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# PAST AND FUTURE SEA-LEVEL CHANGE IN NEWFOUNDLAND AND LABRADOR: GUIDELINES FOR POLICY AND PLANNING

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## ABSTRACT

*Understanding the direction and magnitude of future sea-level change is important in creating policy and planning measures for development in the coastal zone. To determine guidelines for the province, local trends in sea level are estimated by reviewing tide gauge records, salt marsh research and other indicators of past sea-level changes. These local trends are combined with estimates of future global sea-level change to provide predictions of likely changes in the sea level for the province. Estimates of sea-level change leading up to 2050 and 2100 are provided for four zones covering the province. If these prove accurate, areas of the province prone to coastal flooding and erosion will be severely impacted over the next century. Many areas expected to flood with a 1:100-year recurrence interval at current sea level will likely flood once every twenty years or more frequently.*

## INTRODUCTION

Newfoundland and Labrador has 17 540 km of coastline, and over 90% of its inhabitants live close to the sea (Economics and Statistics Branch, 2002). As development progresses, there is pressure on coastal areas for construction of residential and commercial properties. Sea-front property is often considered desirable and sells at a premium. Construction close to the coastline, however, means increasing the exposure to natural hazards, particularly flooding, erosion and landslides. Thus, it is important that planning and policy for development in the coastal zone incorporate accurate scientific knowledge of coastal processes and potential sea-level changes.

Although useful information exists in the scientific literature, this is commonly not accessible or useful to planners and policy makers, being, in some cases, highly technical, or not clearly applicable to local issues. The objective of this paper, therefore, is to review scientific evidence and distill it into clear, practical advice that can be easily applied.

Batterson and Liverman (2006) documented numerous instances of coastal disasters, including the notable Burin Peninsula tsunami of 1929, and also of landslides and flooding. Construction close to the cliff edge may cause problems due to erosion (Plate 1; Batterson *et al.*, 2006) and landslides, *e.g.*, Daniel's Harbour in 2007 and 2008 (Plate 2). Coastal flooding is a serious problem, with detailed flood-risk mapping available for several coastal communities, notably Placentia, Cox's Cove and Stephenville Crossing (Department of Environment and Conservation; http://www.env.gov.nl.ca/env/Env/waterres/ HydMod/ Flooding.asp). In the 21st century, at least 13 incidents of coastal flooding were recorded by Liverman *et al.* (2009), in a wide range of locations (Table 1). Apart from the immediate impact on transportation routes (Plate 3), property and people, these incidents often result in a major economic and social cost to individuals, municipalities and government. It is reasonable to assume that in areas of sea-level rise, the frequency of these incidents will increase. If such disasters can be mitigated by better scientific input in the planning process, then substantial benefit will result.

### POLICY IN NEWFOUNDLAND AND LABRADOR

The provincial government has adopted a land-use policy for flood-risk areas (http://www.ma.gov.nl.ca/ma/for/flood_policy/landusepolicyflood.pdf), based on development restrictions in the 'Floodway' – defined as the 1- in 20-year flood recurrence zone identified in flood-risk mapping; and the 'Floodway fringe' – the 1- in 100-year flood-risk zone. This policy only can be applied in areas where flood-risk mapping exists. However, existing flood-risk mapping does not include any allowance for future sea-level rise.

The Department of Environment and Conservation's "Policy for Development in Shore Water Zones" (http://www.env.gov.nl.ca/env/Env/waterres/Policies/PDWR97-1.asp) restricts development in the shore water zone,

**Plate 1.** *Coastal erosion at Point Verde, Placentia Bay, showing the same structure in 1999 (left) and 2005 (right). Parts of this coastline are eroding at >50 cm per year, although the average for non-rock cliffs on the Avalon Peninsula is ~20 cm per year.*

**Plate 2.** *Daniel's Harbour following the 2007 landslide. The slide resulted in the destruction of several houses, relocation of residents and removal of property within the landslide hazard zone, and led to the moving of the Northern Peninsula highway farther inland. Although this disaster is unrelated to rising sea level, it is reasonable to expect that the frequency of such incidents will increase with rising sea levels.*

**Plate 3.** *Coastal erosion at Admiral's Beach, Avalon Peninsula, undercut this transportation route.*

defined as areas below the high-water level of a water body. This applies both within defined flood-risk zones and elsewhere, and attempts to accommodate future climate and sea-level changes. The high water level is defined as follows: *"The high water level of a water body is taken to be the 1:100 year return period water level. For a fresh water body, this level includes water levels caused strictly by storm runoff or hydraulic effects of ice or both. In marine situations, the level must include maximum waves, wind setup, storm surge, and ultimate mean sea levels under current global climatic forecasts for a 1:100 year design."*

In practice, for a given area, this high-water level is hard to define, requiring forecasting of future climate, modelling wave run-up and storm surge, and understanding future sea-level trends. This paper attempts to provide some guidance on one factor, sea-level trends.

