in the sensitivity assessments.

Infrastructure

Presence of infrastructure in the backshore was classified qualitatively as "abundant," "some," and "little to none." Infrastructure type and proximity to the foreshore were also noted, as was the presence of man-made structures now on the beach or offshore. As well, the presence and type of erosion control measures, such as seawalls or riprap, was also recorded in the field. A more detailed evaluation of backshore infrastructure, particularly around lagoons, was made after the initial field investigation using 1:12 500 black and white aerial photographs (1985-1986) and 1:12 500 colour aerial photographs (1995).

However as hazards are geologic processes that can potentially injure or damage human life and infrastructure, the amount of infrastructure present in a particular coastal segment will not affect whether processes such as erosion or flooding occur (except in the case of protective works such as seawalls or dykes). As the purpose of the hazard sensitivity assessment is to determine the susceptibility of any coastal segment to the effects of erosion or flooding, only the presence of protective works was included in the analysis.

Natural offshore protection

Natural offshore protection was visually noted in the field by the presence or absence of offshore (nearshore) boulders. Coastal segments sheltered by Bell, Little Bell and Kelly's Islands were also noted as having a limited fetch. Additional quantitative measurements of fetch were subsequently made. Effective fetch distance for each unique coastal segment was calculated from 1:50 000 topographic maps based on direction of incidence [shore normal, and shore oblique (45° right and 45° left)] and azimuth. However, similarity in azimuth and effective fetch data values determined through these calculations for the majority of coastal segments led to the exclusion of the fetch geoindicator in the sensitivity assessments.

5.4: Construction of Hazard Sensitivity Maps

The basic concept underlying the field mapping procedure follows that of Howe *et al.* (1994) in that the shore zone was subdivided and described in terms of the systematic collection of physical characteristics (geoindicators). This approach to mapping is descriptive in nature (functional relationships are not incorporated into the classification scheme) and allows non-technical users of the data to recognize the basic nature of the shoreline.

Geoindicator data collection and field mapping (using **Table 5.1**) involved walking the Conception Bay South-Holyrood coastline and subdividing it into unique segments based on along-shore and across-shore morphologic continuity. This resulted in the creation of 65 distinct coastal segments. Morphologic continuity was fundamental to the creation of unique coastal segments, as a change in one or more along-shore components (i.e., a change in form, texture, elevation or vegetation status) defined a new segment **(Plate 5.1 and 5.2)**. Segment boundaries were mapped in the field on 1:12 500 black and white aerial photographs. Additional data on infrastructure were subsequently collected from aerial photographic interpretation, although they were later determined not to be particularly useful to the final hazard sensitivity evaluation and were not included.

Plate 5.1: This photograph illustrates a simple alongshore variation is sediment texture: coarse-grained sediments (cobble to boulder) characterize the western side of the beach (left middleground), while the eastern side has a significant amount of sand present (right foreground). This is segment 8383.5 – 8843.5 m in Kelligrews.

Plate 5.2: This photograph illustrates a more subtle change between two coastal segments. In this case, slight differences in elevation (the middle section, denoted by arrows, is lower that the surrounding landscape). The middle section is segment 6342.5 – 6411.5 m in Foxtrap.

To create the hazard sensitivity maps, the various parameters of **Table 5.1** were classified as either a nearshore, foreshore, or backshore geoindicator **(Table 5.3)**. The morphologic information for each specific nearshore, foreshore and backshore geoindicator was then mapped onto separate 1:12 500 composite orthophoto maps. Each morphology type was assigned a hazard sensitivity score based on its susceptibility to flooding or erosion. These values were then transcribed onto composite maps that combined the relevant geoindicators for each specific hazard being assessed (applicable to determining either flood or erosion sensitivity). Overall hazard sensitivity for each unique coastal segment was determined by totalling the hazard sensitivity scores of applicable geoindicators **(Appendix 2)**. Individual segment boundaries are given as distance alongshore, which was measured in metres starting at the northeastern end of Topsail Beach Rotary Park (0). Distance along lagoons was measured in a clockwise direction starting at the eastern edge.

Table 5.3: Classification of coastal hazard assessment parameters as nearshore, foreshore or backshore geoindicators for use in constructing hazard sensitivity maps.

Parameter	Nearshore	Foreshore	Backshore
Site slope		X	X
Bathymetric slope	X		
form of foreshore		X	
Beach width and slope		X	
Beach material type and size		X	
Beach thickness		X	
Overwash		X	
Cliff configuration			X
Infrastructure			X
Vegetation on site		X	X
Distance to waterbodies			X
Area landward of site and backshore composition			X
Drainage		X	X
Coastal shape		X	
Natural offshore protection - presence of offshore boulders	X		
Offshore shelf	X		

Four hazard classes were created:

Extreme – areas with a very high level of hazard. There is evidence of currently active erosion processes or the presence of low lying, flood sensitive topography.

High – areas of high hazard. There is evidence of past erosion activity or a history of flooding.

Moderate – areas of moderate hazard. There is limited evidence of the presence of a flood or erosion hazard.

Low – areas of extremely low hazard. Areas show little evidence of the presence of a flood or erosion hazard, and it is judged that such geomorphological hazards are only likely to be triggered by extremely low frequency/high magnitude events (i.e. extreme events).

A "no hazard" category was not created because, although some areas may not currently experience geomorphological hazards, this does not necessarily mean that they are completely free from the effects of extreme events, particularly under changing climatic conditions.

5.4.1: Flood Hazard Sensitivity Map

For the flood hazard sensitivity map **(Appendix 1)**, the only geoindicator component map used was backshore slope as this was considered a reasonable proxy for determining which areas were susceptible to inundation: low-lying areas being at greater risk. Flood hazard sensitivity was defined as follows:

Sensitivity Class	Sensitivity Score
Extreme	Slopes less than 2°
High	Slopes between 3° and 7°
Moderate	Slopes between 8° and 14°
Low	Slopes greater than 15°

5.4.2: Foreshore Erosion Hazard Sensitivity Map

Four foreshore morphology geoindicators were considered in the construction of the foreshore erosion hazard sensitivity map **(Appendix 1)**: form of foreshore, sediment type, presence of offshore boulders and bathymetric slope. In terms of the sensitivity scoring, a score of 1 represented a low sensitivity, while a score of 4 represented an extreme sensitivity. Lagoons, watercourses and anthropogenically modified foreshore segments were excluded from analysis and not given a sensitivity score. Assigning numerical sensitivity scores in this manner implies that each geoindicator is of equal weight in the overall sensitivity analysis, i.e. each variable contributes equally to the process of foreshore erosion. While this simplifying assumption may not be strictly valid, it allows for a more uniform estimate of hazard sensitivity.

Form of Foreshore	Sensitivity Score
Marsh	4
Washover fans present*	4
Barrier beach	3
Fringing beach	2
Bedrock dominated coastline	1

Sediment Type	Sensitivity Score
Pebble, cobble	4
Cobble	3
Cobble, boulder	2
Pebble, cobble, boulder	2
Boulder	1
Bedrock dominated coastline	1

Bathymetric Slope	Sensitivity Score
Slopes greater than 20°	3
Slopes between 6° and 20°	2
Slopes less than 5°	1

*The scoring for form of foreshore was unique in that segments classified as *fringing* or *barrier beach* could also be classified as having *washover fans present*, meaning that two forms of foreshore were possible. This was considered the best method for highlighting coastal segments where overwash fans were present. Thus the minimum vulnerability score for form of foreshore is 1 and the maximum is 7.

Offshore Boulders	Sensitivity Score
Absent	2
Present	1

Foreshore erosion hazard sensitivity was defined as follows. As the minimum combined sensitivity score was 4 and the maximum was 16, these formed the end points of hazard sensitivity class extremes. The maximum value of 16 was based on a segment characterized as being a barrier beach, with pebble to cobble sized sediments, with washover present, with bathymetric slope greater than 20° and with offshore boulders absent.

Sensitivity Class	Sensitivity Score
Extreme	14-16
High	11-13
Moderate	7-10
Low	4-6

5.4.3: Backshore Erosion Hazard Sensitivity Map

The construction of the backshore erosion hazard sensitivity maps **(Appendix 1)** was based on consideration of four backshore morphology components: slope, backshore composition, presence of erosion control measures, and status of backshore vegetation.

Backshore Slope	Sensitivity Score
Slopes greater than 15°	4
Slopes between 8° and 14°	3
Slopes between 3° and 7°	2
Slopes less than 2°	1

Backshore Composition	Sensitivity Score
Unlithified	3
Discontinuous unlithified over bedrock	2
Bedrock	1

Erosion Control Measures	Sensitivity Score
Present	2
Absent	1

Vegetation Status	Sensitivity Score
Anthropogenically modified	3
Little to none	3
Moderate	2
Abundant	1

Backshore erosion hazard sensitivity was defined as follows. The highest possible score attainable was 12 and set the upper limit of the extreme category. The lowest possible score was 4. The upper limit of the low backshore erosion sensitivity class was determined as a result of the steep (greater than 15° slope), bedrock dominated coastline in Holyrood. Although the slope value was high, the highly resistant nature of the bedrock meant that the sensitivity of these coastal segments to backshore erosion processes was low. Therefore, the upper limit of the low sensitivity score was set at 7: this value representing the rating for a well vegetated, bedrock dominated coastal segment with slope greater than 15° and no erosion control measures present

Sensitivity Class	Sensitivity Score
Extreme	11-12
High	9-10
Moderate	8
Low	4-7

The foreshore erosion sensitivity hazard scores were not taken into consideration when determining the backshore erosion sensitivity hazard. Even though the potential for foreshore erosion will have a substantial impact on the stability of backshore cliffs (i.e. removal of beach sediments allows for direct wave attack on cliffs with resulting undercutting and removal of cliff sediments), it does not consider hillslope processes that act independently: for example, slope washing and gully headwall retreat. Incorporating the foreshore erosion sensitivity hazard may underestimate the backshore erosion hazard as the threat may not be entirely from foreshore coastal processes.

Chapter 6:
Results

6.1: Coastal Morphology Descriptions

Topsail

Topsail Beach is a combination barrier/fringing beach approximately 30-35 m wide and 1.8 km long. It is composed of a variety of clast sizes (pebbles to boulders), with a distinct alongshore variation in their distribution. In the extreme northeast, cobbles and boulder-sized sediments dominate, with numerous boulders present in the nearshore zone. The barrier beach fronting Topsail lagoon is composed of finer-grained pebbles and cobbles. Two transects (GSC-450 and GSC-451) were installed by the Geological Survey of Canada across the barrier beach as part of a joint provincial-federal coastal monitoring program **(Figure 6.1)** (Liverman et al., 1994). Transect GSC-450, across the eastern end of the barrier, has a weakly convex profile and is dominated by pebble-sized clasts, with occasional cobbles. Transect GSC-451, across the western end of the barrier, has a steeply sloped, concave profile **(Figure 6.2)**. Sediments are in the pebble to cobble range and scattered boulders are present. West of the lagoon, all grain sizes (pebbles to boulders) are present, with pebbles more frequent near the inter-tidal zone. Bathymetric slope averages 1.4° along the entire beach system.

Amalgamated washover fans are present along the entire length of the barrier beach. Lobes to the west are well vegetated and stable, while frequent shifting of the outlet in

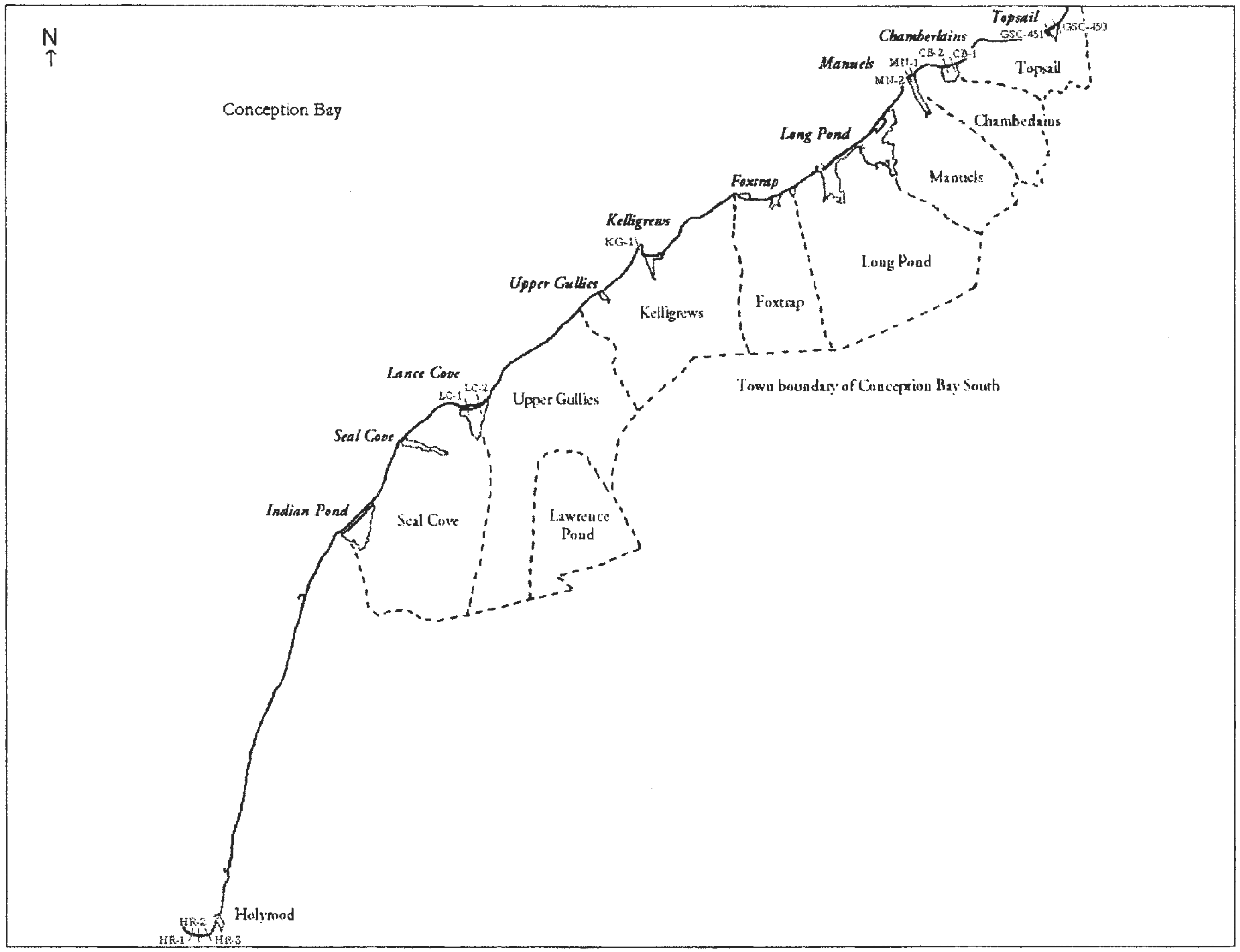

Figure 6.1: Beach transect locations for profiles conducted on Topsail, Chamberlains, Manuels, Kelligrews, Lance Cove and Holyrood beaches. Lagoon names are italicized. (scale approximately 1:130 000)

the east has prevented the establishment of vegetation there. West of the lagoon, landward migration of beach sediments over the former backshore surface has occurred. Extremely well developed cusps are present along the entire length of the beach system, although not at all times. Detailed measurements can be found in Prentice (1993). Cusp horns are composed of relatively coarse-grained clasts (cobbles), while finer-grained sediments dominate the cusp embayments.

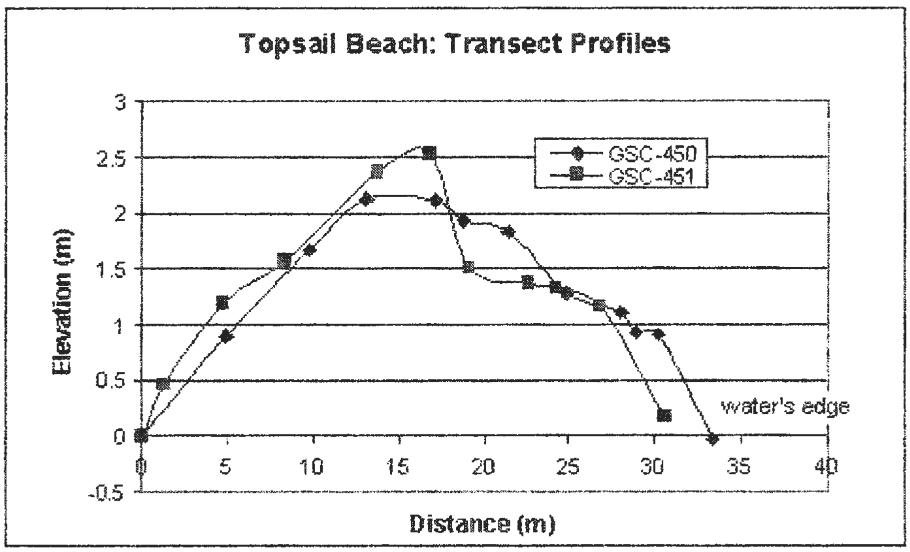

Figure 6.2: Beach transect profiles conducted for Topsail Beach, September 30, 2000.

The majority of the backshore is composed of unlithified Quaternary bluffs, which rapidly rise from less than 2 m elevation west of the lagoon to 20 m elevation. The bluffs west of 1495 m are actively eroding, with vegetation and sediment sliding downslope onto the beach **(Plate 6.1)**. These bluffs were stable prior to 1992 (trees cored by Liverman *et al.* (1994) were found to be over 70 years old). Photographs from the early 20th Century **(Plate 6.2)** indicate that cliff erosion has been an ongoing problem.

Plate 6.1: Photograph taken September 30, 2000 showing eroding slopes behind the Topsail United Church (segment 1702 – 1783 m). The Geological Survey of Canada established survey lines to monitor erosion rates at this location in July 1993.

Plate 6.2: Unlithified bluffs west of Topsail lagoon (coastal segment 1127 – 1392 m). Note exposed sediments in the foreground. Trees are no longer present at this location and current cliff vegetation is dominantly herbaceous (photograph courtesy Provincial Archives of Newfoundland and Labrador – PANL A6-45 – date unknown).

Chamberlains

Chamberlains is also characterized as a combination barrier/fringing beach. The barrier beach at Chamberlains Pond varies between 25 m and 40 m wide and is composed dominantly of pebbles and cobbles, with scattered boulders. Two transects installed by Memorial University's Department of Geography are located at the eastern and western ends of the barrier **(Figure 6.1)**. The barrier morphology is characterized by a steeply sloping, peaked profile with small steps along the seaward face **(Figures 6.3 and 6.4)**. The adjacent fringing beaches are considerably coarser-grained than the barrier beach, with pebbles being absent. Significant offshore boulders extend from the point at 1783 m west to 2303 m and between 3048 m and 3151 m. Cuspate structures are common along the fringing beach west of the barrier, although not at all times. They are approximately 10-15 m long and 2-4 m wide, with their size increasing towards the barrier. Offshore baythmetric slopes average 2.0° east of the barrier, and average 1.1° in front of the barrier and towards Manuels.

A number of unvegetated washover fans are present along the back of the barrier and a permanent lagoon outlet is lacking. This lack of a permanent outlet has often resulted in severe flooding of the low-lying land surrounding the pond. Outlets are occasionally dredged to alleviate flooding, the channels fill quickly as the water level within the lagoon decreases. Infilling occurs rapidly as there is no headland present to deflect the direction of longshore sediment transport. For example, an outlet dredged in the spring of 1999 filled within ten days (Don Pittman, personal communication) **(Plate 6.3)**. With outlet infilling occurring so rapidly, there is not sufficient time for channel migration alongshore.

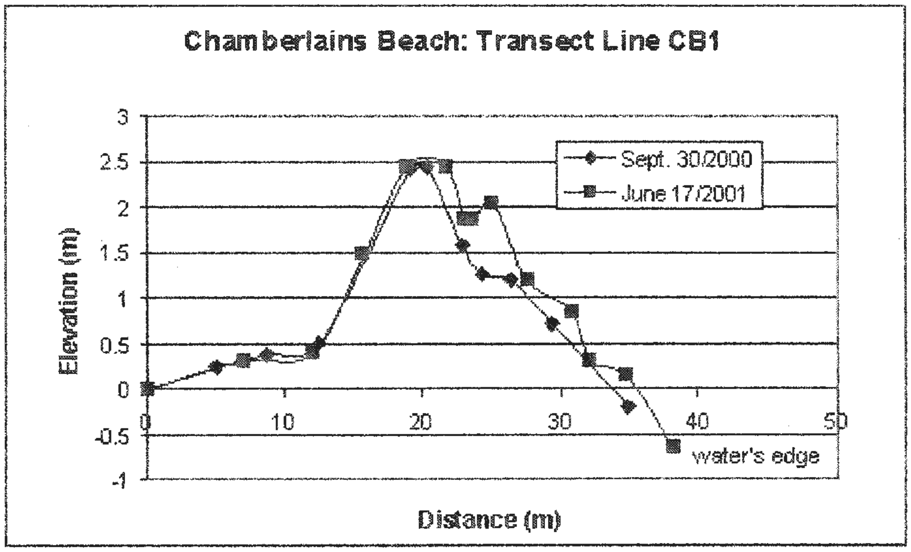

Figure 6.3: Beach transect profile CB1 conducted for Chamberlains Beach, September 30, 2000 and June 17, 2001, showing changes in morphology.

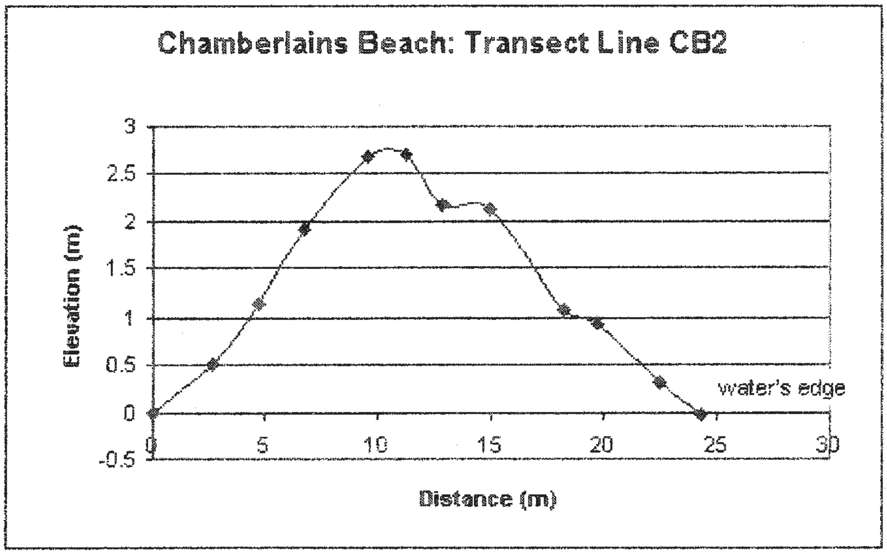

Figure 6.4: Beach transect profile CB2 conducted for Chamberlains Beach, July 23, 2001.

The backshore is characterized by steeply sloping, unlithified bluffs. Bluffs to the east of Chamberlains Pond are moderately to well vegetated with grasses and shrubs, while the bluffs to west of the pond are unvegetated and actively failing.

Plate 6.3: Outlet dredged in the Chamberlains Pond barrier beach (2507 –2818 m) in the spring of 1999 to alleviate flooding problems filled within ten days (photographs courtesy Don Pittman).

Manuels

The barrier beach fronting the Manuels Rivers (forming Manuels Pond) is 30 to 35 m wide and composed of pebble to boulder sized clasts. Two transects installed at either end of the barrier by Memorial University **(Figure 6.1)** indicate a steeply sloped morphology with numerous well-defined convex steps on the seaward face of the barrier **(Figures 6.5 and 6.6)**. Offshore boulders fringe the headland at the western end of the barrier where a small permanent outlet drains the lagoon. This headland protects the outlet against longshore sediment infilling from the southwest. A number of unvegetated washover fans are present along the back of the barrier. Bathymetric slope averages 1.1°.

