Planning for Climate Change in the Town of Lunenburg, NS

Photo Credit:
Justin Forbes and Jacqueline Wightman, February 2013

Inventory of the Built Environment at Risk to Sea Level Rise and Storm Surge

By Justin Forbes and Jacqueline Wightman
Honours Students, School of Planning, Dalhousie University
Prepared for the Bluenose Coastal Action Foundation
April 8th, 2013

Executive Summary

This report discusses projected long-term impacts of climate change, particularly sea-level rise and storm surge, on the Town of Lunenburg's physical infrastructure. The purpose of this report is to assess the vulnerability of the Town of Lunenburg to sea level rise and future storm surges for the near and long term, and to provide recommendations for adaptation to climate change. The 2010-2014 Gas Tax Agreement and the Municipal Funding Agreements requires municipalities to prepare and submit a Municipal Climate Change Action Plan (MCCAP) to Service Nova Scotia and Municipal Relations. This report should serve as a tool to help the Town of Lunenburg prepare its MCCAP.

We collected an inventory of the natural and built environment for analysis in a Geographic Information System (GIS). We undertook site visits as necessary to obtain a more thorough understanding of the Town. We used a multi-criteria approach to develop a vulnerability matrix that considers elevation, slope, vegetation cover, and geology. Each natural feature received a score based on susceptibility to erosion. The result was a map of areas susceptible to erosion. We developed sea level rise and storm surge scenarios for years 2025 and 2100 for the Town of Lunenburg based on Richards and Daigle's (2011) projections. From these scenarios, we created inundation and flood maps, which we overlaid with the susceptibility map to produce a natural environment hazard map. We then compared the water level scenarios with the built environment features to identify vulnerable areas of the Town.

Results of this report indicate that many components of the Town's natural and built environment are vulnerable to projected sea level rise and future storm surge. We developed a set of recommendations for how the Town can begin to adapt to future sea level rise. Finally, we identified relevant planning policies of the Town, and compared these to contemporary adaptation strategies for coastal communities and regions vulnerable to the effects of climate change.

Table of Contents

1.0 Introduction

The planet's climates are changing rapidly due to anthropogenic contributions to global warming. Global climate change affects local communities in different ways. With 7600 kilometres of coastline (Pinfold, 2012), one of the most significant environmental concerns for Nova Scotia is the increased rate of sea level rise due to global warming.

Sea level rise will have profound impacts on coastal communities throughout Nova Scotia. With sea level rise comes coastal erosion and inundation, and increased storm surge extents. Greater storm surge extents may result in runoff and drainage issues, localized flooding, and washout and erosion (Fisher, 2011, p. 6). Hazards such as saltwater intrusion, contamination of groundwater reserves, and building and infrastructure flooding will become more prevalent. These hazards can cause public safety concerns, as well as damage to personal and public property, with economic implications (Fisher, 2011, p.6). However, with adequate preparation, planning, and investment, municipalities can lessen the impacts of sea level rise and storm surges on susceptible communities.

In order to plan for climate change, municipalities must understand the potential risks associated with climate change in their local communities. The Intergovernmental Panel on Climate Change (IPCC) prepares an assessment report every few years that summarizes the latest research on climate change science, impacts, and adaptation strategies (IPCC, 2007). However, the IPCC looks at climate change on a global level, and outlines general impacts for broad geographic regions using research obtained from global climate models. Therefore, Richards and Daigle (2011) downscaled these global climate models in order to determine local impacts for municipalities in Nova Scotia and Prince Edward Island. For this report, we used the projections developed by Richards and Daigle (2011) in order to create and map sea level rise and storm surge scenarios for the Town of Lunenburg. By identifying vulnerable buildings and infrastructure, this report provides information on where the Town should focus adaptation measures.

The Town of Lunenburg is a picturesque historic town in southwestern Nova Scotia (see Appendix B for Context Map). Its vibrant economy has depended on the waterfront for over two hundred years, with the Town's main industries based on fishing, shipping, and ocean-based commerce. Beautiful historic buildings line the waterfront, and houses, churches and public buildings from the late 1700s and early 1800s are well preserved and in use in the Town today. Old Town Lunenburg is the best surviving example of a planned British colonial settlement in North America, and was therefore designated as a UNESCO World Heritage Site in 1995 (Town of Lunenburg, 2013).

Unfortunately, due to its coastal location, the Town of Lunenburg is vulnerable to sea level rise and storm surge. Buildings and infrastructure in both Old Town and New Town will be increasingly impacted by sea level rise and storm surges in the next several years. The Town must therefore understand and plan for these impacts in order to continue to preserve its cultural and natural heritage. This report illustrates the sections of the Town particularly susceptible to future sea level rise and storm surges, and identifies buildings and infrastructure at risk in order to help the Town plan for climate change.

Goal

To assess the vulnerability of the Town of Lunenburg's built environment to sea level rise and future storm surges for the near and long term, and to provide recommendations for adaptation to climate change.

Objectives

- Create scenarios for sea level rise and storm surge for years 2025 and 2100 for Lunenburg based on the most current and best available local climate change projections (estimated by Richard and Daigle, 2011).
- Compile an inventory of the natural and built environment features in the Town of Lunenburg.
- Identify areas likely to be exposed to climate change impacts through an analysis of the natural features of the Town, including elevation, slope, vegetation cover, and geology.
- Predict the impacts of future coastal change and flooding on current infrastructure and built features in the Town.
- Establish recommendations for how the Town of Lunenburg can begin to adapt to future sea level rise and storm surge projections.

Scope and Limitations

This study assesses the effects of future sea level rise and storm surges on the Town of Lunenburg's built environment. The area of study is bounded by the Town boundary (see Appendix B).

This project is limited by the climate change and sea level rise projections currently available. Richards and Daigle's (2011) report contains the best local climate change projections to date; however, municipalities should be aware that future climate change impacts is a topic of ongoing study. As more research becomes available, these local projections may change. Also, scientists have tended to underestimate climate change impacts thus far, so municipalities should plan for the most extreme scenario. We therefore adopted the upper bound of Richards and Daigle's sea level rise and storm surge projections for this study.

Geomorphological factors play an important role in coastal change. Both sea level rise and coastal erosion and deposition from wave and wind action will alter the shape of the coast. These natural phenomena will increase the susceptibility of parts of the Town to coastal inundation and flooding. We accounted for some geomorphological factors by analyzing the slope, vegetation cover, and geology of the area. However, we could not accurately predict geomorphological changes with the available data. We therefore conducted a linear assessment of the shifting coastline landwards based on local sea level projections, but these scenarios do not account for the non-linear coastal processes that will occur in the hundred-year time frame.

Vulnerability to climate change depends not only on the distribution of built structures, but also on the socioeconomic trends within a community. Climate change impacts may negatively impact certain group of people more than others, due to the inability of some groups to adapt to climate change and recover from damages. Our report does not look at the socio-economic vulnerability of Lunenburg; further research into this area is required.

Limitations with the natural and built environment data may have contributed to errors in the study; these are discussed in Section 3.0.

2.0 Background

The Town of Lunenburg

Lunenburg’s waterfront has evolved over the years, but has remained essential to the economy of the Town and region. The waterfront was important for the shipbuilding and fishing industries that dominated Lunenburg’s economy for two hundred years, and is vital to the tourism sector today. Damage to Lunenburg’s waterfront properties due to the effects of climate change will have profound impacts for the community, since the town depends on its waterfront for economic prosperity and social wellbeing. This section explores the history of Lunenburg in order to give context to the town’s current built environment and how it will be affected by climate change.

The Town of Lunenburg was established in 1753 and was the first British Colonial settlement in Nova Scotia outside Halifax (Town of Lunenburg, 2013). It was the first Canadian community of German Ancestry (Sarty, 1953), and was named in honour of King George the II, Duke of Brunschweig-Lunenburg. The British Military oversaw the settlement of “foreign Protestants,” which included settlers from Germany, Switzerland, and France who were promised free land in the New World (Town of Lunenburg, 2013). A group of gentlemen old enough to qualify as landowners gathered in St. Paul’s Church and drew for lots in the new community. Each card was marked with the number and division name for a plot of land within Lunenburg.

The Town was planned in a rectangular grid pattern, and this original layout remains today in what is known as the “Old Town” section of Lunenburg (Lunenburg Board of Trade, 2009). Later on, in 1862, the Town began to outgrow its boundaries, and parts of the surrounding land were subdivided to facilitate the expansion. Further west, an area known as “New Town” was subdivided and eventually populated with wealthy merchants and professionals (Town of Lunenburg, 2013).

Early industries in the Town were farming, fishing, shipbuilding, and ocean-based commerce (Lunenburg Board of Trade, 2009). Although the Town first made its livelihood through lumbering and farming, by the end of the 18th century, Lunenburg became a prominent fishing town. By 1786, the town had a number of small vessels employed in cod fisheries (Sarty, 1953). In 1789, Zwicker & Company started business in the fishing industry, and became one of the largest exporters of fish in Canada (Sarty, 1953). Zwicker & Company is considered the “granddaddy” of Lunenburg’s waterfront business, since it was in business continuously for nearly 200 years, exporting lumber and fish (Allen, n.d.).

Lunenburg was granted ‘free port’ status in 1839, meaning Lunenburg’s port was open to all traders. However, it was in competition with Halifax, a free port with larger and more numerous firms. During the Victorian Era (1837 - 1901), Lunenburg experienced a commercial depression. The Town’s marine insurance business collapsed during this time (Town of Lunenburg, 2013). However, expansion of the fishing industry continued into the 20th century. The 1920s and 1930s were known as the Bluenose Era in the Age of Sail, and the waterfront was filled with fish drying flakes. In the 1940s the salt fishery declined, and frozen and processed fish production grew. During World War II, ship repairing and outfitting were important sectors of the waterfront industry (Lunenburg Board of Trade, 2009).

Today, Lunenburg's established industries include High Liner Foods Inc., one of the largest fish processing plants in North America. Other industries include Lunenburg Industrial Foundry & Engineering Ltd., founded in 1891; Adams & Nickle; Clearwater Seafoods Ltd; ABCO Industries Ltd., founded in 1947; and Lunenburg Marine Railway (Town of Lunenburg, 2013).

Old Town Lunenburg was designated as a National Historic District in 1992, and as a World Heritage Site by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) in 1995: "nearly 250 years after its streets were first laid, the original plans, the architecture and the uses for common spaces remain intact" (Town of Lunenburg, 2013).

Current Statistics

The statistics discussed in this section were taken from the Nova Scotia Community Counts web page, which models data from Statistics Canada, Census of Population, 2001, 2006, and 2011. This section gives a brief outlook of the current demographic and socio-economic conditions in the Town of Lunenburg.

The population of the Town of Lunenburg was 5057 people in 2011, which was 6.4% lower than in 2001. This was a significant decline as compared to the rest of Nova Scotia: the province's population increased by 1.5% from 2001 to 2011. The Town also has an aging population; in 2011, 16.6% of the population was under the age of 20, while 27.2% was aged 65 years or older.

Based on the 2006 Census of Population, the median and average income for individuals in Lunenburg is slightly below the median and average for all of Nova Scotia. About three quarters of the population of Lunenburg holds a post-secondary certificate, diploma, or degree – slightly less than the average for the Province.

The employment rate for Lunenburg residents aged 25 and over increased by 1.3% from 1996 to 2006, but there were 54 fewer employed workers – meaning that the population also declined in this time period. The employment rate was 48% in 2006. The employment rate for residents aged 15-24 years increased by 20.9% to 52.8% between 1996 and 2006, and there were 95 more employed workers.

From 2001 to 2011, total census families decreased by 6.4%. Married families decreased by 7.6%, while common law families increased 36.2% and lone-parent families decreased 36.2%.