## PREVIOUS WORK

There has been considerable research in coastal vulnerability, both regionally and worldwide, over the past decade, based on the implications of climate change modelling. These models predict significant sea-level rise related to climate change over the next century (IPCC, 2007). Shaw *et al.* (1998) provided the first national assessment of sensitivity to sea-level change, using a sensitivity index incorporating predictions of flooding, erosion, beach migration, and coastal dune destabilization. This sensitivity index is obtained by manipulating scores between 1 and 5, attributed to each of seven variables: relief, geology, coastal landform, sea-level tendency, shoreline displacement, tidal range and wave height. They (*op. cit.*) indicated that most of the coastline of Newfoundland and Labrador is of moderate to low

**Table 1.** Incidents of coastal flooding since 2000

| Date | Location | Description |
|---|---|---|
| January 2000 | Lamaline | Heavy rain and high seas caused flooding of at least three homes. |
| January 2000 | Port aux Basques | High waves/storm surge struck the town, damaging houses, wharves and fishing shacks. |
| March 2003 | Cox's Cove | 100 houses damaged following heavy rain and flooding from both river and coastal sources. |
| January 2004 | Beaches, White Bay | The community was swamped by the sea during a period of severe weather. The community was evacuated for two days. No major damage occurred. |
| February 2004 | Ferryland | Waves washed away the breakwater protecting the road that runs out to Ferryland Lighthouse, the archaeological excavation and the "Pool" where many boats anchor. |
| February 2004 | Lamaline, Point au Gaul | A combination of storm surge and high winds resulted in flooding, property damage, destruction or damage of sea walls, and in one case evacuation of houses. |
| September 2004 | Beaches, White Bay | High winds and waves washed out the road leading to the community. |
| March 2005 | Flatrock, Duntara, Hants Harbour Cavendish, Red Head Cove and Sibley's Cove | High winds combined with abnormally high tides resulted in a storm surge that affected many areas of eastern Newfoundland. In Flatrock the breakwater protecting the wharf and harbour was almost completely destroyed. In other communities damage was to sea walls, stages, sheds, boats and fishing gear. Several roads were washed out. |
| January 2006 | Raleigh | A severe storm combined with high winds and high tides caused coastal flooding. The absence of sea-ice meant the coast was comparatively unprotected. One major road was damaged severely, access to some homes cut-off, and power interrupted. |
| February 2006 | Clarke's Beach, Coley's Point, Trepassey | Persistent high winds caused a storm surge that resulted in coastal flooding in Clarke's Beach and at Coley's Point, Bay Roberts. At Coley's Point, the Long Beach barrier was breached for the first time in fifteen years, and one house was flooded. Local roads were washed out. Trepassey was also affected with roads being washed out by coastal flooding. |
| August 2006 | Witless Bay, Bauline East | High winds and large waves destroyed boats in Witless Bay, and Bauline East, Avalon Peninsula. |
| September 2006 | Point May, Trepassey | A beach was severely eroded in Point May and a road near Trepassey was overwashed during a major storm. |
| February 2007 | Trout River, Cow Head | High winds and large waves destroyed parts of the boardwalk at Trout River; there was minor damage to houses and the fish plant. The storm also affected Cow Head, with some roads washed out, and houses threatened by storm surge activity. |
| February 2007 | Daniel's Harbour | A major storm affected the west coast of Newfoundland, with waves of 8 m reported at Daniel's Harbour. |
| August 2008 | Middle Cove | A "rogue wave" impacted Middle Cove beach causing several people to be swept out to sea. The wave covered the entire beach, washing inland as far as the parking area. Four were taken to hospital but no serious injuries occurred. |
| December 2009 | Battery, St. John's | Consistent high winds over a 24-hour period resulted in exceptional high seas impacting the east coast of the Avalon Peninsula. The Narrows (the entrance to St. John's Harbour) experienced large waves and the Battery was impacted, with wharves, stages and fishing huts damaged. |
| December 2009 | Ferryland | High seas washed out part of the road leading from Ferryland out to the lighthouse, damaging property and the breakwater in the area. This is the same part of the road affected in 2004. About 150 m of cribbing was washed away, leaving the area vulnerable to further damage. There had been minor damage in October 2009. |

sensitivity to sea-level change. Notable exceptions to this include the northwest coast of the Burin Peninsula, and St. George's Bay, as well as specific communities (*e.g.*, Placentia; *see* Catto *et al.*, 2003). Paone (2003) conducted a vulnerability assessment on the Avalon Peninsula, focusing on the municipality of Conception Bay South (CBS). She suggested, based on a review of the literature, that a sea-level rise of up to 70 cm should be expected by 2100.

There has been little detailed assessment of increased vulnerability in the future to storm surges in Newfoundland and Labrador. Catto *et al.* (2003) provided a report, again on the CBS coastline, outlining forecast wave heights and run-up distances. Detailed work elsewhere in Atlantic Canada has used more complex modelling methods to attempt to accurately outline areas likely to be prone to storm surge impact under future climate scenarios, *e.g.*, McCulloch *et al.* (2002); Webster *et al.* (2004, 2006); O'Reilly *et al.* (2005); Vasseur and Catto (2008) and Thompson *et al.* (2009).

As this is a global issue, there is a very extensive body of literature to refer to, and in Europe in particular a combination of modelling, GIS mapping and communication research has been integrated into "decision making tools" (*e.g.*, Schmidt-Thomé *et al.*, 2006). In Newfoundland and Labrador a more basic approach is required, as in most cases, the resources to create these more sophisticated tools do not exist. The approach outlined below is based on that developed for New South Wales, Australia (Department of Environment, Climate Change and Water, 2009).

## APPROACH

To determine the likely sea-level rise that will affect an area over the next 50 to 100 years, two factors need to be known:

1. The most likely global sea-level rise due to climate change, and
2. The rate of local sea-level rise due to geological factors.

The global sea-level rise is determined by reviewing international assessments of the likely impact of climate change on global sea level, and recommending the best figure to use, based on scientific consensus.

Local sea level has also varied over the last 10 000 years because of the last glaciation, where the weight of glacial ice depressed the Earth's crust beneath it. These changes are by no means uniform over the province (Liverman, 1994), with complex patterns of sea-level rise and fall (with sea levels either 10s of metres above or below present from 10 000 to 3000 years ago). Sea-level changes over the last 3000 years were smaller, and resulted from continued crustal rebound. The approximate rate of local sea-level change over this period is estimated, based on a review of available literature. For a given area then, the suggested sea-level change over the next 50 to 100 years is estimated by summing the estimates of global sea-level change and local sea-level change.