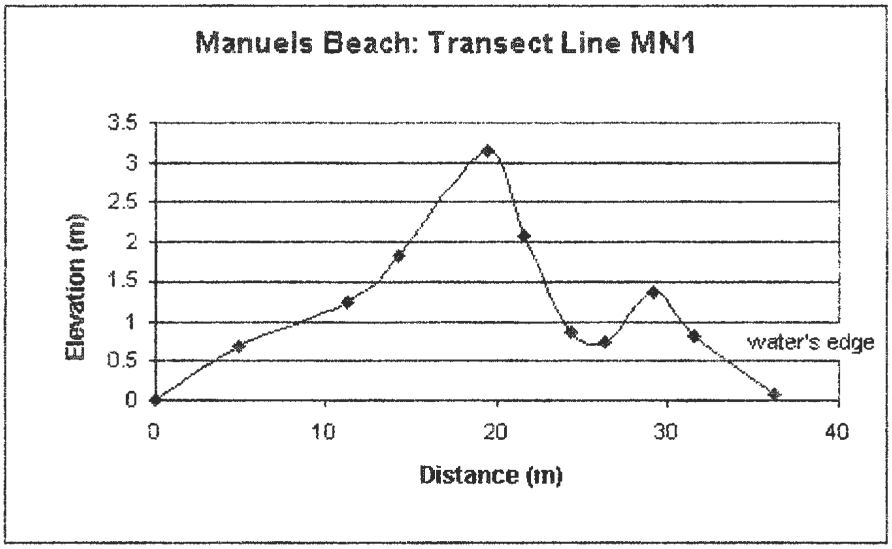

Figure 6.5: Beach transect profile MN1 conducted for Manuels Beach, September 30, 2000.

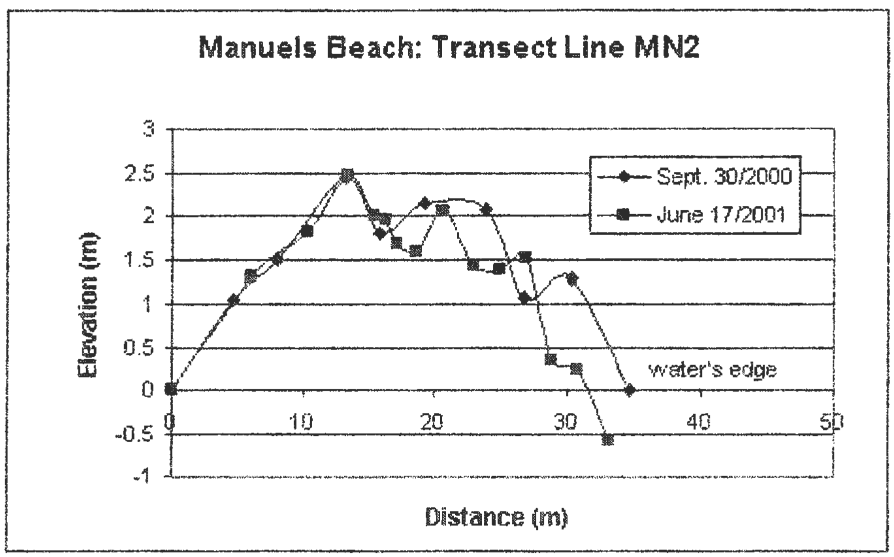

Figure 6.6: Beach transect profile MN2 conducted for Manuels Beach, September 30, 2000 and June 17, 2001, showing changes in morphology.

Bluffs composed of unlithified Quaternary sediments characterize the backshore, although the western edge of the lagoon is characterized by bluffs composed of weathered shale bedrock overlain by Quaternary sediments. Cliff faces lack a protective vegetative cover and are actively eroding.

Long Pond

The initial segment of the Long Pond barrier beach, from 4278 – 4531 m, connects to Burnt Island, a small glaciofluvial outwash feature. Beach sediments along this segment are characterized by pebble to boulder sized clasts and there is an exposure of former backshore vegetation on the present beach face, indicating active terrestrial overstepping. This segment also shows evidence of washover activity, but it has been obscured by recent anthropogenic activity (a road was constructed along the back of the barrier in 2000).

The principal section of the barrier beach, which is approximately 1.3 km long, is very steep, with a well-defined berm and concave profile. It is composed of pebbles and large cobbles, with occasional scattered boulders. Jetties have been constructed at the southwestern end of the barrier (6038 m) and at the Port of Long Pond (6141 m), with a navigation channel behind the barrier being routinely dredged. Bathymetric slopes are quite shallow (1.1° – 1.3°) and offshore boulders are absent. The Long Pond barrier beach is the subject of a detailed geomorphic study by Don Pittman of Memorial University of Newfoundland (M.Sc. Thesis, Department of Geography, in preparation).

Foxtrap

Coarse-grained fringing/barrier beaches also characterize the Foxtrap section of the Conception Bay South-Holyrood coastline. The coastline fronting the pyrophyllite mine storage area (6141 – 6343 m) consists of low (five metres elevation) bluffs, fronted by a narrow fringing beach composed of riprap boulders. The remaining fringing beach in Foxtrap is composed of pebble to cobble sized sediments. Two small, pebble-cobble barrier beaches are located east of the Foxtrap Marina (6659 – 6785 m and 6958 – 7199 m). Washover fan deposits are present along the back of each barrier and there is evidence that each lagoon has a temporary outlet (each barrier has a small, partially infilled channel). Offshore boulders are present from the Port of Long Pond through to the second small pond and at Foxtrap Head, west of the marina. Bathymetric slope averages 1.6°. A small marsh area is located in the backshore of segment 7303 – 7567 m.

Kelligrews

The Kelligrews coastline is characterized by an extensive fringing beach dominantly composed of cobbles and scattered boulders, with the occasional patch of pebbles and coarse sand. A barrier beach fronts Keligrews Pond. Along the backshore, the T'railway recreational trail (which follows the former railway line) begins to parallel the coastline at Foxtrap Head (7866 m). With its seaward side lined with riprap boulders, it offers protection against coastal erosional processes. Backshore elevations are low and vegetative cover varies from moderate herbaceous cover to well-established, mature trees. Nearshore boulders are numerous and extend for nearly the entire length of the Kelligrews coastline. Bathymetric slope averages 1.5°.

The former railway impacted the morphology of the barrier beach fronting Kelligrews Pond, as it ran across the barrier crest. At the northeastern end of the barrier, the beach is less than five metres wide and composed of cobbles and boulders, with some backshore sections heavily riprapped. From 9948 – 10 063 m, the entire barrier is composed of riprap, except for some cobbles in the inter-tidal zone. The back of the barrier beach is extensively vegetated and backed by a low, marshy, wetland and then lagoon. At Kelligrews Point (10 201 – 10 511 m), which is approximately three metres above sea level, the beach widens considerably and is composed of small pebbles and coarse sand, before progressing into a dominantly boulder deposit that continues offshore as a spit. A transect installed at the western end of the point by Memorial University has a fairly straight, sloping profile **(Figure 6.1 and 6.7)**. Herbaceous vegetation is sparse to moderate. At less than one degree, bathymetric slope at the point is extremely low.

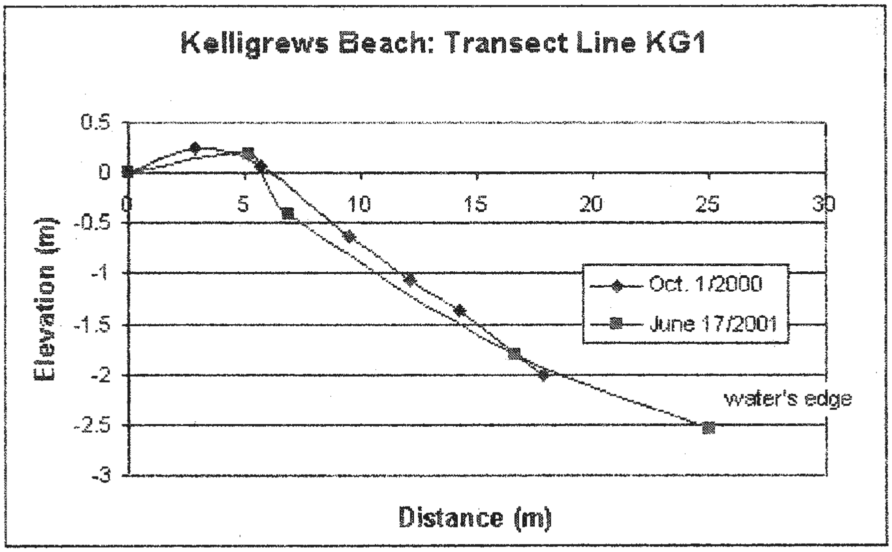

Figure 6.7: Beach transect profile KG1conducted for Kelligrews Beach, October 1, 2000 and June 17, 2001, showing changes in morphology.

Riverdale and Upper Gullies

West of Kelligrews Point, the backshore rapidly rises in elevation to approximately 20 m above sea level. The unlithified cliffs are moderately vegetated with grasses and shrubs, and a small patch of trees from 11 178 – 11 236 m. However, extensive rilling occurs on both the landward and seaward sides of the T'railway. The narrow fringing beach is composed of cobble to boulder sized clasts. Nearshore boulders are numerous and bathymetric slope approaches 2°.

Towards Upper Gullies Pond (11 581 – 11 684 m), the backshore cliffs decrease in elevation until they are approximately 5 to 10 m above sea level and the fringing beach widens. The barrier beach fronting Upper Gullies Pond is composed of boulder riprap.

Boulder riprap. As are two short segments of fringing beach on either side of the barrier beach. Upper Gullies Pond has a permanent, maintained outlet.

Southwest of Upper Gullies Pond, backshore elevation increases to approximately 20 m above sea level and herbaceous vegetation is sparse to moderate. Numerous active failures, with cliff sediments present on the beach, have occurred on the seaward side of the T'railway **(Plate 6.4)** and there is substantial rilling of the landward cliff face. A metal railway tie and boulder riprap seawall has been constructed between 13 076 m and 13 225 m. While the fringing beach remains wide, it is dominated by pebble to cobble sized sediment, with only scattered boulders. Nearshore boulders extend for approximately 400 m alongshore and bathymetric slope varies between 1.2° and 3.2°.

Plate 6.4: Debris flows initiating from the T'railway Recreational trail in Lance Cove (13 225 – 14 203 m).

Lance Cove

The fringing beach east of the Lance Cove barrier is composed of cobble to boulder sized sediments and offshore boulders are absent. Backshore cliffs decrease in elevation to approximately 10 m and are well vegetated with shrubs, grasses and trees. Offshore bathymetry averages 1.1°.

The Lance Cove barrier beach is 55 to 60 m wide and over 6 m high. As a result the back of the barrier is heavily vegetated with abundant shrubs, grasses and a few trees. Two beach transects installed by Memorial University **(Figure 6.1)** reveal a steeply sloping profile with a well-developed berm between 10 m and 20 m wide **(Figure 6.8 and 6.9)**. Bathymetry in front of the barrier averages 1.9°. The barrier is primarily composed of cobble to boulder sized clasts, although pebbles are quite common in the inter-tidal zone and within the embayments of large cusp formations: sand is rarely encountered within the barrier, although it is occasionally present in the nearshore zone. Large, moderately developed cusps are occasionally encountered in the central portion of the barrier. Approximately 11-22 m long and 2-8 m high (dimensions increasing towards the west), they are characterized by coarse-grained horns (cobble-sized clasts), with finer-grained embayments. Pebbles are most common, although coarse sand may form the embayments of smaller cusps formed at the waterline. At either end of the barrier, metal railway ties have been hammered into the beach as a stabilization measure.

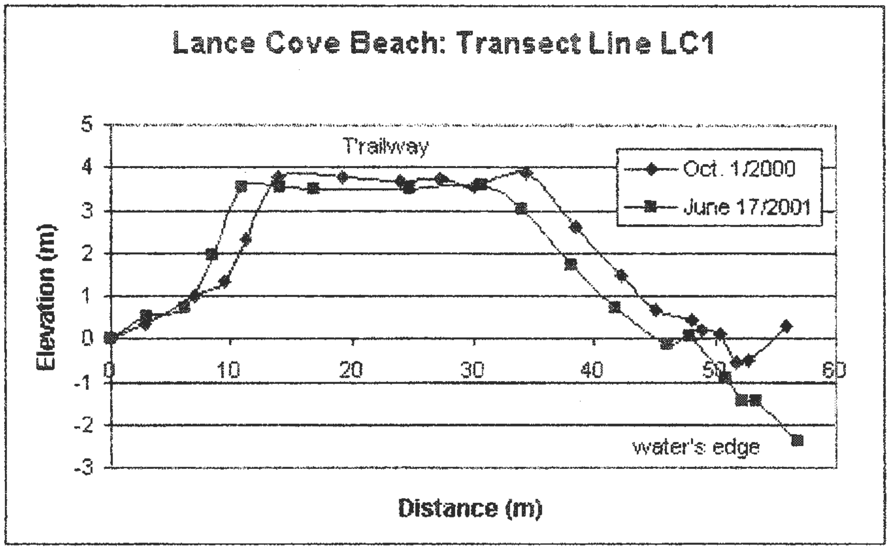

Figure 6.8: Beach transect profile LC1 conducted for Lance Cove Beach, October 1, 2000 and June 17, 2001, showing changes in morphology.

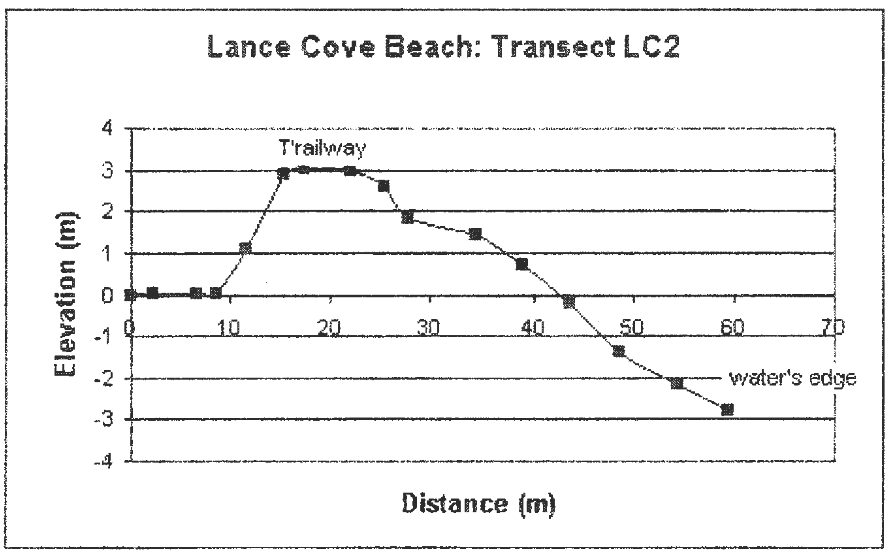

Figure 6.9: Beach transect profile LC2 conducted for Lance Cove Beach, June 17, 2001.

The morphology of the backshore, southwest of the lagoon, has been substantially modified by a sand and gravel excavation operation at Lance Cove Head (15 376 – 15 698 m). Extraction activities are strictly limited to the backshore region. Vegetation is sparse along the 15 m high cliff face and active erosion is occurring. The narrow, fringing beach is composed solely of boulder-sized clasts and is fronted by a nearshore boulder fringe.

Seal Cove

Between Lance Cove Head and Seal Cove, the fringing beach is wide, but narrows in front of the Seal Cove lagoon. It is composed dominantly of boulder-sized sediments, but cobbles are present from 16 434 – 16 549 m. A fringing beach composed of cobbles and boulders occurs southwest of the lagoon. Bathymetic slope averages 1.8° along the eastern portion of the Seal Cove coastline and increases to 2.2° southwest of the Seal Cove barrier.

The short Seal Cove barrier beach is composed of cobbles and boulders and a permanent outlet is artificially maintained. Offshore boulders are found west of the barrier. Bathymetry directly in front of the barrier averages 1.1°. Unlithified slopes east and west of the lagoon are sparsely vegetated and actively eroding, with the slope failures (debris flows) originating off the seaward side of the T'railway.

Indian Pond

The Indian Pond coastline is characterized by a combination fringing/barrier beach composed of cobble to boulder sized sediments. The barrier beach is of considerable width, with numerous grassy washover fans located along the back of the barrier. Offshore boulders are numerous and bathymetric slope averages 2.3°. The backshore is composed of unlithified sediments that are sparsely to moderately vegetated.

Holyrood

From the generating station to the loading wharf (18 941 – 21 344 m), the coastline is dominated by a fringing beach composed of cobbles and pebbles. The unlithified backshore is moderately vegetated with both herbaceous vegetation and mature trees. From 21 344 m to the Ultramar Refinery at 32 994 m, the coastline is dominated by bedrock cliffs. These cliffs are well vegetated with extensive stands of mature trees, shrubs and grasses. Small amounts of pebble to boulder-sized sediments occur at the base of the cliffs. Towards the refinery, the bedrock is overlain by unlithified sediments. Bathymetric slope averages 8.0°.

Holyrood beach is a 20 to 25 m wide fringing beach dominantly composed of pebbles and cobbles. It is weakly concave in profile (**Figure 6.10**). A small creek runs behind the beach, with a permanently maintained outlet at the eastern end of the beach. Offshore boulders are absent and bathymetric slope averages 5.5° within the first 100 m. The former railway embankment, now the T'railway recreational trail, runs across the beach crest and acts as a back berm for the beach, providing a coarse sediment supply and stability to the beach system, and controlling onshore sediment movement. At the Holyrood Marina, the coastline has been anthropogenically modified, as there is a large boulder riprap jetty and extensive wooden seawall. The remainder of the study region coastline (34 995 – 35 788 m) is composed of riprap boulders. Backshore vegetation is moderate and dominantly herbaceous.

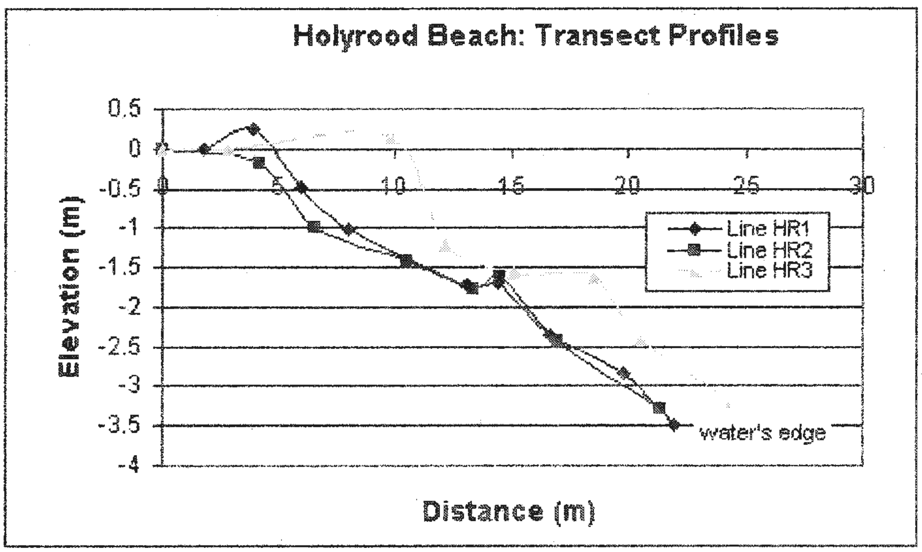

Figure 6.10: Beach transect profiles HR1, HR2 and HR3 conducted for Holyrood Beach, June 17, 2001.

6.2: Hazard Sensitivity Assessments

6.2.1: Flood Hazard Sensitivity Assessment

In the flood hazard sensitivity assessment, 60 263 m of coastline, including lagoons, was analyzed to determine susceptibility to inundation **(Appendix 1)**. Overall, two-thirds of the Conception Bay South-Holyood coastline has a low (42.3%) to moderate (26.6%)

sensitivity to flooding **(Table 6.1)**. However, when analyzed separately, the results of the flood hazard sensitivity assessment for the open water section of coastline facing Conception Bay (subsequently referred to as "straight exposed") differ significantly from the coastline surrounding the inner lagoons. Hazard sensitivity class ratings for individual coastal segments are listed in the flood hazard sensitivity component tables located in **Appendix 2.1 and 2.2**[*].

Table 6.1: Results of the flood hazard sensitivity assessment.

Hazard Sensitivity Class	Sensitive Coastline	
	m	%
Low	25 494	42.3
Moderate	16 033	26.6
High	12 363	20.5
Extreme	6355	10.5

Total coastline assessed: 60 263 m

Table 6.2: Results of the flood hazard sensitivity assessment based on type of coastline.

Hazard Sensitivity Class	"Straight Exposed" Coastline		Lagoon Coastline	
	m	%	m	%
Low	21 956	61.4	3538	14.5
Moderate	8766	24.5	7267	29.7
High	2730	7.6	9633	39.4
Extreme	2404	6.7	3951	16.1

Total "straight exposed" coastline: 35 788 m
Total lagoon coastline: 24 475 m

[*] Distance alongshore was measured in metres starting at the northeastern end of Topsail Beach Rotary Park (0 m). Individual segment boundaries are referred to their distance along the coastline from this point. Distance along lagoons was measured in a clockwise direction starting at the eastern edge.

The "straight exposed" coastline facing Conception Bay is characterized by a low (61.4%) sensitivity to flooding. In contrast, only 14.5% of the lagoon coastlines have a low flood hazard sensitivity, with 39.4% having a high sensitivity to flooding and 29.7% being moderately sensitive. This difference in results reflects the geomorphology of the study area. Twenty to thirty metre high cliffs of unlithified, Quaternary sediments and steeply sloped barrier beaches dominate the coastline of Conception Bay South, while the majority of the Holyrood coastline is backed by steep bedrock cliffs. Low-lying land more susceptible to inundation is seldom encountered along the coastline. It is only found in the Kelligrews region of Conception Bay South, along the numerous lagoons and at the head of Conception Bay in Holyrood.

6.2.2: Foreshore Erosion Hazard Sensitivity Assessment

In the foreshore erosion hazard sensitivity assessment, 35 788 m of coastline fronting Conception Bay was assessed to determine susceptibility to foreshore erosion processes. The majority of the Conception Bay South-Holyood coastline has a low (59.9%) to moderate (27.3%) sensitivity to foreshore erosion **(Table 6.3)**. A reflection of the dominance of very coarse-grained, fringing beaches; relatively shallow bathymetry (averaging 2° within the first 300 m of the shoreline); and a prevalence of nearshore boulders, which dissipate incoming wave energy. Hazard sensitivity class ratings for individual coastal segments are listed in the foreshore erosion hazard sensitivity component tables located in **Appendix 2.3**.

Table 6.3: Results of the foreshore erosion hazard sensitivity assessment.

Hazard Sensitivty Class	Sensitive Coastline	
	m	%
Low	21 446	59.9
Moderate	9755	27.3
High	3047	8.5
Extreme	1437	4.0

Total foreshore assessed: 35 788 m

However, these results consider the overall sensitivity of the entire coastline and mask important differences in sensitivity based on the different types of foreshore. This is especially true as bedrock dominated coastlines represent a third of the entire coastal study length **(Table 6.4)**. Anthropogenically modified and bedrock dominated sections of coastline received only low hazard sensitivity ratings, while no section of coastline classified as barrier beach did. Fringing beaches have a low to moderate sensitivity to foreshore erosion, with no coastal segment receiving an extreme rating. This reflects the coarse-grained nature of beach sediments, as pebble to boulder sized sediments characterize the southern Conception Bay coastline. Coastal segments where nearshore boulders were present received low sensitivity ratings, while the absence of nearshore boulders resulted in a moderate rating. Barrier beaches have a moderate to extreme sensitivity to foreshore erosion process and are the only form of foreshore to receive an extreme erosion sensitivity rating. Segments receiving an extreme rating had relatively finer grained sediments and washover fans were present, indicating past erosion activity.

