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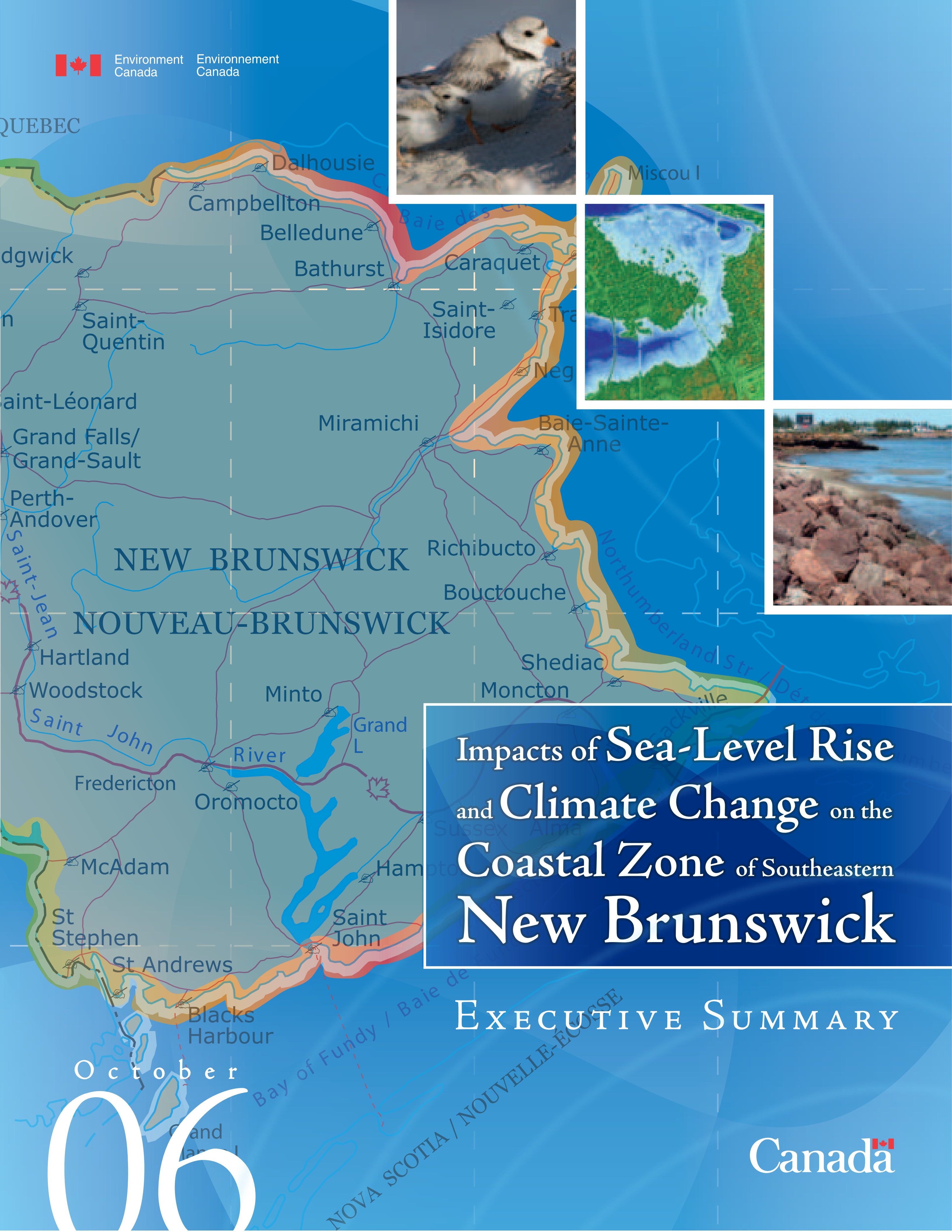

Impacts of Sea-Level Rise and Climate Change on the Coastal Zone of Southeastern New Brunswick

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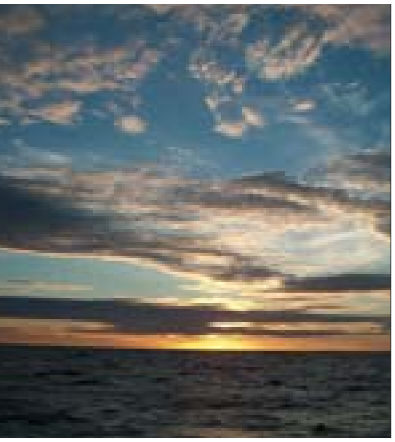

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Government Partners: Environment Canada, Fisheries and Oceans Canada, Natural Resources Canada, Parks Canada Agency, New Brunswick Department of Environment, New Brunswick Department of Natural Resources.

Academic Partners: Centre of Geographic Sciences, Dalhousie University, Laurentian University, Mount Allison University, Université de Moncton, University of New Brunswick.

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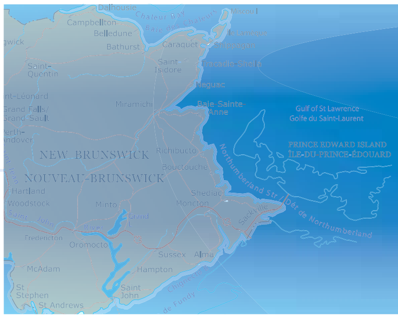
1.0 Introduction



Coastal ecosystems and communities around the world are widely recognized to be vulnerable to rising sea levels and other climate-change impacts, as documented in the various assessment reports of the Intergovernmental Panel on Climate Change (IPCC). In Canada, many parts of the coast have been shown to have significant sensitivity to sea-level rise and associated storm impacts. Areas with the highest sensitivity include parts of the Atlantic coast, particularly in the southern Gulf of St. Lawrence, including sections of the New Brunswick Gulf coast. In this region, sea level is already rising, with demonstrable impacts. Accelerated sea-level rise under greenhouse warming is expected to exacerbate these impacts, increasing the need for adaptation to minimize damage and costs. Threats in this area come primarily from impacts of coastal flooding and erosion, and damage can occur due to forced sea-ice movement caused by storm surge in winter, as was the case with the benchmark storm of January 21, 2000. This coast is also exposed and highly sensitive to wave action during storms in the ice-free season, as demonstrated by shoreline and infrastructure damage experienced in the storm of October 29, 2000. Similar, yet less intense, events occurred again in 2001 and 2002, and other events in 2004. The Boxing Day storm of 2004 caused some damage similar to that witnessed on January 21, 2000.

Light detection and ranging (LiDAR) data have been used to generate a detailed digital elevation model (DEM) of the coast, critical for delineating flooding and inundation zones, natural protection structures such as coastal dunes, and backshore elevation for estimating sediment supply from shore erosion. Meteorological, geological and hydrographic studies include investigations into measured and forecast sea-level changes due to crustal subsidence and climate change. This project modelled the benchmark storm-surge events of January 21, 2000 (declared a disaster by the federal government), and October 29, 2000, and developed a "maximum potential" storm surge along this coast, given our understanding of historical events. These ranges of storm-surge events along with the proposed climate-change-induced sea-level rise scenarios have been placed on the DEM to identify areas along the New Brunswick Gulf of St. Lawrence coast that will be vulnerable to flooding, coastal erosion and inundation over the next 100 years. These impacts are being defined in terms of likely risk, with scales of inland penetration of storm surges based on the scenarios presented and their effect on infrastructure, industry and coastal ecosystems. The coastal zone of southeastern New Brunswick is home to several threatened species of plants and animals. An important aspect of the ecosystem research is to determine how sea-level rise and future storm events will impact critical habitat and species at risk.

The overall objective of this project was to quantify the impacts of climate change — specifically, sea-level rise, storm surge and coastal erosion — on the Gulf of St. Lawrence coastal zone of southeastern New Brunswick. The results of the study will support sustainable management, community resilience and the development of adaptation strategies.

2.0 Summary of Findings

2.1 Sea-Level Rise and Regional Subsidence

Sea level has been rising along the southeastern coast of New Brunswick for several thousand years, gradually flooding Northumberland Strait and the seaward reaches of rivers draining the study area, pushing the shoreline landward and causing vertical growth and landward migration of salt marshes. These changes are continuing slowly and have become evident over a period of several decades. Climate warming, through ocean thermal expansion and melting of ice on the continents, is expected to raise the mean sea level on a global basis by a few decimetres over the coming century, accelerating historical rates of relative sea-level rise (the rise of water level relative to fixed points on land) in Atlantic Canada.