About 80% of the dwellings in Lunenburg are owned, while 20% are rented. In 2006, 35% of dwellings required repairs. The average value of dwellings in Lunenburg increased by 115% between 1996 and 2006, while the average value of dwellings in all of Nova Scotia increased by 83% in the same time period.

Lunenburg has a declining and aging population, but a stable economy primarily based on tourism today.

Climate Change

The Earth's climate is constantly changing. Research has determined that for the past three million years, the Earth has experienced periods of warming and cooling due to changes in the tilt of the Earth's axis, changes in CO2 levels due to tectonic activity, and variations in the energy output of the Sun (IPCC, 2007, The Physical Science Basis).

Although the Earth's climate naturally changes over long time periods, the present concern is due to an increase in the rate of change. There is now scientific consensus that human emissions of greenhouse gases are causing a warming effect of the planet. Thus, global average temperature is expected to increase due to both natural and anthropogenic radiative forcing. Radiative forcing "is the measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system" (IPCC, 2007, Synthesis Report, p. 36). The main factor contributing to global warming is an increase in anthropogenic carbon dioxide emissions (IPCC, 2007, Synthesis Report, p. 39), which is causing the Earth's climate to change rapidly relative to the natural climatic fluxes, forcing changes in all human and natural systems. Many species on Earth, including humans, may have difficulty adapting to a warmer global temperature due to the rate of climate change.

As natural systems evolve in response to global warming, humans are faced with new - or more extreme - environmental hazards. Climatic extremes such as extremely hot days or extremely cold days, droughts, and intense rainfalls, for example, are expected to occur more frequently and be more extreme as average global temperature increases.

One of the hazardous environmental phenomena faced by Nova Scotia is sea level rise. Global sea level has been slowly rising since the end of the last ice age due to the thermal expansion of the oceans, the melting of nonpolar glaciers, and changes in the volume of the ice sheets of West Antarctica and Greenland (Richards and Daigle, 2011, p. 19). In the past 135 years, global sea level has risen about 0.2 metres (Church & White, 2006); however, due to anthropogenic global warming, sea level is rising at an increasing rate. As the warming ocean expands and glaciers and ice caps melt into the sea, coastal communities are increasingly faced with the threats of inundation, storm surge flooding, and coastal erosion.

Not only has global sea level been rising since the end of the last ice age, but Nova Scotia has also been slowly sinking due to the isostatic rebound of the Earth's crust. When the glaciers retreated, a weight was lifted off of the province, and it "bounced" upwards. Now, it is in the process of settling back down - a process known as crustal subsidence. The combined effects of global sea level rise and crustal subsidence determine local sea level rise.

The Intergovernmental Panel on Climate Change (IPCC) estimates that due to anthropogenic global warming, the average global sea level could increase by about half a meter over the next century (IPCC, 2007, Synthesis Report, p. 23). However, a more recent study by Rahmstorf (2007) showed that sea-level rise observations from 1990 are tracking above the upper limit given in the latest IPCC report. Rahmstorf (2007) projects that global sea level could increase by greater than one metre by 2100. Based on

Rahmstorf's global estimate, Richards and Daigle (2011) state that local, or "relative" sea level in the Town of Lunenburg is expected to rise by 0.9 metres by year 2100.

Areas of the coast will be permanently inundated due to sea level rise. Of greater concern, however, are the impacts associated with a higher possible storm surge. With local sea level higher, storm surges will reach further inland and could flood areas of the Town of Lunenburg that have not been at risk of flooding in the past. In addition, storms may become more frequent and intense due to climate change, which means that the likelihood of a disastrous storm surge increases.

While a number of hazards will be more likely to occur in the Town of Lunenburg due to climate change, this report focuses on the hazards associated with sea level rise and storm surge. We provide information on which areas of the Town will likely be affected by coastal inundation or an extreme storm surge, and illustrate the locations of infrastructure, buildings, and other community assets that may be at risk. We conclude by recommending adaptation measures that should be taken in order to prepare for possible sea level rise and storm surge scenarios.

Local Sea Level Rise and Storm Surge Projections

Regional sea level rise depends on local coastline variations, changes in currents, vertical land movements, differences in tidal patterns, as well as global sea level rise (Fisher, 2011, p. 7). Local coastline variations and changes in currents are difficult to predict, but an estimate of local sea level rise can be obtained by taking into account crustal subsidence rates and global sea level rise. Richards and Daigle (2011) provide the best estimate for local sea level rise for the Town of Lunenburg. Their report provides local sea level rise projections for the years 2025, 2055, 2085, and 2100 based on Rahmstorf's (2007) global sea level rise projections as well as the local crustal subsidence rates calculated by Forbes et al. (2009).

Table 1: Estimate of anticipated changes in total sea level for the years 2025, 2055, 2085, and 2100 for the Town of Lunenburg (Richards and Daigle, 2011, p. 28)

Global SLR (2100)	**Crustal Subsidence (2100)**	**Total Change (2025)**	**Total Change (2055)**	**Total Change (2085)**	**Total Change (2100)**
0.9 +/- 0.43	0.16 +/- 0.05	0.15 +/- 0.03	0.43 +/- 0.14	0.83 +/- 0.36	1.06 +/- 0.48

Richards and Daigle (2011) also provide estimates for future storm surges for the Town of Lunenburg, based on return periods calculated from the Halifax tide gauge. "A storm surge can be defined at the coast as the difference between the observed water level and the predicted astronomical tide" (Richards and Daigle, 2011, p. 22). The storm surge projections in Table 2 represent flooding scenarios resulting from the simultaneous occurrence of a significant storm-surge event for the respective return-periods, and the highest astronomical tide possible, or "Higher High Water at Large Tide" (HHWLT)[1].

---

[1] Richards and Daigle present water levels in Chart Datum (CD), "defined to be close to the lower low-water at large tides." However, GIS applications use a geodetic reference level (CGVD28), requiring a conversion between CD to CGVD28 that is

Table 2: Lunenburg, HHWLT 1.63 m (CGVD28), Return period levels estimated as per Halifax tide gauge (Richards and Daigle, 2011, p. 68)

Return Period	**Level 2000**	**Level 2025**	**Level 2055**	**Level 2085**	**Level 2100**
10-Year	2.34 +/- 0.2	2.49 +/- 0.23	2.77 +/- 0.35	3.17 +/- 0.56	3.4 +/- 0.68
25-Year	2.44 +/- 0.20	2.59 +/- 0.23	2.87 +/- 0.35	3.27 +/- 0.56	3.5 +/- 0.68
50-Year	2.51 +/- 0.2	2.66 +/- 0.23	2.93 +/- 0.35	3.34 +/- 0.56	3.57 +/- 0.68
100-Year	2.58 +/- 0.2	2.73 +/- 0.23	3.0 +/- 0.35	3.41 +/- 0.56	3.64 +/- 0.68

The precautionary principle states that we have a duty to prevent harm, when it is within our power to do so, even when all the evidence is not in (Canadian Environmental Law Association, 2012). In keeping with this principle, municipalities should plan for the worst possible storm surge scenario. Critchley et al. (2012) noted that a storm surge occurring at the same time as the highest possible astronomical tide has a low probability of occurring. However, using the worst-case scenario for planning purposes is the only way to avoid the impacts of any storm event. Also, with increasing frequency of intense storms due to climate change, the probability of a benchmark storm occurring again is increasing (IPCC, 2007, Synthesis Report, p. 46).

Richards and Daigle (2011) calculated upper bound water levels for Lunenburg by taking the sum of the upper limit of global sea level rise, local crustal subsidence rates, the HHWLT, and the highest storm surge previously recorded to date. The highest storm surge to date was 1.63 metres, during Hurricane Juan. The plausible upper bound water level for Lunenburg is 4.8 metres, shown in Table 3.

Table 3: Plausible Upper Bound Water Level in Lunenburg for Year 2100 calculated as the sum of: current HHWLT, predicted sea-level rise plus error bar, and the maximum storm surge recorded to date (Richards and Daigle, 2011, p. 78)

HHWLT (m) (CGVD28)	**Sea-Level Rise (2100) + Error Bar (m)**	**Maximum Storm Surge to Date (m)**	**Plausible Upper Bound Water Level (m) by Year 2100**
1.63	1.54	1.63	4.8

Vulnerability

We conducted this study in order to determine the vulnerability of the Town of Lunenburg's built environment to the effects of climate change. The concept of vulnerability in the context of climate change is best described by the IPCC:

> "Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse affects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity." (2007: Summary for Policy Makers, p. 21)

---

specific to each location (Richards and Daigle, 2011, p. 25). We converted Richards and Daigle's (2011) water level projections from CD to CGVD28 by subtracting 0.8 metres.

Vulnerability is thus determined by three factors: exposure, sensitivity, and adaptive capacity. We were able to analyze the exposure and sensitivity of the Town of Lunenburg to sea level rise and storm surge; however, we did not have the resources available to assess adaptive capacity in this study.

Balica et al. (2012) describes exposure as the values that are present at a location where a flood can occur, such as goods, infrastructure, agricultural fields, and people. To determine the amount of exposure to future climate change impacts that Lunenburg will face, we developed sea level rise and storm surge scenarios utilizing Richards and Daigle's (2011) downscaled local climate projections, and then mapped each scenario using a Geographic Information System.

Sensitivity is the degree to which a system is affected by a stimulus; it is the biophysical effect of climate change that can be altered by socioeconomic changes (Know Climate Change, 2013). We assessed the sensitivity of the town by analyzing the physical conditions of the coastal area, including susceptible to erosion, as well as the locations of infrastructure and important buildings in relation to the flood zones. The vulnerability analysis stage is explained in detail in Section 3.

Adaptive capacity is the ability of a system to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2007, Summary for Policy Makers, p. 21). It is influenced by social, economic, and institutional factors specific to each location (Lemmen et al., 2008). For example, attributes that would increase adaptive capacity include a large knowledge base regarding climate change issues, and access to technology and other resources. A community with high adaptive capacity is less vulnerable to the effects of climate change. We provide suggestions for adaptation measures that the Town of Lunenburg could take; however, an assessment of the Town's adaptive capacity is required.

3.0 Methods

3.1 Data Collection

We collected an inventory of the built and natural features of the town through site visits, and by compiling and mapping GIS data from the Town of Lunenburg and the Province of Nova Scotia, Department of Natural Resources (DNR).

We used a Digital Elevation Model (DEM) to map the slope and relief of the town in ESRI© ArcMap version 10.0 (a GIS). We also used the DEM to map the sea level rise and flooding scenarios explained in the next section. We used data provided by DRN to map the soils, forest cover, hydrology, and geology of the area.

We mapped the sewer and water utilities, roads, civic addresses, emergency management offices (EMO), and public buildings using data provided by the Town of Lunenburg.

3.2 Scenarios

We mapped sea level rise and flooding scenarios for both the near and long term using a GIS. We chose year 2025 for the short-term scenario (Scenario 1), and 2100 for the long term (Scenario 2). See Table 4 and Figure 1 for the components of each scenario.

Scenario 1A

Scenario 1A represents the projected sea level rise for year 2025, based on Richards and Daigle (2011). It includes the highest possible tide (HHWLT) and an estimate of relative sea level rise for Lunenburg. Relative sea level rise includes global sea level rise by 2025, extrapolated from Rahmstorf's (2007) projections, and crustal subsidence predictions for 2025 from Forbes (2009) calculations. In order to account for a potential acceleration of global sea level, or a possible increase in tidal amplitude, we included the margin of error in our scenarios. The water level for scenario 1A is 1.81metres.