Table 6.4: Results of the foreshore erosion hazard sensitivity assessment based on form of foreshore.

Hazard Sensitivity Class	Fringing Beach[a]		Barrier Beach[b]		Bedrock[c]		Anthropogenic[d]	
	m	%	m	%	m	%	m	%
Low	8474	23.7	0	0	12 029	33.6	943	3
Moderate	8881	24.8	874	2.4	0	0	0	0
High	575	1.6	2714	7.6	0	0	0	0
Extreme	0	0	1437	4.0	0	0	0	0

a: Total fringing beach coastline: 17 930 m
b: Total barrier beach coastine: 5025 m
c: Total bedrock coastline: 12 029 m
d: Total anthropgenic coastline: 943 m

6.2.3: Backshore Erosion Hazard Sensitivity Assessment

In the backshore erosion hazard sensitivity assessment, 31 941 m of coastline was assessed to determine susceptibility to backshore erosion processes. Barrier beaches were not considered in this sensitivity assessment. Hazard sensitivity class ratings for individual coastal segments are listed in the backshore erosion hazard sensitivity component tables located in **Appendix 2.4**.

Analysis of the overall backshore erosion sensitivity results shows that half of the Conception Bay South-Holyood coastline has a low to moderate sensitivity (54.2%) to backshore erosion, or has a high to extreme sensitivity (44.3%) **(Table 6.5)**. The reason sensitivity is nearly equally split between low and high ratings is mainly due to geology **(Table 6.6)**. Where bluffs of unlithified Quaternary sediments outcrop along the coast, there is a higher sensitivity to erosion processes. In contrast, the granite of the Holyrood Instrusive Suite is highly resistant to erosion. Overall, the unlithified coastline has a high (22.1%) to extreme (11.6%) sensitivity to backshore erosion, while the lithified coastline is characterized by a low (29.0%) sensitivity.

Table 6.5: Results of the backshore erosion hazard sensitivity assessment.

Hazard Sensitivity Class	Senstive Coastline	
	m	%
Low	12 029	38.9
Moderate	4733	15.3
High	9600	31.0
Extreme	4110	13.3

Total backshore assessed: 31 941 m

The presence of vegetation also affected sensitivity to backshore erosion processes. Segments of coastline where vegetation was abundant received lower sensitivity ratings than segments where vegetation was sparse or lacking (see **Appendix 2.4**).

Table 6.6: Results of the backshore erosion hazard sensitivity assessment based on backshore composition.

Hazard Sensitivty Class	Bedrock[a]		Unconsolidated[b]		Discontinuous[c]		Anthropogenic[d]	
	m	%	m	%	m	%	m	%
Low	8964	29.0	1328	4.3	817	2.6	920	3.0
Moderate	46	0.1	1710	5.5	3007	9.7	0	0
High	104	0.3	6847	22.1	441	1.4	0	0
Extreme	0	0	3585	11.6	525	1.7	0	0

a: Total bedrock coastline: 9114 m
b: Total unconsolidated coastline: 13 470 m
c: Total discontinuous coastline: 4790 m
d: Total anthropgenic coastline: 920 m

Chapter 7
Discussion

7.1: Accuracy of Results

The results of the hazard sensitivity assessments conducted as part of this study are only meaningful if they are an accurate description of the actual sensitivity of any particular segment along the Conception Bay South-Holyrood coastline. Therefore, was the geoindicator-based hazard assessment methodology developed in this study able to correctly identify those coastal segments where erosion and/or flooding were known to occur as being highly to extremely sensitive. As well as correctly identifying those segments with known low sensitivities to flooding and erosion processes? In addition, was the method able to highlight the sensitivity of very short segments of coastline, or was it overwhelmed by the results for larger, surrounding segments? Accuracy of the hazard sensitivity assessment results was verified by comparing sensitivity class ratings with a series of sites along the Conception Bay South-Holyrood coastline for which there was pre-existing hazard information.

The coastline west of the Holyrood Thermal Generating Station is steeply sloped and composed of highly resistant granite bedrock. It is therefore not prone to flooding, nor is it susceptible to foreshore or backshore erosion processes. As a result, this section of coastline should receive low hazard sensitivity ratings in the flood, foreshore and backshore erosion hazard sensitivity assessments. This section thereby provides an opportunity to test the accuracy of the methodology developed in the study for identifying coastal segments with low hazard sensitivity. It should be noted that is the only such suitable location within the study area. To confirm the accuracy of coastal segments assigned an extreme hazard sensitivity rating, two sites with known problems for each of the flood, foreshore and backshore erosion hazard sensitivity assessments were chosen for comparison. For the flood hazard sensitivity assessment, Chamberlains and Kelligrews Ponds were selected; for the foreshore erosion hazard sensitivity assessment, the Topsail and Long Pond barriers were selected; and for the backshore erosion hazard sensitivity assessment, the cliffs behind the Topsail United Church and between Long Pond and Chamberlains Pond were selected. Although there are other locations along the Conception Bay South-Holyrood coastline susceptible to flooding or erosion activity, supporting documentation and data is lacking.

Results for the flood hazard sensitivity assessment indicate that the methodology was able to accurately identify sections of coastline with a low flood hazard. However, further refinement may be required to increase the accuracy of the methodology in identifying coastal sections with a high to extreme flood hazard. Flooding has been documented at both Chamberlains and Kelligrews Ponds throughout the 1990s (Taylor, 1994; **Plate 6.3**), with historical accounts of flooding at Kelligrews Pond dating back to the 1920s (Batterson et al., 1999). The flood hazard sensitivity assessment classified the majority of the Kelligrews Pond coastline as having a high to extreme flood hazard, and this result is supported by historical data. However, there were two segments classified as having a moderate hazard and one segment classified as having a low hazard. This suggests that either the flood hazard sensitivity methodology is highly accurate, with more defined descriptions of how extensive past flooding was at each locality being required to test validity. Although further refinement may be required for the flood hazard to be accurately represented, the occurrence of historical flooding indicates that the methodology is valid at least in part. The Chamberlains Pond coastline was classified as having a high to extreme flood hazard, except for one coastal segment that received a moderate rating. These results suggest that more detailed spatial data for historical flood occurrences are required to confirm the accuracy of the flood hazard sensitivity methodology.

Results for the foreshore erosion hazard sensitivity assessment indicate that the methodology is able to accurately identify coastal segments with both low and high to extreme vulnerabilities to foreshore erosion processes. The bedrock foreshore in Holyrood received a low rating, accurately reflecting the highly resistant character of the Holyrood Intrusive Suite granite. The hazard sensitivity assessment identified the Topsail Beach barrier as having an extreme foreshore erosion hazard. This result is supported by previous research that indicates that the Topsail Beach barrier has been reduced greatly in size and extent since the 1940s and remains susceptible to erosion activity (Catto, 1994; Catto et al., 1999; Prentice, 1993). Although the Long Pond Barrier was breached in 1976 and in 1992 (Pittman, in preparation; Taylor, 1994), research by Pittman (in preparation) indicates that various segments of the barrier respond differently. He notes that the extreme western end of the barrier is currently prograding and is not susceptible to erosion processes. This study found that that segment had a moderate sensitivity to foreshore erosion. Pittman found that the middle portion of the barrier, between Burnt Island and the prograding section is highly unstable morphologically. This location is where the breaches in 1976 and 1992 occurred. The hazard assessment accurately identified this segment as having an extreme foreshore erosion hazard. Pittman concluded that the northeastern past of the barrier was stable and not prone to changes in morphology, while this study identified this portion of the barrier as having high erosion sensitivity. However, it is important to consider the variation in the temporal scale between the two studies. Pittman's study assessed historical morphological change, while the purpose of the present study was to assess current and potential future change.

The results for the backshore erosion hazard sensitivity assessment indicate that the methodology is able to accurately identify segments of coastline with either low or high erosion sensitivity. In July 1993, the Geological Survey of Canada in partnership with the Geological Survey of Newfoundland and Labrador established three survey lines to monitor erosion along the cliff behind the Topsail United Church. Prior to 1992, the cliff had been stable for 50 to 80 years based on ring counts obtained from three tree cores (Liverman et al., 1994). After a major nor'easter in early October 1992, the cliff began actively eroding, resulting in the downslope displacement of trees and sediments. This activity has continued to the present with a significant loss of trees **(Plate 6.1)**. With active erosion occurring for nearly a decade and resulting in a substantial loss of vegetation and sediment, it would be expected that this segment would receive an extreme backshore erosion hazard sensitivity rating. As the segment was rated as having a high sensitivity to backshore erosion, the methodology was able to accurately identify a serious backshore erosion hazard.

Analysis of the change in cliff position on rectified aerial photographs from 1951 to 1995 by the Geological Survey of Canada indicate that the cliffs between Long Pond and Chamberlains have retreated 10 to 40 cm/year **(Figure 7.1)**. The backshore erosion hazard sensitivity assessment correctly identified this section of coastline as having an extreme sensitivity. The granite cliffs along the Holyrood coastline were accurately identified as having a low to moderate backshore erosion hazard. Segments where unlithified Quaternary sediments overlay bedrock, received moderate sensitivity ratings, while segments characterized wholly by bedrock received low sensitivity ratings.

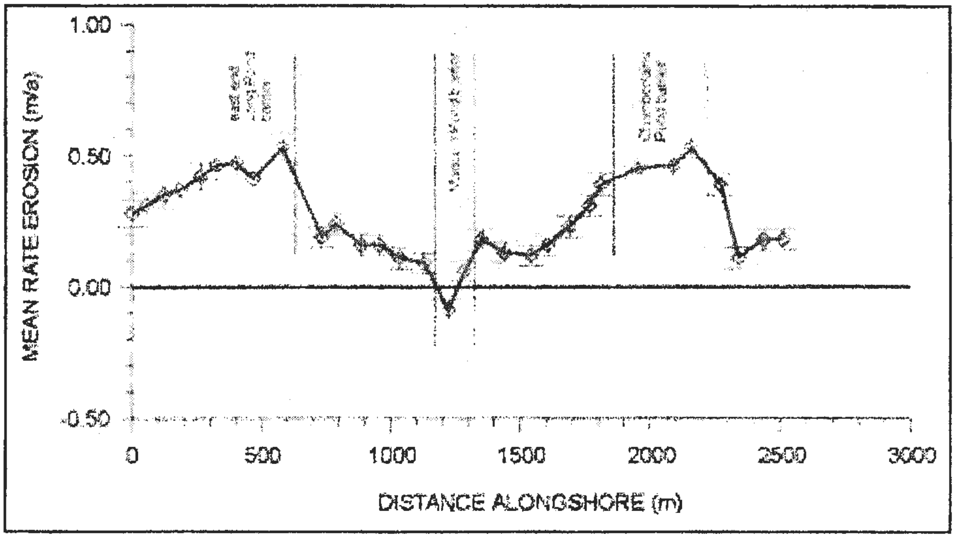

Figure 7.1: Mean erosion rate (cm/year) 1951-1995 for the Long Pond to Chamberlains coastal section of the study area. Barrier retreat rates are in orange, cliff erosion rates are in blue (unpublished data courtesy of Dr. Don Forbes, Geological Survey of Canada, Bedford Institute of Oceanography).

7.2: Limitations of the Methodology and Possible Solutions

Overall, the methodology developed for this project performed well. It was able to accurately identify both low and extremely sensitive coastal segments and was sensitive enough to highlight the sensitivity of very short sections of coastline (the length of which were constrained only by the scale of the display map). However, there were a number of problems with the methodology that resulted in potential under-estimations of the hazard sensitivity.

A significant shortcoming of the flood sensitivity assessment methodology was the dominant use of backshore slope data and not foreshore slope data (except in the case of barrier beaches, as they are backed by lagoons). Although all slope calculations began at the land-water interface, the values generated were a more accurate representation of backshore slope conditions as opposed to foreshore slope conditions. For flat to gently sloping backshore environments, this was not an issue, but where a coastal segment consisted of a beach backed by a steep cliff (as along the T'railway between Kelligrews and Lance Cove), the slope values would favour the cliff and the flood sensitivity of the segment would be underestimated. The lower sloped beach more sensitive to inundation would not be highlighted on the flood sensitivity map.

Another limitation of the flood sensitivity methodology developed for this study was that it was designed to assess flood risk to rising water levels, but not the risk of extreme or storm wave activity. While it is inherent that low-lying areas will be highly susceptible to these processes, this methodology underestimates the potential risks steeper sloped areas face since elevation was not included as a variable in the assessment. Steeply sloped areas at elevations below the one year significant wave height (6.9 m) will have a high to extreme risk of inundation from higher wave events, but may have lower vulnerabilities to steadily rising sea level (Shaw et al., 1998; Catto, in press).

To improve the accuracy of the flood maps, two improvements to the current methodology should be made. First, for geomorphologically complex coastal segments, two slope values (the foreshore and the backshore) should be used to determine both a foreshore and a backshore flood sensitivity. Such detailed, site-specific results would have a greater applicability and usefulness to land use planning. Secondly, determination of flood sensitivity should be based entirely on detailed elevation data rather than slope values. The development of a detailed digital elevation model on to which rising sea-level and current and future predicted storm surge levels were superimposed would produce a more informative flood sensitivity map and allow for more comprehensive land use decision making. This approach has been used with great success in a recent, detailed study of the effects of sea-level rise on Charlottetown, Prince Edward Island (Forbes et al., 2002; McCulloch et al., 2002).

In addition, the flood hazard sensitivity assessment methodology could be improved through the inclusion of additional geoindicators such as vegetation type and the presence of strandlines or elevated water levels. Detailed mapping of coastal vegetation types may indicate the presence of "flood" tolerant species and the absence of high water table intolerant species. Noting locations where these species are present would identify those areas with an increased sensitivity to flooding. Mapping indicators of recent flooding events such as strandlines or water plane levels would also aid in classifying those locations susceptible to flood activity.

A possible weakness with the foreshore erosion hazard sensitivity assessment was the decision to exclude fetch data. Further analysis indicated more variability in wave incidence and azimuth data values than was initially considered. As fetch is an easily quantifiable geoindicator of erosion potential, improvements to the accuracy of the foreshore erosion sensitivity assessment would be made through the inclusion of fetch data, in combination with wind and wave directional data, particularly variations in wave activity due to ice protection and storms.

A potential problem with the backshore erosion sensitivity assessment arose from difficulties with the way the vegetation geoindicator was scored. The coastal segments with the lowest sensitivity to backshore erosion processes were characterized by well-established and abundant vegetation. Generally, areas with well-established forest vegetation are less susceptible to erosion than areas lacking vegetation cover, due to the role roots play in substrate cohesion. As such, segments with abundant, mature vegetation were scored as least sensitive (score of one). However, in eastern Newfoundland, the presence of tuckamore (windswept white spruce) at cliff tops may actually accentuate erosion. As a result, it is possible that the current scoring of the vegetation variable may have underestimated the actual backshore erosion hazard for some segments. Where tuckamore is killed by salt spray, block failure of unlithified Quaternary bluffs and well-jointed bedrock is enhanced. Areas where dead tuckamore cover is present erode more quickly than sites covered by grasses or herbaceous vegetation. The tuckamore roots wedge the substrate apart, while dead vegetation acts as a top-heavy impediment to wind, increasing the risk of failure (Catto, in press). This process can be actively observed along the bluffs backing the Topsail United Church (Liverman et al., 1994). In addition, frost lifting of shallow root systems in areas where peat overlays Quaternary sediments increases the risk of failure due to the higher centre of gravity in the overlying vegetation.

As a result, sites where tuckamore vegetation is present should have received a vegetation sensitivity score of two (sensitive) to reflect their increased susceptibility to erosion.

An additional problem with the backshore erosion sensitivity assessment arose from the scoring of the backshore composition geoindicator. While the Conception Bay South-Holyrood coastline is dominantly characterized by extensive bluffs of either unlithifed Quaternary (Conception Bay South) sediments or highly resistant granite bedrock (Holyrood), there are segments characterized by a discontinuous or thin deposit of unlithifed sediments over bedrock. As a result, a "discontinuous unlithified over lithifed" category was included to increase the accuracy of the backshore erosion sensitivity assessment. However, the thickness of the unlithified sedimentary deposits was not taken into account. The accuracy of the backshore erosion sensitivity assessment will increase if a distinction is made between thin veneers (< 1 m) and thicker blankets (> 1 m) of unlithifed Quaternary sediments that overlie bedrock. Segments characterized by thick blankets of unlithified sediments (i.e. Kelligrews) should receive higher sensitivity ratings (more sensitive) than segments characterized by thinner veneers of unlithified sediments (i.e. eastern end of Topsail Beach). Where the overlying layer of unlithified deposits is thin, the sensitivity of the segment to backshore erosion processes will depend on the geotechnical characteristics of the bedrock.

The constraints and problems intrinsic to the hazard assessment methodology that was developed for this study could be mitigated by establishing more tightly defined geoindicator criteria on which to base the assessment. During the initial field assessment, the state of a number of geoindicators that were not important to the final sensitivity assessments were measured and appraised. Had a pilot assessment been conducted, it would have been found that a number of geoindicators should have been excluded from final analysis and that the evaluation of certain geoindicators should have been modified to more accurately represent the unique conditions of eastern Newfoundland. Site drainage, distance to waterbodies, amount of infrastructure and fetch were geoindicators that were assessed in the field, but not used in the final hazard sensitivity assessment. Reasons for their exclusion are discussed in Chapter 4: Methodology. In addition, a detailed description of vegetation type (i.e. tuckamore) should have been made to reflect the unique conditions of eastern Newfoundland. However, it is also important to remember that this type of approach is subject to temporal variability in local conditions, regardless of the changes made to increase accuracy. Qualitative assessments represent coastal conditions at one moment in time and in a dynamic setting, such as the coastal zone of eastern Newfoundland, changes can occur yearly, monthly, daily and even hourly. As a result, the accuracy of the hazard assessment depends on the long-term maintenance of the conditions on which the sensitivity ratings were initially based. Frequent, short-term changes in the condition of the system will significantly affect the accuracy of the sensitivity assessments. Despite these shortcomings, a qualitative approach to hazard assessment can successfully identify coastal segments susceptible to coastal hazards and is extremely useful where qualitative data are lacking or time is limited (Bush et al., 1998, 1999; Daniels et al., 1998; Petley, 1998)

As well, it must be stressed that the hazard classifications described in this paper are by no means definitive. The hazard classes were based on the observed geomorphology and the nature of the geomorphic processes. For other assessments, a new set of appropriate hazard classes would need to be derived, and as the techniques used to identify, examine and classify the hazards can vary from one practitioner to another, so could the resulting hazard classes (i.e. Catto, in press). As Petley (1998:199) notes, geomorphological mapping "is hindered by the fact that the hazard ratings are based on a qualitative judgement of the conditions and from an analytical point of view the technique, therefore, falls short of the rigorous statistical techniques that tend to be used in conventional hazard mapping."

In spite of these constraints and limitations, overall the methodology performed well. No coastal segments with known and/or documented flooding or erosion problems were identified as having a low sensitivity. Importantly, none of the coastal segments identified by the methodology as having a low sensitivity were historically known to have experienced flooding or erosion activity. Therefore, from a pragmatic planning perspective or an impacts and adaptations perspective, this methodology works well in identifying coastal segments sensitive to flooding and foreshore and backshore erosion processes.

7.3: Justification of Methodology

Although the robustness of the methodology in accurately identifying coastal segments sensitive to flooding or erosion activity would be improved through the inclusion of other, more detailed, geoindicator data, the greatest potential weakness of the method was the ranking and cumulative scoring utilized in predicting the hazard classes. With geoindicator-based hazard assessment methodologies that employ numerical scaling, difficulty arises in the relative weight given to values or characteristics within each geoindicator and the relative weight of geoindicators relative to other geoindcators. Although data specific to Conception Bay existed that stated the relative importance of particular geoindicator characteristics (i.e. with regards to 'form of foreshore,' barrier beaches are more sensitive than bedrock dominated coastlines), data that indicated a precise weight of each characteristic did not exist. Nor did data exist that indicated that relative weight of different geoindictors compared to each other (i.e. form of foreshore compared to sediment type). As a result, in the present study, the decision was made to assume an equal weight between the different values or characteristics within any particular geoindicator rather than assign inaccurate weights. This practice follows that employed by Gornitz (1990) and Shaw *et al.* (1998) in other studies of erosion sensitivity. In addition, the different geoindicators used in the foreshore and backshore erosion sensitivity assessments were assumed to contribute equally to overall hazard sensitivity, as shown below:

Foreshore Erosion Sensitivity = Form of Foreshore + Sediment Type + Bathymetric Slope + Presence of Offshore Boulders

Backshore Erosion Sensitivity = Backshore Slope + Backshore Composition + Presence of Erosion Control Measures + Vegetation Status

With certain geoindicators, such as 'form of foreshore' or 'sediment type,' the difference between certain characteristics was distinct enough (i.e. barrier beach versus fringing beach versus bedrock dominated coastline) that assigning different rank values was simple. However, difficulty arose with the backshore and bathymetric slope geoindicators, as a continuous value was being measured. The result was that arbitrary boundaries in slope values had to be made. The decision to place the boundaries at 2/3°, 7.8°, and 14/15° for the backshore slope and at 5/6° and 20° for bathymetric slope was made in consultation with other researchers familiar with the study area (Don Forbes and Don Pittman, personal communication).

Although four qualitative hazard assessments had previously been conducted within the Conception Bay region (Taylor, 1994; Sheppard, 1997; Shaw et al., 1998; Catto, 2000), in order to accurately evaluate the methodology developed in this study, the results that were generated could only be assessed against known events or sites for which there existed documented evidence of a flooding or coastal erosion problem (Dave Liverman, personal communication). As a result, the lack of documented flooding or erosion events and detailed quantitative data on erosion rates limited the opportunity for rigorous testing of the hazard sensitivity assessment methodology developed in this study. Evaluation of sites predicted to have moderate sensitivities to flooding or erosion hazards was not conducted as there was no historical data available for comparison. Monitoring efforts are generally focused on sites with high to extreme risks to geological hazards. Although highly qualitative observations of current or past coastline behaviour was relied upon for base comparison, it is acknowledged that they only provide evidence of past erosional events. However, coastal processes that have acted in the past can be assumed to act in the future.

Chapter 8
Implications of Climate Change

8.1: Implications of Climate Change in Atlantic Canada

Within Atlantic Canada, climate change impacts will be felt in the coastal zone. Climate change is predicted to cause an increase in global sea-level of 50 cm by 2100 (Kemp, 1991; Forbes et al., 1997; Hengeveld, 2000), as well as changes in atmospheric circulation patterns which may lead to increased storm intensity, and possible changes in storm tracks and frequency, ocean wave climate, sea-ice cover, and ecological zonation (Forbes et al., 1997). All of these factors can potentially affect coastal stability, flood and storm hazards, and socio-economic activity or investment within the coastal zone **(Table 8.1)** (Forbes et al., 1997; Mclean et al., 2001). The impacts of climate change on the coastal zone of Atlantic Canada, including Newfoundland, and their resulting consequences are summarized as (Shaw, 1997a):

- accelerated sea-level rise leading to increased flood risks, enhanced coastal erosion, coastal sedimentation and sediment redistribution;

- increased storm frequency and magnitude leading to increased erosion and risk of storm surge flooding;

- reduced extent and duration of sea ice leading to increases in open water fetch and associated wave energy.

Table 8.1: Potential impacts of climate change and sea-level rise on coastal systems.