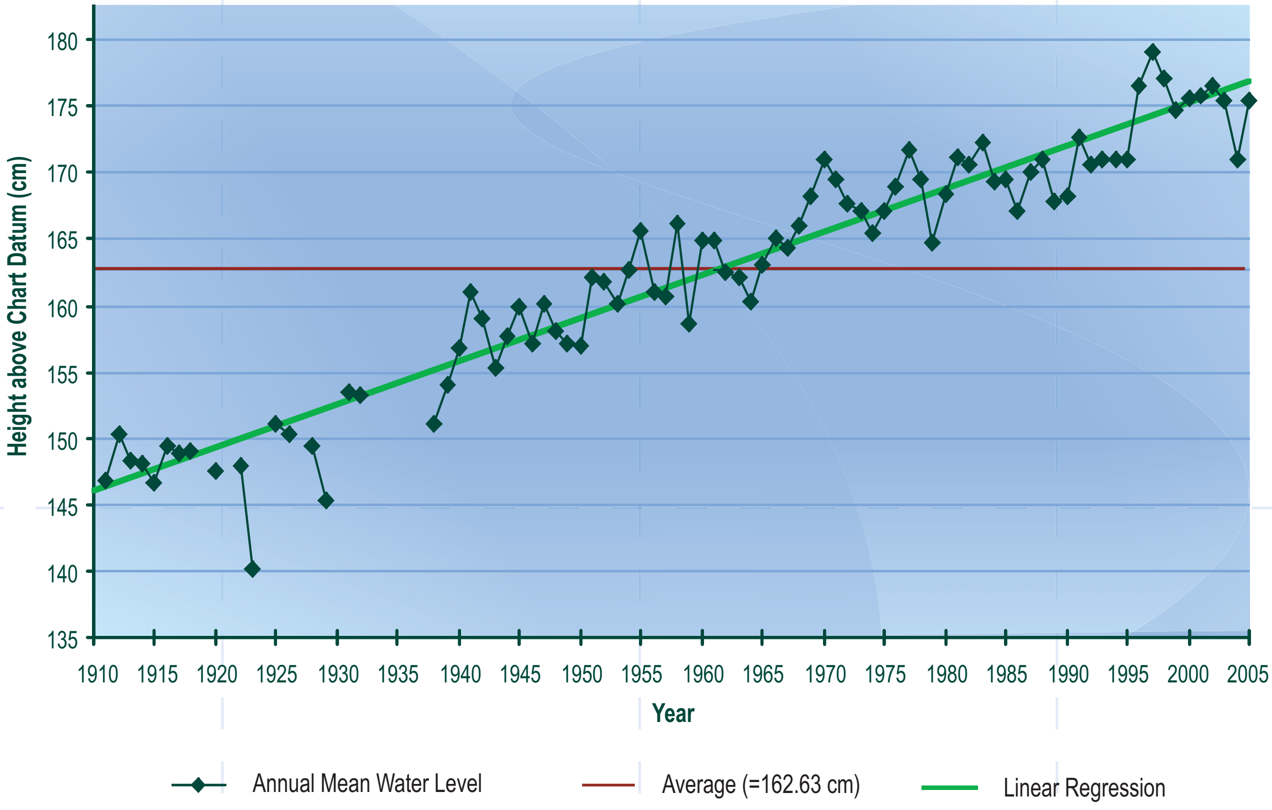
The observed relative sea-level rise results from a combination of regional subsidence and rising sea level in the Northwest Atlantic. The subsidence is a product of glacial loading and unloading more than 10 000 years ago, leading to gradual collapse and migration of a marginal forebulge (area of uplift) that developed around the margins of the North American ice sheets, and additional water loading of the seabed in the Gulf of St. Lawrence as global mean sea level rose more than 100 m from its lowest level during glacial times. Global sea level has continued to rise, accelerating in the second half of the 20th century to a current rate of about 17 cm per century. Because of a gradient in subsidence across the region, the observed relative sea-level rise is less in the northwest and greater in the southeast of the project area. The long tide-gauge record at Charlottetown, PEI, dating back more than 95 years, shows a relative sea-level rise of 32 cm over the past century. At the other end of the study area, the relative sea-level rise at Escuminac is estimated to be about 23 cm over the same time interval. This regional tilting will continue in the future. Therefore, we conclude that future rates of relative sea-level rise will also show a gradient across the region.

Our analysis of isostatic subsidence and tilting presented above and of regional sea-level rise based on the Third Assessment Report of the IPCC, published in 2001, leads to the following estimates of relative sea-level rise for the coming century (2000–2100) across the study region:

• Cape Jourimain	59 ± 35 cm
• Shemogue	57 ± 35 cm
• Cap-Pelé	56 ± 35 cm
• Shediac	54 ± 35 cm
• Bouctouche	53 ± 35 cm
• Kouchibouguac	51 ± 35 cm
• Escuminac	50 ± 35 cm

These rates of sea-level rise need to be considered in the context of storm impacts and associated hazards. During large storms, storm surges cause coastal flooding, large waves cause erosion and

Figure 1: Annual mean height above Chart Datum (cm) for Charlottetown water-level data, 1911–2005



infrastructure damage, and sea ice sometimes moves ashore with damaging effects. Because storm-water levels and waves are superimposed on the mean sea level, rising mean sea level has an important effect on the levels of flooding and wave attack, with implications for ecological and socio-economic impacts and the adaptation measures that need to be taken to reduce losses. These issues are explored in later sections of the report.

2.2 Storm-Surge, Wind, Wave and Ice Climatology

The entire digital inventory of water-level data in the southern Gulf of St. Lawrence was examined in this report to establish the storm-surge climatology of the project study area and to identify extreme storm surges and water-level events. Most storms affecting the southern section of the study area have impacts elsewhere in the Northumberland Strait. The long-term Charlottetown data are therefore crucial to this study, since they allow for an assessment of storm conditions through the decades and demonstrate both the fundamental importance of the storm of January 21, 2000, and the fact that sea-level rise has already played a role in extreme water levels through the period of the data.

The tide-gauge record at Charlottetown is one of the longest available in eastern Canada; it goes back to 1911 and is very complete back to 1938. The water-level record at Escuminac goes back to 1973 but, when combined with earlier records from nearby Pointe-Sapin, goes back to 1963 (43 years). Water-level data from Pointe-du-Chêne are more limited and span the period from 1971 to 1992. The Pointe-du-Chêne tide gauge was re-established for the purpose of this project, and new data from 2003 to 2006 were collected, capturing some very important storms.

Climate warming, through ocean thermal expansion and melting of ice on the continents, is expected to raise the mean sea level on a global basis by a few decimetres over the coming century, accelerating historical rates of relative sea-level rise in Atlantic Canada.

Storm-surge events in excess of 60 cm were extracted from the Charlottetown water-level record taking sea-level rise into account and interpolating where possible for missing events from data at adjacent tide-gauge sites. These events were then collated by decade (1940s to 1990s), by half-decade, by year and by month.

Water-level data from 1960 to 1998 were chosen to represent the storm-surge climatology for Charlottetown. Generally speaking, storm surges above 60 cm are frequent events in Charlottetown, occurring about eight times a year on average (compared with about two or three times a year on average along the Atlantic coast in Halifax). Storm surges of 100 cm or more occur on average about once a year. Storm-surge events above 120 cm are uncommon and occur on average about three times a decade. No events were found in excess of 160 cm. Storm surges at Charlottetown are mainly associated with the stormy period of the late fall and winter. Averaged statistics show an increase in frequency in October and November, with peak activity in December and January. Frequency declines significantly in April, and there are few occurrences in the period from May to September. Storm surges show great variability in frequency from one year to the next, owing to the great range in frequency, severity and track of the storms themselves. Decadal statistics indicate that the storm surges at Charlottetown appear to have become somewhat more frequent from the 1940s to the 1960s and that the larger surges (>120 cm) did not occur at all in the 1940s and 1950s (nor in the somewhat incomplete data prior to that) but show up thereafter. The 1960s, 1970s and 1980s were strong storm-surge decades, with more than two 80-cm events on average each year, and the 1980s showed more than one 100-cm event on average each year. The 1990s generally saw fewer storm surges, although there were a few particularly big events. Many large storm-surge events have shown up since the year 2000. Half-decade statistics draw attention to the fact that some periods are more active than others, particularly the early 1960s and the late 1980s, which were periods of climatologically more frequent northeasterly gales. The period since 2000 has also been very active.

As storms come and go in the coastal zone, large storm surges will eventually phase with sufficiently large tides to produce new record water levels in the study area.