## FUTURE GLOBAL SEA-LEVEL CHANGE

Numerous studies have modelled climate change over the next century, and a major output of these exercises consisted of predictions of global sea-level change. The Intergovernmental Panel on Climate Change (IPCC) issued a series of reports reviewing this research and provided an authoritative consensus view on the magnitude of expected sea-level change (IPCC, 2007; Watson *et al.*, 2001). The most recent report (IPCC, 2007) outlines predictions based on a range of scenarios (Figure 1), with the main variable being $CO_2$ emissions. Following the New South Wales report, it is suggested that emissions scenario A1F1 (which produces the greatest sea-level rise) be used, as the rate of global greenhouse gas emissions already exceeds that used in the scenario. Rahmsdorf *et al.* (2007) indicated that detailed sea-level change studies from tide gauges and satellite altimetry showed the rate of global sea-level rise for the period 1990-2007 was greater than predicted by models (3.3 mm/year as opposed to 2 mm/year). They suggest this is due to the modelled predictions not taking into account melting of non-polar glaciers, and dynamic ice-sheet melting. This would contribute an additional 20 cm of global sea-level rise over modelled predictions. Pfeffer *et al.* (2008) suggested that up to 200 cm of sea-level rise is possible, although unlikely. The New South Wales report suggested based on these studies, that the following figures be used in planning over the next 100 years (Table 2).

**Table 2.** Projected global sea-level rise by 2049 and 2099

| Year | Sea Level Rise | Accelerated Ice Melt | Increase over 1990 sea-level |
|---|---|---|---|
| 2049 | 30 cm | Included in IPCC figures | 30 cm |
| 2099 | 59 cm | 20 cm | 79 cm |

The numbers in Table 2 are also used as an estimate in this report, and they are in the upper range of predictions. They are chosen, in part, based on the arguments put forward by the New South Wales report, and on the principle that given the high level of uncertainty in these predictions, it is wise to plan for this upper range.

## LOCAL-SCALE RELATIVE SEA-LEVEL CHANGES

The effects of local conditions may enhance or reduce

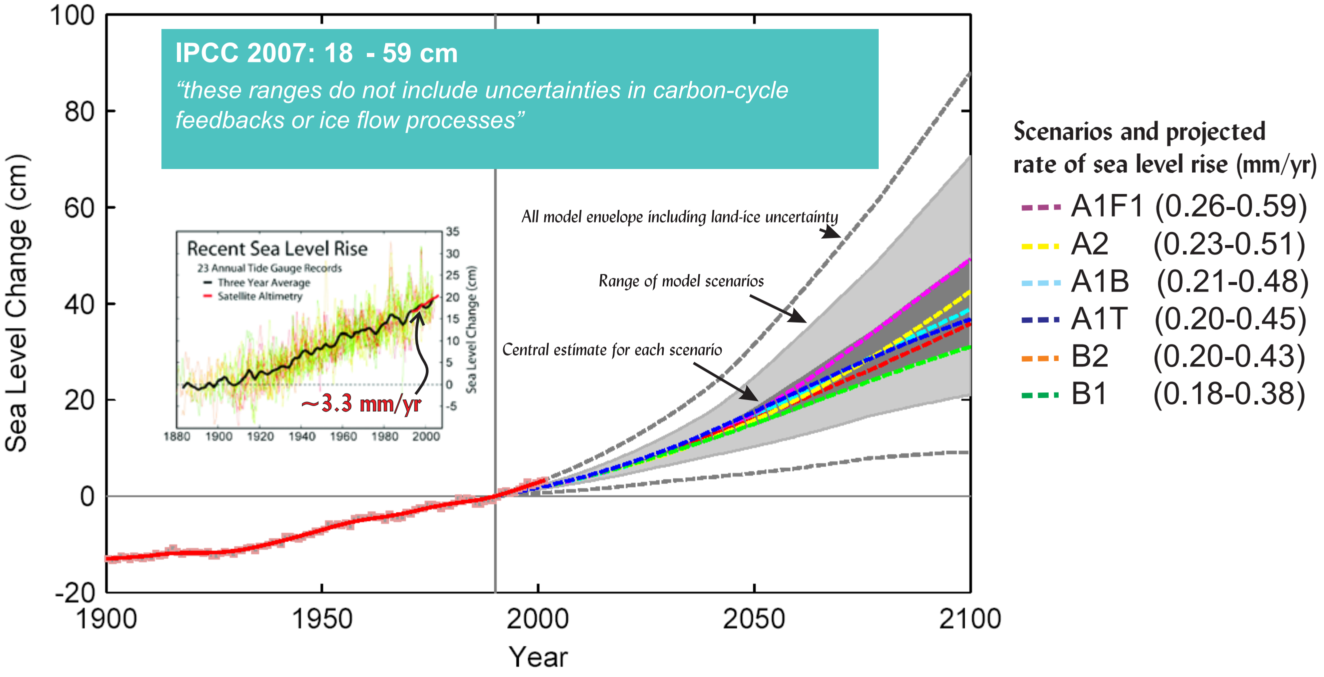


**Figure 1.** *Projections of future global sea-level rise from the Intergovernmental Panel on Climate Change (IPCC) 2007 report. Each scenario is accompanied by a range of sea-level change values, shown in brackets. The dark grey envelope shows the range of central estimates for each scenario, whereas the light grey envelope is the range of combined scenarios. The outer dashed line is the range of all scenarios plus the land–ice uncertainty. The projections are based on various modelled scenarios from a baseline of 1990. The actual global sea-level rise measured from tide gauge records and satellite altimetry is shown in red, and the inset diagram. Note the different baseline in the inset diagram (zero being 1880 rather than 1990).*

global sea-level rise predictions. In some places, such as Louisiana, USA, sea level is rising at a rate of 95 cm per century, or 3 times greater than global figures, due to local ground subsidence. In contrast, much of the Gulf of Alaska is experiencing sea-level fall as a result of crustal rebound following the last glacial period. Thus the concept of 'relative' sea level must be adopted as a balance between changes in the ocean and land surface.

