

Chapter 7 **Sea-Level Rise and Storm Events**

7.1 Introduction

A long-term rise in sea level is occurring in Atlantic Canada and is projected to accelerate due to climate change. Reduced sea ice coverage and increased storm intensities are additional consequences of climate change. As a result, storm events will have ever increasing impacts on people, property, infrastructure, wildlife and ecosystems along the coast. Adaptation, protection and planning for the sustainable use of coastal land in Nova Scotia must, therefore, take into account the risks arising from sea-level rise and coastal storms.

This topic is currently one of intense scientific research. A future coastal zone management strategy and its associated policies should integrate science on an ongoing basis. To help towards such a future integration, this chapter summarizes the present state of knowledge and describes the potential impacts from sea level rise and storm events. Current management actions and initiatives to deal with this issue are also presented.

7.2 Sea Level Rise

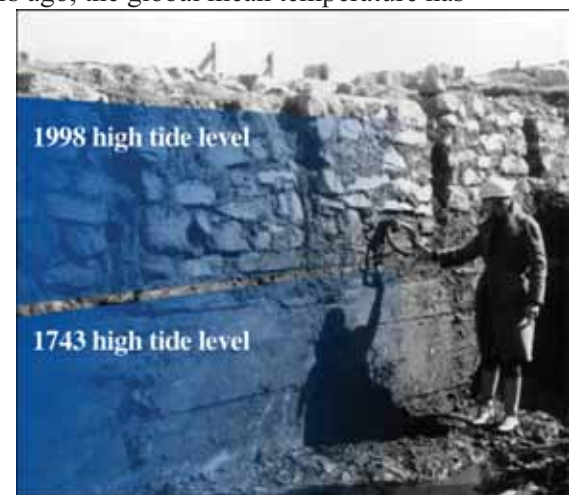
7.2.1 Driving Forces

The rise in relative sea level, i.e., the water level relative to fixed points on land, experienced by Atlantic Canada is due to a combination of processes including:

- Long-term global mean sea level rise since the end of the last ice age;
- Regional land subsidence; and
- Climate warming that will accelerate global sea level rise in the future.

Post-glacial warming of the Earth is causing long-term global mean sea level rise due to the thermal expansion of ocean waters and the melting of the ice sheets (the process is referred to as “eustatic” sea level rise). Since the peak of the last ice age, about 20,000 years ago, the global mean temperature has risen 4°C to 7°C and sea level has risen about 120 m (Rhamstorf, 2007). During the 20th Century, the global mean sea level rose 17±5 cm (an increase over the rate in the 19th century), (Intergovernmental Panel on Climate Change, 2007).

In Nova Scotia, the present rates of relative sea level rise are higher than the global mean; during the 20th Century the increase was about 30 cm. This trend is further exemplified at Fortress Louisbourg where a 1740s ship’s mooring ring is located half a meter below today’s high tide level. Time series of mean annual water levels from tide gauge records and the associated sea level rise trends are shown on Figure



Sea level rise at Fortress Louisbourg
(Source: Taylor *et al.*, 2000).

7.1 for six harbours in Nova Scotia and neighbouring provinces.