On January 21, 2000, a fierce winter storm caused extensive flooding of coastal areas in southeastern New Brunswick and all along Northumberland Strait, including Pointe-du-Chêne and the downtown waterfront areas of Summerside and Charlottetown in Prince Edward Island. In Charlottetown, this storm brought a new record water level of 4.22 m above Chart Datum (CD), which exceeded the previous record (set exactly 39 years earlier) by 39 cm. This storm (and the flood levels it reached through the region) is the definitive benchmark flooding event for this project. Other extreme storm-surge and water-level events have been identified at Charlottetown, and the water-level data have been systematically adjusted to the year 2000 to demonstrate the impacts that sea-level rise, through the period of the existing data, has already had on extremes of water level and on coastal flooding. When sea-level rise is taken into account, the difference between the new and old record water levels at Charlottetown is reduced to 27 cm.

A storm-surge climatology has also been developed for the Escuminac/Pointe-Sapin area just to the north of the present study area (using 28 years of data) and for Pointe-du-Chêne (using 15 years of data). Storm surges at Escuminac/Pointe-Sapin are similar in frequency, timing and size to those at Charlottetown for the period 1960–2004. On average, there are about seven events each year in excess of 60 cm, with close to one event each year above 100 cm. There is great variability in frequency from one year to the next, with no obvious trend. Nine storm surges above 120 cm have been identified at Escuminac/Pointe-Sapin for the period 1963–2005, compared with 13 events at Charlottetown for the period 1960–2005. The very large storm surges were a little more frequent at Escuminac, with three events in excess of 150 cm identified (not including the storm of January 21, 2000) as opposed to two at Charlottetown. The largest recorded storm surge was 160 cm in height on March 17, 1976. These storm surges are mainly associated with the stormy period of the late fall and winter. As at Charlottetown, there was an observed increase in frequency in October and November, with peak activity in December and January. Frequency declines significantly in April, and there were few occurrences in the period from May to September.

Storm surges at Pointe-du-Chêne are larger and more frequent than those at Escuminac or Charlottetown, although their distribution through the year is, of course, similar, since they are usually caused by the same storms. Ten events above 60 cm are observed per year on average, with two to three events above 100 cm per year on average. Storm surges above 150 cm occur once every two or three years, and storm surges as high as 200 cm have been recorded (198 cm on March 17, 1976, and 200 cm on January 21, 2000), representing the largest recorded storm surges in Atlantic Canada known to the authors of the present report.

With global warming, sea-level rise is forecast to accelerate. As storms come and go in the coastal zone, large storm surges will eventually phase with sufficiently large tides to produce new record water levels in the study area and at Charlottetown.

Additionally, with time, flooding at any given lower level will increase dramatically in frequency, and this point is demonstrated quantitatively at Charlottetown and Pointe-du-Chêne through an exceedance count of the existing data (adjusted for sea-level rise) above various thresholds.

Synoptic weather maps were examined for storms that have given rise to storm surges of 90 cm or more at Charlottetown and 110 cm or more at Pointe-du-Chêne, and track maps were produced. These storms are mainly extratropical marine storms that deepen explosively off the east coast and pass to the east of the study area, usually accompanied by a period of northeasterly or northerly gale or storm-force winds across the Gulf of St. Lawrence. The geometry of these storms is usually favourable for bringing large seas into the study area (in the absence of sea ice). The history of tropical cyclones in the study area has been examined using the U.S. National Hurricane Center's hurricane database (HURDAT) or "best tracks" (1851–2004). Although less common than extratropical storm events, tropical cyclones can be very powerful and occur during the tropical weather season (June to November) when there is no

Table 1: Top water-level events (water level in metres)

	Charlottetown				Pointe-du-Chêne				Escuminac			
	Date	**Max Observed Water Level**	**Rank at Pte-du-Chêne**	**Rank at Escuminac**	**Date**	**Max Observed Water Level**	**Rank at Charlottetown**	**Rank at Escuminac**	**Date**	**Max Observed Water Level**	**Rank at Charlottetown**	**Rank at Pte-du-Chêne**
1	Jan 21, 2000	4.22	1	M	Jan 21, 2000	3.62	1	M	Oct 21, 1968	2.47	234	M
2	Jan 21, 1961	3.84	M	M	Feb 19, 2004	3.08	3	5	Oct 29, 2000	2.42	55	M
3	Feb 19, 2004	3.77	2	5	Dec 27, 2004	2.95	121	3	Dec 27, 2004	2.42	121	3
4	Jan 21, 1973	3.76	M	17	Mar 17, 1976	2.90	5	44	Feb 06, 2001	2.41	85	M
5	Mar 17, 1976	3.76	4	44	Jan 04, 1986	2.80	377	11	Feb 19, 2004	2.40	3	2
6	Dec 30, 1993	3.67	M	22	Nov 22, 1986	2.80	200	49	Dec 19, 1963	2.39	165	M
7	Feb 05, 1974	3.65	8	12	Nov 21, 1988	2.80	126	7	Nov 21, 1988	2.38	126	7
8	Dec 25, 1983	3.59	24	M	Feb 05, 1974	2.71	7	12	Dec 07, 1977	2.35	58	9
9	Sep 12, 2002	3.49	M	27	Dec 07, 1977	2.66	58	8	Nov 26, 1974	2.34	406	15
10	Dec 01, 1943	3.44	M	M	Nov 12, 1987	2.63	219	74	Jun 12, 1976	2.30	75	12

Note: M means that the information is not available because that event was not recorded at the particular tide gauge.

wave protection from sea ice. Historically, tropical storms have been an important contributor to the ongoing process of coastal erosion in the region.

The highest water levels at the tide gauge sites of Charlottetown, Escuminac/Pointe-Sapin and Pointe-du-Chêne were used to identify the benchmark storms of the last 40 years, and these are presented as case studies with emphasis on storm impacts. The case studies illustrate, among other things, the important protective role that sea ice plays during the winter months and draw attention to the enhanced rates of coastal erosion that are probable with a shorter ice season in a future warmer climate. The case studies also illustrate the importance of the storm-surge forecasting program to emergency response and short-term mitigation and the value of LiDAR data in real-time flood mapping.

A brief literature survey of flooding events in the area serves to highlight other important storms that predate the tide-gauge data and reminds us that flooding and coastal erosion in the study area are ongoing processes and that damage to coastal infrastructure is nothing new.

It is clear that the flood levels observed during the storm of January 21, 2000, are close to the maximum levels that can be reached in today's climate. However, this storm occurred at a time when the shoreline was protected by sea ice. The storm of October 29, 2000, in comparison, was accompanied by very large waves on elevated water levels and was very damaging to shorelines and coastal infrastructure. It is the worst storm that we know of in the last 40 years in terms of wave damage and coastal erosion. Conditions would have been considerably worse if the storm had been in phase with the higher high tide of the day. Worse circumstances in terms of wave damage can therefore occur today and may indeed have occurred in the past, and we do not need the addition of sea-level rise due to climate change to achieve this.

Based on the ice charts from the Canadian Ice Service, we developed an accurate climatology of sea ice in the Gulf of St. Lawrence. Examination of the total accumulated ice coverage in the Gulf shows high inter-annual variability as well as some cycles that can be associated with the North Atlantic Oscillation and other environmental parameters.

Our records also indicate a decreasing trend in ice cover and duration of the ice season, which, however, is not statistically significant. It is believed that the presence of ice has a dampening effect on storm surges and waves causing flooding and erosion. Ice severity indexes have been calculated and should be used in studies attempting to demonstrate this relationship quantitatively.

Even though this study did not attempt to determine the exact correlation of ice with storm surges and wave erosion, it is still a qualitative observation that the presence of ice has a dampening effect. We therefore surmise that in a future warmer climate with reduced ice concentration and thickness in the Gulf of St. Lawrence, storm surges and wave erosion may be more severe.

Other issues that were not addressed in this study include direct damage caused by ice being carried onshore by wind stress and ice pressure, as observed in the January 21, 2000, storm; and implications of the potential loss of the seasonal protective barrier of landfast ice in a future warmer climate.

2.3 Storm-Surge and Meteorological Modelling

In this study, we developed an approach to evaluate flooding risk along the New Brunswick coast of the Gulf of St. Lawrence that is based on sea-level observations, extremal analysis and a storm-surge model developed by Dalhousie University. The approach included the installation of two new tide gauges to provide independent sea-level data to test the model, as well as the analysis of historical sea-level observations made over the last century. Considerable effort was expended to make the information useful to non-scientists. For example, an open-access web site was developed to provide daily flood forecasts to the general public. We also developed new ways of visualizing flooding risk that could be readily understood by concerned members of the community.

The two new tide gauges were installed at Pointe-du-Chêne and Wood Islands. These locations were chosen in order to obtain data in areas where too few observations were available to allow the skill of our storm-surge model to be accurately evaluated. Subsequent analysis suggests that the one-day forecasts of the storm-surge model at these gauges have an accuracy better than 10 cm.