Sea level rose rapidly at the end of the last glacial period, as water, previously held within ice sheets, was released to the oceans: an average sea-level rise of 10.0-12.5 mm/year from 10 000 years ago to about 4000 years ago (Revelle, 1990; Peltier, 1990) during deglaciation. Evidence of higher sea level around the province's coast is seen by the presence of raised deltas and beaches (Plate 4). Since 4000 years ago however, sea level has continued to rise in some places and fall in others, with a range of over 100 m (Lambeck, 1990). The larger changes are in areas previously covered by ice, or adjacent to them, and result from the weight of ice sheets pushing down on the Earth's crust, displacing material beneath it. When the weight of ice was removed, the crust started to return to its original position, a process that continues today, because the crust responds much more slowly than the rate of ice-sheet melting (Liverman, 1994; http://gsc.nrcan.gc.ca/coast/sealevel/index_e.php). Figure 2 shows the pattern of crustal movement within the province based on geophysical models (Tarasov and Peltier, 2004). Patterns of future sea-level change are directly influenced by these changes in the crust.

## Evidence of Past Sea-level Change

Evidence of sea-level change in the province over the last 3000 years comes from salt marsh development, submerged rooted stumps and bogs, and coastal features such as deltas and raised beaches, and archaeological sites. Raised beaches are features formed along the shoreline that were subsequently stranded as relative sea level fell (Plate 4).

Salt marshes form at, or close to, sea level (Plate 5). If sea level changes, then the marsh will change too, growing thicker if sea level rises. Examination of cores through a salt marsh can provide high-resolution records of relative sea-level change. Salt marshes contain distinct assemblages of plants and micro-organisms that may be related to a specific depth below mean sea level (Chmura *et al.*, 2001). The use of accelerated mass spectrometer (AMS) radiocarbon dating can render a date from as little as 1 to 2 mg of material and can thus provide a detailed history of salt-marsh development. Salt marshes in northern climates, such as Newfoundland and Labrador, form more slowly than in

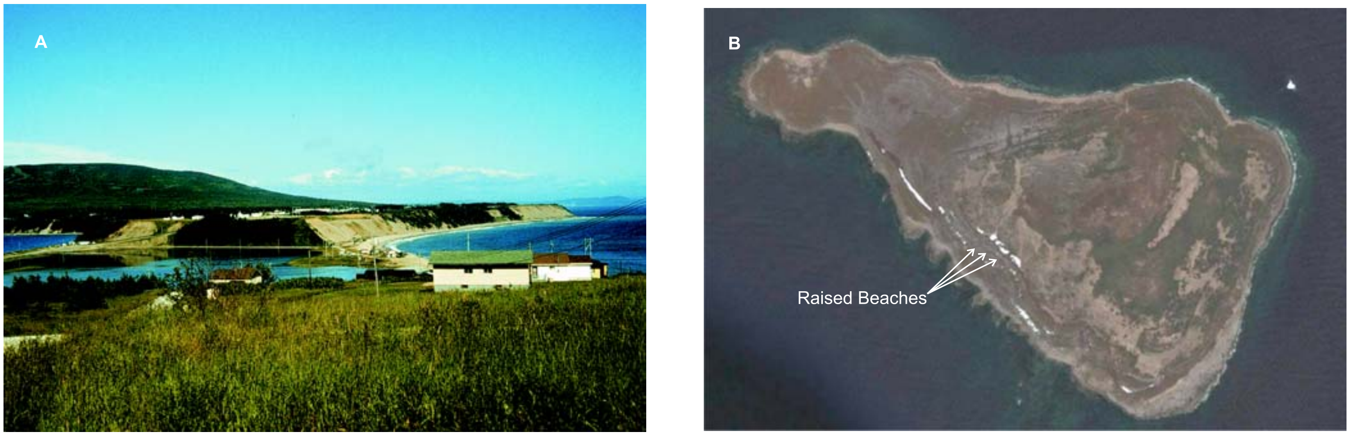


**Plate 4.** *Evidence of former higher sea levels. A) A raised delta at Port au Port East indicates sea level about 25 m higher than present, and B) raised beaches on an island outside Blanc Sablon harbour also show a pattern of sea-level fall.*