Potential Impacts of Climate Change and Sea-level Rise on Coastal Systems
Biophysical impacts can include: - Increased coastal erosion - Inhibition of primary production processes - More extensive coastal erosion - Higher storm surge flooding - Landward intrusion of seawater in estuaries and aquifers - Changes in surface water quality and groundwater characteristics - Changes in the distribution of pathogenic mircoorganisms - Higher sea surface temperatures - Reduced ice cover Related socio-economic impacts can include: - Increased loss of property and coastal habitats - Increased flood risk and potential loss of life - Damage to coastal protection works and other infrastructure - Increased disease risk - Loss of renewable and subsistence resources - Loss of tourism, recreation and transportation functions - Loss of non-monetary cultural resources and values - Impacts on agriculture and aquaculture through soil decline and water quality (Mclean et al., 2001:356)

8.2: Sea-Level Rise

The first Intergovernmental Panel on Climate Change (IPCC) assessment report concluded that sea-level rise was the most significant component of climate change in the coastal zone (Warrick and Oerlemens, 1990). It has been estimated that global sea-level will rise by approximately 50 cm by the year 2100 mainly as a result of the thermal expansion of the oceans, although the melting of temperate glaciers and changes in the volume of the polar ice sheets will also contribute (Kemp, 1991; Forbes et al., 1997; Hengeveld, 2000). The Canadian Centre for Climate Modelling and Analysis' CGCM1 general circulation model predicts a 40 cm rise in the Atlantic Ocean east of the

Maritimes (Hengeveld, 2000). Evidence already indicates that global sea-level is rising at rates of 1 to 2 mm/year and this is expected to accelerate well into the 23rd century (Warrick and Oerlemens, 1990; Mclean et al., 2001). These increases in global sea-level will be in addition to relative sea-level changes due to continuing isostatic rebound and crustal submergence affecting Atlantic Canada, leading to an acceleration of the existing sea-level rise currently being experienced. Within the southern Conception Bay study area, current rates of relative sea-level rise have been on the order of 20 to 30 cm/century through the Holocene (Catto et al., 2000). As a result, the rise in relative sea-level by 2100 within Conception Bay could be as high as 70 cm.

A rise in mean sea-level has a direct impact on the level of tides, storm surges, storm wave run-up and wave energy. An accelerated rise in sea-level, in combination with a possible increase in storm activity, can be expected to increase flood hazards, coastal erosion, storm damage, and associated property losses.

8.2.1: Flooding

Flooding of coastal property, utility infrastructure, and port facilities has been recognized as a potential impact of future sea-level rise (Forbes et al., 1997). Low-lying coastal lands are susceptible to flooding under high tides and storm surges and the frequency and landward extent of such flooding could be expected to increase with a rise in mean relative sea-level (Forbes et al., 1997; Mclean et al., 2001). Significant flooding is known to have occurred at Chamberlains Pond and in Kelligrews. Reports of the sea washing away a considerable length of railroad in Kelligrews date back to 1921 (Batterson et al., 1999). More recently, a severe nor'easter in October 1992 produced considerable damage to property along much of the Conception Bay shore. Numerous boats were damaged or sunk, particularly at the Royal Newfoundland Yacht Club in Long Pond, where the barrier bar was breached, and substantial erosion occurred on the cliffs behind the Topsail United Church. A moderate nor'easter in the autumn of 1994 also caused significant coastal modifications and erosion in the Conception Bay region (Liverman et al., 1994; Batterson et al., 1999).

The flood sensitivity assessment conducted in this study noted that extensive coastal segments with high sensitivity to flooding are found west of the Topsail Beach barrier; along Chamberlains, Long, Upper Gullies and Lance Cove Ponds; along the western side of Kelligrews Pond; and along Holyrood Beach at the head of Conception Bay. Properties surrounding and adjacent to Chamberlains Pond, including the sewage treatment plant, were noted as being extremely sensitive to flooding. As well, the coastline from Foxtrap to Kelligrews, including Cronin's Head, the proposed site of a new sewage treatment plant (Canning and Pitt Associates, 2000a), and commercial properties along the eastern side of Kelligrews Pond are presently extremely sensitive to flooding. With a rise in relative sea-level (including both isostatic and eustatic increases), the frequency and severity of flooding in these areas can be expected to increase. Although the actual increase in sensitivity is site specific and depends on how the level of tides, storm surges, storm wave run-up and wave energy increases with a rising sea-level.

Between 1973 and 2000, coastal flooding has cost the Province of Newfoundland and Labrador over $40 million and the federal government over $27 million **(Table 8.2)** (Dennis Shea, Newfoundland and Labrador Emergency Measures Organization, personal communication).

Table 8.2: Recent expenditures in Newfoundland and Labrador by the Federal-Provincial Disaster Financial Assistance (DFA) Program (1973-2000)*

Date	Event	Total Costs	Federal Share	Comments
1973	Storm	$1 400 000	$435 000	A sudden severe storm struck the Atlantic provinces on June 17, 1973 causing extensive damages to fisherman's gear.
1974	Ice Storm	$5 151 752	$3 540 871	-
1978	Flood	$5 235 779	$3 588 601	-
1983	Flood	$3 979 778	$2 426 000	-
1984	Ice Storm	$3 282 619	$1 786 357	-
1990	Flood	$2 327 777	$1 029 958	-
1990	Flood	-	$3 600 000	Damages associated with flood along West Coast.
1994	Storm	-	-	Request for federal assistance did not meet the DFA threshold.
1995	Storm	$1 675 710	$549 235	-
1995	Hurricane Luis	-	$3 000 000	-
1996	Flood	-	$1 000 000	Damages associated with Flat Bay Flood
1998	Hurricane Earl	-	$1 300 000	Affected Baie Verte Peninsula
2000	Storm Surge	-	$5 000 000	Damages associated with January 22, 2000 storm that affected southwest coast from Port aux Basques to Trepassey.

(data courtesy Dennis Shea, Newfoundland and Labrador Emergency Measures and Planning and Len Leriche, Office of Critical Infrastructure Protection and Emergency Preparedness).

* It is important to note that under the DFA program, the province is wholly responsible for the first $500 000 of expenditures. As a result, the total financial costs incurred through floods, storms and erosion are much greater than those listed above (Dennis Shea, personal communication). For example, the construction of 50 m of gabions and armour stone in Chamberlains, Conception Bay South, to repair erosion sustained during the October 1992 nor'easter cost $13 000 to $28 000 and was covered entirely by the province (Batterson et al., 1999). In fact, damages due to the 1992 storm do not appear on this table as either no request for assistance was made, or the request did not meet the DFA threshold.

These costs can be expected to increase with higher sea-levels, increased property values and greater coastal development. For example, damages following a severe storm in 1966, which completely destroyed the community of La Manche on the Southern Shore, only approached $1 million. Were a storm of similar magnitude to strike today, the cost would be significantly higher, reflecting the increase in land values and coastal infrastructure.

8.2.2: Erosion

Wave action at the base of coastal cliffs is one of the primary factors controlling the rate of shoreline retreat, as toe erosion and undercutting exert a critical control on the cliff profile and its overall stability (Forbes et al., 1997). With higher sea-levels, waves break higher on the beachface, resulting in higher run-ups and shear stresses, thus increasing the potential for overtopping and flooding of coastal landforms and structures and greatly enhancing the potential for subsequent erosion (Forbes et al., 1997). The Conception Bay South coastline is dominated by extensive backshore cliffs composed of unlithified Quaternary sediments with a high to extreme sensitivity to erosion. Cliff sediments are present on the beach in numerous areas indicating active erosion is occurring **(Plate 8.1)**. The sensitivity of these cliffs to erosion can be expected to remain high or increase in the future.

Plate 8.1: Active erosion in the Topsail region (segment 1127 – 1392 m), with cliff sediments on the beach.

However, the coastal response to sea-level rise will likely be quite complex. Erosion of coarse-grained glacial deposits can lead to the accumulation of protective boulder lags at the cliff base and across the nearshore, reducing wave energy and erosion rates (Forbes and Syvitski, 1994). These protective boulder lags are present along extensive segments of the southern Conception Bay coastline from Topsail to Lance Cove. As well, coastal progradation can occur where sediment supply exceeds that required for the maintenance of shoreline stability. In fact, it is possible that accelerated sea-level rise may increase sediment supply from eroding coastal cliffs, leading to more rapid shoreline progradation downdrift. The unlithified coastal bluffs between Seal Cove and Lance Cove and between Manuels and Topsail are presently important sediment sources. Allowing natural erosion processes to continue at these sites will provide much needed sediment to downdrift beaches to mitigate against the effects of a rising sea-level, and acts as a natural adaptation measure. As such, it is important that the serious implications of preventing the continued erosion of these cliffs are fully understood before any mitigative work is undertaken. Changing sediment budgets can also lead to the closure of tidal inlets or to changes in inlet configuration, causing localized erosion and flooding (Forbes et al., 1997). For barrier beaches currently susceptible to significant changes in morphology, such as the Topsail Beach barrier, the impacts will be substantial.

8.2.3: Coarse Clastic Barrier Evolution

In addition to unlithified coastal cliffs, the coastal areas with the greatest sensitivity to accelerated sea-level rise are coarse gravel beaches and barriers, especially if sediment starved (Bijlsma et al., 1996; Mclean et al., 2001). As the Conception Bay South coastline is dominated by the nearly continuous development of extensive gravel barriers and beaches, this is of great importance. Shaw *et al.* (1994, 1998) noted the region as susceptible to coastal erosion. The results of the present study showed that the barrier beaches had a moderate to extreme sensitivity to erosion.

Gravel barriers develop under both rising and falling sea levels (Orford et al., 1991), and thus their evolution and morphological stability are closely linked to changes in relative sea-level. Indeed, research has shown that the majority of coarse clastic barriers in Atlantic Canada show a constant landward migration under stationary and rising sea-levels, due to the lack of seaward directed sediment transport (Carter et al., 1987, 1989;

Forbes et al., 1995). When and where sediment supply is constrained, the barriers must respond by altering their morphology to withstand the impact of rising sea-level (Orford et al., 1991, 1995b; Dubois, 2002). Morphological change can be accomplished through modification of barrier geometry (slope, width and height) or through the reworking (or cannibalization) of existing forms to supplement some, or even all, of the deficits in the sediment budget. These changes lead to barrier stretching, segmentation and ultimately breaching and sediment dispersal away from the coastline (Forbes et al., 1989; Shaw et al., 1993). Where sea-level rise is rapid (>20 cm/century), there is less opportunity for a barrier to mature in terms of sediment distribution and morphology, as it must constantly readjust to an ever-changing sea-level. As barriers not only provide limited protection against direct wave attack, but also control the delivery and pattern of sedimentation within estuaries and lagoons, the effects of rapid fluctuations in barrier form and behaviour are directly transferred to these adjoining waterbodies (Carter et al., 1989). Where substantial anthropogenic development has occurred along a lagoon, as at Chamberlains, Kelligrews and Long Ponds, the effects could be significant.

8.3: Variable Storminess and Extreme Events

While the potential impacts of a rise in sea-level have been studied extensively, much less attention has been given to the effects of changes in wave climate and storminess (Mclean et al., 2001). Temporal variations in storminess, including possible increases in storm frequency or intensity, wind climatology, and wave patterns can be expected to have significant effects on rates of coastal erosion and storm surge flooding (Forbes et al., 1997; Mclean et al., 2001). The greatest risks of climate change are associated with changes in the frequency and intensity of extreme events (Bijlsma et al., 1996; Hengeveld, 2000). Omission of changes in extreme events and/or climate variability will likely underestimate climate change impacts and sensitivity (Schneider et al., 2001). Future hazard assessments, development guidelines and environmental impact assessments will need to not only consider future changes in climatic conditions, but also climate variability and changes in climate extremes. As Forbes *et al.* (1997:55) state,

> "[t]he challenge in determining probable impacts of changing storm climate in the coastal zone lies both in the specification of storm climatology (frequency, intensity, storm track) and in predicting the coastal response…It is not always clear to what extent changes are driven by extreme events, by secular changes in climate, or by internal feedback within the coastal system. The response of a given coastal system, particularly gravel-dominated ones, may depend critically on the antecedent conditions of the shore and its susceptibility to erosion or overtopping."

Nor'easters are the extreme events most likely to affect the southern Conception Bay study region. The most recent nor'easters to affect this area occurred in the autumn of 1992 and 1994. The severe storm of October 1992 caused rapid coastal erosion (1-2 m near Chamberlains Pond) **(Plate 8.2 and 8.3)** and beach modification, including the formation of large swash cusps, and a major breach of the Long Pond barrier. This breach cost over $40 000 to repair and resulted in hundreds of thousands of dollars of damage to boats and infrastructure at the Royal Newfoundland Yacht Club. With an increase in the frequency and intensity of severe nor'easters in the future, erosion events can be expected to become more frequent, with greater rates of retreat.

Plate 8.2: Chamberlains beach (segment 2818 – 2898 m) before the passage of the October 1992 nor'easter (photograph courtesy Martin Goebel, Department of Environment, Government of Newfoundland and Labrador).

Plate 8.3: Severe erosion to the beach and nearby road following the passage of the October 1992 nor'easter (photograph courtesy Martin Goebel, Department of Environment, Government of Newfoundland and Labrador).

Research in the New England states indicates that since nor'easters affect larger areas and occur more frequently than hurricanes, their potential to cause damage is greater (Davis and Dolan, 1993). In Newfoundland, however, hurricanes are more frequent than nor'easters. As well, nor'easters tend to occur during the winter, when there is protective ice cover on the beaches. The extreme sensitivity of beaches in Conception Bay South to damage from nor'easters results from the northeast orientation of Conception Bay. With the maximum fetch direction oriented in the direction of the storm, the coastline of southern Conception Bay is directly impacted by refraction of the largest storm-generated waves. With population density along the coast continuing to grow, severe storms will have an even greater impact upon the lives and livelihoods of coastal residents.

8.3.1: Storm Surge Flooding and Wave Action

The key to determining the impact of increased storminess and extreme events lies in studying the effects of waves produced by these storms. For example, although nor'easters are capable of generating strong winds, the majority of damage is caused by high waves (heights of 5 to 10 m are common) and storm surges (the most severe storms can produce surges up to 2.5 m high in Eastern Canada) (Dolan et al., 1988; Davis and Dolan, 1993). Increases in water depth at the coast due to storm surges contribute to conditions that permit higher wave action closer to the shoreline, thus increasing the potential for infrastructure damage and coastal erosion (Davis and Dolan, 1993; Forbes et al., 1997). Coastal segments noted as having high to extreme sensitivies to flooding and foreshore erosion in the present study, particularly those where there is significant anthropogenic development, will be the most vulnerable. The most damaging storms are those with storm surges that coincide with a high tide, or storms of long duration that last over several tidal cycles, particularly spring tides (Forbes et al., 1997; Douglas et al., 2002).

Changes in coarse clastic barrier morphology under rising sea-level conditions are primarily the result of wave action and erosion along the shoreline (Orford et al., 1991, 1995a, 1995b; Dubois, 2002). Barriers respond to extreme wave activity, which may result in surge and swash overwashing and destabilization of the barrier crest as shoreface sediments are moved onto the backbarrier slope, thus generating barrier rollover (Carter et al., 1987; Orford et al., 1995a; Taylor and Frobel, 1999; Dubois, 2002). The barrier at Long Pond has been breached by extreme wave activity associated with major winter storms in 1976 and 1992, and is vulnerable to flooding and overtopping during surges associated with exceptionally high tides (Don Pittman, personal communication).

In the North Atlantic, a multi-decadal trend of increased wave height has been observed, with visual estimates from merchant ships and instrumental records suggesting significant wave height increases of 0.1 to 0.3 m, although the cause is poorly understood (Canavan, 1997; Mclean et al., 2001). Examination of storm wave data between 1957 and 1995 off eastern Canada by Swail (1997) showed an increase in storm wave height off the Scotian shelf. This was accompanied by a similar increase in wind speed. Wave analyses for the northeast Atlantic also indicated an increase in significant wave height over the previous 30 years. However, data from the Grand Banks and in the Labrador Basin showed no change and a decrease, respectively, in storm wave height (Thomas, 1996).

Several recent extreme storm and wave events in the northwest Atlantic Ocean have exceeded published estimates of extreme wave climatology. These include the Halloween Storm of October 1991, which was characterized by 17.3 m significant waves and maximum waves greater than 31 m, and the Storm of the Century in March 1993, with significant wave heights of 16.3 m (Thomas, 1996; Swail, 1997). Hurricane Luis, in September 1995, hit the ocean liner Queen Elizabeth II with maximum waves estimated at 29 m in height. A nearby moored buoy measured 17 m significant waves and estimated maximum waves exceeding 30 m (Swail, 1997). Large waves associated with Hurricane Gert-Harvey (1999), estimated at 16 m height, caused hundreds of thousands of dollars worth of damage to the St. Bride's, Newfoundland harbour and boats moored within (Anonymous, 1999; Freake, 1999).

8.3.2: Coastal Erosion

The length and intensity of any particular storm, the specific characteristics of incident waves, and storm impacts can vary considerably **(Figure 8.1)**. Extreme events can leave an imprint on the coast that lasts many years, such as swash cusps, which may then control washover processes and other aspects of beach response during subsequent large wave run-up events (Carter and Orford, 1984; Orford et al., 1991; Forbes et al., 1997).

On gravel-dominated systems along Newfoundland's Avalon Peninsula, swash cusps older than three years have been observed and reflect the long recurrence intervals of storms that can generate waves of significant strength to mobilize cobble-sized sediments. Swash cusps formed on Topsail Beach during the October 1992 nor'easter were still visible in the late 1990s and were known to focus washover activity, as were cusps formed on the Long Pond barrier.

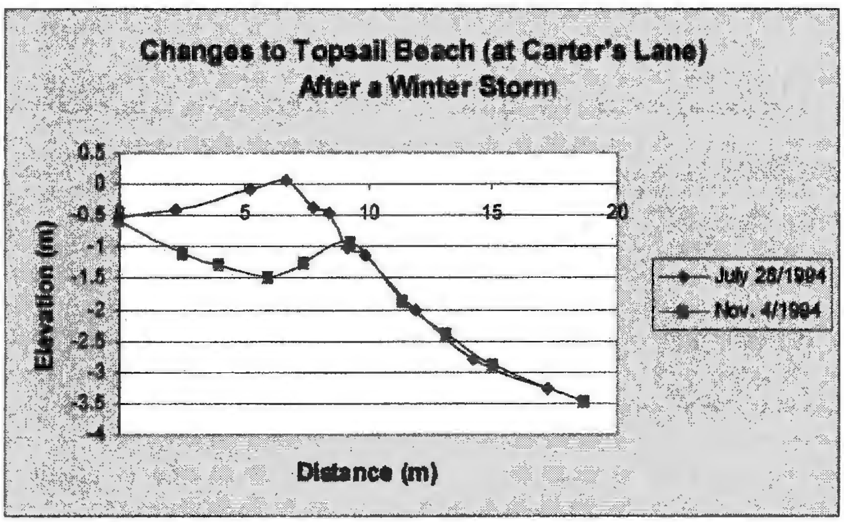

Figure 8.1: Significant beach modification resulting from the passage of the October 1994 nor'easter (data courtesy David Liverman, Geological Survey of Newfoundland and Labrador).

Coastal erosion can be a major cause of concern where valuable land, residential dwellings, and other infrastructure are threatened by cliff retreat. In Topsail, the loss of shorefront property initially resulted in a new landowner being prevented from constructing a new house (Batterson, 1999). However, permission has been recently granted and a new home has been constructed **(Plate 8.4)**. Although the 30 m construction setback from the high tide line has been met (Canning and Pitt Associates, 2000a), a boulder seawall was previously constructed along the low bluff fronting the property to halt erosion activity (**Plate 8.5**). The bluffs fronting the adjacent property are actively eroding and mitigation measures have not been put in place, potentially undermining the effectiveness of the seawall.

Plate 8.4: New home in Topsail (segment 679 – 759 m) constructed within a coastal hazard area.

Plate 8.5: Boulder seawall constructed to halt erosion activity in segment 679 – 759 m. Note that the adjacent property is actively eroding and mitigation measures have not been put in place, potentially undermining the effectiveness of the seawall.

Cliff erosion may occur through removal of material at the cliff base, a process largely controlled by wave energy (which increases with the square of the wave height) and water level (enhanced by high tide, storm surge, wave setup or run-up), or through slumping and gullying of the cliff top, processes dominated by lithological and geotechnical properties of the soil and by runoff and groundwater conditions. The latter can lead to rapid headwall erosion and property loss. Weather conditions (wind, storm surge, waves versus precipitation) may favour one type of erosion over another, complicating the prediction of climate change impacts (Forbes et al., 1997). Significant cliff erosion has occurred behind the Topsail United Church, along the unlithified cliffs between Chamberlains and Manuels Ponds, and along the T'railway east of Lance Cove through to Seal Cove. Erosion activity has been episodic rather than continuous, with significant erosion events (0.5 – 1.0 m retreat) often triggered by a single storm event (Catto, 1994; Liverman et al., 1994; Batterson, 1999). Rates are dependent on shoreline orientation, wave climate, slope vegetation and human interference. Annual recession rates approach 0.5 m (Batterson, 1999).

8.4: Reduced Extent and Duration of Sea-Ice

Possible increases in open-water fetch and wave energy during the winter months, due to higher sea-surface temperatures and a reduction in the extent and duration of winter sea-ice may also contribute to increases in wave energy and coastal erosion losses (Forbes et al., 1997; Mclean et al., 2001). Ice-foot development is an important winter phenomenon along the coastline of Atlantic Canada. It commonly serves a protective role on beaches by acting as a natural seawall and resulting in the seaward displacement of breaking waves. Less common or persistent ice-foot development under warmer climate conditions might contribute to shore erosion in a minor way (Forbes and Taylor, 1994). As sea-ice has a negligible to non-existent impact on southern Conception Bay and ice-foot development is not very extensive, pervasive or persistent (Catto, in press), the likely impacts of a reduction in sea ice and ice-foot development on the Conception Bay South-Holyrood coastline will be limited. However, increases in winter storm wave climate, combined with a reduction in ice-foot development could lead to an increase in winter beachface erosion and washover. Northeast-facing segments of coastline currently highly sensitive to the effects of winter storms, and the numerous barrier beaches of Conception Bay South will be particularly sensitive.

Chapter 9
Adapting to Climate Change and Sea-level Rise

9.1: Adapting to Climate Change and Sea-level Rise

Rising sea levels and changes in storm frequencies and intensities, along with associated storm-surge flooding and coastal erosion, only become a hazard when they impact human populations and developments (Lawrence, 1994; Godschalk et al., 2000; Mclean et al., 2001). The southern Conception Bay coastline is already experiencing a rise in relative sea-level and is susceptible to the effects of extreme events, such as hurricanes and nor'easters. With predicted rises in global sea-level, an increase in storminess and potentially higher than average winds, it is reasonable to expect that more substantial coastal modifications will result from climate change. In 1992, the Intergovernmental Panel on Climate Change (IPCC) defined three options for coastal adaptation to sea-level rise and other impacts of climate change:

- retreat or avoidance
- accommodation
- protection

Retreat or avoidance involves abandoning settlements or structures in currently threatened coastal areas and preventing future development in areas that may be affected by future sea-level rise (Al-Farouq and Huq, 1996; Rijsberman and van Velzen, 1996; Klein and Nicholls, 2001). While retreat may be the optimal adaptation response for areas with limited development, it is impractical for areas with substantial coastal infrastructure or with significant heritage resources (Forbes et al., 2002).

Accommodation involves a continued, although altered, occupation and usage of sensitive coastal lands (Al-Farouq and Huq, 1996; Rijsberman and van Velzen, 1996). It can involve the redesign of buildings and other structures to minimize impacts, changes in zoning laws to encourage appropriate land use, and the rehabilitation of disturbed ecosystems, such as dunes, to enhance natural resilience (Klein and Nicholls, 2001; Forbes et al., 2002). Typically, accommodation measures involve using advance planning, modification of current land use patterns and building codes, protection of natural ecosystems, and the development of hazard zone regulations to avoid the negative impacts of climate change (Forbes et al., 2002). In both avoidance and accommodation, natural coastal erosion and flooding processes are allowed to continue, with the resulting loss or change of some coastal functions and values (Klein and Nicholls, 2001).