A 40-year hindcast of storm surges was performed for the Northwest Atlantic to quantify the return period of extreme sea levels. We were encouraged to find that the standard deviation of the hindcast error (the difference between the observed tidal residuals and the surges reconstructed by the model) is typically 8 cm and compares well with the typical operational forecast error. The surge hindcasts also exhibited the same seasonal and inter-annual variations in standard deviation as the observed residuals. Having demonstrated the quality of the hindcast, we produced maps of the standard deviation of surges for the Northwest Atlantic by season. As expected, the surge variance was highest during the fall and winter. We also showed that the regions with the highest surge variance were in the southern Gulf of St. Lawrence and along the eastern shore of Newfoundland.

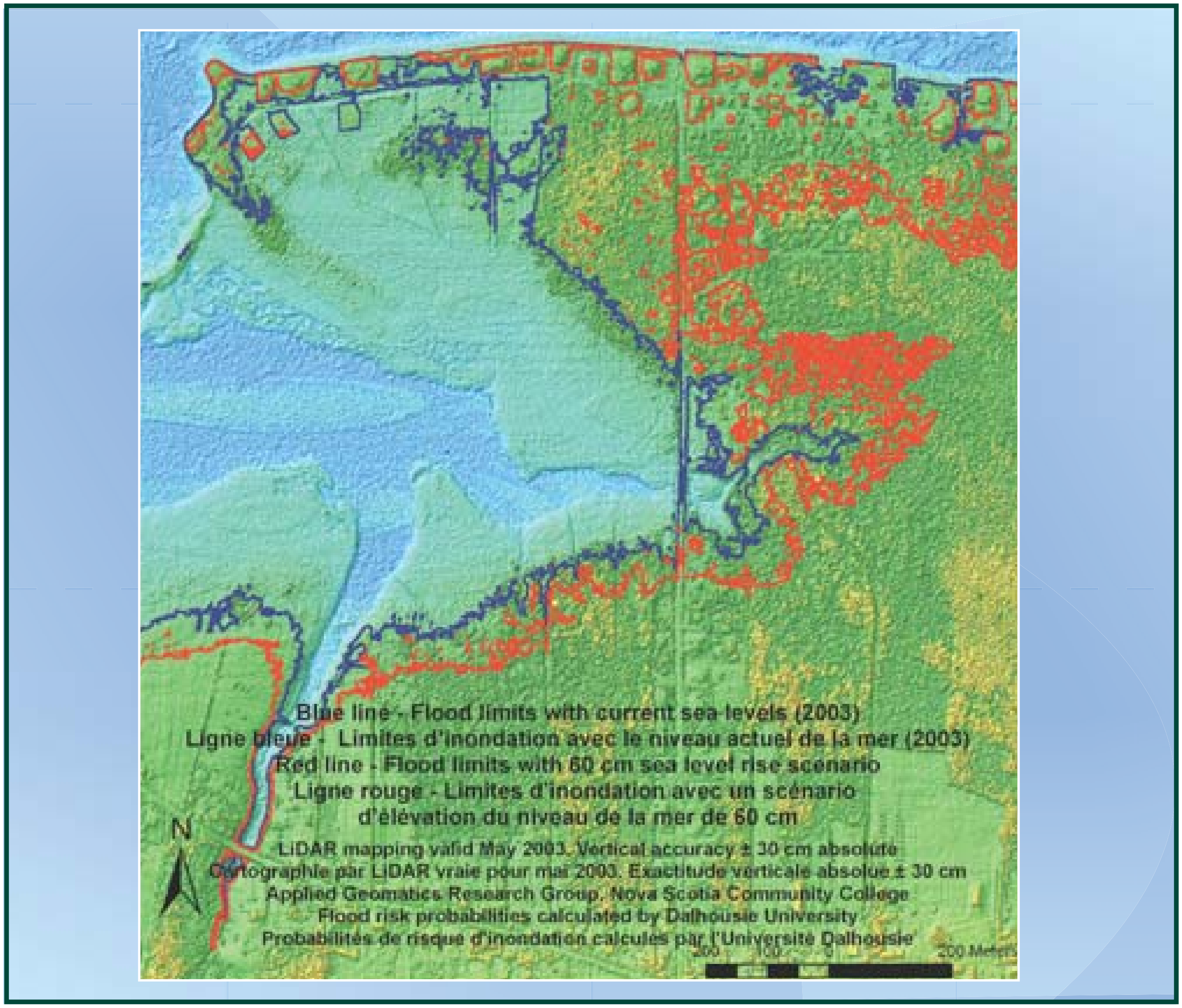
To estimate the frequency of extreme total sea levels (in contrast to extreme surges), we added the tide and other physical processes not resolved by the storm-surge model. An important point to note is that the approach in this study requires only a few years of hourly sea-level observations to estimate multidecadal return levels of total sea level. Overall, the predicted 40-year return levels of total sea level (tide plus surge) are within about 10 cm of the observed 40-year return levels. The method was also adapted to calculate the return period of extreme events over any season of interest.

The current 40-year storm-surge return level is expected to become closer to a 5-year return level with a 60-cm sea-level rise scenario, expected by 2100.

Allowing for changes in the frequency and severity of storms (based on climate change scenarios) is difficult, and ultimately such changes should be based on reliable climate-change scenarios from global climate models. Given that such downscaled forcing fields were not available, we carried out some sensitivity studies of the effect of changes in the surge distribution on the frequency of extreme total sea levels and compared the impacts with those of sea-level rise. The effect of significant changes in storminess, represented by large changes in the distribution of the surges, on the return period of extreme sea levels was found to be less than the effect of the large sea-level rise predicted for some areas of the study region (e.g., Scotian Shelf). This does not imply that changes in storm severity have little impact on the return period of extreme events. Rather, this sensitivity study suggests that in regions where sea-level rise over the next century is considerable (in the order of 1 m), it alone will result in a dramatic reduction in the return period of extreme events.

With the availability of a DEM, it was possible to downscale the results of an extremal analysis to produce maps of the return period of flood extent. The return-period maps presented in this study have the advantage of simplicity. They are easy to understand and allow rapid visual identification of areas most at risk of flooding.

Figure 2: Storm Surge – 10-Year Return Period, Pointe-aux-Bouleaux



They can therefore be used by planners and policy-makers to identify zones where development should be limited, adaptation measures put in place or ecosystem management considered.

A set of return-period maps, covering regions close to Shediac Bay, is presented in Section 5.0 of the main report (Annex A). The methodology used to calculate the maps is based on extreme return levels calculated from the Pointe-du-Chêne sea-level record. For the remaining regions, maps have been produced to depict flooding extents that resulted from the January 21, 2000, storm with present sea levels and with a 60-cm sea-level rise scenario. These maps are presented in Section 5.0 of the main report (Annex B).

It should be noted that in Shediac Bay, the current 40-year storm-surge return level is expected to become closer to a 5-year return level with a 60-cm sea-level rise scenario, expected by 2100.

2.4 LiDAR Digital Elevation Models and Flood-Risk Mapping

LiDAR mapping involves an aircraft emitting laser pulses towards the ground and measuring the travel time of the pulse to and from the point of reflection. The laser scan is acquired by rapid repetition of the laser pulse transmitter and cross-track deflection of the beam using an oscillating mirror to produce a zig-zag pattern of laser hits on exposed surfaces below the aircraft.

LiDAR surveys in southeastern New Brunswick were carried out in 2003 and 2004 in order to build a high-resolution DEM of flood-prone areas along the coast for most of the study area. Additional LiDAR products in the form of digital surface models (showing buildings and trees) and intensity backscatter maps were also constructed for the survey areas. These surveys met the accuracy specifications and provided the high-resolution point sampling along the coast required to construct the DEM as a basis for flood-risk and flood-depth mapping. The flood extents and flood depths associated with the January 2000 storm surge have been qualitatively validated by field visits to sites where the water levels are known. The extents of the flooding associated with the January 2000 storm generally agree, and the flood depths are typically within 10 cm of observed water depths. The elevation datum for the LiDAR DEM was taken to be Canadian Geodetic Vertical Datum 1928 (CGVD28) or orthometric zero. This is about 20 cm below mean water level as determined at the Pointe-du-Chêne tide gauge.

Using innovative methods to model hydraulic pathways to low-lying areas landward of causeways and other barriers, it was possible to determine potential flood extents at 10-cm intervals up to a water level of 4 m above mean sea level for the survey areas. This allowed near-continuous flooding simulations and animations to be constructed. The ability to generate a full sequence of water levels allows emergency measures and planning officials to access more information for use in designing disaster-mitigation and climate-change adaptation plans.