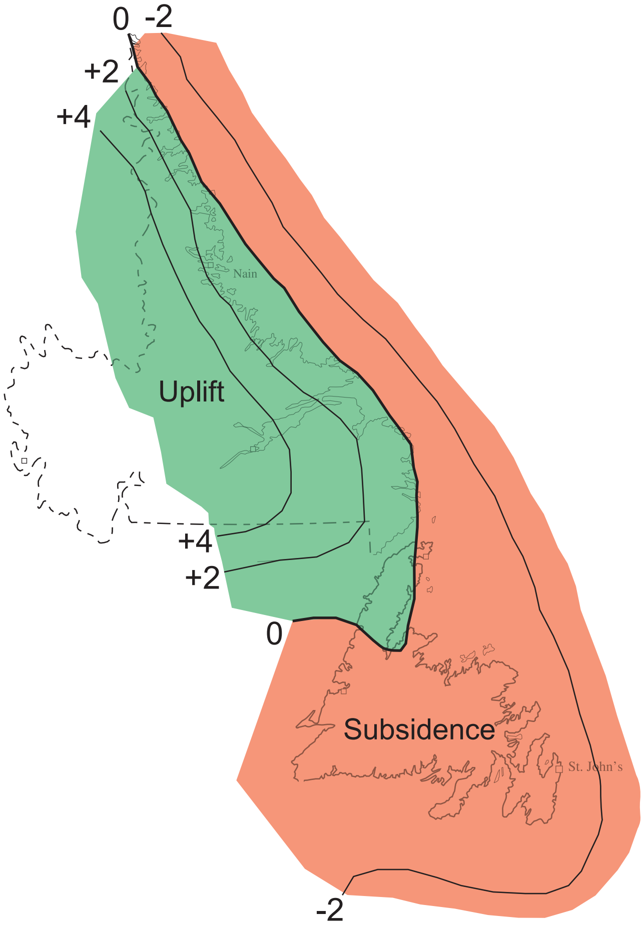


**Figure 2.** *Map showing present day rates of vertical uplift and subsidence derived from geophysical modelling (adapted from Tarasov and Peltier, 2004). The number lines indicate rates of uplift (or subsidence) in mm/year. Areas of subsidence are thus experiencing sea-level rise as a result of crustal adjustment, which will be superimposed on the predicted global rise in sea level. Areas of uplift will show lesser amounts of sea-level rise compared to the global trends.*

**Plate 5.** *Salt marsh on the Port au Port Peninsula. Coring within these features has produced evidence to indicate relative sea-level rise over much of the province.*

warmer climates (Chmura *et al.*, 2001). There are no studies to determine if salt-marsh accretion is in equilibrium with sea-level rise detected from tide gauge records.

Several salt marshes have yielded data on recent sea-level changes in the province. Research on salt marshes on the Port au Port Peninsula, at Placentia and at Deadman's Bay all indicate rising sea level, whereas a marsh at St. Paul's Inlet shows little recent change. The Port au Port Peninsula has marshes at Victor Brook and Hynes Brook described by Brookes *et al.* (1985); Wright and van de Plassche (2001); and Daly *et al.* (2007). Both marshes yielded broadly similar results, suggesting an average sea-level rise in the last 3000 years of ~1 mm per year (10 cm per century), with a 1.3 mm per year rise over the last 1000 years. A salt marsh at Placentia on the Avalon Peninsula records an average 0.6 mm per year rise (Daly *et al.*, 2007), whereas one at Deadman's Bay on the northeast coast shows a 0.2 mm per year rise (Daly *et al.*, 2007). The salt marsh at St. Paul's Inlet on the Great Northern Peninsula shows little change, or slight sea-level lowering, over the past few thousand years (Daly *et al.*, 2007).

The presence of rooted dead tree stumps in areas below mean sea level shows that sea level has risen (Plate 6). Most trees cannot grow with their roots in salt water, so if sea-level rises the trees are killed. By comparing the relationship of modern trees to sea level, measuring the depth below sea level of the dead trees, and determining their age with radiocarbon dating, an approximate rate of sea-level rise can be obtained. The geographical relationship of the tree stump to sea level, the saltwater tolerance of individual species and the actual timing of the death of the tree must all be taken into consideration. Catto *et al.* (2000) and Catto (2006) used radiocarbon dating of rooted tree stumps, found below the mean sea level at Mobile, Ship Harbour and Port de Grave on the Avalon Peninsula, and parts of the archaeological site at The Beaches (Bonavista Bay) to suggest that relative sea level may have risen at a rate of 2 to 3 cm per decade during the last 3000 years at Ship Harbour and Port de Grave; and ~2 cm per decade along the northern Trinity Bay shoreline. Rates derived from Mobile (6.5 cm per decade) are likely too high (Catto, 2006).

**Plate 6.** *Rooted stumps found below modern sea level, such as this example in the inter-tidal area at Burgeo, are powerful evidence of recent sea-level rise.*

### Sea-level Change over the Last 100 Years

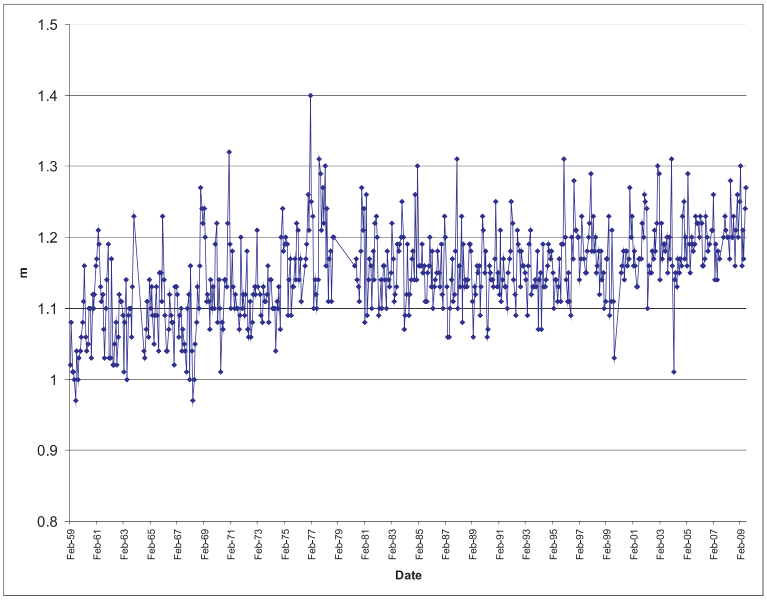
Salt-marsh and tree-stump studies provide evidence for the trends of sea-level change at a decadal or longer time period, but do not provide enough detail to indicate sea-level changes over shorter time periods, because of the intrinsic error in radiocarbon dating. Tide gauges directly measure sea level and provide useful indicators of annual trends (Forbes and Liverman, 1996), but interpreting tide gauge data can be difficult for several reasons, not least of which is the limited time frame for which data are available and the geographical distribution of gauges; most tide gauge records date back less than 60 years (Douglas *et al.*, 2000). Tide gauges not only record tides, obviously, but also the effects of oceanic circulation, meteorological forcing of ocean water, local and regional uplift, vertical movement of the platform on which the gauge is mounted, and errors with the gauge itself (Douglas *et al.*, 2000). The Global Sea Level Observing System (GLOSS) aims to establish high-quality global and regional sea-level networks by accounting for the inherent errors in tide gauge data. It has developed standards and protocols for tide gauges, and has a 'Global Core Network' of 290 sea-level stations around the world for long-term climate change and oceanographic sea-level monitoring. Two stations in Newfoundland and Labrador are within this network: St. John’s and Nain.