Protection attempts to maintain the present shoreline position by constructing protective structures, such as seawalls and revetments ('hard' protective measures) or by artificially nourishing or maintaining beach and dune systems ('soft' protection measures) (Pope, 1997; Klein and Nicholls, 2001; Forbes et al., 2002). Often the most widely applied strategy to protect coastal settlements against existing coastal hazards, it has the potential to severely modify the natural coastal system, by affecting wave conditions, currents and sediment supply, particularly downdrift from the protection structure (Pethick, 1984; Pope, 1997).

9.2: Recommendations

Along with attempting to maintain the present shoreline position through the construction of protective measures, or abandoning development in threatened areas, recent studies of coastal sensitivity and adaptation to sea-level rise have concluded that appropriate adaptation responses should also include (United Nations Department of International Economic and Social Affairs, 1982; Godschalk et al., 2000; Healy and Dean, 2000; Burton et al., 1998; Forbes et al., 2002):

- raising public awareness;
- planning urban growth;
- preserving wetlands;
- improving coastal zone management planning, including developing setbacks and lowering financial incentives for developing high risk areas.

Indeed, there are a number of specific adaptation options that can be recommended in preparation of accelerated sea-level rise and climate change in southern Conception Bay.

9.2.1: Hazard Identification and Monitoring

The preliminary erosion hazard sensitivity ranking scheme based on shore-zone morphology and sediments developed in this study was useful for obtaining an overall qualitative view of risk distribution. However, detailed quantitative methods are required for purposes of specifying setback distances and further consideration needs to be given to a realistic definition of erosion rates and potential future erosion, especially considering that coastal erosion in Conception Bay South tend to be episodic as opposed to continuous (Catto, 1994; Liverman et al., 1994; Batterson, 1999). The Geological Survey of Canada – Atlantic (GSCA) has started to analyze longterm erosion rates using aerial photogrammetry and detailed field surveys. Initial results have indicated a high variability in the historical erosion measurements (a function of variable storminess and differing coastal responses) **(Figure 8.1)** (Don Forbes, personal communication). Not only does this variability need to be recognized, but so does the potential for barrier breaching, overtopping and overwashing during extreme storm events. This is especially true as these sort of changes are not captured in historical retreat rate estimates (Forbes et al., 2002). As well, with an increase in relative sea-level and a possible increase in wave energy, erosion rates could accelerate. *An active partnership between the Towns of Conception Bay South and Holyrood and the GSCA needs to be developed and fostered with active sharing of both data and technical expertise to help develop realistic and workable development setbacks that consider the dynamic condition of the southern Conception Bay shoreline.*

Changes in a location's sensitivity to erosion and the need for regular reassessment of erosion rates points to the need for ongoing environmental and coastal monitoring. Existing coastal erosion and beach profile monitoring reference sites provide control points for the derivation of more accurate erosion rates and provide baseline data for future studies. It is highly desirable that these control sites be maintained in support of the planning, adaptation and ongoing risk assessment needs (Forbes et al., 2000). In order to provide an adequate database for reassessment, fluctuations in the position of the shoreline should be monitored at least once or twice a year (Gibb, 1983). Memorial University of Newfoundland's Department of Geography, the Geological Survey of Newfoundland and Labrador and the GSCA have all established monitoring reference sites in southern Conception Bay in the last ten years (Liverman et al., 1994; Pittman, in preparation). Continued monitoring of these sites is required on an annual to semi-annual basis and after every significant storm event. However, with three different organizations collecting data, a concerted effort needs to be made to streamline data collection and analysis. Responsibility for data collection and analysis should be given to one organization, although the availability of highly accurate global positioning system (GPS) equipment and processing facilities may mean that this responsibility needs to be shared. The Towns of Conception Bay South and Holyrood need to have one designated organization from which they can acquire the necessary monitoring data for developing appropriate land use management strategies. *It is recommended that the communities assume responsibility for undertaking beach and cliff profile monitoring using simple Emery Pole (Emery, 1961) surveying techniques, with detailed GPS surveys being undertaken by the federal or provincial geological surveys as they would have the necessary equipment and expertise.*

Most importantly, the development of a digital elevation model (DEM) for accurate flood hazard zone delineation and mapping needs to be undertaken, particularly for the many coastal lagoons in Conception Bay South. Detailed ground truthing would be required to validate the results of the DEM and any derived flood hazard maps. Additionally, a statistical analysis of flood levels and recurrence probabilities would be required to accurately define the flood hazard. *With a historical record of severe flooding events in the community* (Taylor, 1994; Sheppard, 1997; Batterson et al., 1999), *the creation of an accurate DEM and flood hazard zone map is seen as a priority for the Town of Conception Bay South.*

9.2.2: Managed Retreat or Avoidance

The simplest form of avoidance is to restrict development in sensitive locations, since minimizing development in erosion and flood-prone locations is more cost-effective than constructing expensive protection works (Al-Farouq and Huq, 1996; Rijsberman and van Velzen, 1996; Klein and Nicholls, 2001; Forbes et al., 2002). The maintenance of protective environmental features such as dunes, maritime forests, vegetation and wetlands which reduce wind and wave impacts is also important (Godschalk et al., 2000). *It is recommended that the situation of new developments and infrastructure in sensitive areas, such as the proposed sewage treatment plant in Kelligrews at Cronin's Head* (Canning and Pitt Associates, 2000a), *be avoided and that other less sensitive locations be actively considered.* Where existing development may become increasingly sensitive to the effects of flooding and erosion; such as on the low lying land surrounding

Kelligrews and Chamberlains Ponds, along the failing slopes in Topsail, and along the back beach at Holyrood, it is recommended that they be relocated to safer locations. The relocation of the sewage treatment plant in Chamberlains, already affected by erosion, should be considered once it becomes obsolete or when maintenance costs (due to increased erosion and the effects of sea-level rise) become prohibitively high. Where building lifespans are relatively short (less than twenty-five years), it may be more acceptable to allow the current landuse to continue as at present, but for the property to be abandoned once the building needs to be replaced.

9.2.3: Accommodation

Since retreat may not be a feasible option in a (sub)urban setting, alternative adaptation strategies such as accommodation may need to be considered. Accommodation strategies allow for a continued use of the land, while still protecting developments and infrastructure from hazards (Al-Farouq and Huq, 1996; Rijsberman and van Velzen, 1996). Accommodation measures can include land use zoning, creation of development setbacks, strengthening buildings and infrastructure through amendments to building codes and engineering design (i.e. floodproofing basements and raising foundation heights or the heights of protection structures, wharves, and other coastal infrastructure) in an effort to increase the resilience of structures exposed to hazards, to more stringent assessments of building proposals in potentially hazardous locations (Godschalk et al., 2000: Forbes et al., 2002). As Gibb (1983:16) notes, "prevention is better than cure."

Land use zoning is a particularly effective accommodation strategy as it allows for more stringent control of coastal land development. Development in sensitive coastal locations can be limited by designating a site as suitable only for green space development or limiting development to temporary structures (lifespans less than 25 years) than can be easily removed, relocated or rebuilt in a less sensitive location. Land use zoning is a proactive adaptation strategy that requires forward thinking and an understanding of future conditions. It is best used in combination with setbacks.

Primarily used to protect development from coastal hazards, particularly erosion, setbacks provide a buffer zone between the shoreline and coastal infrastructure (Gibb, 1983; Healy and Dean, 1999). They can also be used to preserve the natural character of the coastline or to protect sites of special interest (Healy and Dean, 1999). As tourism in Conception Bay South and Holyrood is and has been historically tied to the marine and natural environment (Grandy, 1969; Hyde, 1973; Rowe, 1980; Hochwald and Smith, 1988; Catto, 1994; Poole, 1994; Veitch, 1989; Canning and Pitt Associates, 2001), the ability to maintain the unique natural character of the coastline for the future is of particular concern. In addition, such coastline preservation will allow natural erosion processes to continue, thereby providing much needed sediment to downdrift beaches to mitigate against the effects of a rising sea-level.

The Town of Conception Bay South has already developed a 30 m development setback from the high tide line (Canning and Pitt Associates, 2000a:38) in an attempt to protect existing development from coastal hazards. However, although it is mentioned in the *Conception Bay South municipal plan 2001-2011: strategy for growth* (Canning and Pitt Associates, 2000a:38), the shoreline protection development setback is not found in the *Town of Conception Bay South development regulations 2001-2011: land use zoning, subdivision and advertisement regulations* (Canning and Pitt Associates, 2000b). In addition, the development setback does not take elevation into account or the area influenced by storm waves, meaning buildings can continue to be constructed in highly hazardous coastal locations. As well, in areas where flooding is the primary hazard, a horizontal setback distance will not be appropriate, as elevation is not considered. In this situation, a vertical setback based on elevation and flood probability may be more effective in reducing sensitivity (Forbes et al., 2002). *It is recommended that the Town of Conception Bay South consider implementing new development setback limits that include topography and elevation, such as minimum flood heights or landward limit of storm wave impact damages, particularly for the land surrounding the numerous coastal lagoons.*

The communities are cautioned against using setback distances based on fixed time intervals (i.e. X metres of erosion over a century), as it implies an ability to predict erosion rates into the future over a specific time interval. Simple extrapolation of historical rates may not be appropriate, particularly when erosion is episodic and not continuous, as in Conception Bay South (Catto, 1994; Liverman et al., 1994; Batterson, 1999). And if the potential for a significant increase in the rate of coastal retreat is not incorporated into the calculations, the intended factor of safety may not be achieved (Forbes et al., 2002).

Another accommodation strategy is to limit government expenditures for construction of infrastructure, such as roads and bridges, in sensitive areas. Public subsidies can "discourage sound economic decisions by artificially lowering the cost of developing property and creating a market bias in favour of development and against preservation of property in its natural state" (Godschalk et al., 2000:17). It is recommended that the Towns of Conception Bay South and Holyrood do not extend municipal services, such as sewer and water, to areas sensitive to the effects of coastal flooding and erosion that have not yet been fully developed. *Where municipal services have been extended to developments in sensitive areas, it is recommended that the towns implement a hazard notification requirement for real estate transactions, whereby hazard conditions and their potential impacts on a property are disclosed to potential purchasers prior to purchase* (Godschalk et al., 2000).

9.2.4: Protection

Although managed retreat and accommodation are more cost-effective and perhaps sensible adaptation strategies, there are situations, such as when high-value properties or infrastructure are involved, where these strategies will not work and protection is required. However, serious consideration should first be given to accommodation or retreat and soft protection measures should be examined as alternatives to hard structural solutions (Pope, 1997; Forbes et al., 2002). As coastal protection structures have the potential to alter coastal dynamics, by influencing nearshore wave fields, nearshore currents, and sediment transport, careful consideration of the entire relevant coastal system is required when selecting the location and design of coastal protection works (Pethick, 1983; Pope, 1997; Allsop and McConnell, 2000; Headland et al., 2000; Forbes et al., 2002). If seawalls or revetments are determined to be an appropriate solution, they need to be designed in light of an acceleration in sea-level rise and be based on potential changes in sea ice and wave climate as determined from the most recent global and regional climate models. As well, whenever protection is chosen as an adaptation strategy, future maintenance needs, as well as the longterm feasibility of "holding the line" must be considered from the start (Forbes et al., 2002).

In Conception Bay South, areas where protection will be required include the sewage treatment plant in Chamberlains (already subject to erosion), the Port of Long Pond, and the Foxtrap Marina. In Holyrood, protection will be required for the seaward side of the Holyrood Thermal Generating Station at Indian Pond, the Ultramar Refinery storage site and the Port of Holyrood. At these sites, consideration will need to be given to the resulting implications on coastal dynamics and it is therefore recommended that qualified engineers undertake the development of possible protection strategies.

9.2.5: Coastal Management

Adequate provision needs to be made in planning schemes for the sensible management of land exposed to coastal hazards and to protect existing developments from their effects **(Plate 9.1)** (Gibb, 1983). Integrated coastal zone management is increasingly being seen as a valuable tool for incorporating adaptation requirements, to both present climate variability and future climate change, into the planning process (Forbes et al., 2002). Defined as the "management of the coastal zone as a whole in relation to local, regional, national and international goals," integrated coastal zone management focuses "on the interactions between the various activities and resource demands that occur within the coastal zone, and between coastal zone activities and activities in other regions (Penning-Rowsell, 1993:16)."

Plate 9.1: This building, adjacent to the Foxtrap Marina (segment 7866 – 7947 m), is located within the 30 m development setback and is less than five metres from the bluff edge. Although the placement of riprap will halt erosion processes, the site can still be impacted by storm waves.

With the passage of the *Oceans Act* in 1997, Canada committed to a comprehensive approach for the protection and development of its oceans and coastal waters. As it had been recognized that past management strategies operated independently, without considering the long-term impacts on social, economic and environmental systems (Fisheries and Oceans Canada, 2002). Although there is a long-term goal of developing a system of integrated management plans for all of Canada's coastal waters (Fisheries and Oceans Canada, 2002), there is at present, no effective process for short-term integrated coastal management in Canada (Forbes et al., 2002). Previous attempts to develop a comprehensive national approach to managing the coastal zone have never come to fruition partially due to the fact that no single department, at any level of government, has primary or overall authority over the coastal zone as a whole (Butler and LeBlanc, 1993). The Government of Canada's new *Policy and Operational Framework for Integrated Management of Estuarine, Coastal and Marine Environments in Canada* notes that the main role of the federal Department of Fisheries and Oceans is to act as facilitator in the development of integrated coastal management plans. Many of the important management issues that need to be addressed, including effects of land use and climate change, fall within provincial/territorial or municipal government jurisdiction (Fisheries and Oceans Canada, 2002). For local levels of government that may lack the necessary technical expertise and that often work in isolation of surrounding communities, the lack of a designated lead agency has serious implications on the success of any integrated management plan.

Integrated coastal zone planning and management needs to be holistic in its approach: incorporating both terrestrial and marine systems and moving beyond approaches that focus on individual coastal segments or properties rather than the coastal system as a whole. Strategies that are property specific tend to have inconsistent results and often unintended consequences (Forbes et al., 2002). *It is recommended that the Towns of Conception Bay South and Holyrood base their coastal zone/land use management and planning strategies on a consideration of the entire southern Conception Bay coastal system and indeed, strive to work together to develop mutually beneficial management plans, rather that considering their communities in isolation.*

9.2.6: Public Education

For adaptation to climate change to be successful, the public needs to be educated as to the various hazards, including their location and intensity, and the potential adaptation strategies that can be implemented in a region (Gibb, 1983; Godschalk et al., 2000). Hazard information should be made available through regional and municipal planning schemes, with sensitive locations identified on the planning maps (Gibb, 1983). Such hazard maps should be readily available to the general public, regularly updated, and easily understandable (Godschalk et al., 2000). *The creation of a climate change impacts and adaptations poster that is specific to the study region would be an excellent way of providing information to the public. In combination with the poster, it is recommended that the Towns of Conception Bay South and Holyrood develop a website that provides* *climate change information and community specific adaptation strategies to further educate their residents.*

Regardless of the adaptation strategies adopted, they need to be adaptable themselves. Sensitivity, understanding, technology and coastal dynamics can change with time, indicating that adaptation needs should be reassessed and possibly adjusted on a regular basis: such as when municipal plans are re-evaluated, usually every five to ten years (Gibb, 1983; Forbes et al., 2002).

Chapter 10
Conclusion

With increasing development pressure, many coastal regions are experiencing rapid alteration of their natural environment, leading to widespread impacts on natural systems (Lawrence, 1994) and increasing hazards for human populations. Coastal processes such as sea-level rise, storm surge flooding, wave attack, sea-ice impact and shoreline erosion are important components of the climate-driven marine environment (Catto, in press). When human developments coincide with these physical processes, naturally occurring events become geologic hazards (Lawrence, 1994; Godschalk et al., 2000; Mclean and Tsyban, 2001).

Over the last fifty years, the population growth rate in Conception Bay South has exceeded that of the Province of Newfoundland and Labrador. Historical data indicates that Conception Bay South's population has approximately doubled every twenty years. With an improved provincial and regional economy, there has been consistent population growth and demand for new housing (Canning and Pitt Associates, 2001). With the majority of development in Conception Bay South and Holyrood occurring within 2 km of the coastline, there are important implications for coastal land use management, especially since rapid urbanization, recreation and tourism have become significant economic activities within both communities over the past decade. With more and more people moving into the coastal environment, steps must be taken to ensure that people, property and infrastructure are not situated in environmentally sensitive locations, now or in the future. This is particularly true when future environment conditions are likely to change. For the most immediate effects of climate change and variability on the physical environment and on social and economic activity will be felt along the coastline (Bijlsma, 1996; Forbes et al., 1997; Klein and Nicholls, 2001; Mclean and Tsyban, 2001).

Scientific research has shown that climate change is a reality in Newfoundland. Analysis of average annual temperature records for St. John's, Newfoundland show a general rise in temperatures during the first half of the twentieth century, a peak near 1950, followed by a general decline in temperature (Pocklington et al., 1994). Atlantic Canada in general, experienced an overall cooling of 0.7 °C between 1948 and 1991 (Gullett and Skinner, 1992; Pocklington et al., 1994; Lewis, 1997). More recent data indicates that three of the ten warmest years in Atlantic Canada for the period 1948-2002 have occurred since 1998 (1998, 1999 and 2001), with 1999 being the warmest year on record (Climate Trends and Variations Bulletin, Environment Canada). Over the next 100 years, temperature increases of 3 to 4 °C are projected for the Atlantic Provinces. Along with anticipated changes in precipitation patterns and an increase in extreme events (Government of Canada website). The implications of regional and global climate change on the Conception Bay South-Holyrood coastline are substantial. Climate change is predicated to cause an increase in global sea-level, as well as changes in climate variability and extremes which may lead to increases in storm frequency or intensity, possible changes in storm tracks, wind climatology, wave patterns and sea ice cover. (Forbes et al., 1997; Mclean and Tsyban, 2001). All of these factors can potentially affect coastal stability, flood and storm hazards, and socio-economic activity or investment within the coastal zone (Forbes et al., 1997; Mclean and Tsyban, 2001).

Results of the hazard sensitivity assessment indicate that overall, the Conception Bay South-Holyrood coastline has a low to moderate sensitivity to coastal flooding and erosion. However, subsequent analysis reveals that these results mask important differences in sensitivity based on differences in morphology. Results of the flood hazard sensitivity assessment indicate that the most sensitive segments of coastline surround the numerous lagoons located in Conception Bay South. The majority of the "exposed straight" coastline has a low sensitivity to flooding. In the foreshore erosion hazard sensitivity assessment sections of coastline classified as barrier beach are highly to extremely sensitive to foreshore erosion processes, while segments classified as fringing beach or bedrock dominated receive low to moderate sensitivity ratings. Results of the backshore erosion hazard sensitivity assessment indicate that the majority of the Conception Bay South-Holyrood coastline has a low sensitivity to backshore erosion, a reflection of the fact that a third of the coastline is composed of highly resistant, granite bedrock. Sections of backshore classified as unlithified are highly to extremely sensitive to erosion and there are a number of segments actively eroding.

With portions of the Conception Bay South-Holyrood coastline currently sensitive to coastal flooding and erosion and anticipated changes in climatic conditions and accelerated rates of sea-level rise potentially increasing the risk, there is a need for town management and planning decision-making processes that are capable of supporting sustainable community practices. In anticipation of this increased risk, a number of specific adaptation options, including hazard identification and monitoring; managed retreat or avoidance; accommodation; protection; coastal management and public education, have been recommended to enable current protection and facilitate preparation for accelerated sea-level rise and climate variability in southern Conception Bay.

To further assist the provision of accurate climate change impacts and adaptation information to Newfoundland coastal communities, there exist a number of opportunities for future research.

- It is recommended that small scale, high resolution, climate change models that are specific to the Island of Newfoundland be developed to enable more accurate forecasting of future climate change, variability and extremes, along with their associated impacts, at a local scale.

- It is recommended that detailed socio-economic impact analysis of future climate change on the coastal communities of Newfoundland be undertaken. With livelihoods still dependent on ocean resource extraction and with the majority of the population living along the coastline, detailed research on what the economic costs of climate change are and its related social impact is needed.

- It is recommended that research focus on providing highly accurate, relative sea-level rise estimates for the Island of Newfoundland to allow for creation of detailed coastal flooding models and hazard maps.

- It is recommended that research focus on developing a provincially applicable, non-specialist, climate change hazard assessment model that would allow all coastal communities to quickly and accurately assess their risk to the impacts of climate change for the purposes of town planning and land use management.