Repetitive LiDAR surveys at La Dune de Bouctouche demonstrated the utility of this technology to measure change in dune systems. A significant amount of change was mapped between the 2003 and 2004 DEMs. The modifications of the dune morphology are attributed to a significant storm event that occurred on February 19–20, 2004. The precision of the technology enables the detection of vertical changes on the order of decimetres in the elevation of coastal features, as demonstrated by erosion of the dune crests observed in this study.

In summary, the airborne LiDAR topographic mapping provided the high-resolution DEM required as an essential foundation for assessment of flooding and erosion hazards in all other components of the project.

2.5 Coastal Erosion

Southeastern New Brunswick is an area of low relief developed on flat-lying, friable, sandstone bedrock. As described in Section 2.1, the area was flooded by the sea immediately after deglaciation, after which the land rose and relative sea level fell to expose large parts of the floor of Northumberland Strait. For the past 8500 years, the sea level has been rising against the land, gradually pushing back the shoreline in a process of long-term flooding and coastal erosion. There is thus nothing new in the trend of coastal retreat

Most sites currently experiencing erosion can be expected to show continuing erosion in the future, and rates are likely to increase. Therefore, planning and development should not be based simply on historical rates of erosion, but should add an appropriate additional setback to account for more rapid erosion over the life of a structure or other development.

observed over recent decades, but the impact on human habitation and infrastructure is increasing as the rate of waterfront development accelerates.

The rate of coastal erosion is primarily a function of mean water level (driven by relative sea-level rise), storm and wave forcing, sediment supply, and the form and response of the shore zone (coastal morphodynamics). Where there is no excess sand supply, the rate of coastal retreat is likely to be correlated with the rate of relative sea-level rise, other factors being equal.

Although large quantities of sand are present along the New Brunswick coast, much of this is stored in coastal dunes (largest in the north) or in large tidal bedforms (largest in the southeast). The volumes of sand in the immediate shore zone are limited. Some sites, such as the mouths of Shemogue and Little Shemogue harbours, have extensive multiple bar and tidal bedform complexes of sand on the inner shoreface, but these are thin, and the beaches themselves are invariably thin. For this reason, despite the limited wave energy, rapid changes in the shoreline can occur when beaches and low barriers are overtopped and breached in storms. Evidence from old maps shows that some former barrier beaches or spits (such as in the Robichaud and Cocagne areas) have disappeared, leaving only hints of their former presence in shoals on the shoreface. A low sand ridge mapped in 8- to 10-m water depth off Pointe-Sapin is believed to be a similar relict barrier beach abandoned on the inner shelf.

The present study has shown that rapid changes have occurred in the form and extent of some spits in the Shemogue area during the past 60 years of the airphoto record (since 1944), while others in the same area (Grants Beach) have remained stable. The large spit and barrier island system in Kouchibouguac National Park has high dunes that prevent overtopping and act as a buffer against storm-wave attack. However, there are a number of low areas where inlets have opened or closed at various times over the past century, causing abrupt changes that affect coastal stability and habitat conditions, both on the barrier itself and in the adjacent lagoons, marshes and other coastal habitats. Despite the high dunes in this area, large sections of the Kouchibouguac barrier system are low enough to be overtopped in a major storm with high surge and waves. However, the sand volumes are high enough to limit the rate of coastal retreat. The large flying spit at Bouctouche (La Dune de Bouctouche) has moderately high dunes and multiple dune ridges, particularly in its distal part. Other parts of this system have narrow dunes or none at all. In these areas, particularly the proximal (updrift) part, overtopping, breaching and landward barrier migration have occurred in response to major storms or storm intervals since the earliest airphotos in the 1940s, and long before that.

Some sections of the coast consist of low sandstone or till cliffs, up to a few metres in height, typically showing long-term (multidecadal) erosion rates between 0.1 and 0.4 m per year. Although these rates are slow, some roads and buildings have been partially destroyed and abandoned (e.g., in the area of Cap-Lumière). Erosion impacts on infrastructure and buildings, including homes, are locally important. Homes and other buildings have been damaged or destroyed by storm waves and storm-driven sea ice in several locations within the past decade. Large sections of the coast are now protected by seawalls, rubble mounds or other structures, and this hardening of the coast has accelerated over the past 20 years. However, the long-term efficacy of these adaptation measures is questionable, and many will require substantial investment in maintenance, reconstruction or replacement to maintain their protective function.

Rates of coastline change on beaches, spits and barriers range from negative to positive. Erosion rates greater than 0.5 m per year are common on many beaches, and some sites show even higher rates. The point of attachment of the Pointe-aux-Bouleaux spit retreated at an average rate of 2.4 m per year between 1944 and 2001. In other cases, local sand supply is sufficient to maintain the shoreline position or prograde seaward. Some spits have extended in length, showing typical patterns of deposition and growth in the distal (downdrift) area, while erosion, overtopping and rollover, or bypassing has occurred in the narrow proximal section (near the point of attachment to the coast). In very general terms, this is the pattern observed at La Dune de Bouctouche. Other systems, such as Grants Beach (east side of Little Shemogue Harbour), have maintained a dynamic equilibrium between intervals of dune cut and intervening deposition. Such systems may be continuing to accumulate sand from updrift sources in the bay mouth or on the inner shelf. In other cases, where sand volumes are low, spit truncation or breaching has occurred. At Cap Bimet, the end of the spit has completely disappeared. The spit on the east side of Shemogue Harbour (Shemogue Head spit) was breached prior to 1971 and eventually split into two by 2001, exposing the large salt marsh behind to wave erosion and washover. The vulnerability of this spit to overtopping and breaching was enhanced by its northwesterly exposure, low crest elevation, narrow width and limited sand volume. Major changes in the morphology and extent of the spit opposite (on the west side of the estuary) may also have been a factor. These observations underscore the importance of changes in coastal morphology (which may create changes in wave shoaling and energy at particular sites), of waves and storm surges associated with individual large storms or clusters of storms and of preconditioning by erosion of dunes or other changes in the shore zone. Combinations

Figure 3: Evolution of a coastal landscape over the past 60 years (Pointe-aux-Bouleaux area)

Notes:
A: rapid retreat of a sand spit.
B: complete destruction of a coastal dune as a result of housing development.

of these factors may trigger rapid change. If sand is available and supplied to the site, breaches can be repaired (infilling of the former dredged channel through La Dune de Bouctouche is an example), but morphological changes sometimes lead to positive feedback, increasing susceptibility to storm damage. The Petit-Cap spit in Shemogue Harbour has built an entirely new and realigned spit ridge seaward of the 1944 spit, fed by erosion of the updrift beaches at rates of between 0.2 and 0.8 m per year.

These results demonstrate the highly variable nature of coastal response to storm forcing as well as gradual changes associated with sea-level rise and climate change. It is unrealistic to attempt a common projection of future response over the entire study area. However, there are several common points of understanding that can be applied to the analysis of individual sites.

Most sites currently experiencing erosion can be expected to show continuing erosion in the future, and rates are likely to increase. Therefore, planning and development should not be based simply on historical rates of erosion, but should add an appropriate additional setback to account for more rapid erosion over the life of a structure or other development.

The rate of regional subsidence declines from the southeast to the northwest. As a result, the most rapid rates of relative sea-level change will be in the southeast. This is also the area where the barriers and dune volumes are smallest, making them more sensitive to rapid change. Systems in this area with higher dunes (such as Grants Beach) will be more stable, but accelerating sea-level rise, reduced sea ice or other climate-related changes may increase the sensitivity even at these sites. Some increase in the rate of cliff erosion can be expected, but the rates are likely to remain less than 0.5 m per year in most places, particularly where sandstone is exposed at the base of the cliff.

Farther north, from Bouctouche to Kouchibouguac, much larger dune volumes and higher crest elevations will partly offset the higher wave energy in this region. Nevertheless, some areas are extremely sensitive to erosion or overtopping, including the proximal part of La Dune de Bouctouche, where a sequence of storms beginning in 2000 removed the dune ridge and led to successive washover events, which deposited sand sheets across the barrier crest and the marsh behind. A large breach also developed halfway out the spit. Similar extensive breaching has occurred in the past, notably in the early 1940s, and storm clustering (successive large storms within a few years) is an important factor. However, accelerating rates of relative sea-level rise and possible increases in storm intensity may lead to more frequent and more severe impacts in the future. There is no immediate likelihood of spit detachment at Bouctouche, but the highest average rates of shoreline erosion along the spit since 1944 (almost 2 m per year in one section) are between 6.0 and 8.5 km down-spit, just before the down-drift transition to long-term progradation. We conclude that the possibility of detachment within 30–50 years cannot be ruled out.