Scenario 1B

Scenario 1B includes the HHWLT, relative sea level rise, as well as the largest storm surge to date, Hurricane Juan. We decided to use the benchmark storm level instead of a storm with a smaller return period in order to ensure that the Town can plan for the worst-case scenario. The water level for scenario 1B is 3.44 metres.

Scenario 2A

Scenario 2A is the projected sea level rise for year 2100, based on Richards and Daigle (2011). It includes the present HHWLT, as well as global sea level rise and crustal subsidence for year 2100. The water level for scenario 2A is 3.17 metres.

Scenario 2B

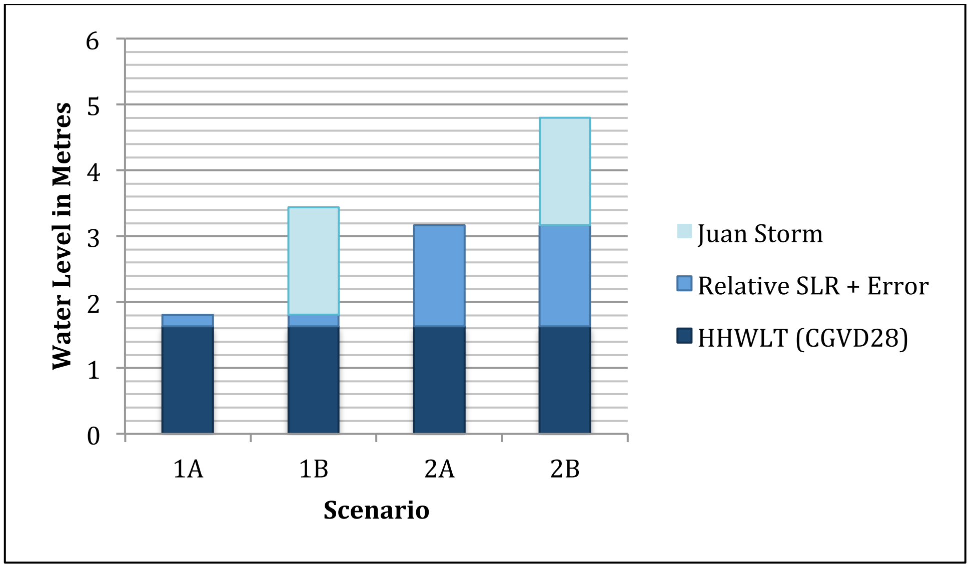
Scenario 2B includes the projected sea level rise for year 2100 and the benchmark storm surge. The water level for scenario 2B is 4.8 metres.

Table 4 and Figure 1 below shows the components and total water level for each scenario.

Table 4: Sea Level Rise and Storm Surge Scenarios for Years 2025 and 2100 (adapted from Richards and Daigle, 2011)

Year 2025 Scenarios	HHWLT (CGVD28)	SLR + Subsidence (+/-0.03)	Benchmark Storm: Hurricane Juan	Total (m)
1A: Sea Level Rise	1.63	0.15 + 0.03		**1.81**
1B: Storm Surge	1.63	0.15 + 0.03	1.63	**3.44**
Year 2100 Scenarios	HHWLT (CGVD28)	SLR + Subsidence (+/-0.48)	Benchmark Storm: Hurricane Juan	Total (m)
2A: Sea Level Rise	1.63	1.06 + 0.48		**3.17**
2B: Storm Surge	1.63	1.06 + 0.48	1.63	**4.8**

Figure 1: Components of Water Level Scenarios for Years 2055 and 2100 (adapted from Richards and Daigle, 2011)



3.3 Hazard Mapping

The inventory stage provided the framework necessary to identify areas susceptible to erosion. We considered multiple criteria when identifying areas susceptible to erosion. The multi-criteria approach considered elevation, slope, vegetation cover, and geology to develop an environmental hazard matrix to identify areas susceptible to erosion. We developed a natural hazard matrix consisting of environmental attributes and their corresponding erosion potential (see Table 5).

Table 5: Natural Environment Hazard Matrix

Scenarios	**Elevation**			
1A	**1.81m**			Land below this elevation will be inundated.
2A	**3.17m**			
1B	**3.44m**			Environmental attributes within flood plain were assessed for erosion potential
2B	**4.8m**			
Environmental Attribute	**Erosion Potential**			**Rationale**
	Low	**Med.**	**High**	
Slope				
Slope 0 – 15%	0			Slope has a direct influence on coastal erosion. The steeper the slope, the more susceptible it is to erosion.
Slope >15 – 25%		1		
Slope > 25%			2	
Geology				
Silty Drumlin			2	Surficial geology types have varied sediment sizes and can erode at different rates. Silty drumlin has higher erosion potential as the till is finer and thicker relative to the other surficial geologies.
Silty Till Plain		1		
Stony Till Plain		1		
Vegetation				
Barren			2	Areas lacking vegetation along coast have high rates of wind erosion. Forested areas act as a barrier to wind flow resulting in less erosion due to wind action.
Vegetated		1		
Developed	0			

We selected each environmental attribute and assigned an appropriate erosion potential score (low, medium, or high). Each environmental attribute was overlaid and the summation of the corresponding scores gave a total erosion potential score. We then divided the total erosion potential score by the maximum possible score to normalize the total natural hazard score. The total natural hazard score can be understood by the following equation:

$$Total\ natural\ hazard\ score = \frac{\sum S + \sum G + \sum V}{\sum EA}$$

Where $\sum S$ is the sum of the slope hazard score, $\sum G$ is the sum of the geology hazard score, $\sum V$ is the sum of the vegetation hazard score, and $\sum EA$ is the sum of all environmental attribute hazard scores.

3.4 Vulnerability Assessment

We used information collected in the inventory stage for the vulnerability assessment, which identified built environment features along the Town's coast that will be affected by sea level rise and storm surge.

To complete the built environment vulnerability assessment, we used overlay mapping. We intersected the physical infrastructure and land use data with the sea level rise and storm surge water levels to identify features that will be affected. The analysis focused on several features of the built environment and sea level rise and storm surge scenarios for years 2025 and 2100. Maps in Appendix H show features of the built environment affected by sea level rise and storm surge for the Town. We developed a built environment vulnerability table to summarize what features of the built environment will be affected in each scenario (see Appendix I).

The information collected in the 2025 year built environment vulnerability analysis can be utilized by the town for planning purposes to prioritize infrastructure renewal and consider relocating projects based on vulnerability to sea level rise and storm surge. The long-term vulnerability assessment should be considered for future land use development patterns and implementation of major infrastructure projects.

3.5 Data Limitations and Error

Spatial data is an extracted representation of the real world. It is impossible to perform error free spatial analysis due to the inherent weaknesses with accuracy tied to data representation. It was our continuous goal to reduce error as much as possible so that it did not interfere with the conclusions drawn from our findings. Mapping accuracy and precision are two issues that must always be considered in spatial data analysis. It is to our knowledge that the data provided for this project is up-to-date, accurate and the best information available. That said, accuracy cannot be guaranteed.

Throughout our analyses, the built and natural environment is represented as points, lines, and polygons. There may be issues associated with the representation of data. Data is represented as a simplification of reality, which must be taken into consideration when using the findings of this report for planning, policy, and decision-making. For example, some buildings are represented by points, while others are represented by polygons of the building footprints. Building points may not coincide with the actual center point of the building in reality. It is possible that a building could experience inundation because the point representing the building is within the flood line in reality, even though the data shows that the building is outside the flood area. Similar issues can be applied to road data. Roads are represented by lines and do not take into account the true width of the road. It is possible that some roads could be affected that are not identified in our assessment.

4.0 Inventory

The information gathered in the inventory will provide the Town with a foundation from which to identify resources, both natural and built, that are at risk to sea level rise and storm surge. We gathered baseline information about the relief, slope, geology, soils, forest cover, and hydrology of the area (Appendix C). The natural environment inventory helped us identify areas that will likely be inundated or flooded in the future due to sea level rise, and parts of the coast that may be more vulnerable to erosion. The Town provided us with roads, buildings, parcels, zoning, and utilities data, which we mapped (see Appendix D) in order to determine infrastructure at risk to flooding and sea level rise in the analysis section. Both the natural and built environment inventories were used to conduct the hazard mapping and vulnerability assessment in Section 5.

4.1 Natural Environment

Relief

A LiDAR digital elevation model (DEM) was used to generate the relief map (Appendix C). The relief map shows the range in elevation of the Town of Lunenburg. This information is essential to determine which areas are more at risk of flooding. Lands that have a lower elevation are more likely to be affected by sea level rise and storm surge. The highest elevations are generally found in the northwest area of the town. Areas along the coast are generally low lying and do not contain areas of high elevations.

Old Town features many high elevations, some exceeding 50 meters, while New Town is generally low lying at 10 meters elevation. Powerful storm waves increase the risk of storm surges putting low-lying coastal areas at risk of flooding. This means that areas which have experienced flooding could potentially experience these floods more frequently, and areas previously safe from flooding could now be at risk. Sea level rise may also increase the risk of salinization to groundwater in low-lying areas and threaten the viability of freshwater coastal aquifers (The Road Ahead - Adapting to Climate Change in Atlantic Canada, 2003).

Slope

Slope has a direct influence on coastal erosion; the steeper the slope, the more likely it is to erode. Similar to the elevation map, the slope map (Appendix C) was created using the DEM and shows the slope percent rise, from flat areas (0-3%) to those considered very steep (>25%). The coastal area of Old Town has many areas of very steep slope rising up from the harbour, while the coastal area of New Town is composed of flat to shallow terrain. During events of heavy precipitation or wave action, steep coastal slopes become more susceptible to erosion. Back Harbour is affronted by areas of steep slopes, as is Puffeycup Cove.

Bedrock Geology

Bedrock is the foundation geologic component of the environment that is typically covered by surficial geology, which is then covered by soil. Bedrock erodibility is influenced primarily by the compositions of physical and chemical attributes as well as the relative hardness of the composition. Bedrock erodes more quickly when made up of soft, chemically unstable material, while bedrock composed of hard, stable materials is more resistant and weathers more slowly.

The town is situated upon a Cunard bedrock formation (Figure 2). This bedrock type is composed of black, finely laminated slates, as well as a type of quartzite inter-bedded with fine-grained siltstone and sandstone called metasiltstone (Maritime Testing Limited, 2011). The Cunard bedrock formation of the area is soft and weathers relatively easily. An inventory map for bedrock geology was not produced as the most detailed data identifies the entire town to be situated upon the Cunard formation.

Figure 2: Outcrop of Cunard Unit slate and metasiltsone. Inset: fresh sulphide in hand sample (Goodwin, 2004).

Surficial Geology

The surficial geology overlying the Cunard bedrock formation is representative of Nova Scotia's glacial history and material released from the base of an ice sheet through melting. The three surficial geology types found in the Town are silty drumlin, silty till plain, and stony till plain (Appendix C). Till plain surficial geology types are generally located in flat areas, and silty drumlin is found on drumlins. Both surficial types are considered highly erodible and were considered in the assessment of natural environment hazard mapping for the Town (see Table 5 in Section 3.3).

Soil

Soil types are derived from the underlying parent material that is physically altered by erosion and weathering. The Town is predominately covered with Wolfville soil, but also contains Bridgewater soils along the coast (Appendix C). Wolfville soil is moderately permeable by water and surface drainage is good; this soil is thus well drained (Cann and Hilchey, 1958). It is also one of the best agricultural soils in the area. Bridgewater soil is developed from medium texture parent materials of loam till derived from slates (Hilchey et al., 1991). Soils are highly erodible, but do not have a major influence on vulnerability, as surficial formations are a better indicator of erodibility.