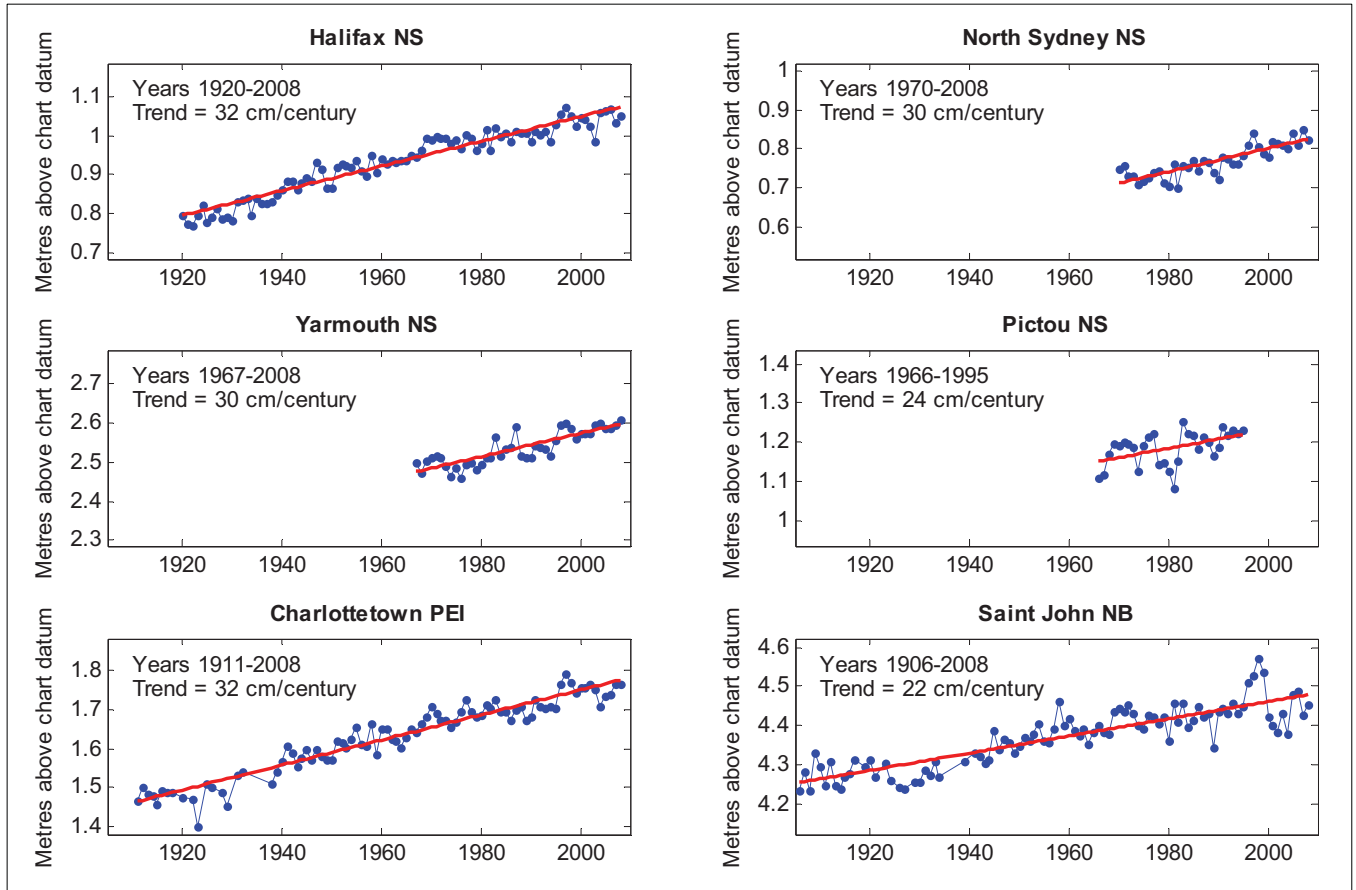


Figure 7.1: Mean annual water levels at six harbours in Nova Scotia, Prince Edward Island and New Brunswick (Source: Marine Environmental Data Service, Ottawa)

Sea level rise in the province is due to the combined effect of an increased global mean sea level and the additional effect of regional subsidence of the Earth’s crust. The subsidence is a manifestation of the crust’s long-term response to the end of the last ice age, referred to as the “glacial isostatic adjustment”. It is caused by the gradual collapse and migration of an area of uplift that developed around the margins of the North American ice sheets and by additional water loading on the seabed in the Gulf of St. Lawrence as global mean sea levels rose (Forbes *et al.*, 2006). In Nova Scotia, subsidence rates are not uniform and are estimated to be up to 20 cm/century (Peltier, 2004; Koozhare, 2005). Reliable data are lacking, and only models can be used for estimates (see Figure 7.2). Most of Atlantic Canada is subsiding, whereas the north shore of the Gulf of St. Lawrence in Quebec and Labrador is rebounding.

Starting in 2001, measurements using a continuous land global positioning system (GPS) site at the Bedford Institute of Oceanography show that land in the Halifax area is subsiding at 17 ± 15 cm/century; the uncertainty will diminish as the record length is extended (Forbes *et al.*, 2008). The 32 cm/century relative sea level rise value measured from tide gauge records at Halifax is consistent with the sum of 17 cm for 20th Century global mean sea level rise and 17 cm for subsidence.

7.2.2 Projections

7.2.2.1 GLOBAL PROJECTIONS

Scientific findings summarized by the Intergovernmental Panel on Climate Change (IPCC), Fourth Assessment Report (AR4) (Intergovernmental Panel on Climate Change, 2007) indicate that global warming, due in large part to human releases of GHGs, will accelerate global mean sea level rise. In particular:

- Projected warming due to the emission of GHGs during the 21st Century will contribute to sea level rise for many centuries;
- Sea level rise due to thermal expansion and the melting of ice sheets could continue for centuries or millennia, even if greenhouse gas emissions were to be stabilised;
- Sea level rise was not geographically uniform in the past and will not be in the future; and
- There is a great uncertainty associated with the magnitude of global warming. If sustained, it could lead to the elimination of the Greenland Ice Sheet. In recognition of this uncertainty, IPCC AR4 sea level rise projections do not account for the accelerated outflow of ice sheets.

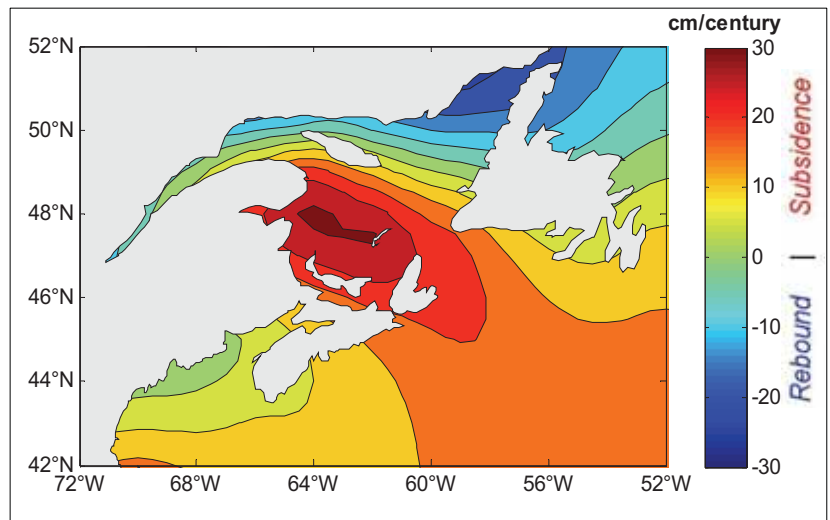


Figure 7.2: Regional rates of relative sea level rise due to glacial isostatic adjustment according to the Ice-5G model (Peltier, 2004) (The effect of global mean sea level rise is not included)

Climate scenarios examined by the IPCC project a global mean temperature increase of 1.1°C to 6.4°C by 2100. The corresponding sea level rise, excluding future rapid dynamical changes in ice flow, is 18 cm to 59 cm by 2100. However, the post-AR4 analyses of observed sea ice extent indicate that the Arctic Ocean is losing sea ice 30 or more years ahead of model projections (Stroeve *et al.*, 2007). In addition, the recent global sea level rise trend appears to be already at the upper end of the AR4 projections. Based on strong empirical correlations between global mean air temperature and sea level rise in the 20th Century, Rhamstorf (2007) estimates that a global mean sea level rise of up to 120 cm by 2100 for strong warming scenarios cannot be ruled out. This would nearly double the maximum IPCC AR4 projection.