Losses of coastal salt marsh have occurred in the region from excessive infilling for development. Coastal squeeze is already a concern at a number of sites in the study area, where roads and fill present hard boundaries to marsh expansion. Some salt marshes in the area may experience loss of area through erosion of the seaward margin, degradation of the marsh surface and gradual expansion of low marsh at the expense of high marsh. Impacts for many coastal habitats are discussed in greater detail in Section 2.6.

Management of coastal erosion in a changing climate will be most successful if it considers all aspects of the coastal system in the area of concern. This involves analysis of the relevant coastal cell and its sediment budget, as well as environmental forcing (sea level, storms, surges, waves, wind and ice) and interactions among various components of the coast, including the whole system above and below water. Such an integrated approach is needed to ensure a full understanding of the system, so that adaptation measures adopted in one location are not counterproductive in another. Sections 2.8 and 2.9 later in this report suggest further considerations in the development of appropriate and effective adaptation strategies.

2.6 Ecosystem Impacts

The research on the impacts of sea-level rise and climate change focused on coastal habitat and associated wildlife. The short duration of this work necessitated the use of existing data sources on wildlife resources and habitat requirements. It is hoped that this study will encourage future research on coastal wildlife populations and habitat to incorporate analyses of the impacts of sea-level rise and climate change.

An analysis of the DEM showed that a flood level of 2.55 m above DEM datum (approximate present mean water level), as occurred in the storm of January 21, 2000, results in the flooding of 1397 ha of upland, 1634 ha of coastal marsh, 388 ha of dune, 159 ha of swamp and 226 ha of beach. The average depth of flooding for the 2.55-m storm flood was determined to be 0.84 m for swamp, 1.13 m for dune, 1.58 m for beach and 1.64 m for coastal marsh. These analyses indicate that large areas of coastal habitat will be influenced by future increased water levels associated with storm surges superimposed on rising sea level.

Whereas there were limited data on vertical accretion rates for salt marshes and sediment dynamics of beaches and dunes along the Northumberland Strait, a retrospective airphoto-based analysis was conducted at five study sites. These analyses provided insight on how marshes, dune habitat and beaches have responded to past storms and changes in sea level, as a basis for considering how they may respond in future.

For Cape Jourimain, the area of vegetated salt marsh was 28% (88 ha) less in 2001 than in 1944. This change was primarily due to the construction of a road through the marsh in 1966, which changed the hydrology and also physically destroyed some marsh area. For Shemogue, there was 5% (15 ha) less vegetated salt marsh in 2001 compared with 1944, and open water increased by 18% (9 ha). These changes at Shemogue were consistent with the hypothesis that marsh vertical accretion and horizontal migration were not sufficient to compensate for rising sea levels. The amount of vegetated salt marsh area decreased by 27% (23 ha) for the Aboiteau study site, with visible evidence that 24 ha of coastal wetland had been infilled between 1944 and 2001. For Shediac, 40 ha of human infrastructure were built in coastal wetland and 9100 m of seawall were constructed during the period between 1944 and 2001, with a 21% (19 ha) decrease in vegetated salt marsh. There was a 35% (19 ha) decrease in vegetated salt marsh and infilling of 19 ha of coastal wetland in the Cocagne area between 1944 and 2001.

At all study sites, the amount of beach and dune habitat was lower in 2001 than in 1944, with a greater decline in beach habitat compared with dune habitat. For Cape Jourimain, there was 22% less beach and dune habitat in 2001 compared with 1944; for Shemogue, there was 8% less; at Aboiteau, there was an overall decline of 12%; for the Shediac study area, there was a decline of 32% in the area of beach and dune habitat between 1944 and 1971, with little additional loss occurring between 1971 and 2001; and in Cocagne, beach area decreased by 40%. Removing sand from beaches for the production of aggregate during the period between 1944 and 1971 probably had an impact on beach area in the region, as did the expansion of hard shore protection. The loss of beach habitat during the last 60 years makes any additional loss of beach habitat in the future due to sea-level rise more critical from both a wildlife habitat and a recreational perspective. An increasing demand for beach recreational areas coupled with decreasing availability due to sea-level rise and climate change would increase human development and disturbance pressures on those beaches that currently provide wildlife habitat.

For the Aboiteau, Shediac and Cocagne study sites, there was a substantial increase in the amount of hardened shoreline present in 2001 compared with the earlier periods. The amount of hardened shoreline in 2001 was 8324 m in Aboiteau, 9408 m in Shediac and 13 287 m in Cocagne. Hardening of the shoreline has an impact on the amount of beach available for recreational and wildlife habitat purposes and also reduces sediment supply, which could lead to more beach loss in the future.

An increasing demand for beach recreational areas coupled with decreasing availability due to sea-level rise and climate change would increase human development and disturbance pressures on those beaches that currently provide wildlife habitat.

Overall, the results of these retrospective airphoto analyses indicate that our ability to understand and manage the impacts of climate change on coastal ecosystems will be confounded by human activities in the coastal zone and that rising sea levels have the potential to further reduce salt marsh, beach and dune habitat in areas that have already lost a substantial amount due to human activities.

The relationship between vascular plant species' zonation and surface elevation in salt marshes along the coastline of the Northumberland Strait was determined and compared with results from the Bay of Fundy. Results indicate that elevation can be used to predict the impacts of sea-level rise on coastal wetland plant communities.

The potential impacts of sea-level rise and storm surge on colonial nesting gulls and terns were evaluated by determining which colonies would flood under the different scenarios of sea-level rise and storm-surge flooding. Of the known nesting sites in the study area, only Cocagne Bar would be flooded at mean water level by a sea-level rise of 60 cm, but many if not all are vulnerable to destruction by flooding or wave runup in a large storm, even without further sea-level rise. Most (11/14) nesting locations would be impacted by a storm surge combined with tide to reach a water level of 2.55 m above DEM datum. The largest Common Tern colony in the study area (Tern Island in Kouchibouguac National Park) contained over 6020 nests in 2005 and would be flooded at a water level of 2.55 m above DEM datum. A summer storm event comparable to the January 21, 2000, storm would therefore have a devastating impact on the breeding success of the Common Tern population in New Brunswick along the Gulf of St. Lawrence. However, accelerated sea-level rise leads to an increased probability of maximum storm-water levels reaching this level.

We also examined the potential impacts of sea-level rise and storm surges on nesting Red-breasted

Mergansers on four barrier islands in Kouchibouguac National Park. The elevation of most nests was higher than 0.60 m but well below the maximum observed storm flood level of 2.55 m above DEM datum. Impacts on nesting Red-breasted Mergansers are not hypothetical, as a storm in 1993 resulted in many nests being flooded and an annual reproductive success of only 22%. Sea-level rise and increased frequency and intensity of summer storm surges would have a negative impact on Red-breasted Merganser nesting success.

The endangered Atlantic Canadian breeding population of Piping Plover was estimated at only 255 breeding pairs in 2003. Breeding habitat availability and suitability for Piping Plovers were studied in an effort to predict the impacts of projected sea-level rise on habitat. Analyses indicated that beaches currently occupied by Piping Plovers are longer, have a greater mean width and have a greater area of sand than beaches that do not have nesting Piping Plovers. In addition, occupied beaches have a greater number of dune breaches, have access to back bays, outflows or ephemeral pools, and have less human development than non-occupied beaches. Coastline changes over time were mapped and measurements were taken for two beaches in the Shemogue area. There were no obvious trends detected in habitat change; rather, these analyses indicated temporal variability presumably related to storm events. It is known that Piping Plovers prefer to use the early-succession habitat created by dune breaches and that the conversion of spits to barrier islands through storms also improves habitat suitability. The hypothesis that sea-level rise and climate change will result in a decrease in preferred breeding habitat for Piping Plovers needs to be further tested and quantified. The observation that Piping Plovers predominantly use protected beaches indicates the importance of managing human impacts now and in the future as society responds to rising sea levels. To successfully manage Piping Plover habitat, it is important to increase our understanding of which beaches will be negatively impacted by sea-level rise.