Forest Cover

The forest cover of the landscape influences the rate of erosion, because forested areas provide better surface stability. Thus, barren coastal areas will be more susceptible to erosion from wave and wind action than forested areas. Much of the Town's coastline is not forested as a result of relatively extensive development. The scarce forest cover that exists on the coast (on the south side of the Bluenose Golf Club) is predominately mixedwood forest with assemblages of softwood forest.

Hydrology

The Town does not feature any major coastal streams, lakes, or rivers. Much of the land in the New Town area is characterized by a relatively shallow water table water table (0-2m). Comparatively, the water table depth in Old Town is extremely deep (>10 m) (Appendix C). Saltwater intrusion is a potential hazard that could occur due to sea level rise, and could lead to contamination of drinking water supplies. More research is necessary in regards to the potential for saltwater intrusion, as this area was outside the scope of our project. Saltwater intrusion can be worsened in the event of an extreme storm surge, so the Town should note the locations of wells in relation to the potential storm surges (mapped in Appendix E) and conduct an assessment accordingly.

4.2 Built Environment

The built environment includes the man-made physical components of the Town. These components include roads and bridges, infrastructure, and public and residential buildings. Information is this section is based on site visits and digital data provided by the Town of Lunenburg. We mapped the roads and building points, emergency management offices and other buildings, property parcels, sewer and water utilities, and the Town zoning (see Appendix D). This section describes some key information about each aspect of the built environment as it relates to potential climate change vulnerability.

Roads

There is approximately 42.1 km of roads located in the Town (see Appendix D). The roads data includes highways, major streets, and secondary streets. Old Town is based on a rectangular grid pattern. Roads are an important component of the inventory as they provide the foundation on which people in the town travel. Road infrastructure is also important when considering EMO services in the event of an emergency situation or evacuation. Several major streets in the Town are located parallel to the coastline which are vulnerable to flooding. In addition to coastal neighboring roads, many residential streets in the New Town area are low lying and are also considered vulnerable.

Buildings

The majority of GIS data for buildings in the Town consists of point data. Many buildings are represented by the center point of the building structure and therefore size and dimensions of the buildings are not available. Some data is available for other buildings and is represented by polygons. Notable buildings located close to the coast include the Fisheries Museum of the Atlantic, Lunenburg Foundry and Engineering Ltd., the Lunenburg Community Center and Area, and the Bluenose Academy (Appendix D). There is also a dense area of building points located along the coastline of Old Town within the Heritage Conservation District.

Sewer and Water Utilities

Sewer and water utilities underlie most major roads (Appendix D). Vulnerability of this infrastructure will increase when their access is restricted in the event of a flood. Utility lines located close to the coast will be subject to erosion, sea level rise, and storms surge. Several fire hydrants vital for emergency use are located in close proximity to the coast. Although manhole and storm water drain data was not available, they can be considered at risk of flooding and inundation when located within the sea level rise and flood scenarios.

The Town of Lunenburg water supply comes from Dares Lake, located 4.8 km northwest of the Town center. Water is pumped to an open reservoir in Lilydale at an elevation of 66 meters, and this 3.02 million liter reservoir feeds water by gravity pressure throughout the town. Water treatment involves liming and chlorination.

With the exception of Centennial Avenue and Victoria Road, storm and sanitary sewers are combined and sewage that is collected is discharged untreated into the Front Harbor through outfalls. Tannery Road and Old Town waterfront have a number of private sewers that discharge into the harbor at several points shown in Appendix D.

Zoning

The town has a wide variety of zoned land (Appendix D) allowing commercial, institutional, residential, industrial, recreational, and tourism uses. The areas located immediate to the coast are mostly designated for marine industrial, open shoreline, recreation, and tourism marine land uses, but slightly further inland there are areas designated as various residential zoning types. Of particular importance is the way in which important residential and economic zones will be affected by inundation and/or flooding. Zones that allow developments associated with a high level of investment or public importance to occur in a potential flood zone should be amended to prepare for climate change. The zoning implications in terms of adaptation to sea level rise are further explored in the vulnerability analysis (section 5) and policy review (section 7).

5.0 Vulnerability Analysis

This section presents the results of the hazard mapping and vulnerability assessment described in the Methods (sections 3.3 and 3.4). Appendix E shows the extent of future sea level rise and flooding in the Town of Lunenburg for the years 2025 and 2100 with an aerial photo as the base for each map. Appendix F contains the hazard maps for years 2025 and 2100, which take into account sea level rise and erosion potential within the future flood projection. Appendix G is the Scenario Map, which illustrates all of the scenarios on one map, and was used to generate the Vulnerability Maps in Appendix H.

5.1 Natural Environment Hazard Assessment

When considering sea level rise and storm surge, it is important to consider areas susceptible to erosion as rates of erosion can be exacerbated by their affects. To identify areas susceptible to erosion, we considered multiple criteria through an environmental hazard matrix that was informed by the inventory findings and research. We produced the natural environment hazard maps in Appendix F.

Much of the coastal development is underlain by silty drumlin, which is easily eroded. Areas of steep slopes are particularly vulnerable to erosion, effects of which are exacerbated when paired with easily erodible soils. Areas which are not vegetated or forested are also vulnerable to erosive processes. The majority of the immediate coastline has a medium to high erosion potential score while areas further inland have erosion potential that is generally lower on average. Although inland areas received lower erosion potential scores, many of these areas are low in elevation, and could also be exposed to wave action in storm surge situations, making their natural environmental elements even more vulnerable to erosive processes. High erosion potential areas are areas that may experience exacerbated effects of sea level rise and storm surge, including increased erosion and coastline degradation with increased storm activity and rising sea level.

Areas susceptible to erosion within the 2025 storm surge scenario mainly lie in the New Town coastal area. Most of the area is considered low erosion potential but is does contain areas with medium and high erosion potential. The south-facing coast of the Bluenose Golf Course has the highest erosion potential area, which is attributed to steep slopes and easily erodible surficial materials. Coastal areas south of Burma Road contain significant areas of medium erosion potential. Erodible surficial geologies and steep slopes contribute to the high erosion potential on the north facing coast of Back Harbor.

5.2 Built Environment Vulnerability

By combining topographic maps and sea level rise scenarios with the location of major infrastructure, areas with existing developments, land use zoning, roads, and utility corridors, the Town can get a better indication of where climate impacts and hazards may become significant issues which warrant action. The built environment vulnerability maps in Appendix H identify vulnerable parts of the town and the geographical extent of the impact. The findings can be utilized by the town for planning purposes to prioritize infrastructure renewal and consider relocating projects based on vulnerability to sea level rise and storm surge.

The Town of Lunenburg has relied on and will continue to rely on its waterfront industries and infrastructure. Because the Town has developed as a coastal community, much of the Town's utilities, roads, and infrastructure are heavily concentrated along the coast. The Town has already begun to feel the effects of sea level rise and storm surge. This section gives an indication of what the Town can expect in the future in terms of inundation and flooding, and can be used to create an adaptation strategy. The Maps in Appendix H illustrate the extent to which the roads, buildings, property parcels and sewer and water utilities in the Town will be affected by near-term and long-term sea-level rise and storm surges. We also created a map that illustrates each scenario on the present zoning map, which can be used to identify where policy changes need to occur (see section 7.0 for a policy review).

The results of the built environment vulnerability analysis are found in Appendix I. Graphs representing built environment vulnerability by built environment attribute can be found in Appendix K. The results of the built environment vulnerability analysis suggest that the flooding impacts of sea level rise and storm surge will have an effect on some important infrastructure on the coast as early as 2025. The Town will need to set priorities for addressing infrastructure affected by sea level rise and storm surge. The long-term vulnerability assessment should be considered for future land use development patterns and implementation of major infrastructure projects.

Scenario 1: Year 2025 Sea Level Rise and Storm Surge

In the Town, sea level rise by the year 2025 could inundate 2 buildings and 63 Ha of parcel property. The relatively large amount of parcel property is attributed to the fact that many of the parcel boundaries along the coast extend into Lunenburg Harbor. Storm surge flooding could affect 8 buildings including the Fisheries Museum of the Atlantic, Lunenburg Foundry and Engineering Ltd, and the Lunenburg Community Center.

Year 2025 storm surge could affect up to 7.7 additional hectares of property parcels. Roads in the town are not majorly affected by sea level rise inundation but 4,800 meters of road could be affected by storm surge flooding. Roads potentially affected include Victoria Road, Tanyard Road, Lorne Street, Knickle Road, Kissing Bridge Road, Highway 332, Cove Road, Burma Road, Buenavista Court, Brook Street, Bluenose Ave, Tannery Road, and Starr Street.

Inundation and flooding will have an effect on Highway 332, Bluenose Ave, and Burma Road, which may compromise transportation corridors to Old Town and access to the coast. The road running the length west of Lunenburg Harbour is at risk from the impacts of storm surge, which would affect residents of the area. Other infrastructure of concern includes 1.7 kilometers of sewer and water utilities and one hydrant in the flood area.

Zones affected by the 2025 sea-level rise scenario include: commercial shoreline, general commercial, highway commercial, industrial, institutional, marine industrial, open shoreline, residential, recreation, rural residential, and tourism marine. Large portions of lands zoned marine industrial, residential and recreation will potentially be affected in Scenario 1.

Scenario 2: Year 2100 Sea Level Rise and Storm Surge

Sea level rise by the year 2100 will potentially inundate 27 buildings and 19.1 hectares of parcel property, in addition to the buildings and property parcels affected by year 2025 sea level rise. In addition to the 27 affected buildings, projected sea level rise scenarios for year 2100 will affect the Fisheries Museum of the Atlantic and Lunenburg Foundry & Engineering Ltd. Storm surge flooding could inundate 45 additional buildings and will reach, in addition to the previously stated buildings, the Lunenburg Community Center and Arena and to the Bluenose Academy. Year 2100 storm surge could affect an additional 24.1 hectares of parcel property.

Roads in the town will be majorly affected by sea level rise inundation in the year 2100 sea level rise scenario. 6000 meters of road will be affected by sea level rise inundation. 700 meters of road could be affected by storm surge flooding. Roads potentially affected include Green Street, Broad Street, Falkland Street, Archibald Street, and Montague Street in addition to the roads mentioned in the built environment scenario analysis. It is expected that 2.7 kilometers of sewer and water utilities and 4 hydrants will be affected by year 2100 sea level rise. Additionally, 4 kilometers and 9 hydrants could be affected by storm surge.

There are many zoned land uses affected by the 2100 sea-level rise scenario. Similar to the zones affected in Scenario 1, large portions of lands zoned marine industrial, residential and recreation will be affected in Scenario 2.

6.0 Adaptation Strategies

The IPCC identifies three basic adaptation strategies: protect, accommodate, and retreat (Nicholls et al., 2007). We used the work of Boateng (2012) in this section to summarize the advantages and disadvantages of each strategy. We also discuss the various options that the Town should take in adapting to climate change.

The Town should consider the use of protective measures if the cost of **protection** is less than the value of land and the properties that would be lost. However, sea level rise is an increasing threat, so this strategy is most effective as a planned temporary measure. Hard protective measures, such as seawalls, and soft measures, such as beach feeding, both require constant maintenance and monitoring. The protection strategy may be the best option for cultural heritage buildings.

The **retreat** strategy is often used for highly vulnerable coastlines, and involves moving vulnerable populations and infrastructure away from hazardous zones, as well as implementing regulations that prevent development on vulnerable coastal lands and property. This strategy should be used where the cost of protection exceeds the value of vulnerable land and property. The Town should utilize the retreat strategy for currently undeveloped waterfront properties, by applying setback requirements in these areas should any new development occur.