There have been as many as 91 tide gauges in the province, although most were temporary, and/or have been decommissioned. There are currently 6 operating tide gauges, at St. John’s, Bonavista, Argentia, St. Lawrence, Port aux Basques, and Nain, and of those only St. John’s and Port aux Basques contain over 50 years of data (Figure 3). All of the stations, except Nain, record sea-level rise of 2 to 3.3 mm per year (20 to 33 cm per century). Nain (Figure 3) records a sea-level fall at a rate of about 1 mm per year (10 cm per century).

## DISCUSSION AND RECOMMENDATIONS

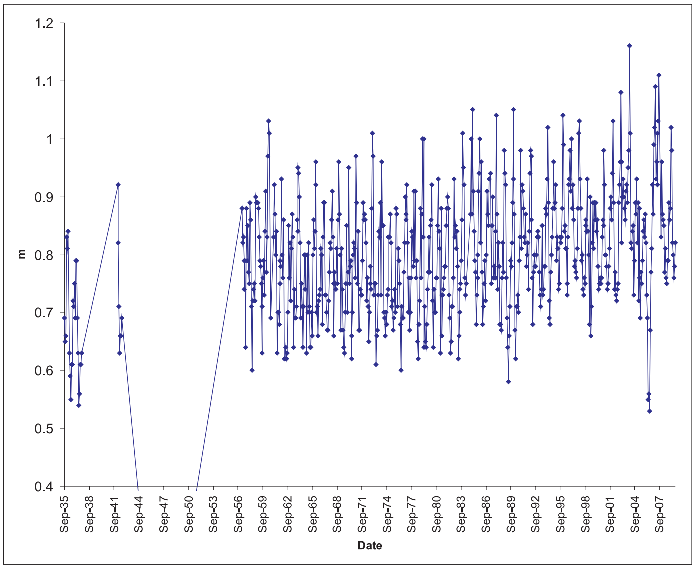
The rate of sea-level change in the province is a combination of global factors and local/regional influences. The current global rate of sea-level rise is estimated at about 3 mm per year, based on both satellite altimetry and tide gauges. The main influence on the sea-level record is the response of the Earth’s crust to the last glacial period. This current rate of increase likely has only occurred over the last 100 to 200 years in relation to climate change, and the main influence on the (provincial) sea-level record is the isostatic response of the crust to the last glacial period.

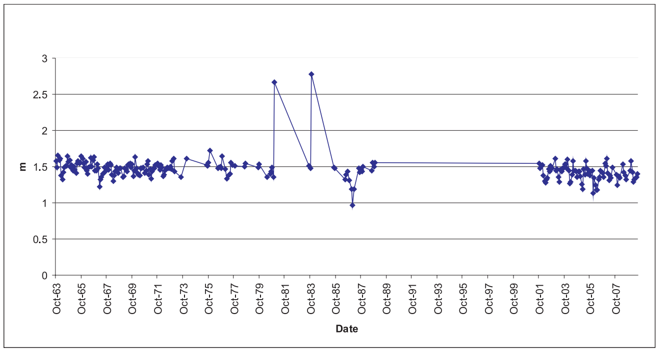
The available data in the province on recent sea-level change all indicate that relative sea level is currently rising across much of the Island of Newfoundland, stable or rising in northern Newfoundland and southern Labrador, and falling in much of central and northern Labrador. The rate of sea-level rise and fall over the last 1000 years varies across the province from a rise of about 2 mm per year on the Avalon Peninsula, to 1 mm per year on the southwest coast, to about 0 mm per year along the Great Northern Peninsula. These changes occurred during a period of stable global sea



Port aux Basques

St. John's





Nain

**Figure 3.** *Tide gauge plots of mean monthly sea-level data from Port aux Basques (top left), St. John's (middle) and Nain (bottom). Data gaps exist in each of the records, within the periods 1978-1980 (Port aux Basques), 1938-1940 and 1942-1946 (St. John's), and 1981-1985 and 1988-2001 (Nain). The upper plots indicate sea-level rise at a rate of about 3 mm per year, while the record from Nain shows a slight fall in sea level.*

**Table 3.** Projections of sea-level rise in Newfoundland and Labrador by 2049 and 2099 over 1990 mean sea levels, based on IPCC predictions, potential accelerated ice melt, and regional trends of crustal rebound; all figures in centimetres, unless otherwise stated

| Zone | Sea Level rise by 2049 (IPCC) | Sea Level rise by 2099 (IPCC) | Accelerated Ice Melt by 2099 | Regional trends (mm per year) | 2049 Projected rise | 2099 Projected rise |
|---|---|---|---|---|---|---|
| 1 | 30 | 59 | +20 | + 2 | 40 | 100+ |
| 2 | 30 | 59 | +20 | +1 | 40 | 90 |
| 3 | 30 | 59 | +20 | 0 | 30 | 80 |
| 4 | 30 | 59 | +20 | -1 | 30 | 70 |

levels, and are thus related to crustal rebound. Rates of relative sea-level fall are about 1 mm per year in Labrador. Recent sea-level rise over the last 100 years, as determined by tide gauge records, is about 20 to 30 cm, consistent with the global sea-level rise.