The number of adult Piping Plovers attempting to breed and reproductive success at Kouchibouguac National Park during the period 1985–2005 were highly influenced by summer storm-surge events. In 1985, there were no young raised to fledging, and many nests were flooded. Water-level data from the Escuminac tide gauge showed a storm event and water levels above 2.0 m CD on June 8, 1985. There was also lower than average reproductive success in 1991 associated with a major storm event on June 14, 1991, when a water level of 2.12 m CD was recorded at Escuminac. Breeding success was once again low in 1993, and field observations indicated nest-flooding events, with a recorded water level of 2.07 m CD at Escuminac. An examination of historical water levels at Point Escuminac indicated that nine 60-cm or greater storm-surge events during the Piping Plover nesting season occurred during the period 1964–2004. There was one event during the period 1964–1969, one during the 1970s, three during the 1980s and four events during the 1990s. There have been no events yet during the 2000s. Assuming co-occurrence with high tides, some or many of these storm events would have had an impact on reproductive success and perhaps on population dynamics during the past 20 years. Currently, there is no statistical evidence that the frequency of June storms is increasing in the southern Gulf of St. Lawrence, but increased frequency of summer surges would have a negative impact on Piping Plover populations. This may require actions to protect nests and eggs from flooding.

An analysis of Piping Plover population dynamics was conducted in order to understand how changes in climate and habitat may affect Piping Plover populations. These analyses suggested that during the period 1998–2003, there was population stability in southern Nova Scotia (+0.4% per year) and a decline in the Gulf of St. Lawrence

The effects of climate change are an increasing concern for tourism operators in southeastern New Brunswick, because ecotourism and cultural tourism sectors have developed rapidly in the last decade, and tourism operations are feeling the effects of erosion and storm surges from extreme storms.

(–3.5% per year). The negative growth projected for the Gulf was largely driven by low estimated juvenile post-fledging survival. Threats to juveniles following departure from nesting beaches need to be quantified. Similarly, population growth in both subpopulations was particularly sensitive to changes in adult survival. Very little is understood about the threats to Piping Plover survival during migration and overwintering periods. It would therefore appear that efforts to protect Piping Plovers from predators and human disturbance on breeding beaches have been successful and that annual climate-induced variability in reproductive success or habitat conditions is not controlling population growth at present. We suggest that future recovery efforts for Piping Plovers should quantify and manage the largely unknown sources of both adult and juvenile mortality during non-breeding seasons while maintaining current levels of nesting habitat protection.

Overall, our analyses indicate that coastal ecosystems have a natural capacity to respond to climate and water-level variability. Human alteration and disturbance have historically had a larger impact on coastal wildlife habitat and wildlife populations than sea-level rise and climate change. Any future impacts of sea-level rise and climate change could be exacerbated by development pressures or infrastructure protection projects. Continued monitoring of climatology, water levels, wildlife populations and habitat is required in order to develop adaptation strategies that will protect both human infrastructure and wildlife habitat from increased water levels and storm-surge events.

2.7 Socio-Economic Impacts

Sea-level rise, coastal erosion and increased intensity and frequency of storm-surge events have significant socio-economic impacts on coastal communities, ecosystems and various economic sectors. This analysis has evaluated some of the costs and benefits associated with adapting to these impacts through both a community engagement and a case-study approach.

Important elements of this project are the engagement of the community and building upon local knowledge and understanding of coastal-change processes and adaptation. The following are among the key findings from the community engagement process:

- Initial interviews in the communities showed that attitudes towards the impacts of extreme events were primarily reactive; however, it is very much in the interests of the communities to adopt a more proactive approach.
- The community engagement process enabled this research to respond more effectively to the needs of the communities and propose relevant recommendations for adaptation. It also provided an opportunity to increase the communities' awareness of climate change.
- For this study to help in building local capacity for adaptation to climate change, the communities in the study area will have to take ownership and interpret the results in their local context, involving all appropriate stakeholders and decision-makers.

Case studies were chosen to represent the types of impacts and issues expected under climate change and to enable a detailed analysis. The information and data used to estimate the economic impacts are limited to the geographical area of each case study. While the methodology and approaches used in this analysis are transferable, the results will not be directly applicable to other geographical locations.

The effects of climate change are an increasing concern for tourism operators in southeastern New Brunswick, because ecotourism and cultural tourism sectors have developed rapidly in the last decade, and tourism operations are feeling the effects of erosion and storm surges from extreme storms. The Bouctouche area was selected as a case study to evaluate the economic impacts associated with climate change on the tourism industry. This case study estimated the economic benefits to the tourism sector of implementing adaptation measures. Conversely, this analysis estimated the economic losses as a result of the tourism sector failing to mitigate or protect itself from the impacts of sea-level rise, coastal erosion and storm-surge events. Some key findings from the Bouctouche case study follow:

- Many visitors to Bouctouche recognize that climate change is impacting coastal communities across eastern North America. Through thoughtful adaptation and mitigation strategies, the tourism sector of Bouctouche may see economic growth. In contrast, failure to adapt to climate change may result in losses to the tourism sector. Appropriate adaptation measures will be a key element in determining if the tourism industry in the Bouctouche area grows or declines over time as a result of the consequences of climate change.

Table 2: Existing Shediac Bay coastal properties at risk of flooding with a water level of 2.5 m above DEM datum water level*

Flood Class	Residential		Commercial & Industrial		Institutional		Recreational		Farms & Woodland	
	Number	Assessed Value	Number	Assessed Value	Number	Assessed Value	Number	Assessed Value	Number	Assessed Value
1	535	$48,812,700	23	$4,165,900	9	$2,169,800	600	$32,105,700	21	$457,100
2	98	$8,501,700	8	$4,163,200	3	$39,700	234	$12,212,900	2	$57,400
3	20	$1,509,600	0	$0	1	$60,000	65	$3,309,200	1	$1,200
4	4	$14,400	1	$800	0	$0	7	$196,800	2	$2,700
5	1	$10,000	0	$0	1	$128,300	2	$3,300	0	$0
6	0	$0	1	$3,500	0	$0	0	$0	0	$0
Total	**658**	**$58,848,400**	**33**	**$8,333,400**	**14**	**$2,397,800**	**908**	**$47,827,900**	**26**	**$518,400**

Note:
*Flood Classes 1, 2, 3, 4, 5 and 6 imply flooding depths of, respectively, >0–0.5 m, >0.5–1.0 m, >1.0–1.5 m, >1.5–2.0 m, >2.0–2.5 m and >2.5 m.

- Under an optimistic scenario, whereby the tourism sector manages climate-change impacts through adaptation strategies, there is a potential for economic gains, compared with the estimated baselines, in Kent County and New Brunswick. Employment in Kent County could increase by 8–18% and gross domestic product (GDP) in Kent County could increase by 11–19%. Provincial and federal tax revenues could potentially increase by 11–18%.

- Under the pessimistic scenario, whereby the tourism sector does not adapt to climate-change impacts, there is a potential for economic losses, compared with the estimated baselines, in Kent County and New Brunswick. Employment in Kent County could decrease by 25–30% and GDP in Kent County could potentially decrease by 25–27%.

Property and infrastructure within coastal communities of southeastern New Brunswick are also threatened by sea-level rise and storm-surge events. After the January 21, 2000, storm-surge event, declared a disaster by the federal government, there were 198 damage claims submitted to the New Brunswick Emergency Measures Organization, 43 of which were eligible for funding totalling close to $1.5M (K. Wilmot, New Brunswick Emergency Measures Organization, personal communication). In order to understand the magnitude of these impacts on coastal communities, the Shediac Bay case study has identified those properties that are at risk of flooding and has quantified the potential damage costs associated with storm-surge events. In addition, the analysis has estimated some of the types of costs associated with retreat, protection and accommodation adaptation options. Key findings from this case study include the following:

- Future scenarios were developed by community stakeholders based on storylines that described changes to key drivers. Under an optimistic economic development scenario, the community identified 10 new residential zones (estimated value $114.1M), expansion of three commercial zones, expansion of two marinas and nine new green zones. Under a pessimistic economic development scenario, the community identified five new residential zones (estimated value $26.7M), closure of some commercial enterprises, new public services and one new green zone. This study estimated damage costs to residential properties. All new residential zones identified under both the optimistic and pessimistic scenarios are estimated to be either at no risk of flooding or at minimal risk of flooding (less than 0.5 m flood depth); therefore, damage costs to new residential zones identified under both scenarios are assumed to be zero.

- Non-residential property and infrastructure in the Shediac Bay case-study area are at risk of flooding during storm-surge events. A storm-surge event with a water level 2.5 m above DEM datum (approaching the January 21, 2000, storm-water level) places approximately 1639 existing properties in the Shediac Bay case-study area at risk of flooding to some depth. The total assessed value of these properties is estimated at $117.9M. In the event of a storm surge with a water level 3.0 m above DEM datum, approximately 2003 existing properties in the case-study area are at risk of flooding to some depth. The total assessed value of these properties is estimated to be $139.3M.