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Appendix 1
Hazard Sensitivity Maps

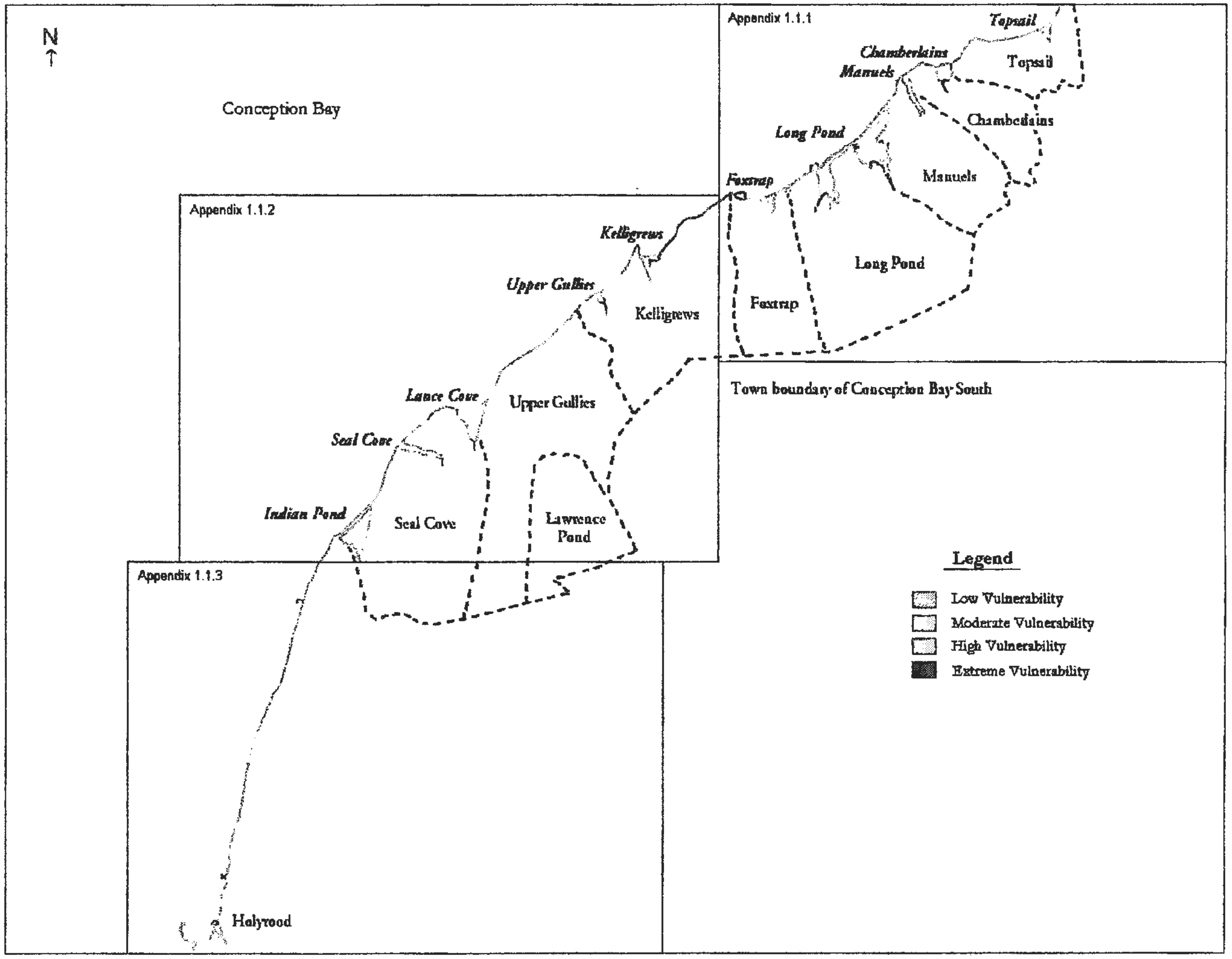
Appendix 1.1
Flood Hazard Sensitivity Maps

Quantification and Limitations of the Hazard Sensitivity Maps

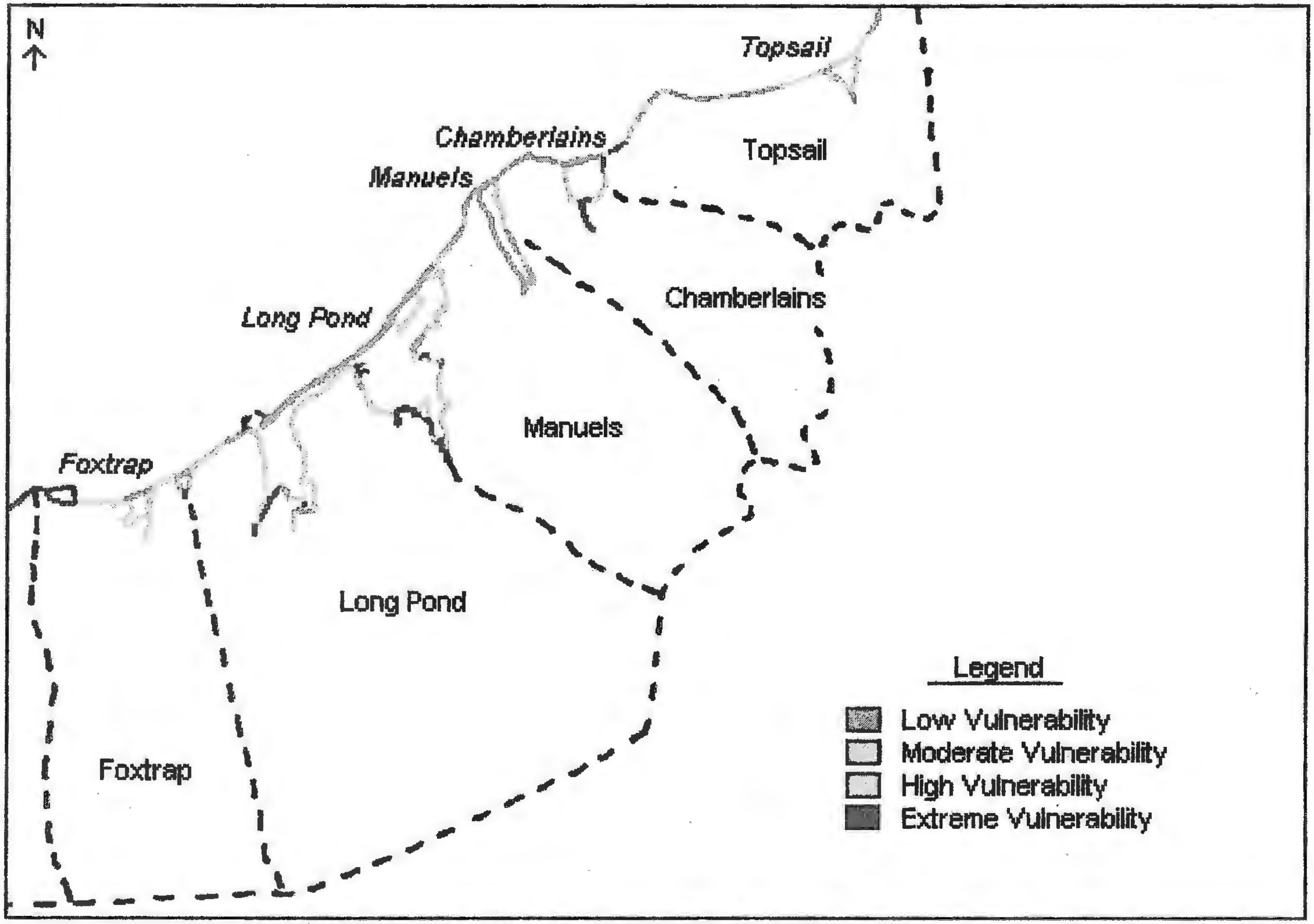
These maps are intended for regional purposes only, such as landuse planning, and should not be used for site-specific evaluations.

These maps can be used with other criteria to help planners select potential areas for development, while avoiding geomorphologically vulnerable areas. *However, they do not replace the need for site-specific geotechnical evaluations by qualified professionals* prior to new construction or upgrading of existing buildings and facilities.

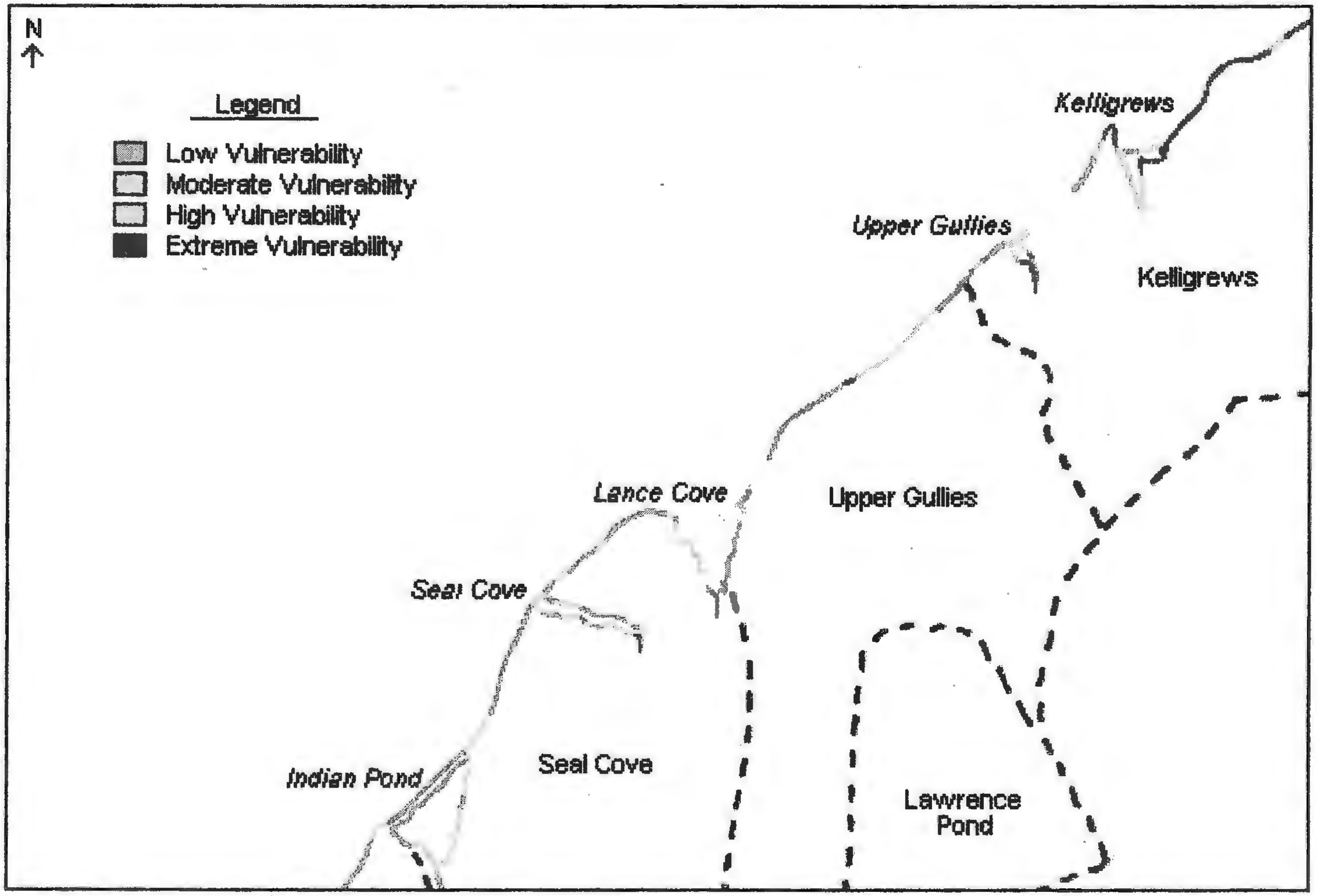
Also, it should be noted that a low hazard on these maps does not mean freedom from coastal hazards, because all areas could be subject to significant modification during extreme storms and changing relative sea-levels. **These maps cannot be used to directly predict the amount of damage that will occur at any one site.**



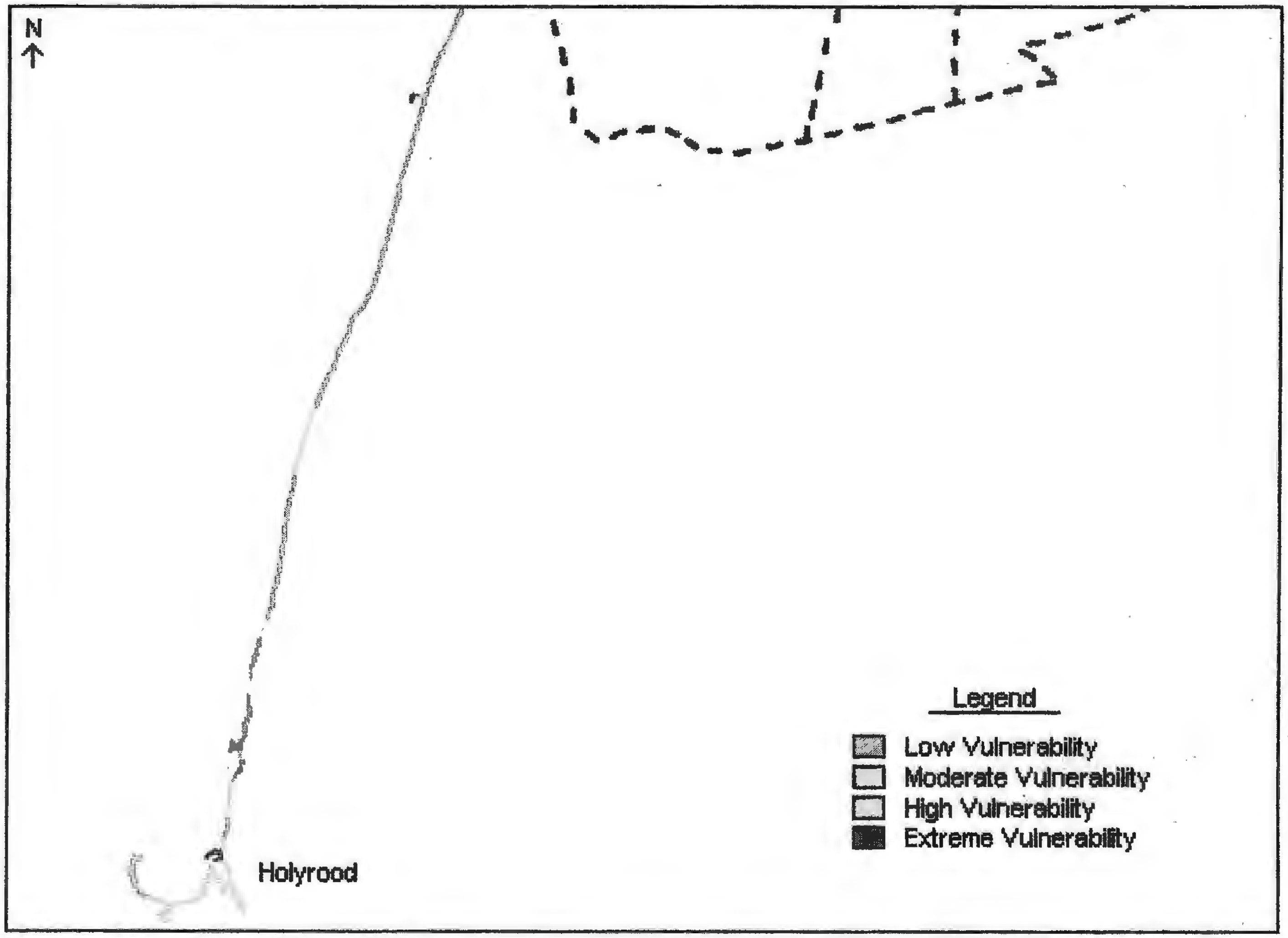
Appendix 1.1: Flood hazard sensitivity map. Note location of inset appendices.
(scale approximately 1:130 000)



Appendix 1.1.1: Flood hazard sensitivity map – Topsail to Foxtrap region.
(scale approximately 1:54 000)



Appendix 1.1.2: Flood hazard sensitivity map – Kelligrews to Indian Pond region.
(scale approximately 1:54 000)



Appendix 1.1.3: Flood hazard sensitivity map – Holyrood region.
(scale approximately 1:54 000)

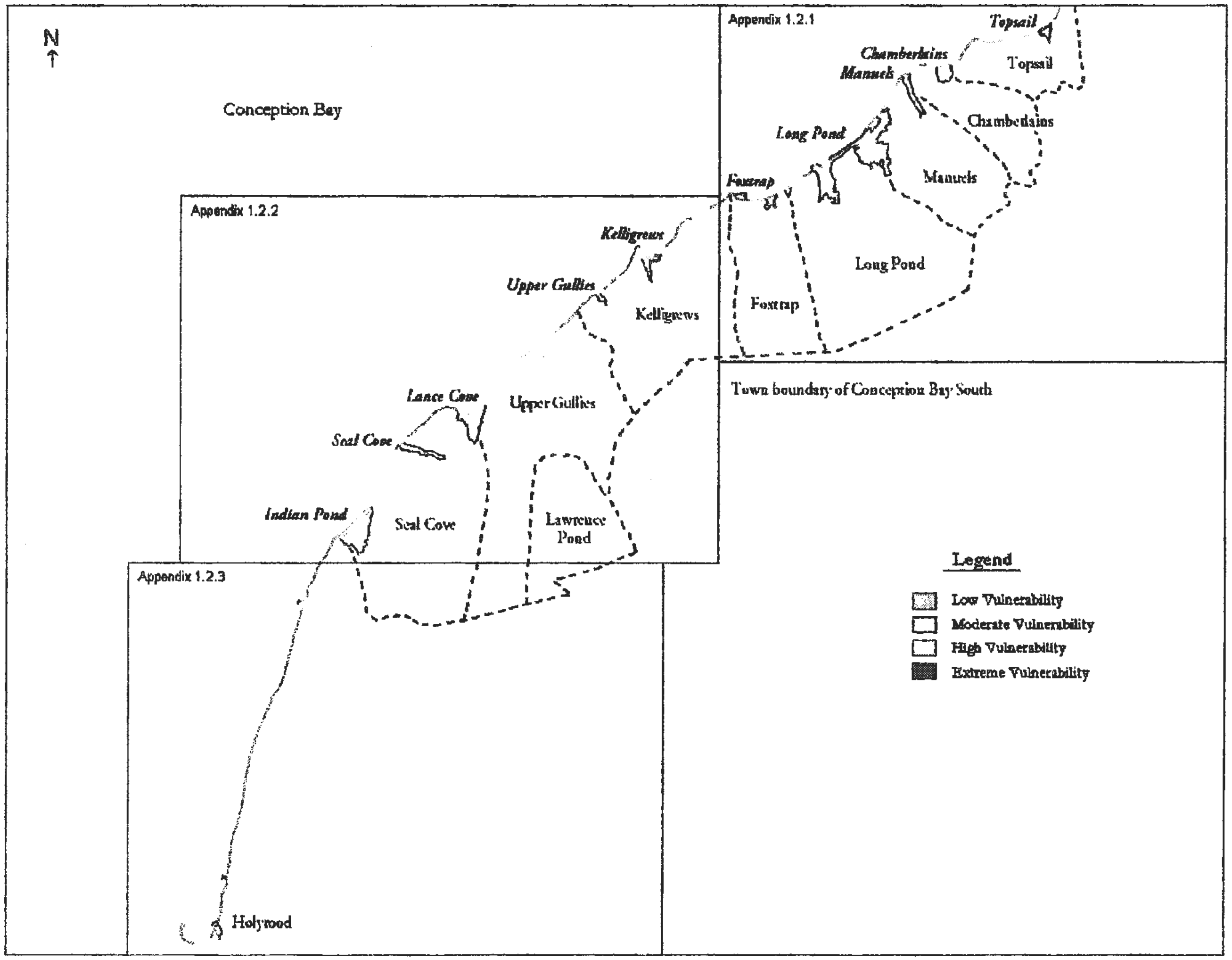
Appendix 1.2
Foreshore Erosion Hazard Sensitivity Maps

Quantification and Limitations of the Hazard Sensitivity Maps

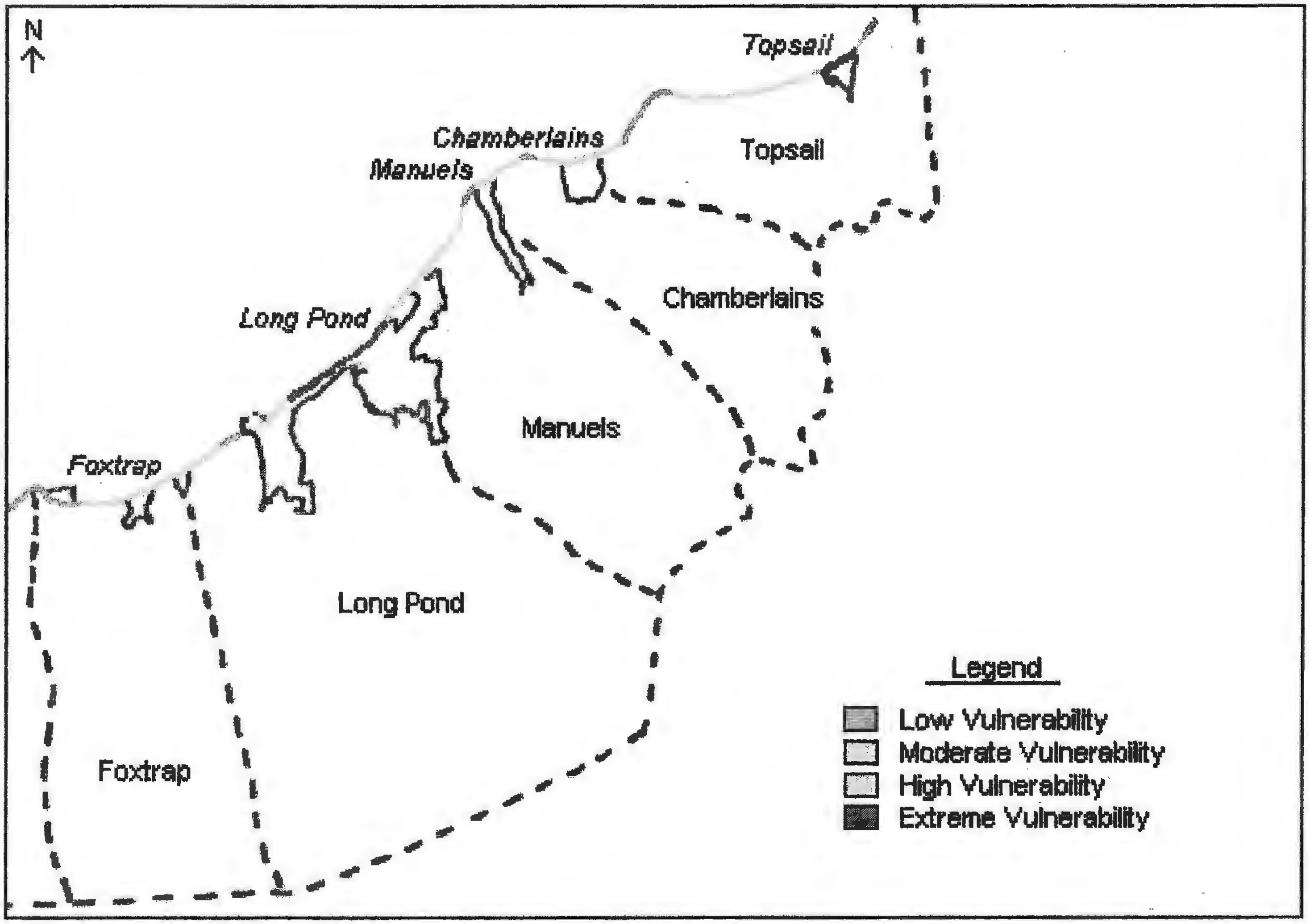
These maps are intended for regional purposes only, such as landuse planning, and should not be used for site-specific evaluations.

These maps can be used with other criteria to help planners select potential areas for development, while avoiding geomorphologically vulnerable areas. *However, they do not replace the need for site-specific geotechnical evaluations by qualified professionals* prior to new construction or upgrading of existing buildings and facilities.