In the absence of more data from the province it is reasonable and prudent to assume the following:

1. Crustal adjustment (isostatic rebound) will continue for the foreseeable future.
2. The rise in global sea level will continue, and
3. Planning must consider both the isostatic response and the global changes in sea level.

Combining the estimates of global rise with local changes allows a simple estimate of sea-level rise for planning purposes over the province. Although relative sea level is currently falling in Lake Melville and Nain, higher relative sea levels are probable in the future. The increase in general sea level will gradually exceed the effects of isostatic depression in these areas: even though Happy Valley–Goose Bay will continue to rebound, the overall change will result in slowly rising sea level here. This is expressed as increases in centimetres over 1990 sea-level (Table 3, Figure 4). Figures are rounded to the nearest 10 centimetres, so not as to give the impression that these estimates, that contain considerable uncertainty, are of great precision.

In many areas of the province, the presence of relatively steep-sloping bedrock-exposed coastlines means that such sea-level rises indicated above will have little impact. However in low-lying or low-sloping coastal areas, these changes are highly significant. It is likely that this rise in sea level will have an impact on erosion rates of unconsolidated coastal cliffs where sand beaches or low bluffs of gravel are present, by allowing greater access to the base of steep slopes. The increased steepening of costal cliffs may also increase the risk of landslides. Sea-level rise will threaten the stability of barrier beaches (Plate 7); these beaches may remain stable if sufficient sediment supply exists but may change drastically if cut off from a supply of new sediment.

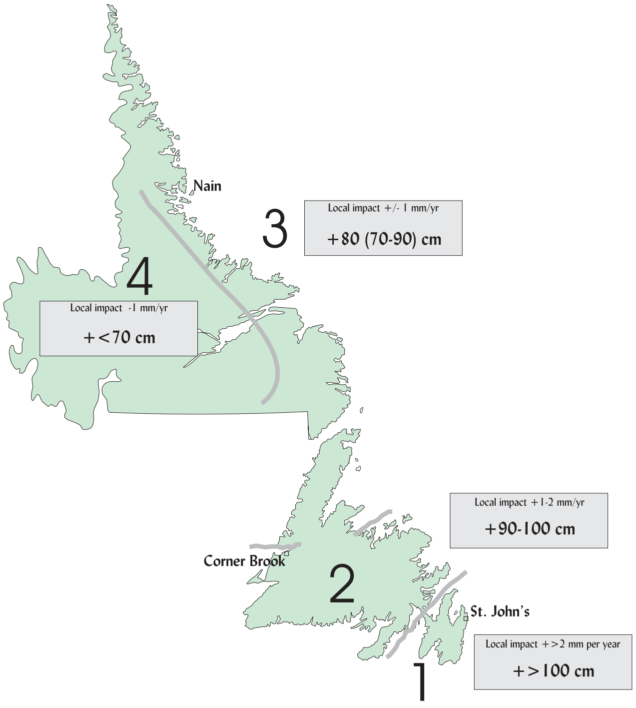


**Figure 4.** *Projections of potential relative sea-level rise in Newfoundland and Labrador by 2099.*

Based on the predictions of sea-level rise outlined here, there is a need to repeat the detailed flood risk modelling performed in coastal areas mapped as part of provincial flood-risk mapping in the 1980s; these earlier studies did not take into account future sea-level change. Although no substitute for a full re-evaluation, an examination of the previous flood-risk mapping gives some pointers as to the implications of sea-level rise in these flood-prone communities. Although a sea-level rise of less than 1 m may seem insignificant, this can make a critical difference in low-lying coastal areas. Some idea of the potential effect of such a change can be gained by examining existing flood-risk models (Table 4).

**Plate 7.** *Vertical aerial photograph of part of the Town of Conception Bay South showing an extensive barachois beach system. This beach protects low-lying areas inland (2 m contour shown), much of which have been developed. Future relative sea-level rise, plus storm surge, could breach the barachois beach and inundate coastal properties.*

By 2050, therefore, the existing 1:100 flood zone for these three communities may well effectively be the 1:20 zone (Figure 5) with far more frequent flooding, with new areas formerly outside of the 1:100 zone now prone to flooding. For Placentia, remedial measures were installed based on protection from the 1:100 predicted flood. These are likely to be inadequate by 2050. The provincial government Land Use Policy for Flood Risk areas uses the 1:20 and 1:100 flood zones to define the ’Floodway’ and the ‘Floodway fringe’ areas with specific restrictions on development in each case. For example, it permits flood-proofed residential construction in the flood fringe, and prohibits it in the floodway.

When planning for residential construction, the time frames discussed here (40 years and 90 years from present) are directly relevant, as residential structures have a planned life of at least 50 years. There is a high likelihood that permitting development in the ‘flood fringe’, in areas vulnerable to coastal flooding will result, in the long term, in significant negative economic and social cost, as these areas become increasingly vulnerable to flooding.

**Table 4.** Potential sea-level trends by 2099 and effect on flood-risk zone delineation

| **Community** | **Projected sea-level rise (cm; 2050/2099)** | **Difference between 1:20 and 1:100 flood risk zone elevations*** |
|---|---|---|
| Cox’s Cove (Zone 2-3) | 30/80 or 40/90 | 30-90 cm |
| Stephenville Crossing (Zone 2) | 30/80 | 24 cm |
| Placentia (Zone 1) | 40/100 | 16 cm |

*Sources of flood-risk data: Acres (1985); Martec (1988); Shawmont Newfoundland (1985)

## CONCLUSIONS

The available data from tide gauges and satellite altimetry confirm that global sea level is rising at a rate of ~3 mm per year. This rate is likely to increase as ice sheets continue to melt and the ocean warms. In Newfoundland and Labrador, this global trend in sea-level change is superimposed on local trends, but for those areas with the greatest concentration of our population, the Avalon Peninsula and the west coast, a potential sea-level rise of 80 to 100+ cm by 2099 is to be anticipated. Continual monitoring of both coastal erosion rates and the patterns of beach migration is critical to understanding change in the coastal environment.