- In the event of a storm surge with a 2.5-m water level above DEM datum in the Shediac Bay case-study area, it is estimated that 277 residential properties (including cottages) would incur damage. The total assessed value of these properties is $21.7M, and the estimated structural damage costs are close to $7.1M, approximately 33% of the total assessed values. If the storm flood level reached 3.0 m above DEM datum, it is estimated that 644 residential properties would incur damage. The total assessed value of these properties is estimated to be close to $48.9M, and the estimated structural damage costs are close to $17.6M, approximately 36% of the total assessed values.

- Minimizing the impacts of sea-level rise and flooding from storm-surge events can be achieved through implementing adaptation strategies. When evaluating various adaptation strategies, the full costs and benefits of each strategy should be incorporated into the decision-making process. Although this analysis has not assessed the total costs and benefits associated with specific adaptation options, it has estimated some of the possible costs associated with generic adaptation options. If retreat is an option under consideration, the estimated minimum compensation required for 94 property owners with properties in Flood Classes 4, 5 and 6 is close to $3.4M, and the total forgone property tax revenue (provincial and municipal) is estimated to be $100K annually. A few protection and accommodation options have also been estimated based on dialogue with various communities and stakeholders. The estimated capital cost to build a seawall, based on various discussions with community members, is $1,000 per square metre of base surface.[1]

The results from this analysis should not be interpreted literally, as they are estimates based on the best available information. They can be used as indicators and estimates of magnitude to educate and raise awareness. They can also be applied to local decision-making processes concerning governance, coastal zone management and adaptation.

2.8 Adaptation Strategies

Finding the crucial balance between stakeholders' unique environmental, social, political and economic interests is dependent upon participation of a wide range of stakeholders, including residents, community leaders and government representatives, among others. Each brings unique expertise, insights, priorities and power to the community adaptation process. Effective adaptation strategies — ones that are implemented and have goals that respect local values — come from the ground up (i.e., from the community affected), rather than from the top down.

National and provincial strategies can be effective only if they address local issues and conditions; provide opportunities for local input and respect local values; and provide resources and expertise to the communities expected to implement the strategies. Even the best-intentioned provincial or national initiatives, if not effectively implemented at the local level, can lead to lack of trust and can even undermine the goals of the strategies.

Critical elements in developing community-level responses to sea-level rise and storm-surge threats are awareness of the issues, building of trust and communication, sharing of information and expertise, and having a champion (an individual or group) to lead the process. Successful community adaptation relies on continually fortifying the local conceptual lens by increasing the community's adaptive capacity and implementing best practices.

Appropriate adaptation strategies may take many forms and may include components at different scales. The provincial Coastal Areas Protection Policy provides an umbrella for coastal management and adaptation measures at a local level. Communication and coordination of efforts between various levels of government, community leadership, local organizations and citizens are essential ingredients for success.

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[1] Based on personal communication with New Brunswick sea-level rise study team and members of the case-study community.

There needs to be a balance in adaptation strategy design between addressing isolated issues and developing a comprehensive plan that addresses every dimension of the problem. The latter may require more research and organization than communities can absorb and still make meaningful changes. The former fails to address the needs of all stakeholders and can lead to strategies that further deteriorate other situations. Each community is unique and must determine its own balance.

Adaptation strategies need to include a wide spectrum of approaches, from policy and law to engineering and technology. Environmentally sensitive approaches can also be effective in minimizing change and cost. Raising public awareness and changing cultural values and perspectives can also be cost- and results-effective.

Past examples of adaptation in the study area include abandonment of erosion- and flood-prone lands and retreat from the coast. In many cases, older homes and infrastructure (except for port- and fishing-related infrastructure) were located well back from the coast and on higher ground. Low-value cottages were located along the shore but did not represent a large capital investment. More recently, the pattern of development in the region has been partly driven by market demand for homes with a view of the sea. Improved road infrastructure has favoured greater commuting distances, enabling those working in the growing Moncton economy to live along the coast. The result has been highly maladaptive, with expensive homes constructed along the coast in places where ice incursion, flooding and storm waves, and coastal erosion are all threats to the long-term stability and safety of the structure. Similarly, the demand for coastal land has encouraged infilling and reclamation of coastal wetlands, reducing available habitat.

Appropriate adaptation strategies may take many forms and may include components at different scales. The provincial Coastal Areas Protection Policy provides an umbrella for coastal management and adaptation measures at a local level. Communication and coordination of efforts between various levels of government, community leadership, local organizations and citizens are essential ingredients for success. Hard and soft engineering, land-use regulation, innovative development policies and designs, land trading and institutional arrangements to promote exchange of ideas are among the many options that communities may consider to reduce future impacts and costs.

Communities need and want information and access to expertise. A simple web page giving “where to go if...” instructions can centralize desired data, foster communication and satisfy a large number of needs.

Local researchers at community colleges and universities can provide an effective link between communities beginning to organize and government agencies shaping regional and provincial policies and plans.

To be most effective, strategies for adapting to climate change need to be “owned” and driven by the local communities that are directly affected. Efforts to mobilize action at the local level require the support of planning agencies and governments at all levels.

2.9 Building Adaptive Capacity

The coastal area selected for this study offered various examples, from ecotourism to suburban development, of community activities that will be affected by climate change. The integration of the human dimension from the social and economic risk perspectives into environmental assessment might help planners and decision-makers in those communities to deal with future projects. Few projects have integrated these aspects within a high-precision geographic information system in the past. However, as shown here, such an approach can lead to greater understanding of the linkages between various components of the ecosystem and the human communities. The main advantage of such an approach is to bring recommendations regarding ways to enhance the adaptive capacity of communities and to reduce vulnerabilities to climate change through suggested tools such as environmental impact assessments and strategies such as protection, accommodation or retreat.

One of the main reasons often cited for the limited inclusion of climate-change impacts and adaptations into a community planning and decision-making process is the lack of methodologies and clear directions on how to integrate such parameters into the planning process. Most communities do not completely understand the issues regarding climate change and the potential impacts they may face. Among the possible tools that can help communities, the environmental impact assessment process should ensure that climate-change considerations are included prior to any new development projects being started. Similarly, discussion should occur regarding the need to enhance the flexibility and the adaptive management of the New Brunswick Coastal Areas Protection Policy in order to adaptively respond to climate-change impacts.

Adaptive capacity is linked to the potential actions that communities can initiate to help promote sustainable development. Some components of the ecosystem can be controlled and managed; for other components, control of the impacts is not possible, and communities must adapt to change. In addition, climate-change impacts are complex in the way in which they can influence, either directly or indirectly, some components of the ecosystem. In this project, the level of vulnerability varied greatly as a function of the location, exposure, adaptive capacity and resilience of the infrastructure. For La Dune de Bouctouche and the Village of Bouctouche, tourism along the coast is certainly more at risk than many other socio-economic activities of the region, such as agriculture. On the other hand, the results from Pointe-du-Chêne showed that human infrastructure (e.g., housing and wharves) is more vulnerable due to the greater pressure that human development projects have exerted over the past decade. The need for better planning in this case is greater, since more socio-economic activities may be threatened by climate-change impacts in the near future.

One conclusion that can be drawn from this research project is that without relevant information, adaptation policies and planning may not be fully effective. This applies to information on changes in climate forcing and physical forcing as well as biophysical impacts in the coastal zone. Adequate information is equally critical to ensure that social

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considerations can be integrated into the adaptation planning process, and also into more general planning and policy-making that incorporate awareness of potential climate-change impacts. Climate change is rarely the primary issue in any community-planning context, but incorporation of climate-change impacts and proactive adaptation measures in all environmental assessment, planning and development activities is one way to avoid expensive mistakes and in many cases will result in the most cost-effective adaptation.

Although the information is still not complete, the visualization of scenarios using maps to portray different outcomes helps community participants to evaluate their own personal risks in terms of a possible future reality. The descriptive models can gradually be quantified using the level of risk, exposure, adaptive capacity and vulnerability of the components applicable to the communities. This will help define the real degree of adaptive capacity and vulnerability of the communities and their natural ecosystems.

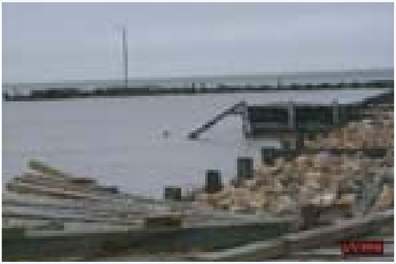
The storm of October 29, 2000


Head of Bouctouche Bay


Head of Bouctouche Bay


La Dune de Bouctouche


La Dune de Bouctouche


Wharf damage at Escuminac


Erosion on the Acadian Peninsula