The **accommodation** strategy reduces the risks associated with sea-level rise without the expense of full protection. It involves continuing to occupy the land, but making adjustments as necessary, including redesigning structures by elevating buildings and strengthening foundations. Legislation could be put in place that encourages low-capital investment on vulnerable lands. The main drawback with this strategy is that it does not completely reduce the risk, and could result in future costs to infrastructure and human health if structures are damaged in a storm surge.

Table 6: Advantages and Disadvantages of Sea Level Rise Adaptation Strategies (based on Boateng, 2012)

Strategy	Example	Advantages	Disadvantages
Protect (coastal hardening)	Vancouver Seawall	- Maintains current shoreline - Protects highly valued buildings on the coast	- Requires constant maintenance and monitoring - Costly - Not a long-term solution - Measures may fail in a storm surge
Retreat (Avoid building/ move structures in flood plain)	Freiston Shore, England (Friess et al., 2008)	- Financially sustainable, saves on cost of defense	- Loss of land/ heritage - Difficult, especially with heritage districts - Politically challenging
Accommodation (continue to occupy land, with adjustments)	Elevate buildings, strengthen foundations	- Reduces risk without full expense of protection	- Cost of redesigning structures - Does not completely reduce risk, potential for damage still high

Abel et al. (2011) did a study on principles of governance that enable planned retreat, but some of the principles can be applied to other forms of adaptation planning. One principle stated that municipalities should “change rules and incentives to influence stakeholders.” Legislation should be put in place that encourages adaptive responses by developers and owners to sea level rise. Another principle is “expect the unexpected” – in other words, rules should be accompanied by methods for changing them.

We believe that these two principles embody the necessary actions that must be taken to adapt to sea level rise. On the one hand, sea-level rise and storm surge is an increasing threat, and the municipality must prepare accordingly. This involves enforcing regulation that discourages people from building in hazardous zones, or taking actions to build defenses and accommodations for sea level rise on valued property. On the other hand, predicting and preparing for the future is surrounded with uncertainties. Due to the number of factors involved, estimates of future sea level rise may change, and predictions may prove to be inaccurate. Therefore, municipalities should plan for the worst-case scenario based on current knowledge through regulation, but should be aware of the possibility of change and make adjustments as necessary.

One option that adheres to these principles is creating legislation that allows certain types of temporary developments to be built in a hazardous zone, under the condition that when the sea reaches a pre-specified distance, the owner removes the development (Boateng, 2012). This type of policy would only apply to currently vacant lands, however. Other types of policies and actions must be taken to protect or relocate buildings and infrastructure currently at risk.

The adaptation or accommodation strategies may be necessary for buildings lying within the Heritage Conservation District of Lunenburg. Lunenburg places high value on preserving the cultural heritage of the town; these historic buildings attract tourists and make the town a vibrant place to live. Unfortunately, both the Heritage Conservation District and Architectural Control Area (which may become a future Heritage Conservation District) will be affected by sea-level rise and storm surge. The Town should look into engineering techniques for protecting the most valued at-risk structures.

The Town of Lunenburg should consider all adaptation options. Protection or accommodation may be necessary due to the number of valued structures; however, the Town should also consider legislative measures that discourage future investment in vulnerable structures at risk of flooding. A cost-benefit analysis would provide insight into the most suitable adaptation strategy.

In order to effectively apply any adaptation measure, the support of the public is necessary. Future examination into appropriate adaptation measures should focus on informing the public about the threat of sea-level rise, and seeking their input with regard to possible solutions.

7.0 Policy Review

Coastal areas are managed by all levels of government, so climate change adaptation involves the cooperation of all three groups. The Federal government has interests in ports, fisheries, tourism, and foreign affairs. The Provincial government also has interests in ports, fisheries, and tourism, as well as land planning. The Municipal government regulates health, engineering, parks and recreation, and land use planning. This project focuses on planning for climate change at the local level, but municipal decisions must adhere to the policies set out by the Province. We therefore started our policy review by looking at the Municipal Government Act.

Municipalities within Nova Scotia are governed by the Municipal Government Act. Although the Municipal Government Act does not contain policies that directly address coastal management and sea-level rise, it does contain a Statement of Provincial Interest Regarding Flood Risk Areas. We discuss how the Municipality can apply these principles to potential future sea-level rise and storm surge areas in section 7.1.

Land use planning decisions today will affect the vulnerability of Lunenburg's waterfront in the future. We summarize the goals of the Strategic Plan and Municipal Planning Strategy, and give suggestions for how climate change can be incorporated into these documents in sections 7.2 and 7.3. In section 7.4, we summarize the allowed uses in the zones most impacted by each scenario, and give suggestions for how the Land Use Bylaw could be amended to adhere to the adaptation strategies discussed in section 6.

7.1 Statement of Provincial Interests

The Statement of Provincial Interests contains a statement regarding flood risk areas. The statement applies to a specific list of areas and relates mainly to river floodplains, but it also applies "where local knowledge or information concerning floodplains is available." This document provides information about potential future flood plains, so the municipality should attempt to adhere to the guidance of the Provincial interest statement regarding flood plains as much as possible in order to prepare for climate change. The provisions of this statement are listed below:

> **1.** Planning documents must identify *Flood Risk Areas* consistent with the Canada-Nova Scotia Flood Damage Reduction Program mapping and any locally known floodplain.
>
> **2.** For *Flood Risk Areas* that have been mapped under the Canada-Nova Scotia Flood Damage Reduction Program planning documents must be reasonably consistent with the following:
>
> **(a)** within the *Floodway*,
>
> > (i) development must be restricted to uses such as roads, open space uses, utility and service corridors, parking lots and temporary uses, and
> >
> > (ii) the placement of off-site fill must be prohibited;
>
> **(b)** within the *Floodway Fringe*,
>
> > (i) development, provided it is flood proofed, may be permitted, except for

(1) residential institutions such as hospitals, senior citizen homes, homes for special care and similar facilities where flooding could pose a significant threat to the safety of residents if evacuation became necessary, and

(2) any use associated with the warehousing or the production of hazardous materials,

(ii) the placement of off-site fill must be limited to that required for flood proofing or flood risk management.

3. Expansion of existing uses must be balanced against risks to human safety, property and increased upstream and downstream flooding. Any expansion in the *Floodway* must not increase the area of the structure at or below the required flood proof elevation.

4. For known floodplains that have not been mapped under the Canada-Nova Scotia Flood Damage Reduction Program, planning documents should be, at a minimum, reasonably consistent with the provisions applicable to the *Floodway Fringe*.

5. Development contrary to this statement may be permitted provided a hydrotechnical study, carried out by a qualified person, shows that the proposed development will not contribute to upstream or downstream flooding or result in a change to flood water flow patterns.

Although the flood risk areas identified in this project are potential future flood risk areas, and are not necessarily present flood risk areas, the same principles listed in the Provincial statement should apply in order to prepare for the future and increase the Town's resilience to climate change.

In order to plan for the 2025 future sea level rise scenario, the Town should adhere to the restrictions placed by the Province on known flood plains as much as possible, since this land could be inundated in the near-future. For example, the statement suggests that only infrastructure such as roads and temporary uses should be permitted within a known flood plain. The Town should thus place severe restrictions on development within the 2025 sea-level rise scenario area.

In order to plan for the 2025 future storm-surge scenario, the town should adhere to the restrictions placed by the Province on the "floodway fringe" in order to protect the safety of the town and reduce damage to valued infrastructure and structure. The statement suggests that the development of residential institutions, such as special care homes, within a floodway fringe should be avoided in order to protect the safety of residences in the event of an emergency. Since this area will likely be at risk of flooding in the near future, the Town should direct these types of vulnerable developments away from the 2025 storm surge scenario area.

7.2 The Town of Lunenburg Strategic Plan

The purpose of the Town of Lunenburg Strategic Plan is "to establish some broad parameters which will serve as a guide in decision making to effectively position the Town to meet the challenges of the future." One of the major challenges that the Town will face in the future is climate change. By creating measures to adapt to sea level rise as soon as possible, the Town will reduce costs significantly for the future generations.

While the document does address mitigating climate change impacts by suggesting that the Town seek long-term source of clean energy, it does not address the challenges that the Town will face due to sea level rise.

One of the goals of the plan is to better utilize the UNESCO designation through developing relations with other funding partners. Since we identified that some of the UNESCO sites are at risk to sea level rise and storm surge flooding, we suggest that one of the objectives of the plan be to seek funding to protect or modify these sites in preparation for sea level rise.

In order to effectively adapt to climate change, the community must be willing to make adjustments related to planning, zoning, and building design. Whichever direction the town takes with respect to climate change adaptation, it must have the support of the general public. We therefore suggest that other objectives of the plan be to create awareness around the hazards associated with sea level rise and climate change, and to create a formal adaptation plan with the public's input.

7.3 The Town of Lunenburg Municipal Planning Strategy

The purpose of the Municipal Planning Strategy (MPS) is to set the policy framework for land use and development control in the Town of Lunenburg. It was approved by the Minister of Municipal Affairs on July 19, 1973, and was last amended August of 2010. The intent of the MPS is carried out legally through the Land Use By-Law and Subdivision By-Law.

The MPS does not address climate change issues directly; however, one of the objectives of the MPS is to "control land use and development in a manner that will preserve, enhance, and protect both the natural and built environment." Hazards associated with climate change, such as increased frequency of extreme events and sea level rise, could threaten the built environment and safety of the Town. Land use decisions should therefore take into account sea level rise and storm surge flooding potential.

Industrial activity currently occurs primarily on the front harbour waterfront, and the MPS states that continued industrial use of the waterfront will be accommodated and encouraged. This is in keeping with adaptation strategies, as many industrial uses are water-compatible and built to withstand extreme events. However, the MPS also encourages tourism development of the waterfront, which could place vulnerable uses such as hotels in harms way. Since the historic waterfront is essential to the Town's tourism industry, perhaps this use could continue within a potential flood area under conditions that structures are built to certain standards that can withstand flooding.

The MPS contains a Future Land Use Map, which guides the future zoning and development in the town. In the Land Use Map there is an Institutional designation along the north side of the harbour, in an area currently zoned as Marine Industrial. The Institutional Zone would permit the following uses: "(a) a broad range of institutional uses including but not limited to churches, public buildings and uses, schools and museums; and (b) occasional or temporary outdoor or indoor markets, bake sales, flea markets, vegetable and produce markets."

Section (b) permits temporary structures along the waterfront, which does coincide with adaptive strategies. However, by permitting the uses listed in section (a), this designation would allow development that is associated with high investment and vulnerable populations, such as schools, to occur in a potential flood zone. In addition, this portion of the harbour is associated with medium and high potential for erodibility, due to the steep slopes and underlying geology (see Appendix F), which exacerbates the potential for damage.

We suggest that the MPS be amended to include policies that address future sea level rise and increasing storm surge extents, in accordance with the flood risk areas guidelines of the Statement of Provincial Interests.

7.4 The Town of Lunenburg Land Use By-Law

It is important to consider the present zoning in any adaptation plan, because the zoning affects the types of uses that are to be allowed in future flood plains. Appendix H shows that the largest area that will be most significantly affected in the short term is zoned Marine Industrial. The Marine Industrial zone allows for a wide range of uses, some of which could potentially be vulnerable to sea level rise and flooding. While uses such as wharves, docks, parking lots, marine uses, and fish establishments are all water compatible, other uses permitted in the zone, such as medical clinics and places of entertainment, recreation, and assembly are less water-compatible. The Town should therefore take measures to ensure that these more vulnerable uses are built to withstand flood impacts, or else amend the zoning so that these uses are not permitted.

Much of the land affected by the near and long term is currently zoned residential. Many of the uses in this zone are water compatible, since they are not associated with a large amount of investment and are often temporary structures. These include: parking lots, playgrounds, and temporary indoor markets, for example. Some of the allowed uses, however, should not be in a potential flood zone since they would create safety issues in the event of a storm. These uses include community centres, and tourist trailer parks.