7.2.2.2 NOVA SCOTIA PROJECTIONS

Local sea level rise projections must account for:

- Global mean sea level rise – the range for the next century may be 18 cm to 59 cm based on IPCC AR4, but could be up to 120 cm (Rhamstorf, 2007); and
- Regional land subsidence – a representative value of 20 cm/century may be used for the province at a preliminary stage.

Based on the above assumptions, relative sea level rise in Nova Scotia for the next century could range from 70 cm (Forbes *et al.*, 2006) to double that value (140 cm). It is, however, recognised that the exercise of making projections for Nova Scotia is hindered by significant uncertainties associated with the following factors (Forbes *et al.*, 2008):

- IPCC projections, which depend on future global emissions' scenarios and model error bars;
- Accelerated ice melting in Greenland and Antarctica;

- Regional sea level response to the global mean sea level (there is currently no reason to use a different value for Nova Scotia than the global mean); and
- Regional land subsidence.

Projections will be updated as climate models improve and more data are collected. The planning process should, therefore, be informed by science on an ongoing basis.

7.3 Storm Events

Sea level rise is a concern because the mean sea level acts as a carrier wave for the tide, carrying storm surges and waves generated by marine storms. A rise in sea level would allow storm surges to reach further inland.

7.3.1 Storm Types

Nova Scotia is subject to a wide range of storms, including extratropical (mid-latitude) and tropical cyclones. Extratropical cyclones form as eastbound cold, dry air originating over the continent meets warm, moist air originating over the Caribbean Sea. The temperature difference between these air masses is greatest during winter and late fall, which leads to the most intense extratropical cyclones. In winter, the most common are extratropical cyclones that form offshore of the southeastern United States and track northeastward towards the Maritimes. Year-round, these storms can also form over the continent east of the Rocky Mountains, or farther north in the Arctic (Parkes *et al.*, 2006). The Atlantic storm of January 21-22, 2000, is an example of an extratropical storm when the storm surge coincided with high tide in the Gulf of St. Lawrence, causing extensive damage (see http://gsc.nrcan.gc.ca/coast/storms/atlantic_storm_e.php).

Tropical cyclones, i.e., hurricanes and tropical storms, form during the tropical weather season in the Atlantic (June to November). They originate in the tropical and subtropical North Atlantic and may track northeastward along the eastern coast of the United States. They then typically weaken and dissipate over colder ocean waters north of the Gulf Stream current, south of Nova Scotia. During infrequent occurrences of warmer-than-usual water temperature, however, they may continue on and make landfall in Nova Scotia, as did hurricanes Hortense in 1996 and Juan in 2003 (Meteorological Service of Canada, 2005). These tropical cyclones can be very powerful and occur before the formation of sea ice, which would typically protect the Northumberland shores of Nova Scotia from direct wave attack. During a tropical storm's transition to post-tropical, the strongest winds

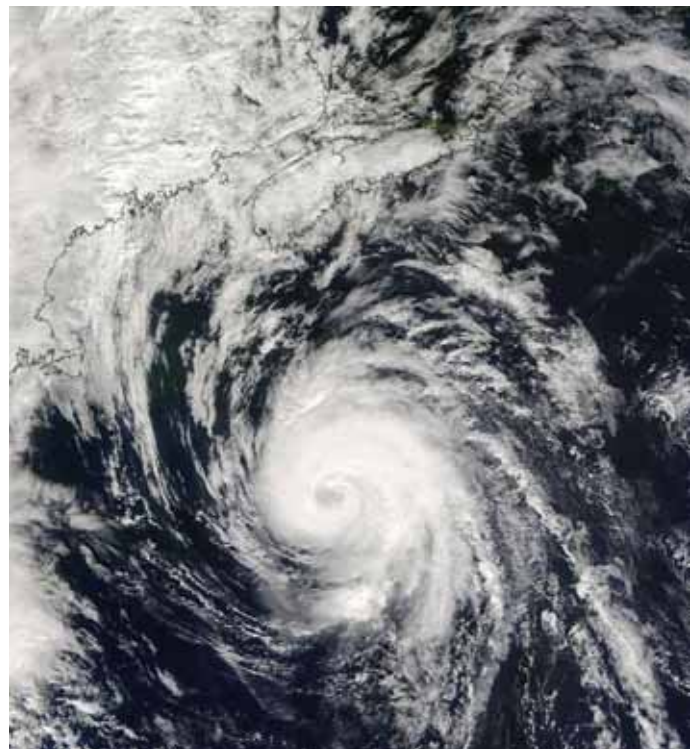


Figure 7.3: Hurricane Juan approaching Nova Scotia (Source: Environment Canada, www.atl.ec.gc.ca/weather/hurricane/)

spread out from the core and the storm then resembles an extratropical system. Post-tropical Storm Noel (November 2-3, 2007) is a recent example that caused damage along the Atlantic coast of Nova Scotia (see http://gsc.nrcan.gc.ca/coast/storms/atlantic_storm_e.php).