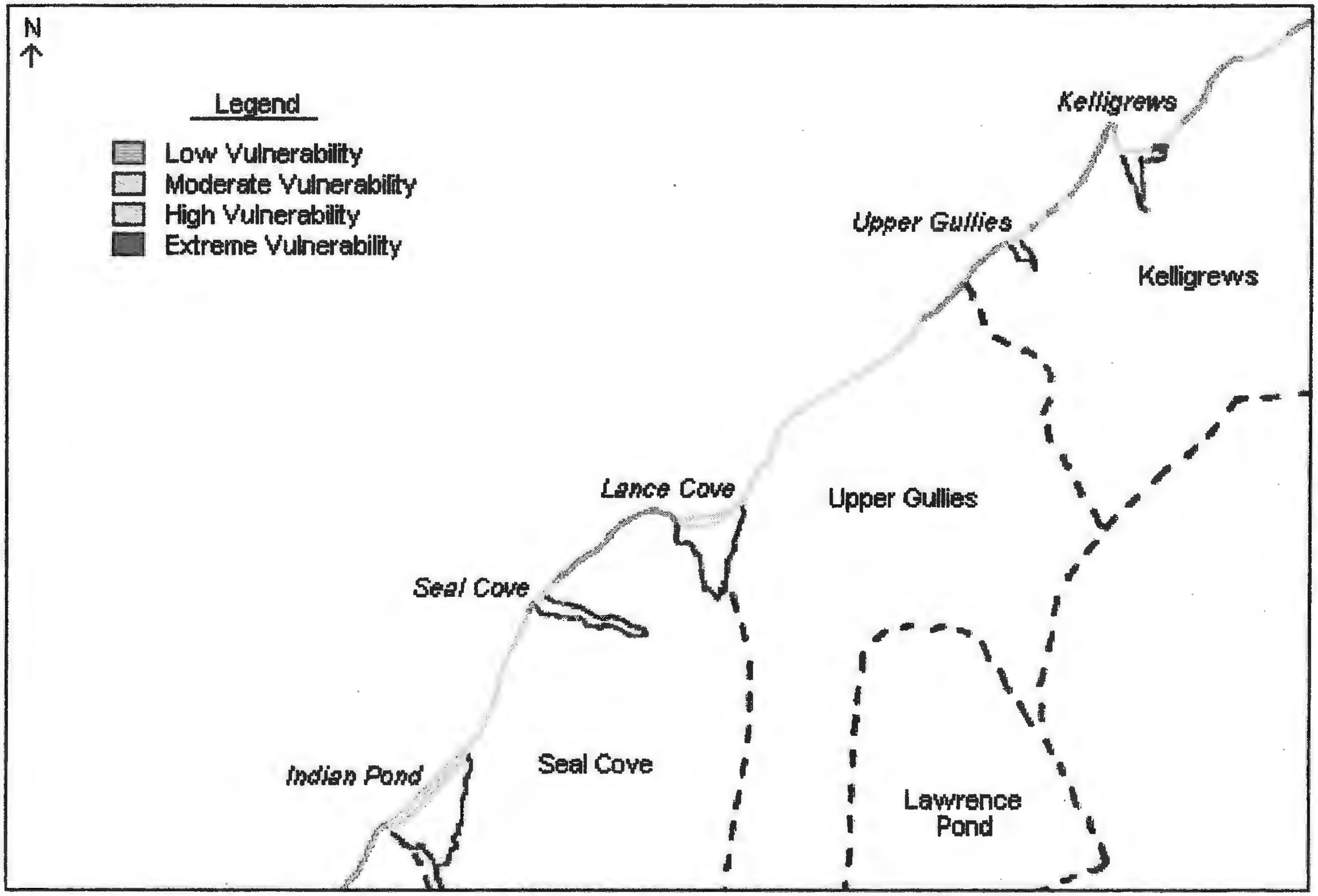
Also, it should be noted that a low hazard on these maps does not mean freedom from coastal hazards, because all areas could be subject to significant modification during extreme storms and changing relative sea-levels. **These maps cannot be used to directly predict the amount of damage that will occur at any one site.**



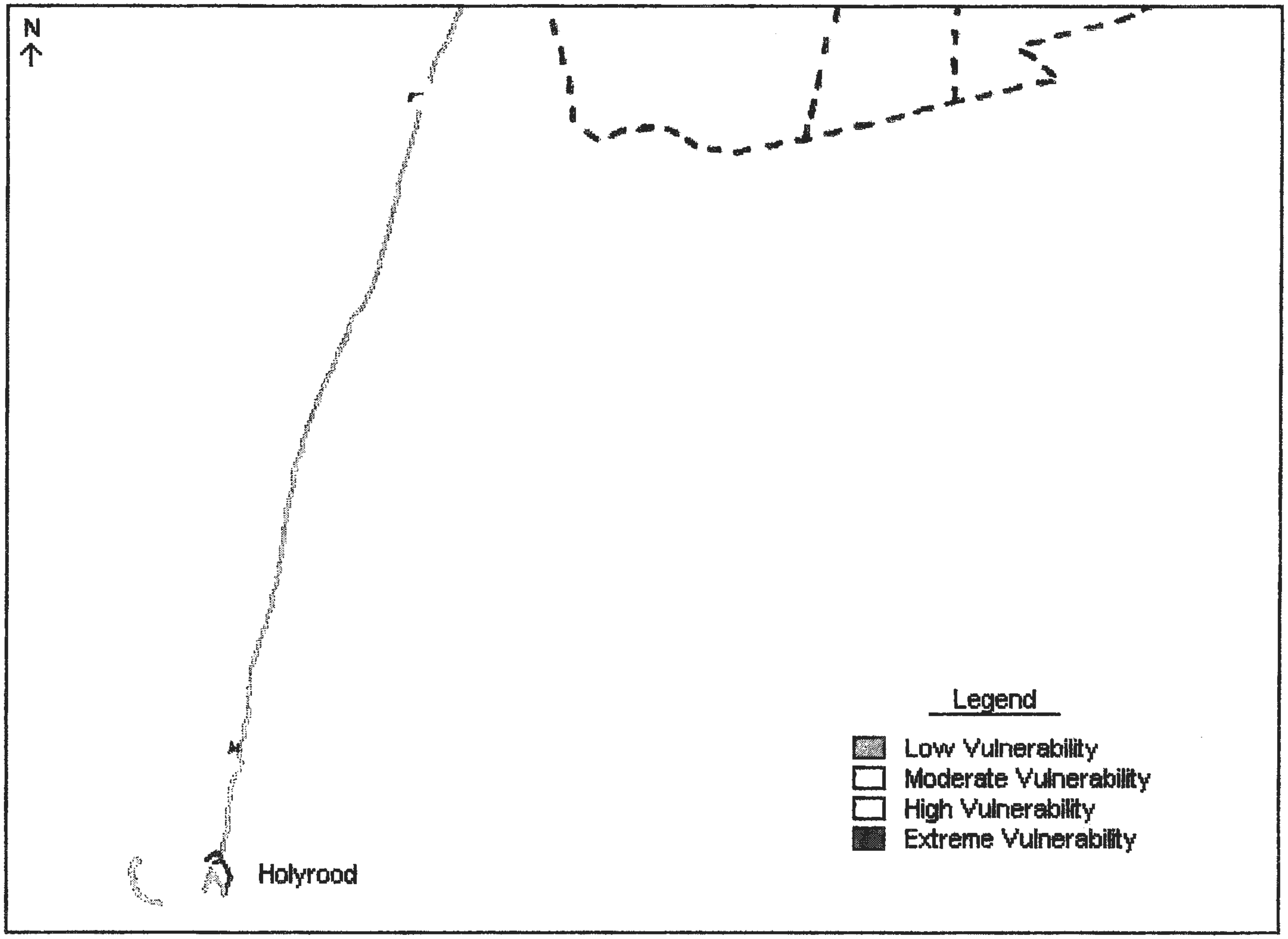
Appendix 1.2: Foreshore erosion hazard sensitivity map. Note location of inset appendices. (scale approximately 1:130 000)



Appendix 1.2.1: Foreshore erosion hazard sensitivity map – Topsail to Foxtrap region.
(scale approximately 1:54 000)



Appendix 1.2.2: Foreshore erosion hazard sensitivity map – Kelligrews to Indian Pond region.
(scale approximately 1:54 000)



Appendix 1.2.3: Foreshore erosion hazard sensitivity map – Holyrood region.
(scale approximately 1:54 000)

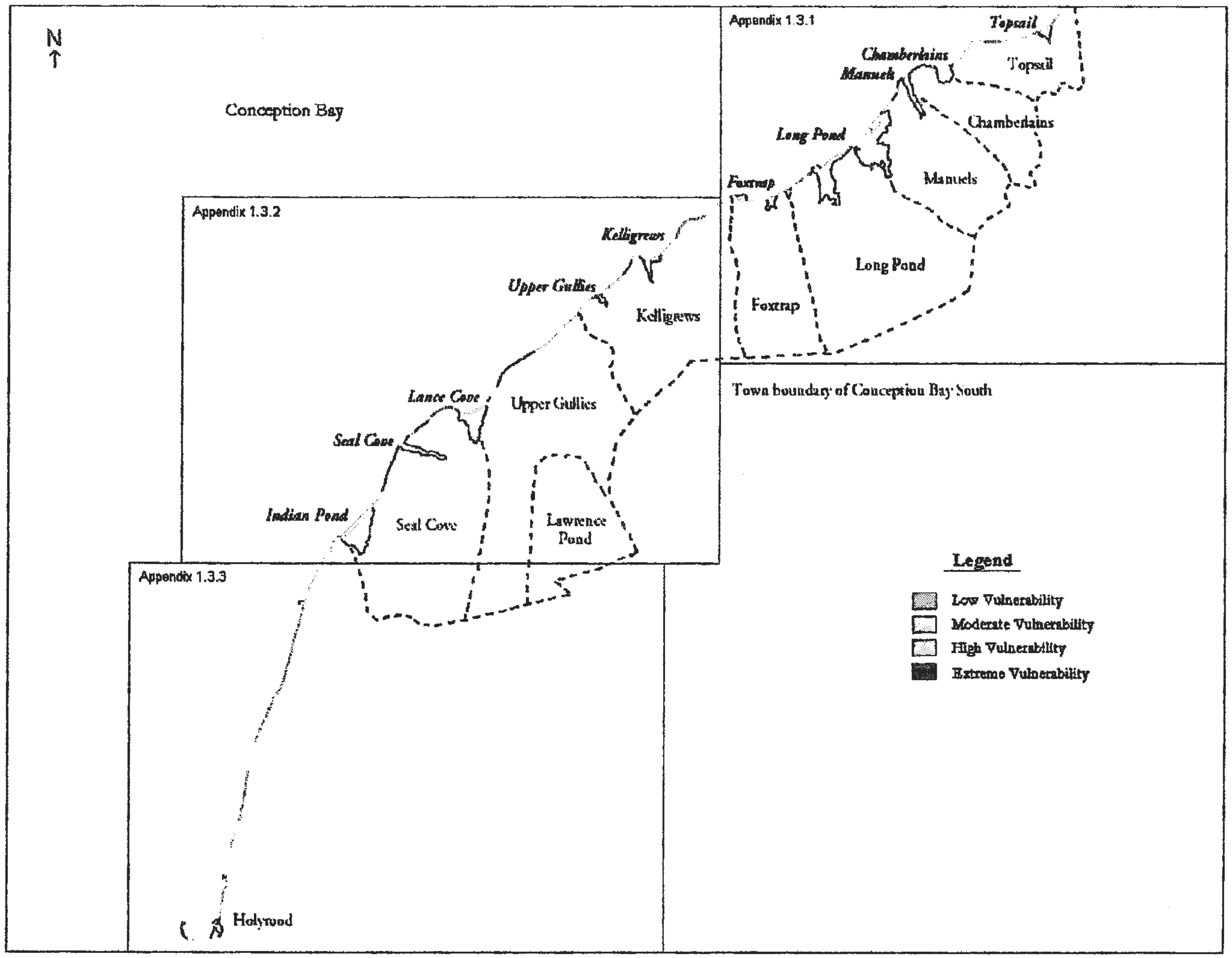
Appendix 1.3
Backshore Erosion Hazard Sensitivity Maps

Quantification and Limitations of the Hazard Sensitivity Maps

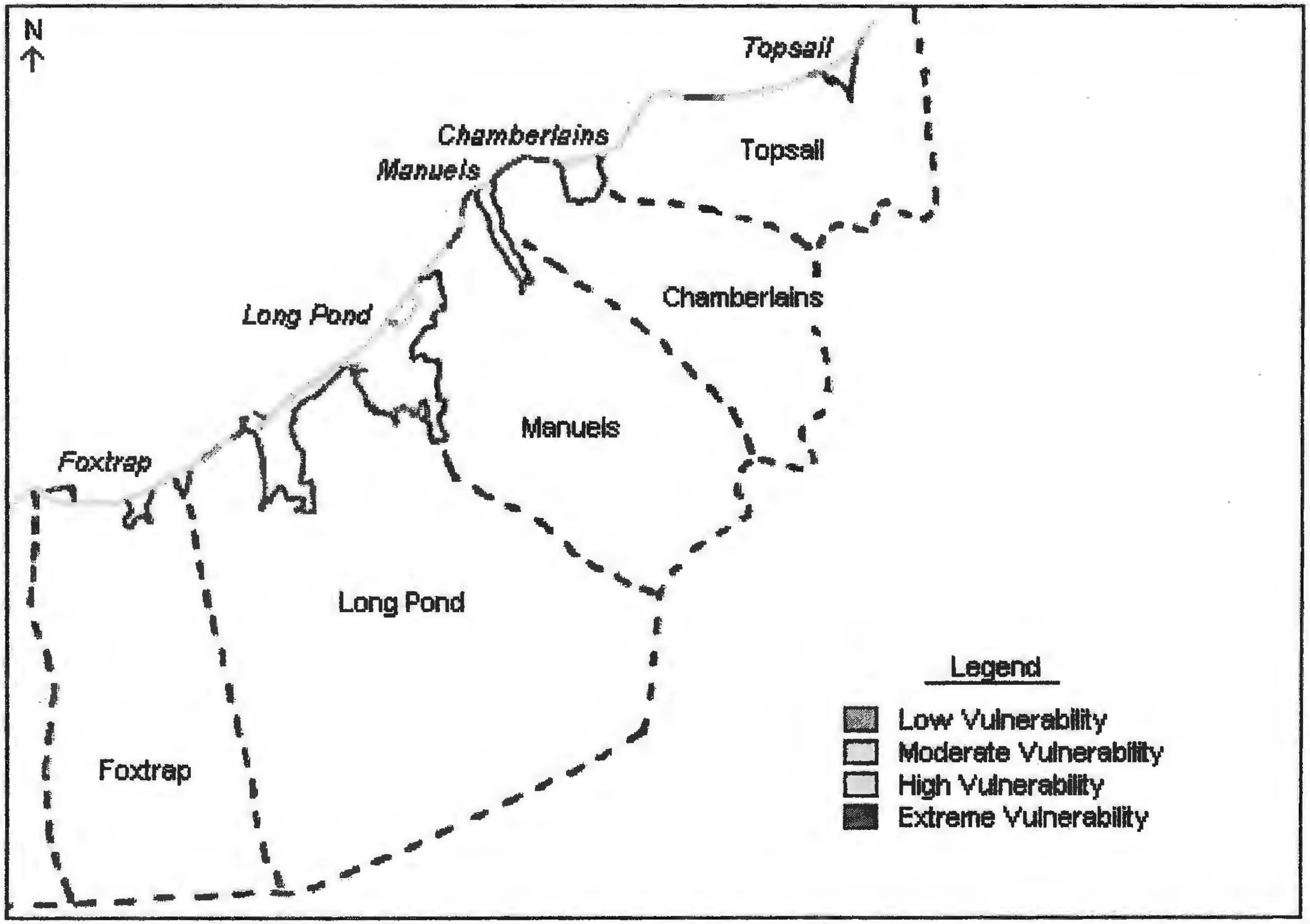
These maps are intended for regional purposes only, such as landuse planning, and should not be used for site-specific evaluations.

These maps can be used with other criteria to help planners select potential areas for development, while avoiding geomorphologically vulnerable areas. *However, they do not replace the need for site-specific geotechnical evaluations by qualified professionals* prior to new construction or upgrading of existing buildings and facilities.

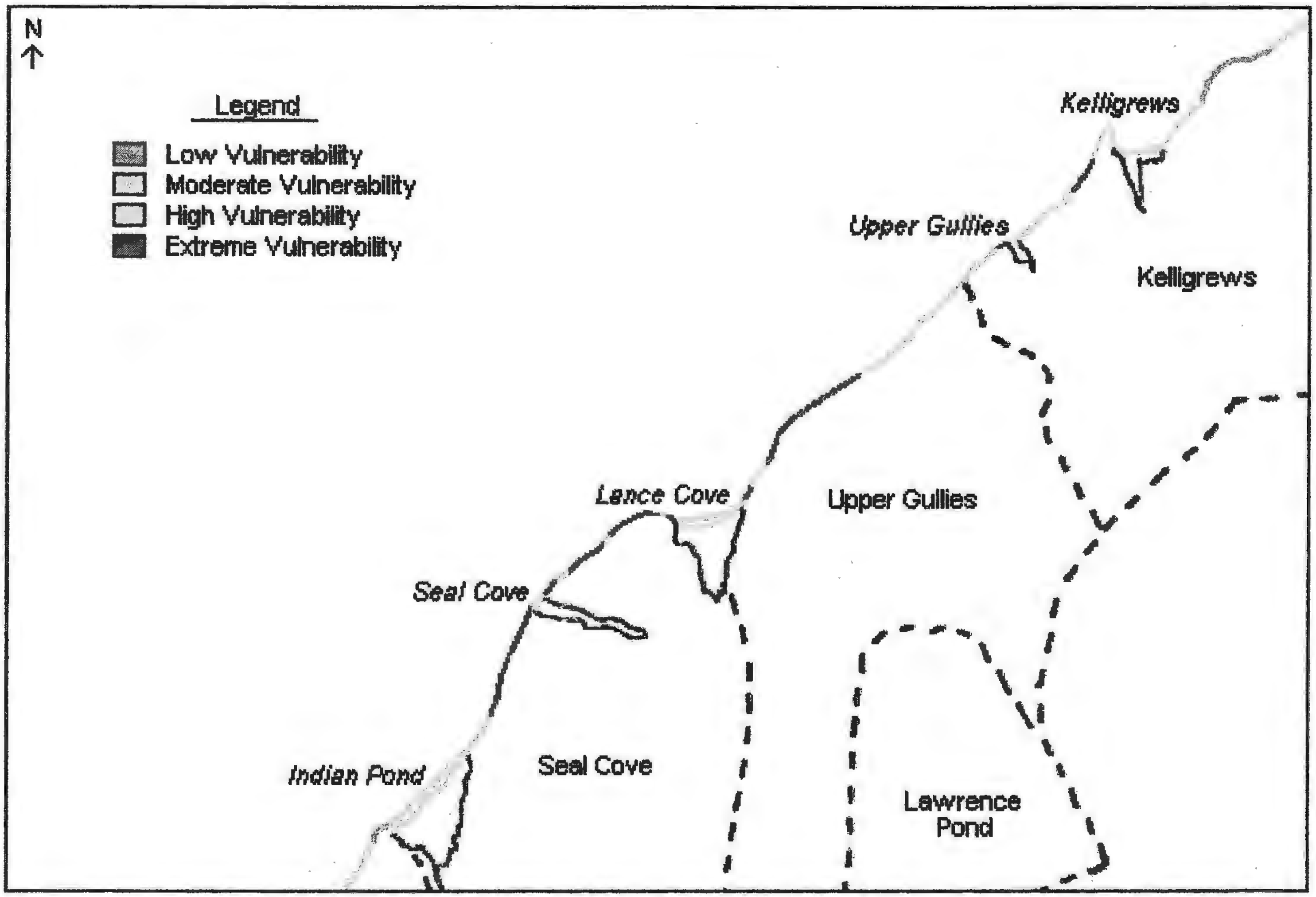
Also, it should be noted that a low hazard on these maps does not mean freedom from coastal hazards, because all areas could be subject to significant modification during extreme storms and changing relative sea-levels. **These maps cannot be used to directly predict the amount of damage that will occur at any one site.**



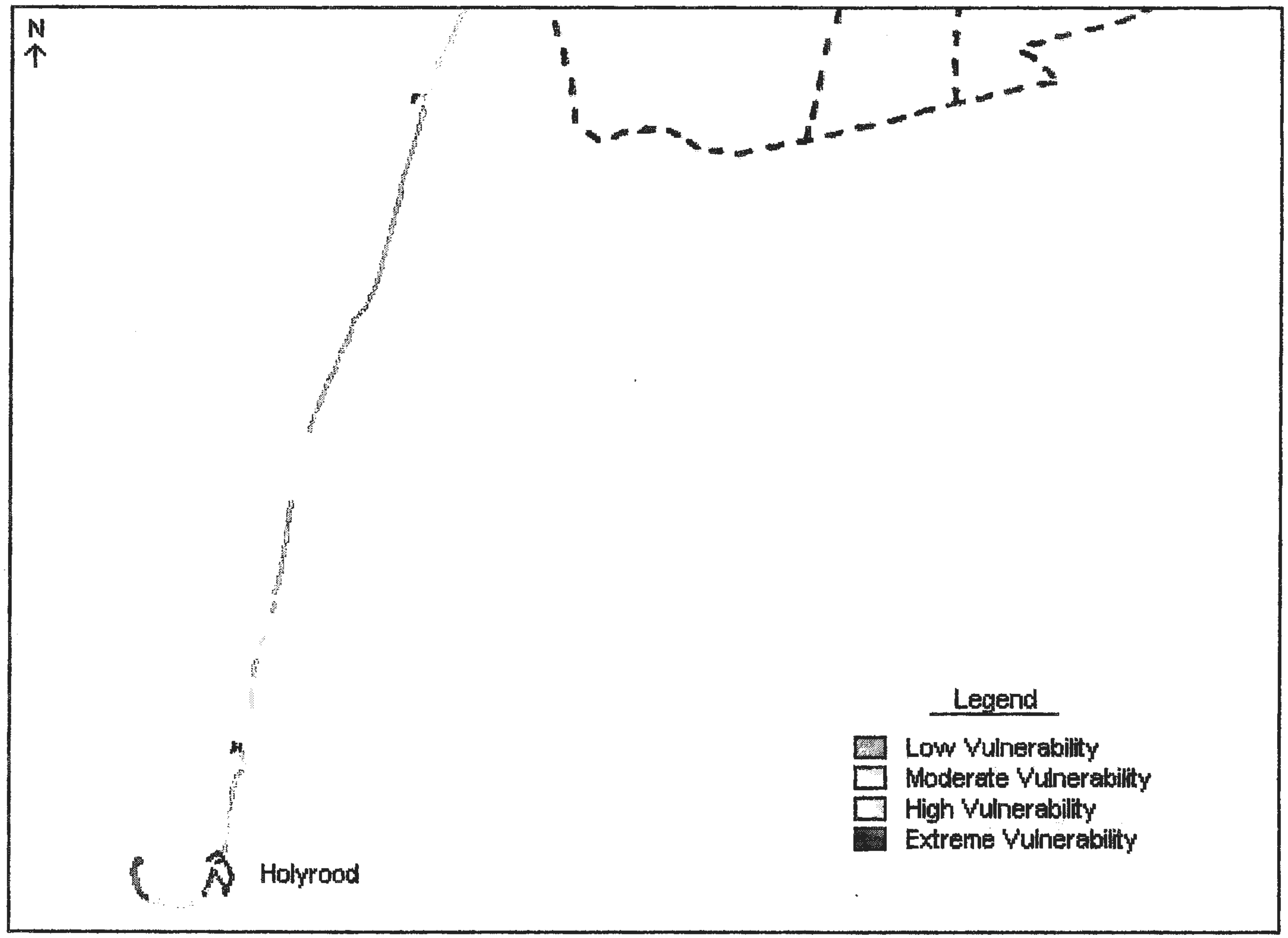
Appendix 1.3: Backshore erosion hazard sensitivity map. Note location of inset appendices. Barriers excluded from analysis and shaded grey. (scale approximately 1:130 000)



Appendix 1.3.1: Backshore erosion hazard sensitivity map – Topsail to Foxtrap region. Barriers excluded from analysis and shaded grey. (scale approximately 1:54 000)



Appendix 1.3.2: Backshore erosion hazard sensitivity map – Kelligrews to Indian Pond region. Barriers excluded from analysis and shaded grey. (scale approximately 1:54 000)



Appendix 1.3.3: Backshore erosion hazard sensitivity map – Holyrood region. Barriers excluded from analysis and shaded grey. (scale approximately 1:54 000)

Appendix 2
Hazard Sensitivity Map Component Tables

Appendix 2.1
Flood Hazard Sensitivity Component Tables:
Lagoonal Coastline

Location	Distance Alongshore (m)	Segment Length (m)	Hazard Sensitivity Score	Sensitivity Rating
Topsail Pond	0 - 69	69	2	Moderate
	69 - 256	187	3	High
	256 - 450	194	2	Moderate
	450 - 531	81	1	Low
	531 - 681	150	1	Low
	681 - 881	200	2	Moderate
	881 - 1063	182	3	High
	1063 - 1156	93	2	Moderate
Chamberlains Pond	0 - 119	119	4	Extreme
	119 - 338	219	3	High
	338 - 681	343	4	Extreme
	681 - 718	37	4	Extreme
	718 - 776	58	3	High
	776 - 900	124	2	Moderate
	900 - 938	38	3	High
	938 - 1025	87	2	Moderate
Manuels Pond	0 - 113	113	1	Low
	113 - 286	173	3	High
	286 - 389	103	2	Moderate
	389 - 726	337	1	Low
	726 - 846	120	2	Moderate
	846 - 1035	189	1	Low
	1096 - 1146	50	1	Low
	1146 - 1554	408	4	Extreme
	1554 - 2411	857	1	Low
Burnt Island	0 - 380	380	2	Moderate
	380 - 541	161	3	High
Long Pond Lagoon	0 - 188	188	3	High
	188 - 306	118	2	Moderate
	306 - 463	157	3	High
	463 - 506	43	2	Moderate
	506 - 638	132	3	High
	638 - 782	144	1	Low
	782 - 913	131	2	Moderate
	913 - 963	50	4	Extreme
	963 - 1088	125	3	High
	1088 - 1119	31	2	Moderate
	1119 - 1138	19	4	Extreme
	1138 - 1857	719	3	High
	1857 - 1951	94	4	Extreme
	1951 - 2151	200	4	Extreme
	2151 - 2199	48	3	High
	2199 - 2329	130	4	Extreme
	2329 - 2667	338	2	Moderate
	2667 - 2985	318	4	Extreme