We suggest that the Town create a new zone that governs development within the near-term sea level rise and storm surge scenarios, since many of the areas affected are zoned to allow for developments that are not compatible to storm surges, which could have safety or economic implications. Only temporary or water-compatible should be allowed to develop within the 2025 sea-level rise project, and new structures built within the flood zone should be of sufficient standard to withstand storm impacts. The Town should also create a zone for the year 2100 sea level rise and storm surge that is more lenient but also places restrictions on high-investment, long-term development.

8.0 Conclusions

This study presented the findings of projected long-term impacts of climate change, particularly sea-level rise and storm surge, on the Town of Lunenburg's physical infrastructure. The Town is a coastal community, and depends on the waterfront for its economic and social livelihood. Damages to the Town's coast due to the effects of climate change will have profound impacts on the community. This project illustrated that areas of the coast will become permanently inundated, that storm surges will reach further inland than they have previously due to sea level rise, that some parts of the coast have high erosion potential, and that all of these phenomena will have significant impacts on the Town's built environment.

The analysis of built environment vulnerability showed that there are significant components of the Town's infrastructure that are vulnerable to projected sea level rise and storm surges. The Town will need to set priorities for addressing infrastructure affected by each sea level rise and storm surge scenario. Long-term vulnerability should be considered for future land use development patterns and implementation of major infrastructure projects.

We determined that the Town should consider a mix of protection, retreat, and accommodation adaptation strategies, which should be supported with legislative measures and include the input of the public with regard to possible solutions. We explored several facets of policy and gave suggestions for how climate change can be incorporated into the Town's land use policy.

Our study provided a thorough overview of vulnerability of the Town of Lunenburg's built environment to sea level rise and future storm surge. It is our hope that our efforts will help the Town prepare its MCCAP for the 2010-2014 Gas Tax Agreement and the Municipal Funding Agreements.

9.0 Further Studies

Although this study introduced a comprehensive overview of sea level rise and storm surge effects on the Town, there are additional factors that could be incorporated into the many findings in the report. For example, our natural environment hazard mapping could include exposure to wave energy and places of active erosion criteria if the data was available. Our technique used the most recent and accurate sea level rise projections and an overlay methodology. Future studies could consider a more sophisticated modeling technique which utilizes more complex mathematical processes to consider wave run, wave overtopping, and overland flow. This method is similar to our technique but it is able to forecast inundation by including ocean waves. This methodology was not chosen due to unfamiliarity with the procedure.

Our study had a strong focus on infrastructure and did not consider socioeconomic vulnerability. Further studies should incorporate socioeconomic vulnerability, as people's ability to respond and adapt to sea level rise scenarios is an important consideration; this would contribute to further understanding of the Town's vulnerability. It may be valuable for the Town to consider disseminating a survey to citizens to collect information about their experiences with climate change and related events (storm surge, flooding, inundation, sea level rise) and to gain knowledge of their perception of which Town features and planning initiatives are most important. Survey dissemination could also collect information about preferred adaptation strategies.

As global sea level rise projections change over time, the Town should revisit the sea level rise and storm surge scenarios to reevaluate how infrastructure will be impacted based on new information. It is also important to continually revise the sea level rise and storm surge scenarios as new or updated infrastructure data becomes available. To guide understanding of the implications of sea level rise and storm surge, future studies should begin to evaluate infrastructure lifespan, maintenance cost, and other asset management information.

Works Cited

Abel, N., Gorddard, R., Harman, B., Leitch, A., Langridge, J., Ryan, A., Heyenga, S. (2011). Sea level rise, coastal development and planned retreat: analytical framework, governance principles and an Australian case study. *Environmental Science & Policy, 14*. 279 – 288.

Allen, S. (n.d.) Lunenburg Waterfront Walk. Retrieved from http://lunenburgwaterfrontwalk.com/introduction--english/.

Balica, S.F, Wright, N.G., and van der Meulen, F. (2012). A flood vulnerability index for coastal cities and its use in assessing climate change impacts. *Natural Hazards, Vol. 52*. Springer.com

Boateng, I. (2012). Integrating Sea-Level Rise Adaptation into Planning Policies in the Coastal Zone. *Integrating Generations, FIG Working Week 2008.* Stockholm, Sweden. Retrieved from http://www.fig.net/pub/fig2008/papers/ts03f/ts03f_03_boateng_2722.pdf

Canadian Environmental Law Association. (2012). *The Precautionary Principle.* Retrieved from http://www.cela.ca/collections/pollution/precautionary-principle.

Cann, D., & Hilchey, J. (1958). Soil Survey of Lunenburg County. Truro: Nova Scotia Department of Agriculture.

Church, J. & White, N. (2006). A 20th century acceleration in global sea-level rise. *Geophysical Research Letters, 33* (1). Retrieved from http://onlinelibrary.wiley.com/doi/10.1029/2005GL024826/abstract

Critchley, J., Muise, J., Rapaport, E. & Manuel, P. (2012). Future Sea Level Rise and Extreme Water Level Scenarios for the Municipality of the District of Lunenburg, Nova Scotia. *Atlantic Climate Adaptation Solutions Association.* School of Planning, Dalhousie University. www.atlanticadaptation.ca

ESRI. (n.d.). GIS Dictionary. http://support.esri.com/en/knowledgebase/GISDictionary/term/DEM.

Fisher, G. (2011). Municipal Climate Change Action Plan Guidebook: Canada-Nova Scotia Agreement on the Transfer of Federal Gas Tax Funds. Province of Nova Scotia. Service Nova Scotia and Municipal Relations. Retrieved from http://www.nsinfrastructure.ca/pages/Municipal-Climate-Change-Action-Plan-Guidebook1.aspx

Forbes, D., Manson, G., Charles, J., Thomson, K., Taylor, R. (2009). *Halifax Harbour Extreme Water Levels in the Context of Climate Change: Scenarios for a 100-Year Time Horizon.* Geological Survey of Canada Open File 6346. Natural Resources Canada. Retrieved from: http://www.halifax.ca/regionalplanning/documents/OF6346final.pdf

Friess, D., Möller, I., & Spencer, T. (2008). Managed Realignment and the Re-establishment of saltmarsh habitat, Freiston Shore, Lincolnshire, United Kingdom. CCRU, Cambridge University, UK, prepared for the report ''The Role of Environmental Management and Eco-Engineering in Disaster Risk Reduction and Climate Change Adaptation'' (ProAct Network 2008). Retrieved from www.proactnetwork.org.

Goodwin, T. (2004). *Bedrock, Glacial, Economic and Environmental Geology of the HRM.* Halifax: Nova Scotia Department of Natural Resources, Mineral Resource Branch.

IPCC. (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

IPCC. (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 p.

IPCC. (2007). Summary for Policymakers. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 7-22.

Know Climate Change. (2013). Adaptation and Mitigation. Retrieved March 31, 2013 from http://know.climateofconcern.org/index.php?option=com_content&task=article&id=144#;

Lemmen, D.S., Warren, F.J., Lacroix J., and Bush, E., editors (2008). From Impacts to Adaptation: Canada in a Changing Climate 2007; Government of Canada, Ottawa, ON.

Lunenburg Board of Trade. (2009). *A Brief History of Lunenburg.* Retrieved from http://www.lunenburgns.com

MacDougall, J., Cann, D., & Hilchey, J. (1981). Soil Survey of Halifax County Nova Scotia. Truro: Nova Scotia Department of Agriculture.

MacKenzie, Kyle. and Parlee, Kathryn. (2003) The Road Ahead: Adapting to Climate Change in Atlantic Canada. Canadian Climate Impacts and Adaptation Research Network.

Maritime Testing Limitied www.halifax.ca/boardscom/documents/SlateManagementPlanOverviewpreparedbyMaritimeTestingdatedSept272011.pdf

Nicholls, R.J., P.P. Wong, V.R. Burkett, J.O. Codignotto, J.E. Hay, R.F. McLean, S. Ragoonaden and C.D. Woodroffe, 2007: Coastal systems and low-lying areas. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 315-356.

Nova Scotia Community Counts. (2011). http://www.gov.ns.ca/finance/communitycounts/profiles/

Pinfold, G. (2012). Climate Change and Emergency Management in Nova Scotia. *Atlantic Climate Adaptation Solutions Association.* Nova Scotia Emergency Management Office. www.atlanticadaptation.ca

Rahmstorf, S. (2007). A Semi-Empirical Approach to Projecting Future Sea-Level Rise. *Science, 315,* 368 – 370. Retrieved from www.sciencemag.org

Richards, W. and Daigle, R. (2011). Scenarios and Guidance for Adaptation to Climate Change and Sea Level Rise – Nova Scotia and PEI Communities. August 2011. *Atlantic Climate Adaptation Solutions Association.* www.atlanticadaptation.ca/ns_projects

Sarty, R. (1953). *The Founding of Lunenburg.* Lunenburg's Bicentennial.

Town of Lunenburg. (2013). "Welcome to Lunenburg, Nova Scotia, Canada." Retrieved From www.explorelunenburg.ca.

Appendices

List of Appendices

Appendix A: Glossary

Adaptation refers to any activity that reduces the negative impacts of climate change and/or positions us to take advantage of new opportunities that may be presented (Lemmen et al., 2008).

Anthropogenic means resulting from or produced by human activity (Lemmen et al., 2008).

Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer (Lemmen et al., 2008).

DEM refers to a Digital Elevation Model: the representation of continuous elevation values over a topographic surface by a regular array of z-values, referenced to a common datum (ESRI).

HHWLT means the highest astronomical tide possible for a given location (Richards and Daigle, 2011, p. 25)

Inundation refers to the rising of a water body to cover normally dry land.

Radiative forcing is measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system (IPCC, 2007, Synthesis Report).

Relative sea-level rise occurs where there is a local increase in the level of the ocean relative to the land, which might be due to ocean rise and/or land subsidence (Lemmen et al., 2008).

Resilience is the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the same capacity for self-organization and the same capacity to adapt to stress and change (Lemmen et al., 2008).

Return period means the average time between occurrences of a defined event (IPCC, 2007, Physical Science Basis).

Risk refers to the combination of the likelihood (probability of occurrence) and the consequences of an adverse event (e.g. a climate-related hazard) (Lemmen et al., 2008).

Scenario refers to a plausible and often simplified description of how the future may develop, based on coherent and internally consistent set of assumptions about driving forces and key relationships (IPCC, 2007, Physical Science Basis).

Sea-level rise refers to an increase in the mean level of the ocean.