7.3.2 Storm Surges

The storm surge is the height difference between the water level due to astronomical tides and the total water level at the peak of the storm. It is due to storm winds piling water onshore, low atmospheric

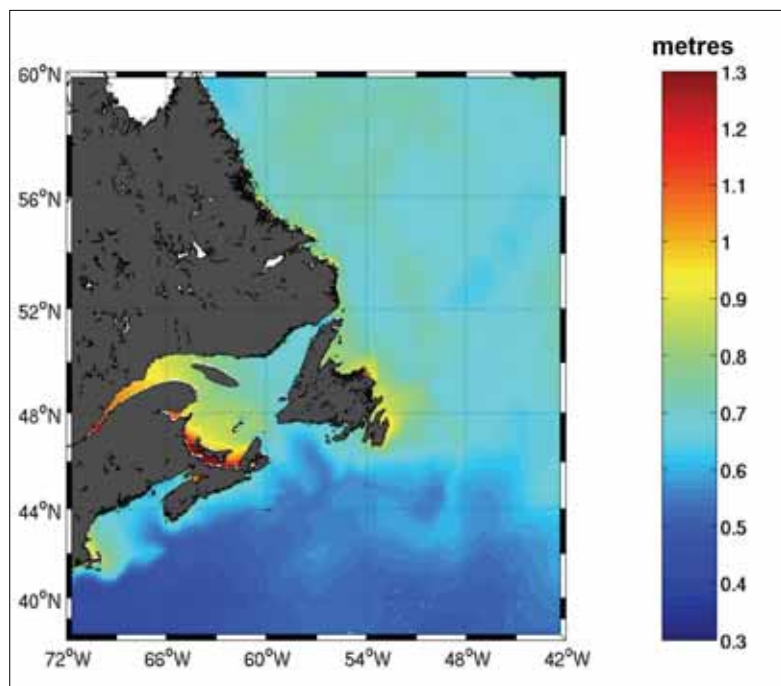


Figure 7.4: 40-year Return level of extreme storm surges based on a hindcast (reproduced from Bernier *et al.*, 2006). Note: The colourbar indicates the 40-year surge levels independent of tidal elevations. Estimates for other return periods are available on Environment Canada's atmospheric hazards website (<http://atlantic.hazards.ca>).

pressure, wave setup, possible resonant effects within a bay and the coastal response to these factors (Parkes *et al.*, 1997). Storm surges are typically associated with large-scale weather systems and affect large areas. The surges mostly occur during extratropical storms in the fall and winter, but can also be caused by tropical cyclones reaching Nova Scotia in the summer and fall. Figure 7.4 shows positive storm surge heights that are exceeded on average once in 40 years. The highest surges around Nova Scotia tend to occur along the North Shore, western Cape Breton Island and the head of the Bay of Fundy (the map does not include potential surge amplification in bays and harbours). The tidal phase during the storm peak determines the total water level. The most damaging storms are those occurring at high tide, or storms of long duration (over several tidal cycles) coinciding with spring tides.

7.3.3 Future Trends

It is expected that climate change will cause an increase in the intensity of storms in the northern hemisphere, as well as a possible northward shift of storm tracks (McCabe *et al.*, 2001; Wang *et al.*, 2006). This northward shift will increase Nova Scotia's exposure to the warmer southeastern side of storm tracks, which may alter local wind patterns and cause increased precipitation. Trends in hurricane frequency are difficult to extrapolate in the long-term because of the cyclical nature of their occurrence. Still, intense tropical cyclone activity has increased since approximately 1970, with a trend towards longer lifetimes and greater storm intensity, and such trends are strongly correlated with sea surface temperatures. Based on 1981–2000 averages, the number of hurricanes in the North Atlantic has been above normal in nine of the last 11 years, culminating in the record-breaking 2005 season (Intergovernmental Panel on Climate Change, 2007).

For coastal Nova Scotia, the consequence of rising sea levels will be far greater than that of increased storms, i.e., storm intensity and/or frequency. To illustrate this point, the probabilities of extreme water levels in Halifax from sea level rise alone, and from a combination of sea level rise and increased storms, are shown on Figure 7.5. This figure also shows that the impact of sea level rise is so important that extreme water levels with a current return period of 100 years, as during Hurricane Juan, are expected to become regular events by the end of the century.

7.4 Impacts of Sea Level Rise and Storm Events

7.4.1 Biophysical Impacts

Sea level rise will allow storm events to have increasing impacts on the coast of Nova Scotia. Physical impacts to the coast such as flooding, erosion, increased frequency of overtopping or beach migration are the most obvious consequences. Figure 7.6 depicts the broad regional scale sensitivity of Atlantic Canada to such physical impacts. Sensitivity is defined here as the likelihood of physical changes at the coast due to sea level rise. The index is based on general relief, rock type, coastal landform, sea level rise trend, shoreline displacement, tidal range and wave height using large-scale 1:50,000 maps (Shaw *et al.*, 1998). There is no accounting for small areas of very high or low sensitivity, so the map should not be used for developing local, site-specific policies.

A summary of likely biophysical impacts is provided in Table 7.1. In addition to direct sea level rise impacts, climate change, through increased temperatures and changing precipitation patterns, will also impact coastal biophysical systems (DeRomilly *et al.*, 2005). Sensitivities of marine ecosystems and fisheries are summarized by Vasseur and Catto (2008).

Direct climate change impacts on biological species are difficult to quantify at this point. Such change, for example, will arise from changes in water temperatures (a sensitive parameter for aquatic species), changes in sea ice patterns and physical changes to coastal habitat used for spawning and feeding.