There is, of course, uncertainty in any discussion of future trends. In this paper, we have adopted the upper limits of projected scenarios due to current trends in global $CO_2$ emissions and recent data on ice-sheet decay and global sea-level rise.

Informed planning for development in areas potentially affected by sea-level rise is critical. Planners and policy makers will need to balance the economic impact of restricting development based on this maximum estimate against the possible future economic costs of more frequent and larger floods, and increased coastal erosion. The impact of flooding in coastal areas can only be fully understood by comprehensive hydrological modelling and flood-risk mapping that takes into account probable sea-level rise.

These guidelines for likely sea-level change over the next century provided here aim to assist in development of such flood-risk studies and to provide a basis for developing and implementing development policy in the coastal zone.

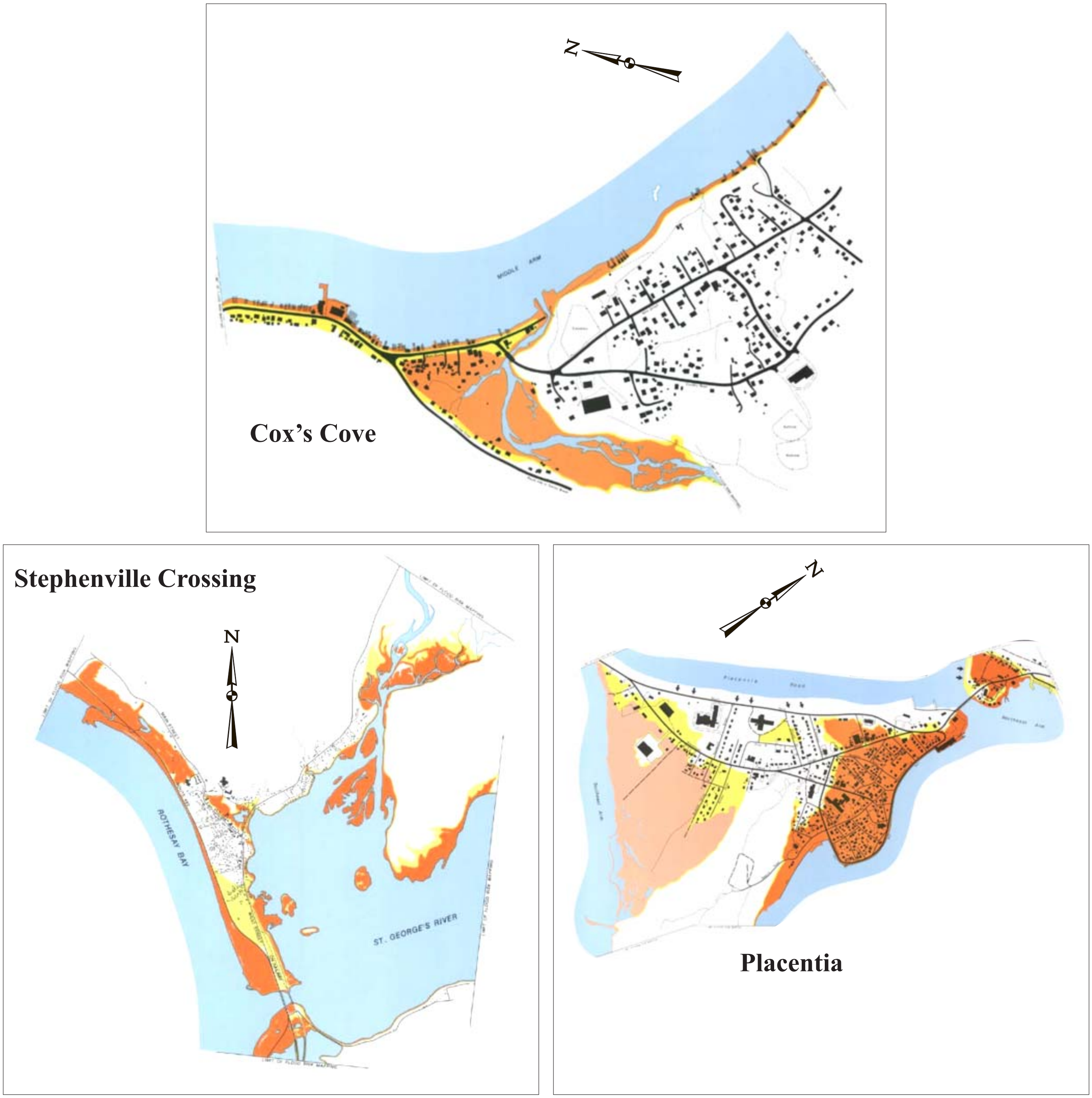


**Figure 5.** *Flood-risk information maps for Cox's Cove (top), Stephenville Crossing (bottom left), and Placentia (bottom right). Orange areas indicate the 1:20-year flood zone, and yellow areas are the 1:100-year flood zone. If projected amounts of sea-level rise occur, many of the zones designated as the 1:100 year flood zone will be within the 1:20 year levels.*

It should be noted that other effects of climate change may well be noted in the province, and affect coastal stability and development. These include more frequent extreme storms, higher rainfall, and increased storm surges.

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