Location	Distance Alongshore (m)	Segment Length (m)	Hazard Sensitivity Score	Sensitivity Rating
Long Pond Lagoon	2985 - 3198	213	3	High
	3198 - 3298	100	2	Moderate
	3298 - 3354	56	1	Low
	3354 - 3485	131	2	Moderate
	3485 - 3929	444	3	High
	3929 - 4118	189	2	Moderate
	4118 - 4474	356	3	High
	4474 - 4539	65	2	Moderate
	4539 - 4817	278	3	High
	4817 - 4892	75	2	Moderate
	4892 - 5210	318	3	High
	5210 - 5242	32	2	Moderate
	5242 - 5292	50	1	Low
	5292 - 5342	50	3	High
	5342 - 5423	81	1	Low
	5423 - 5660	237	2	Moderate
	5660 - 5908	248	3	High
	5908 - 5948	40	4	Extreme
	5948 - 6117	169	2	Moderate
	6117 - 6160	43	4	Extreme
	6160 - 6423	263	3	High
	6423 - 6473	50	1	Low
	6473 - 6704	231	3	High
	6704 - 7037	333	4	Extreme
	7037 - 7123	86	2	Moderate
	7123 - 7209	86	4	Extreme
	7209 - 7723	514	2	Moderate
	7723 - 8004	281	3	High
Foxtrap Pond (1)	0 - 56	56	2	Moderate
	56 - 119	63	3	High
	119 - 175	56	2	Moderate
	175 - 225	50	4	Extreme
	225 - 256	31	2	Moderate
	256 - 344	88	3	High
Foxtrap Pond (2)	0 - 163	163	3	High
	163 - 250	87	2	Moderate
	250 - 475	225	3	High
	475 - 769	294	3	High
	769 - 1381	612	2	Moderate
Kelligrews Pond	0 - 606	606	4	Extreme
	606 - 950	344	2	Moderate
	950 - 1644	694	3	High
Upper Gullies Pond	0 - 119	119	2	Moderate
	119 - 169	50	3	High
	169 - 231	62	4	Extreme

Location	Distance Alongshore (m)	Segment Length (m)	Hazard Sensitivity Score	Sensitivity Rating
Upper Gullies Pond	231 - 371	140	3	High
	371 - 469	98	2	Moderate
	469 - 988	519	4	Extreme
	988 - 1318	330	3	High
	1318 - 1394	76	2	Moderate
Lance Cove Pond	0 - 32	32	3	High
	32 - 119	87	2	Moderate
	119 - 755	636	3	High
	755 - 994	239	2	Moderate
	994 - 1219	225	4	Extreme
	1219 - 1288	69	3	High
	1288 - 1407	119	2	Moderate
	1407 - 1819	412	3	High
	1819 - 1888	69	2	Moderate
	1888 - 1944	56	3	High
Seal Cove Pond	0 - 44	44	3	High
	44 - 75	31	1	Low
	75 - 319	244	3	High
	319 - 675	356	1	Low
	675 - 719	44	2	Moderate
	719 - 788	69	1	Low
	788 - 900	112	2	Moderate
	900 - 1081	181	3	High
	1150 - 1419	269	4	Extreme
	1419 - 1481	62	3	High
	1481 - 1575	94	2	Moderate
	1575 - 1681	106	3	High
	1681 - 1788	107	2	Moderate
	1788 - 1875	87	1	Low
	1875 - 1919	44	2	Moderate
	1919 - 2000	81	1	Low
	2000 - 2050	50	2	Moderate
	2050 - 2119	69	3	High
	2119 - 2288	169	1	Low
	2288 - 2356	68	2	Moderate
Indian Pond Lagoon	0 - 181	181	2	Moderate
	181 - 225	44	3	High
	225 - 294	69	2	Moderate
	294 - 350	56	3	High
	350 - 480	130	1	Low
	480 - 1024	544	2	Moderate
	1024 - 1181	157	3	High
	1181 - 1203	22	2	Moderate
	1203 - 1388	185	1	Low
	1388 - 1969	581	3	High

Location	Distance Alongshore (m)	Segment Length (m)	Hazard Sensitivity Score	Sensitivity Rating
Indian Pond Lagoon	1969 - 2006	310	2	Moderate
	2006 - 2275	272	1	Low

Statistical Information:

Sensitivity Rating	Shortest Segment Length (m)	Longest Segment Length (m)	Range (m)	Mean (m)
Low	31	857	826	272
Moderate	31	544	513	148
High	32	719	687	321
Extreme	19	606	587	198

Appendix 2.2
Flood Hazard Sensitivity Component Tables:
"Exposed Straight" Coastline

Location	Distance Alongshore (m)	Segment Length (m)	Hazard Sensitivity Score	Sensitivity Rating
Topsail	0 - 104	104	1	Low
	104 - 518	414	2	Moderate
	518 - 575	57	1	Low
	575 - 1070	495	3	High
	1070 - 1392	322	1	Low
	1392 - 1495	103	3	High
	1495 - 1783	288	1	Low
Chamberlains	1783 - 1863	80	2	Moderate
	1863 - 1932	69	1	Low
	1932 - 1990	58	2	Moderate
	1990 - 2105	115	1	Low
	2105 - 2174	69	2	Moderate
	2174 - 2266	92	3	High
	2266 - 2335	69	4	Extreme
	2335 - 2565	230	2	Moderate
	2565 - 2875	310	1	Low
	2875 - 2898	23	2	Moderate
	2898 - 3048	150	1	Low
Manuels	3048 - 3692	644	1	Low
Long Pond	3692 - 3887	195	1	Low
	3887 - 3968	81	3	High
	3968 - 4071	103	1	Low
	4071 - 4278	207	3	High
	4278 - 6038	1706	1	Low
Foxtrap	6141 - 6343	202	1	Low
	6343 - 6412	69	2	Moderate
	6412 - 6601	189	3	High
	6601 - 6659	58	2	Moderate
	6659 - 6785	126	1	Low
	6785 - 6958	173	2	Moderate
	6958 - 7303	345	1	Low
	7303 - 7567	264	2	Moderate
	7567 - 7947	380	4	Extreme
Kelligrews	7947 - 8430	483	4	Extreme
	8430 - 8648	218	3	High
	8648 - 9752	1104	4	Extreme
	9752 - 9948	196	2	Moderate
	9948 - 10 063	115	1	Low
	10 063 - 10 201	138	3	High
	10 201 - 10 511	310	4	Extreme
	10 511 - 10 580	69	3	High
Riverdale	10 580 - 10 672	92	2	Moderate
	10 672 - 10 882	210	1	Low
	10 882 - 11 466	584	2	Moderate
	11 466 - 11 581	115	3	High

Location	Distance Alongshore (m)	Segment Length (m)	Hazard Sensitivity Score	Sensitivity Rating
Riverdale	11 581 - 11 684	103	2	Moderate
	11 684 - 11 960	276	1	Low
	11 960 - 12 029	69	2	Moderate
	12 029 - 12 466	437	1	Low
	12 466 - 12 547	81	2	Moderate
Upper Gullies	12 547 - 12 627	80	2	Moderate
	12 627 - 12 754	127	3	High
	12 754 - 13 122	368	2	Moderate
	13 122 - 13 179	57	3	High
	13 179 - 13 237	58	4	Extreme
	13 237 - 13 294	57	3	High
	13 294 - 14 203	909	1	Low
Lance Cove	14 203 - 14 283	80	1	Low
	14 283 - 14 513	230	2	Moderate
	14 513 - 14 582	69	1	Low
	14 582 - 14 674	92	3	High
	14 674 - 15 215	541	2	Moderate
	15 215 - 15 272	57	1	Low
	15 272 - 15 376	104	2	Moderate
	15 376 - 15 698	322	1	Low
Seal Cove	15 698 - 15 962	264	1	Low
	15 962 - 16 020	58	2	Moderate
	16 020 - 16 307	287	1	Low
	16 307 - 16 445	138	2	Moderate
	16 445 - 16 549	104	1	Low
	16 549 - 16 687	138	2	Moderate
	16 687 - 17 227	540	1	Low
Indian Pond	17 227 - 17 549	322	1	Low
	17 549 - 17 963	414	2	Moderate
	17 963 - 18 837	874	1	Low
	18 837 - 18 941	104	3	High
Holyrood	18 941 - 27 121	8180	1	Low
	26 896 - 28 666	1770	2	Moderate
	28 666 - 29 647	981	1	Low
	29 647 - 29 774	127	2	Moderate
	29 774 - 30 786	1012	1	Low
	30 786 - 30 889	103	2	Moderate
	30 889 - 31 821	932	1	Low
	31 821 - 31 913	92	2	Moderate
	31 913 - 32 200	287	1	Low
	32 200 - 32 430	230	2	Moderate
	32 430 - 32 695	265	3	High
	32 695 - 32 994	299	2	Moderate
	32 994 - 33 431	437	1	Low
	33 431 - 33 865	434	2	Moderate

Location	Distance Alongshore (m)	Segment Length (m)	Hazard Sensitivity Score	Sensitivity Rating
Holyrood	33 865 - 34 186	321	3	High
	34 186 - 35 263	1077	2	Moderate
	35 263 - 35 788	525	1	Low

In addition, the area behind the Holyrood Marina and both sides of the creek behind the beach are rated as having a high flood vulnerability.

Statistical Information:

Sensitivity Rating	Shortest Segment Length (m)	Longest Segment Length (m)	Range (m)	Mean (m)
Low	57	8180	8123	593
Moderate	23	1770	1747	266
High	57	495	438	161
Extreme	58	1104	1046	401

Appendix 2.3
Foreshore Erosion Hazard Sensitivity Component Tables

Location	Distance Alongshore (m)	Segment Length (m)	Form of Foreshore	Sediment Type	Bathymetric Slope	Offshore Boulders	Hazard Sensitivity Score	Sensitivity Rating
Topsail	0 - 173	173	2	2	1	1	6	Low
	173 - 242	69	2	2	1	2	7	Moderate
	242 - 575	333	3 + 4[1]	4	1	2	14	Extreme
	575 - 1783	1208	2	4	1	2	9	Moderate
Chamberlains	1783 - 2300	517	2	2	1	1	6	Low
	2300 - 2507	207	2	2	1	2	7	Moderate
	2507 - 2818	311	3 + 4[1]	2	1	2	12	High
	2818 - 3048	230	2	2	1	2	7	Moderate
Manuels	3048 - 3151	103	2	2	1	1	6	Low
	3151 - 3370	219	2	2	1	2	7	Moderate
	3370 - 3565	195	3 + 4[1]	2	1	2	12	High
	3565 - 3692	127	2	2	1	1	6	Low
Long Pond	3692 - 4336	644	2	2	1	2	7	Moderate
	4336 - 4531	195	3 + 4[1]	2	1	2	12	High
	4531 - 4773	242	2 + 4[1]	4	1	2	13	High
	4773 - 5773	1000	3 + 4[1]	4	1	2	14	Extreme
	5773 - 6038	265	3	4	1	2	10	Moderate
Foxtrap	6141 - 6348	207	2	2	1	1	6	Low
	6348 - 6659	311	2	4	1	2	8	Moderate
	6659 - 6785	126	3	3	1	2	8	Moderate
	6785 - 6958	173	2	3	1	2	7	Moderate
	6958 - 7314	356	3 + 4[2]	3	1	2	13	High
	7314 - 7544	230	2 + 4[2]	3	1	2	12	High
	7544 - 7866	322	anthropogenic	anthropogenic	1	2	3	Low
	7866 - 7947	81	2	1	1	1	5	Low
Kelligrews	7947 - 8384	437	2	2	1	1	6	Low
	8384 - 8844	460	2	2	1	2	7	Moderate

[1] washover fans present
[2] marsh present

Location	Distance Alongshore (m)	Segment Length (m)	Form of Foreshore	Sediment Type	Bathymetric Slope	Offshore Boulders	Hazard Sensitivity Score	Sensitivity Rating
Kelligrews	8844 - 9568	724	2	2	1	1	6	Low
	9568 - 9752	184	2	2	1	2	7	Moderate
	9752 - 9856	104	3 + 4[1]	4	1	2	14	Extreme
	9856 - 9959	103	2 + 4[2]	2	1	2	11	High
	9959 - 10 201	242	3	1	1	2	7	Moderate
	10 201 - 10 339	138	2	4	1	2	9	Moderate
	10 339 - 10 580	241	2	1	1	1	5	Low
Riverdale	10 580 - 11 006	426	2	1	1	1	5	Low
	11 006 - 11 133	127	2	2	1	2	7	Moderate
	11 133 - 11 259	126	2	2	1	1	6	Low
	11 259 - 11 351	92	2	2	1	2	7	Moderate
	11 351 - 11 408	57	2	2	1	1	6	Low
	11 408 - 11 581	173	2	2	1	2	7	Moderate
	11 581 - 11 684	103	3	1	1	2	7	Moderate
	11 684 - 11 799	115	2	1	1	1	5	Low
	11 799 - 12 547	748	2	2	1	1	6	Low
Upper Gullies	12 547 - 14 249	1702	2	2	1	2	7	Moderate
Lance Cove	14 249 - 14 674	425	2	2	1	2	7	Moderate
	14 674 - 15 215	541	3	4	1	2	10	High
	15 215 - 15 560	345	2	1	1	1	5	Low
	15 560 - 15 698	138	2	1	1	2	6	Low
Seal Cove	15 698 - 16 422	724	2	1	1	2	6	Low
	16 422 - 16 549	127	2	2	1	2	7	Moderate
	16 549 - 16 641	92	3	2	1	2	7	Moderate
	16 641 - 16 687	46	3	2	1	1	7	Moderate
	16 687 - 16 744	57	2	2	1	1	6	Low
	16 744 - 17 227	483	2	2	1	2	7	Moderate
Indian Pond	17 227 - 17 963	736	2	2	1	2	7	Moderate

[1] washover fans present

[2] marsh present

Location	Distance Alongshore (m)	Segment Length (m)	Form of Foreshore	Sediment Type	Bathymetric Slope	Offshore Boulders	Hazard Sensitivity Score	Sensitivity Rating
Indian Pond	17 963 - 18 837	874	3 + 4[1]	2	1	2	12	High
	18 837 - 18 941	104	2	2	1	1	6	Low
Holyrood	18 941 - 21 068	2127	2	2	1	1	6	Low
	21 068 - 21 160	92	2	2	2	1	7	Moderate
	21 160 - 21 344	184	2	2	2	2	8	Moderate
	21 344 - 32 522	11 178	1	1	2	2	6	Low
	32 522 - 33 373	851	1	1	1	2	5	Low
	33 373 - 33 477	104	2	1	1	2	6	Low
	33 477 - 34 098	621	anthropogenic	anthropogenic	2	2	4	Low
	34 098 - 34 995	897	2	4	1	2	9	Moderate
	34 995 - 35 788	793	2	1	1	2	6	Low

[1] washover fans present
[2] marsh present

Statistical Information:

Sensitivity Rating	Shortest Segment Length (m)	Longest Segment Length (m)	Range (m)	Mean (m)
Low	57	11 174	11 117	607
Moderate	46	1208	1162	348
High	103	874	771	339
Extreme	104	1000	896	479

Appendix 2.4
Backshore Erosion Hazard Sensitivity Component Tables

Location	Distance Alongshore (m)	Segment Length (m)	Backshore Slope	Backshore Composition	Erosion Control	Vegetation Status	Hazard Sensitivity Score	Sensitivity Rating
Topsail	0 - 104	104	4	1	1	3	9	High
	104 - 150	46	3	1	1	3	8	Moderate
	150 - 242	92	3	2	1	1	7	Low
	242 - 575	333	-	-	-	-	-	-
	575 - 679	104	2	3	1	1	7	Low
	679 - 759	80	2	3	2	3	10	High
	759 - 1070	311	2	3	1	3	9	High
	1070 - 1392	322	4	3	1	1	9	High
	1392 - 1495	103	2	3	1	1	7	Low
	1495 - 1702	207	4	3	1	3	11	Extreme
	1702 - 1783	81	4	3	1	2	10	High
Chamberlains	1783 - 1863	80	3	3	1	2	9	High
	1863 - 1932	69	4	3	1	2	10	High
	1932 - 1990	58	3	3	1	2	9	High
	1990 - 2105	115	4	3	1	2	10	High
	2105 - 2174	69	3	3	1	3	10	High
	2174 - 2266	92	2	3	1	3	9	High
	2266 - 2335	69	1	3	1	3	8	Moderate
	2335 - 2565	230	3	3	1	3	10	High
	2565 - 2818	253	-	-	-	-	-	-
	2818 - 2875	57	4	3	1	3	11	Extreme
	2875 - 2898	23	3	3	1	3	10	High
	2898 - 3048	150	4	3	1	3	11	Extreme
Manuels	3048 - 3416	368	4	3	1	3	11	Extreme
	3416 - 3565	149	-	-	-	-	-	-
	3565 - 3692	127	4	2	1	3	10	High
Long Pond	3692 - 3887	195	4	3	1	3	11	Extreme
	3887 - 3968	81	2	3	1	3	9	High
	3968 - 4071	103	4	3	1	3	11	Extreme
	4071 - 4106	35	4	3	2	3	12	Extreme
	4106 - 4163	57	2	3	2	3	10	High

Location	Distance Alongshore (m)	Segment Length (m)	Backshore Slope	Backshore Composition	Erosion Control	Vegetation Status	Hazard Sensitivity Score	Sensitivity Rating
Long Pond	4163 - 4278	115	2	3	1	3	9	High
	4278 - 4531	253	-	-	-	-	-	-
	4531 - 4773	242	4	3	1	1	9	High
	4773 - 6038	1265	-	-	-	-	-	-
Burnt Island	0 - 380	380	3	3	2	2	10	High
	380 - 541	161	2	3	1	1	7	Low
Foxtrap	6141 - 6343	202	4	3	2	3	12	Extreme
	6343 - 6412	69	3	3	1	1	8	Moderate
	6412 - 6601	189	2	3	1	1	7	Low
	6601 - 6659	58	3	3	1	1	8	Moderate
	6659 - 6785	126	-	-	-	-	-	-
	6785 - 6958	173	3	3	1	2	9	High
	6958 - 7303	345	-	-	-	-	-	-
	7303 - 7569	266	3	3	1	1	8	Moderate
	7567 - 7866	299	1	anthropogenic	anthropogenic	3	4	Low
	7866 - 7947	81	1	3	2	3	9	High
Kelligrews	7947 - 8119	172	1	3	1	3	8	Moderate
	8119 - 8430	311	1	3	2	3	9	High
	8430 - 8648	218	2	3	2	3	10	High
	8648 - 8867	219	1	3	1	1	6	Low
	8867 - 9097	230	1	3	1	2	7	Low
	9097 - 9315	218	1	3	1	1	6	Low
	9315 - 9419	104	1	3	2	3	9	High
	9419 - 9752	333	1	3	1	3	8	Moderate
	9752 - 10 201	449	-	-	-	-	-	-
	10 201 - 10 511	310	1	3	1	3	8	Moderate
	10 511 - 10 580	69	2	3	1	3	9	High
Riverdale	10 580 - 10 672	92	3	3	1	3	10	High
	10 672 - 10 882	210	4	3	1	3	11	Extreme
	10 882 - 11 178	296	3	3	1	2	9	High
	11 178 - 11 236	58	3	3	1	1	8	Moderate

Location	Distance Alongshore (m)	Segment Length (m)	Backshore Slope	Backshore Composition	Erosion Control	Vegetation Status	Hazard Sensitivity Score	Sensitivity Rating
Riverdale	11 236 - 11 466	230	3	3	1	2	9	High
	11 466 - 11 581	115	2	3	2	3	10	High
	11 581 - 11 684	103	-	-	-	-	-	-
	11 684 - 11 753	69	4	3	2	3	12	Extreme
	11 753 - 11 960	207	4	3	1	2	10	High
	11 960 - 12 029	69	3	3	1	2	9	High
	12 029 - 12 466	437	4	3	1	2	10	High
	12 466 - 12 547	81	3	3	1	2	9	High
Upper Gullies	12 547 - 12 627	80	3	3	1	2	9	High
	12 627 - 12 754	127	2	3	1	2	8	Moderate
	12 754 - 13 122	368	3	3	1	2	9	High
	13 122 - 13 179	57	2	3	2	3	10	High
	13 179 - 13 237	58	1	3	2	3	9	High
	13 237 - 13 294	57	2	3	2	3	10	High
	13 294 - 14 203	909	4	3	1	3	11	Extreme
Lance Cove	14 203 - 14 237	34	4	3	1	3	11	Extreme
	14 237 - 14 485	248	3	3	1	1	8	Moderate
	14 485 - 14 554	69	4	3	2	3	12	Extreme
	14 554 - 14 674	120	2	3	2	3	10	High
	14 674 - 15 215	541	-	-	-	-	-	-
	15 215 - 15 272	57	4	3	1	3	11	High
	15 272 - 15 376	104	3	3	1	3	10	High
	15 376 - 15 698	322	4	3	1	3	11	High
Seal Cove	15 698 - 15 916	218	4	3	1	3	11	High
	15 916 - 15 997	81	3	3	1	3	10	High
	15 997 - 16 307	310	4	3	1	3	11	High
	16 307 - 16 434	127	3	3	1	3	10	High
	16 434 - 16 469	35	3	3	2	3	11	Extreme
	16 469 - 16 549	80	4	3	2	3	12	Extreme
	16 549 - 16 687	138	-	-	-	-	-	-
	16 687 - 17 227	540	4	3	1	3	11	Extreme

Location	Distance Alongshore (m)	Segment Length (m)	Backshore Slope	Backshore Composition	Erosion Control	Vegetation Status	Hazard Sensitivity Score	Sensitivity Rating
Indian Pond	17 227 - 17 549	322	4	3	1	3	11	Extreme
	17 549 - 17 963	414	3	3	1	2	9	High
	17 963 - 18 837	874	-	-	-	-	-	-
	18 837 - 18 941	104	2	3	1	1	7	Low
Holyrood	18 941 - 19 278	337	4	3	1	2	10	High
	19 278 - 20 735	1457	4	3	1	2	10	High
	20 735 - 21 344	609	4	2	1	1	8	Moderate
	21 344 - 26 896	5552	4	1	1	1	7	Low
	26 896 - 28 666	1770	3	1	1	1	6	Low
	28 666 - 29 572	906	4	1	1	1	7	Low
	29 572 - 29 647	75	4	2	1	1	8	Moderate
	29 647 - 29 774	127	3	2	1	1	7	Low
	29 774 - 30 786	1012	4	2	1	1	8	Moderate
	30 786 - 30 889	103	3	2	1	1	7	Low
	30 889 - 31 821	932	4	2	1	1	8	Moderate
	31 821 - 31 913	92	3	2	1	1	8	Moderate
	31 913 - 32 200	257	4	2	1	1	8	Moderate
	32 200 - 32 430	230	3	2	1	1	7	Low
	32 430 - 32 695	265	2	2	1	1	6	Low
	32 695 - 32 994	299	2	1	1	2	6	Low
	32 994 - 33 431	437	3	1	1	2	7	Low
	33 431 - 33 477	46	4	2	1	2	9	High
	33 477 - 33 865	388	3	anthropogenic	anthropogenic	3	6	Low
	33 865 - 34 098	233	4	anthropogenic	anthropogenic	2	6	Low
	34 098 - 34 995	897	-	-	-	-	-	-
	34 995 - 35 263	268	2	2	2	3	9	High
	35 263 - 35 788	525	4	2	2	3	11	Extreme

Barriers excluded from analysis.

Statistical Information:

Sensitivity Rating	Shortest Segment Length (m)	Longest Segment Length (m)	Range (m)	Mean (m)
Low	92	5552	5460	573
Moderate	46	932	886	278
High	46	1457	1411	188
Extreme	34	909	875	228