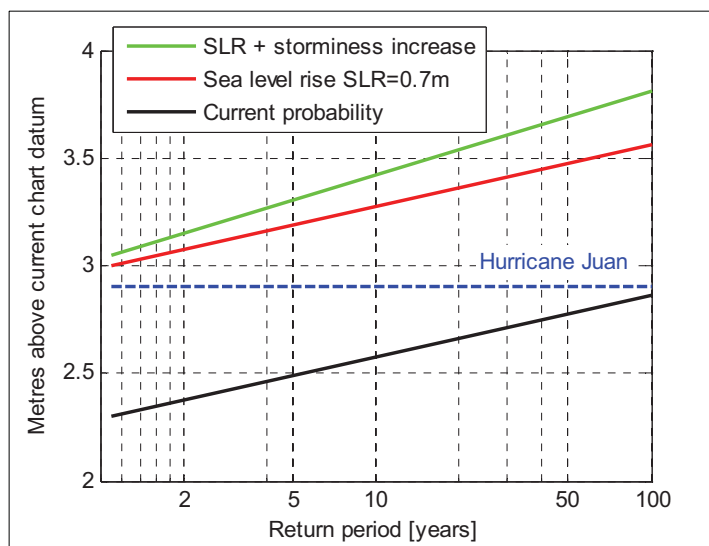


Figure 7.5: Return period of extreme sea levels into the next Century at Halifax (from Bernier *et al.* 2007)

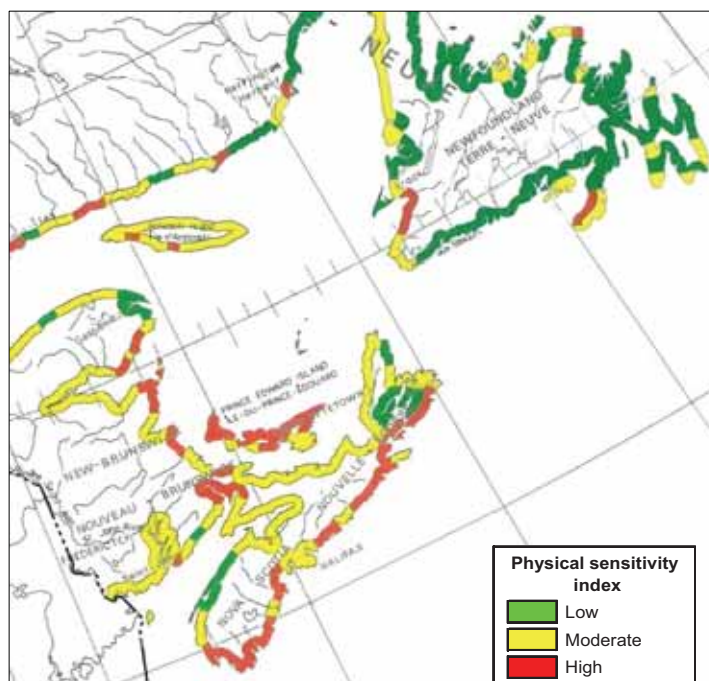


Figure 7.6: Regional physical sensitivity of coastlines to sea level rise in Atlantic Canada (after Shaw *et al.*, 1998)

Notably, the extent and duration of winter ice cover along the North Shore of Nova Scotia and Cape Breton Island will be much reduced by climate change. Results from climate models, for example, indicate that by the year 2045, the Gulf of Saint Lawrence may be free of ice (McCulloch *et al.*, 2002). The main consequences will be an increased frequency of wave events and associated sediment mobilization in the winter. The loss of ice will also contribute to accelerate sea level rise, due to both the lack of the albedo effect (reflectively) of the ice, and the capture of heat by the dark body of water.

Table 7-1: Summary of Qualitative Impacts of Increased Sea Level Rise and Storm Events on the Natural Coastal System

<i>Element of Natural Coastal System</i>	<i>Impacts of Increased Sea Level Rise and Storm Events</i>
Beaches	Large-scale morphologic adjustments to absorb the wave energy, including: - Overwashing and increased erosion - Potential formation of new beaches downdrift of erosion areas - Landward migration of barrier beaches (Geological Survey of Canada, 2008)
Unconsolidated cliffs	Accelerated erosion
Estuaries and tidal rivers	Increase in tidal volume and exchange Further saltwater penetration
Freshwater marshes	Gradually become salt marshes or migrate landward
Salt marshes	More frequent tidal flooding Sedimentation and possible landward migration at a rate commensurate with sea level rise depending on sediment and organic matter supply (Van Proosdij and Baker, 2007; Chmura and Hung, 2004)
Small islands	Submergence
Aquifers	Potential saltwater intrusion affecting potable and agricultural groundwater supplies. In some areas this may be mitigated by recharge from increased annual precipitation (Grant Ferguson, St Francis Xavier University, pers. comm., 2008)
Species and ecosystems	<i>Sea level rise and storm impacts:</i> Modification of coastal habitat as listed above <i>Other climate change impacts:</i> Threatened viability from changes in numerous factors including, but not limited to, water temperature, salinity, sea ice patterns (e.g., seals), runoff and water quality.

The Bay of Fundy is another area at greater risk. Sea level rise and land subsidence will increase the water depths in the Bay of Fundy-Gulf of Maine region. As a result, the tide will propagate faster and the natural oscillation period of the Bay, presently close to 13 hours, is expected to decrease towards the 12.4 hour period of the semi-diurnal tidal forcing. This will bring the system closer to resonance and thereby amplify the range of the tides in the Bay. The increase in tidal range may be in the order of 10% of the sea level rise, e.g., 0.1 m for a 1 m sea level rise over the next century. In such an area where flooding levels are already close to the present high tides, any increase in high water will cause considerably greater flooding risks (Greenberg, 2001).