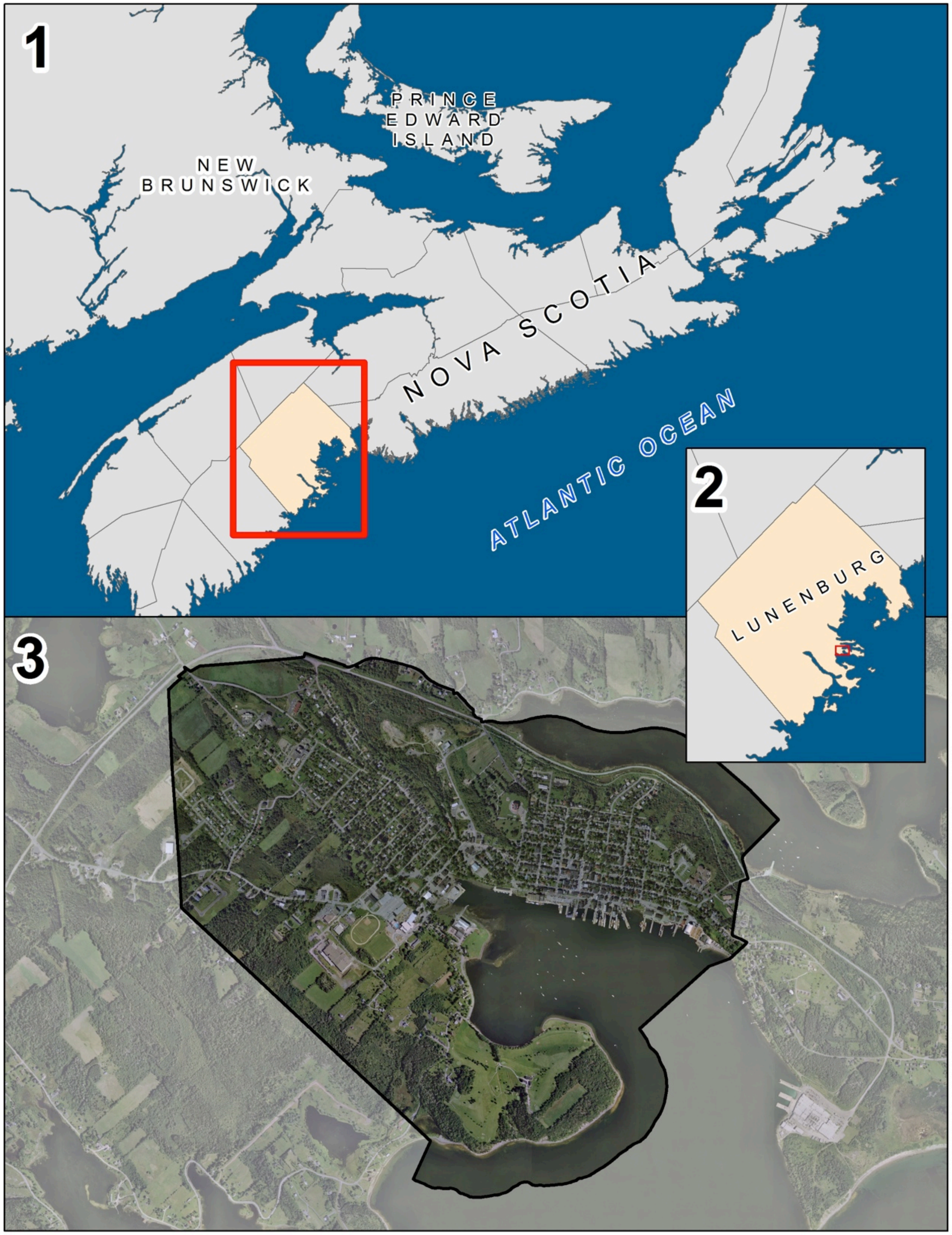
Storm surge refers to the difference between the observed water level and the predicted astronomical tide (Richards and Daigle, 2011).

Subsidence refers to the gradual sinking of land due to the isostatic rebound of the Earth's crust.

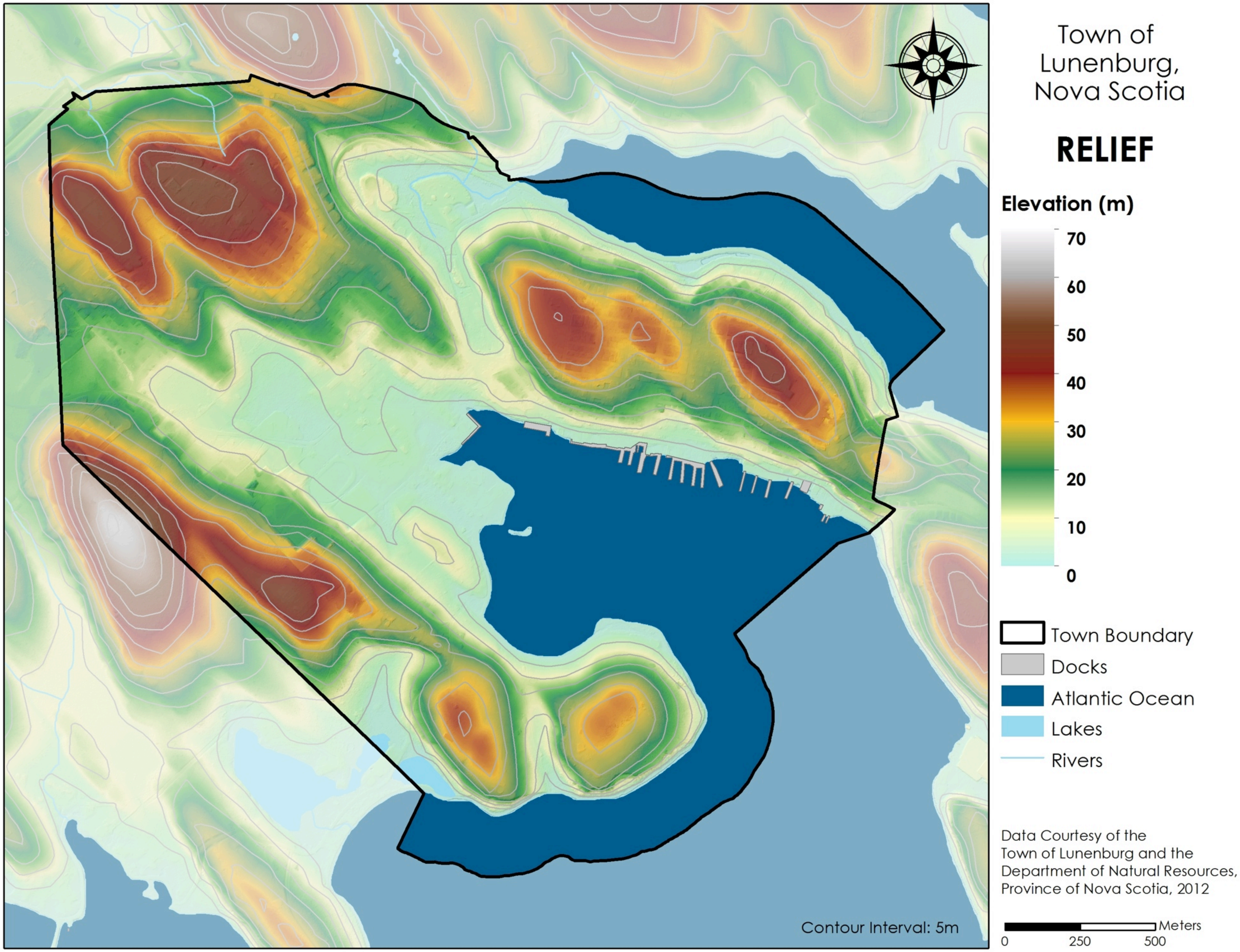
Vulnerability is the degree to which a system is susceptible to, and unable to cope with, the adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC, 2007, Summary for Policy Makers).