7.4.2 Socio-Economic Impacts

Coastal property and infrastructure will be increasingly at risk from sea level rise and storm events. Risk is the combination of hazard, e.g., flooding from storm surge, wave attack, erosion, etc., and vulnerability, e.g., from being located too low or close to the water, or on soft geology. The costing of socio-economic impacts is a challenging exercise. It must take into account the elements listed in Table 7.2, including natural systems that provide ecological services valuable to coastal communities (MacCulloch *et al.*, 2002).

Table 7-2: Summary of qualitative socio-economic impacts of sea level rise and storm events

<i>Socio-Economic Element</i>	<i>Impacts of Sea Level Rise and Storm Events</i>
Coastal land	Shoreline erosion
Property, transportation infrastructure and municipal waste treatment facilities	Flooding, structural damage caused by loss of substrate, wave attack or rafting ice
Dykelands	Saltwater flooding of dyked areas (Van Proosdij and Baker, 2007), with impacts on agricultural crops (especially if during growing season), property and infrastructure Upstream freshwater flooding due to higher downstream tidal elevations Structural damage to dykes from overtopping and erosion
Sewer systems	Increased frequency of backups and associated upstream flooding
Human health and safety	Spread of water borne illnesses during flooding Isolation of communities due to infrastructure damage Storm-related injuries or deaths
Aquaculture	Disruption of operations from increased storminess, coastal erosion of protective barrier dunes and changes in water temperature and salinity impacting species
Ports and harbours	Access for deeper draft vessels (if no sedimentation) Storm damage to coastal structures Increased length of shipping season due to climate change
Beaches, dunes, coastal trails and boardwalks	Erosion resulting in loss of coastal protection value, and loss in tourism revenue for recreational areas
Wetlands and forests	Loss of coastal protection and associated ecosystem services (e.g. water filtration, removal of air pollutants, control of runoff and erosion)
Heritage resources	Loss due to flooding



Storm damage at Prospect from Hurricane Juan in September 2003 (photo: Doug Mercer), and at Queensland Beach from post-tropical storm Noel in November 2007

Hurricane Juan in 2003 caused the greatest recent storm damage recorded in Nova Scotia. The total loss reported by the Insurance Bureau of Canada (2008) was \$130 million. For this event, \$35 million were eligible costs submitted to the federal Disaster Financial Assistance Arrangements (DFAA) program. These values would be biased towards wind damage, which is unrelated to direct storm surge damage. Under the DFAA, in the last 10 years, the value received by claimants in Nova Scotia (private property owners, small businesses, fishermen and not-for-profit organisations) for all storm surge damage was \$3.3 million (Adam Rostis and Paul MacNeil, Emergency Management Office, Nova Scotia Department of Public Safety, pers. comm., 2008). These figures do not include damage to public infrastructure. For federal infrastructure, repair costs are generally tallied within yearly maintenance budgets (Paul Davison, Public Works and Government Services Canada, pers. comm., 2008). Gross repair costs to provincial coastal infrastructure (mostly roads and shoreline structures) after hurricane Juan (2003) and post-tropical storm Noel (2007) were \$2 million and \$580,000, respectively (Shawn Ramey, Financial Services,

NSTIR, pers. comm., 2009). It is also noted that Canadian insurance companies in general only cover sewer-back-up related flooding and not coastal flooding, or gradual erosion damage (Insurance Bureau of Canada, 2008).



Storm impacts on February 1, 2006 at the Avonport Dyke (Source: Van Proosdij and Baker, 2007)

Of particular concern to Nova Scotia are the Acadian dykelands (Andrew Cameron and Ken Carroll, Nova Scotia Department of Agriculture, Land Protection Section, pers. comm., 2008). Sea level rise will cause the dykes to be more exposed to damage, and the protected dykelands to flooding as described in Table 7.2. Dykelands were first constructed by the French settlers in the 1700s

to expand agricultural land along the Bay of Fundy, where marine sediments deposited by high tides form fertile soils. At low tide, rivers drain through aboiteaux (culverts with a flap gate on the downstream end). The Province today has responsibility for the maintenance of 17,519 hectares of land protected by the 243 km of dykes, with an annual budget of just over \$1 million in recent years. The dyke elevations are maintained to reflect current sea levels, based on surveys conducted every five years. In 2002 the construction elevation was raised by 30 cm for all dykes. “Topping” (the addition of material to the height) is done if the dyke elevation has fallen some critical value below construction elevation; several factors are taken into consideration including dyke location (upriver versus coastal, storm exposure, land use), topping length (spot locations, or full dyke length) and topping material. Construction elevations are generally set at 60 cm above high tide for exposed dykes, with adjustments based on local factors, e.g., settlement rate, or frequency of past overtopping. The last significant storm event to damage dyke protected lands was in 1976 when the dyke in St. Mary’s Bay was completely destroyed. In addition to agricultural crops and property, a few critical transportation links are particularly vulnerable, e.g., the Trans Canada Highway across the Tantramar Marsh at the New Brunswick–Nova Scotia border, which this was flooded during the great ‘Saxby Gale’ of 1869 (Desplanque and Mossman, 2004).

Strategic decisions will be required by communities and governments, and funds will be needed for programs to protect key public infrastructure and flood and hazard-prone communities, e.g., dyke lands, transportation systems. Impacts of sea level rise and storm events will be very site-specific, in that the flood lines depend on the local terrain and exposure to the key driving forces.

7.5 Policies, Programs and Initiatives

7.5.1 Legislation and Policy

Generally, coastal risk needs to be dealt with at a municipal level with assistance from the Province. Existing coastal legislation and policies have been summarized in Section 3.4 with further detail provided in Appendix 3. A recent extensive review of the challenges and opportunities associated with regulatory standards for coastal development in Nova Scotia is provided by Burbidge (2008). As an example of local ongoing work, HRM’s recent planning policies include coastal setback requirements (Halifax Regional Municipality, 2006), and further initiatives are underway as described in Section 7.5.2. One of the important lessons learned from other jurisdictions, such as New Brunswick, is that regulations restricting coastal development must be enacted immediately to prevent a building rush (Vasseur and Catto, 2008).