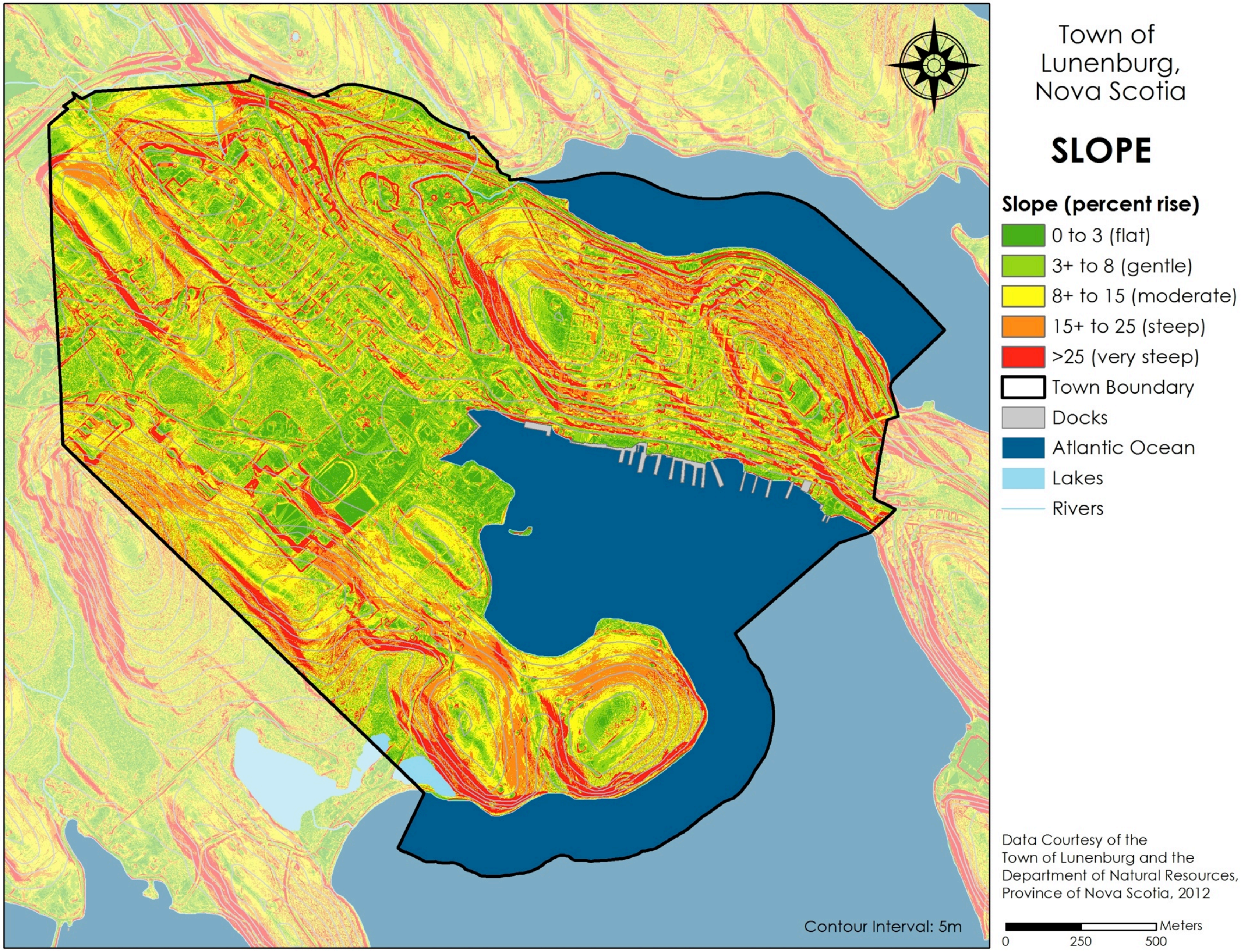
Appendix B: Context Map

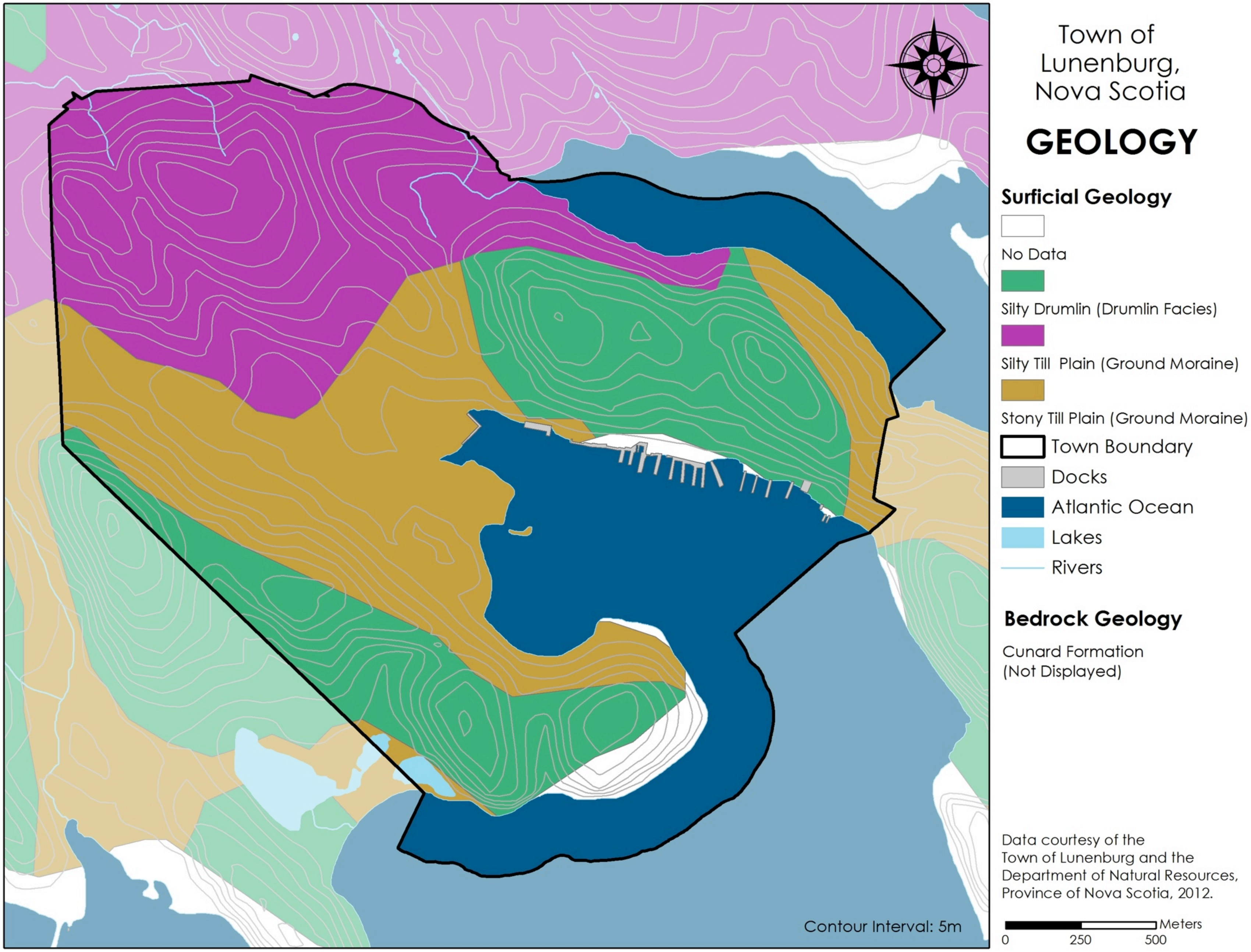
1. Nova Scotia
2. The County of Lunenburg
3. The Town of Lunenburg

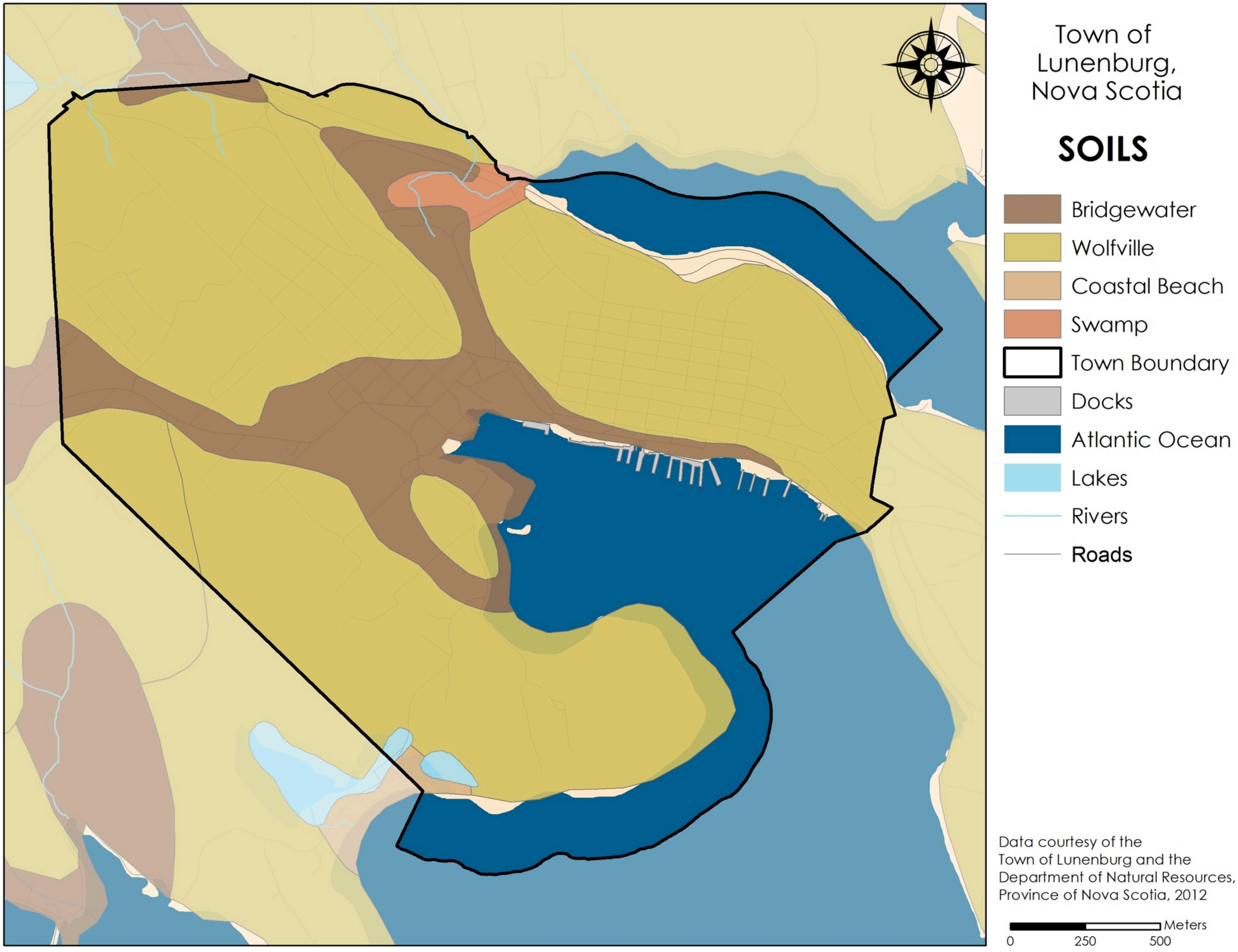


Appendix C: Natural Environment Inventory



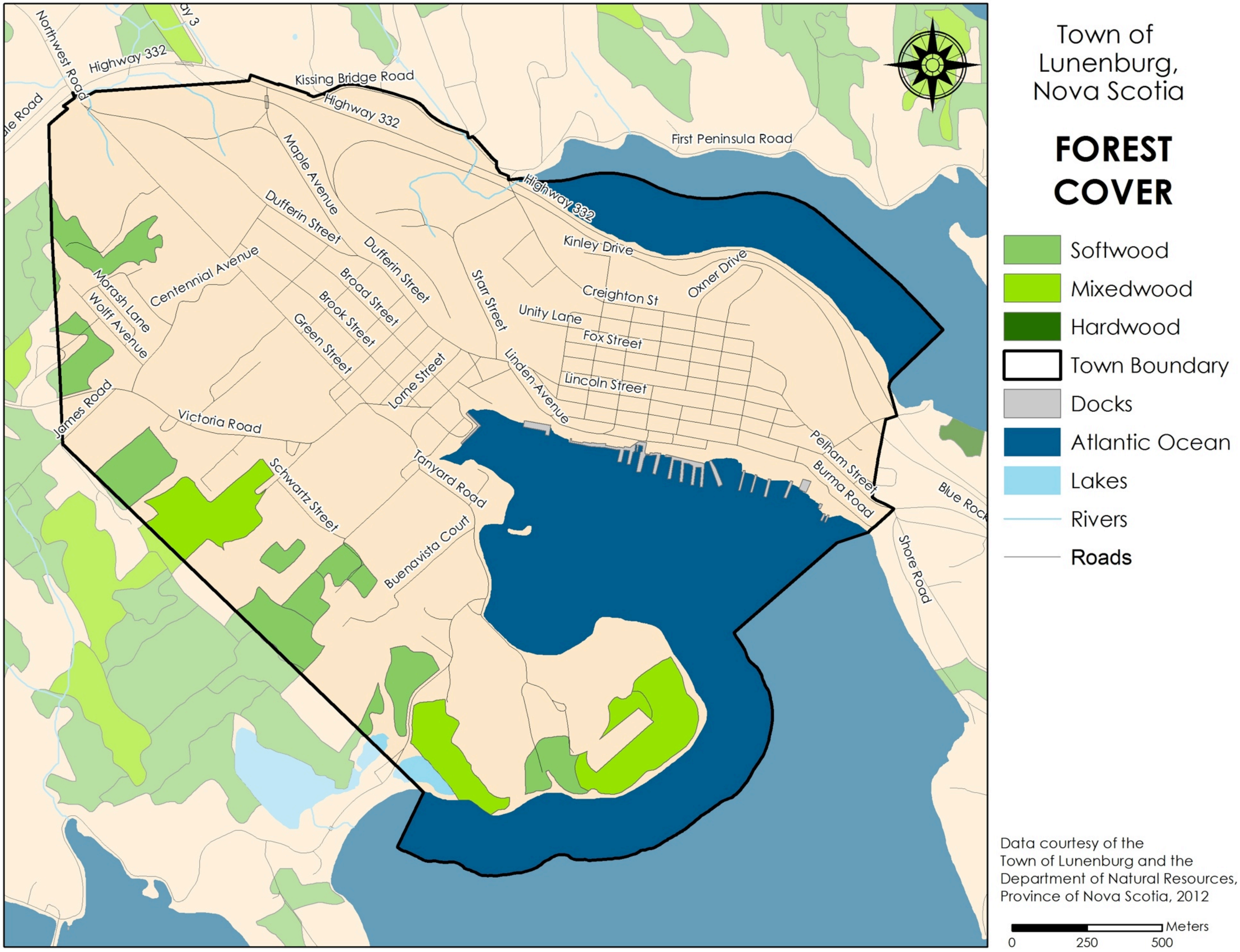

Town of
Lunenburg,
Nova Scotia
SLOPE
Slope (percent rise)
0 to 3 (flat)
3+ to 8 (gentle)
8+ to 15 (moderate)
15+ to 25 (steep)
>25 (very steep)
Town Boundary
Docks
Atlantic Ocean
Lakes
Rivers
Data Courtesy of the
Town of Lunenburg and the
Department of Natural Resources,
Province of Nova Scotia, 2012
Contour Interval: 5m
Meters
0
250
500


Town of Lunenburg, Nova Scotia
GEOLOGY
Surficial Geology
No Data
Silty Drumlin (Drumlin Facies)
Silty Till Plain (Ground Moraine)
Stony Till Plain (Ground Moraine)
Town Boundary
Docks
Atlantic Ocean
Lakes
Rivers
Bedrock Geology
Cunard Formation (Not Displayed)
Data courtesy of the Town of Lunenburg and the Department of Natural Resources, Province of Nova Scotia, 2012.
Meters
0
250
500
Contour Interval: 5m



Data courtesy of the
Town of Lunenburg and the
Department of Natural Resources,
Province of Nova Scotia, 2012

Appendix C: Natural Environment Inventory



Town of Lunenburg, Nova Scotia

FOREST COVER

Data courtesy of the
Town of Lunenburg and the
Department of Natural Resources,
Province of Nova Scotia, 2012