7.5.2 Current Studies and Initiatives

The following sections reference representative examples of current initiatives being undertaken to better understand and prepare for impacts of sea level rise and storm events in Nova Scotia.

7.5.2.1 FEDERAL INITIATIVES

Federal initiatives include:

- Environment Canada’s Atlantic Storm Prediction Centre, which issues storm surge forecasts based on a meteorologically-driven ocean model developed at Dalhousie University (used to produce the map shown on Figure 7.3) and validated by water level data;

- The Geological Survey of Canada which maintains an array of coastal monitoring sites that provide information on shoreline position, morphology and the impact of storms (Geological Survey of Canada, 2008);
- The Canadian Hydrographic Service (CHS) that operates tide gauges in Nova Scotia at Yarmouth, Halifax and North Sydney. Data for the Bay of Fundy and Northumberland Strait are collected at Saint John NB and Charlottetown PEI, respectively. The gauges were recently upgraded to be part of a real-time storm surge and tsunami warning system, in recognition of the fact that tsunamis, although rare, can happen in the Maritimes as occurred in 1929 in Newfoundland (O'Reilly *et al.*, 2007). CHS is also responsible for managing vertical datums, which are being updated to reflect sea level rise; and
- A GPS system that was installed to monitor land subsidence at the Bedford Institute of Oceanography (Forbes, 2008).

7.5.2.2 PROVINCIAL INITIATIVES

The *Environmental Goals and Sustainable Prosperity Act* passed by the Province in 2007 sets its long-term environmental and economic agenda, under which the 2009 Climate Change Action Plan (Nova Scotia Environment, 2009) specifically addresses the following:

- Provision of funding to municipalities to plan for the consequences of climate change focusing on the impacts of sea-level rise, land use planning and wastewater treatment plant design;
- Release of a Sustainable Coastal Development Strategy by 2010 to address increased coastal risks; and
- Taking sea level rise into consideration and placing priority on conserving coastal wetlands in preparing a policy to prevent the net loss of wetlands.

Current examples of site-specific provincial initiatives include (Philip Finck and Garth Demont, Nova Scotia Department of Natural Resources, Geological Services Division, pers. comm., 2008):

- Coastal Hazard Assessment Project, St. Margaret's Bay – This involves the preparation of paper and GIS maps (1:10,000 scale) to classify coastal areas based on a range of natural and man-made factors relating to existing and future hazards. These factors include bathymetry, morphology, angle of wind and wave attack, coastal structures or armouring, location of infrastructure and property, etc. These maps will provide essential, basic information for a wide range of stakeholders including property owners, planners, infrastructure engineers and coastal zone managers;
- Central Antigonish County Land-Use Planning and Climate Change Risk Assessment Pilot Project – Geoscience and elevation (LiDAR) data are being collected. The end products will be maps of geology, groundwater, mineral resources, flood risk and coastal risk (as for St Margaret's Bay), to be used in developing policies and procedures for sound land use planning towards year 2010; and
- Tide gauge and meteorological station at the Windsor Avon River Causeway operated by Saint Mary's University (SMU) and NS Agriculture, and environmental assessments and flood risk models prepared by SMU and Acadia University in cooperation with NS Agriculture and DFO to support NSTIR's plans to twin Highway 101 (Van Proosdij and Baker, 2007 and other publications from <http://www.gov.ns.ca/tran/publications/publication.asp>).

7.5.2.3 HALIFAX REGIONAL MUNICIPALITY

The HRM is currently leading a project on coastal risks to integrate science into land use planning including setback guidelines, standards for minimum foundation levels and security for critical

infrastructure as input to the forthcoming Halifax Harbour Plan (Halifax Regional Municipality, 2008). Digital elevation models are being combined with sea level rise and storm surge projections to estimate risks in flood-prone areas (see Figure 7.7).

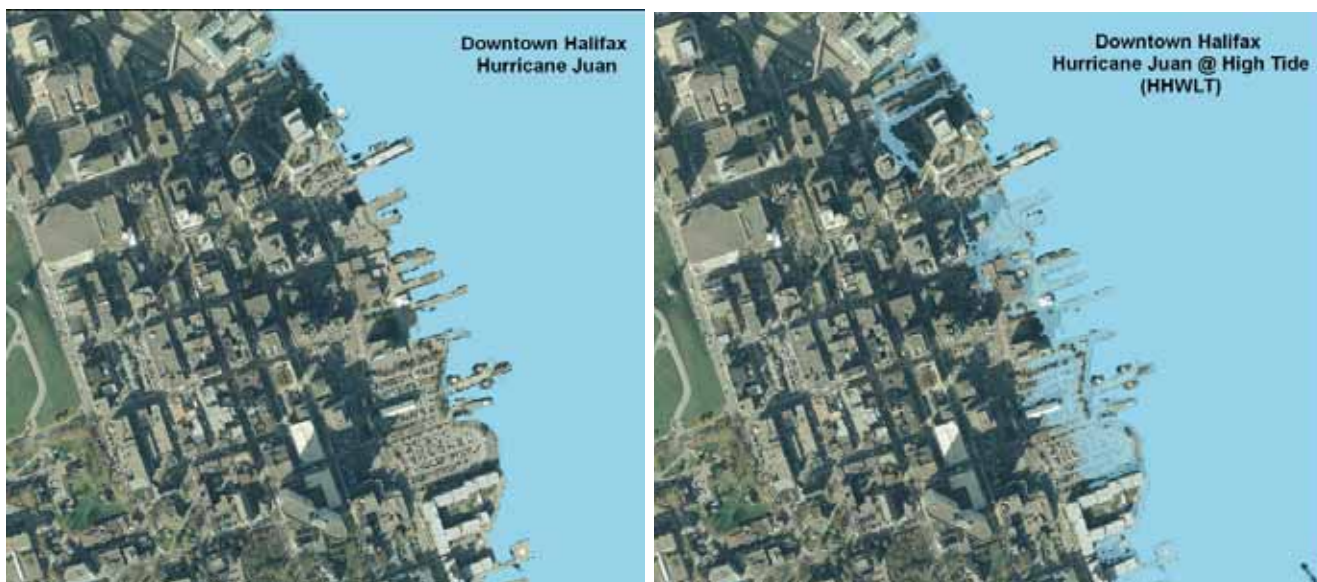


Figure 7.7: Flooding scenarios for downtown Halifax. The peak water level during Hurricane Juan was 2.9 m chart datum (left panel). It could have been 3.4 m had the surge coincided with the high tide 2 hours earlier, or it could have been 3.6 m (right panel) had it coincided with the 'higher high water large tide' (the average of the 19 annual predicted highest high waters) (Source: Manson *et al.*, 2008).

7.5.2.4 OTHER INITIATIVES

In Annapolis Royal, the Tidal Surge Study conducted by the Clean Annapolis River Project, a citizen-based group, is an example of what can be accomplished with relatively few resources (Belbin and Clyburn, 1998). The community is located on low-lying, vulnerable reclaimed land. Risks were assessed from 2 m elevation maps and historical storm records including the 1869 Saxby Gale used as the extreme storm benchmark. The study showed that the fire department would be located on an island during a flood (Figure 7.8). To increase



Figure 7.8: Example of flood risk mapping for Annapolis Royal (Belbin and Clyburn, 1998)

the community's adaptive capacity to the risk of increased coastal flooding, the emergency rescue equipment, previously stored at the fire department was relocated around town, and the fire department acquired a boat (Vasseur and Catto, 2008). The results of this case study are currently being used to develop a desktop kit for land-use planners that includes tools for the analysis of climate change scenarios, coastal and inland flooding, hydrogeology, cost-benefit and policy implementation (Parks, 2006).

7.6 Key Points and Sustainability Issues

Nova Scotia has experienced sea level rise since the peak of the last ice age, about 20,000 years ago. Global warming and regional land subsidence, however, will increase the rate of relative sea level rise, from about 30 cm over the last century to possibly above 1 m this century. This will dramatically increase the occurrence of extreme water levels. Storms are also likely to become more intense. The biophysical impacts (flooding, coastal instability, changes to biophysical systems) and the socio-economic impacts (damage to property, infrastructure, human safety risks, etc.) will increase. In terms of sustainability, this represents a significant socio-economic challenge to coastal areas.

The greatest risks are associated with the following elements (Parkes *et al.*, 1997):

- Low-lying areas, especially those with small tides relative to storm surge potential;
- Areas with frequent storm conditions and high storm surge levels;
- Areas of coastal infrastructure and property;
- Areas of sensitive ecology;
- Areas of rapid coastal erosion; and
- Perigean spring high water, i.e., the largest monthly tides.

Dealing with this long-term problem requires strategic decisions for key public infrastructure and flood and hazard-prone communities. General strategies for adaptation towards sustainability include the response options summarized in Table 7.3.

Table 7-3: Summary of response options to sea level rise and storm events (after McCulloch *et al.*, 2002)

<i>Response</i>	<i>Examples</i>
Protection	Hard structures, e.g., dykes, seawalls, breakwaters Soft options, e.g., beach nourishment, wetlands, vegetation strips, allow beaches and salt marshes to migrate inland
Accommodation	Upgrade infrastructure, raise buildings, improve emergency response systems
Retreat or avoidance	Establish setback lines for coastal development from the landward limit of coastal features

In coastal zone management, these options should be considered in combination and at a local level where public outreach and community engagement are critical. Response options should be adapted to the resource being considered. For heritage resources, for example, increased documentation is an option for areas where extensive protection is not practical. The planning process should be informed by science on

an ongoing basis and should take into account the following points regarding local scientific data in Nova Scotia:

- Mapping of flooding hazards associated with rising sea levels requires high-resolution topography, which is not available from current provincial elevation maps. Airborne laser altimetry (LiDAR) surveys, in conjunction with estimates of future extreme water levels, are one of the tools available to produce flooding risk maps for low-lying areas;
- Data gaps with respect to ground elevations and historical erosion rates should be further addressed to inform the planning process; and
- Existing data on coastal risks, e.g., elevations related to water levels, erosion rates and wave climate, are presently disseminated across various government levels and universities. The process of collecting these data and making them publicly available would be enhanced if one central agency was mandated with the responsibility.

As awareness of the threats increases, more initiatives are being conducted and more data are being collected. There is, however, no single coordinating agency responsible for collecting and maintaining data on coastal hazards such as surge return periods and flood maps, so studies are presently done on a voluntary basis when funds can be obtained. To be useful, these data have to be publicly available (to municipalities, property owners, insurance companies, etc.) from a central archival site or website.

Data gaps

- High-resolution topography for flood mapping;
- Local erosion rates and geology;
- Socio-economic value of exposed property, infrastructure and natural systems; and
- Uncertainties in rates of land subsidence and relative sea level rise.

Additional limitations

- Existing data on coastal risks disseminated across government levels and universities, not easily accessible by public; and
- No government entity presently mandated to study coastal risks or do flood-mapping.

7.7 References

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