Atlantic Climate Adaptation Solutions Association

Solutions d'adaptation aux changements climatiques pour l'Atlantique

Sea-Level Rise and Flooding Estimates for New Brunswick Coastal Sections

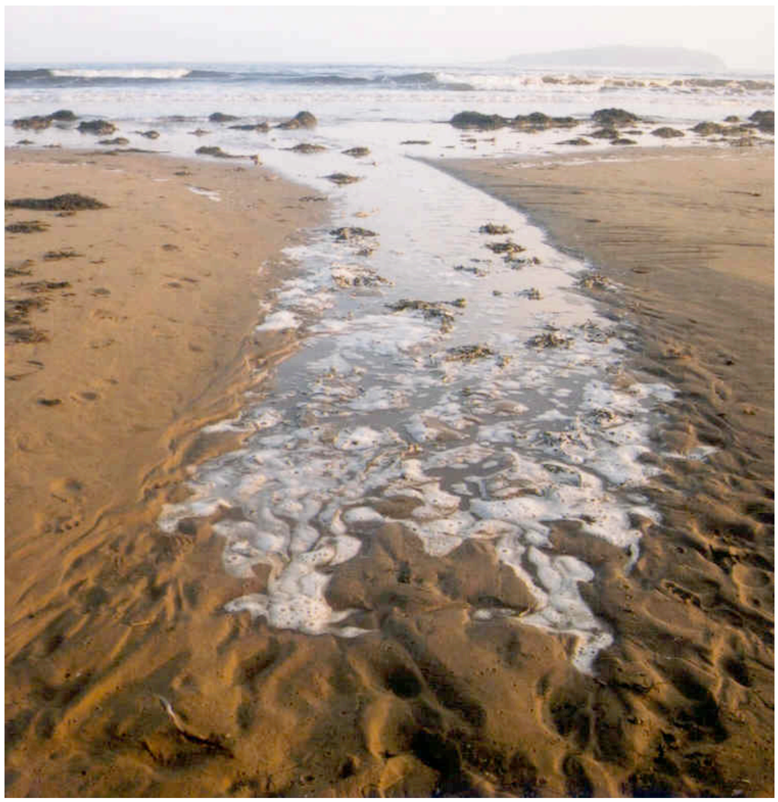

Photo: P. Jordan

By

Réal Daigle

R.J. Daigle Enviro

January, 2012

Natural Resources Canada / Ressources naturelles Canada

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Sea-Level Rise and Flooding Estimates for New Brunswick Coastal Sections

Final Report

January 2012

Report Title

Sea-Level Rise and Flooding Estimates for New Brunswick Coastal Sections

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New Brunswick Department of Environment

Atlantic Canada Adaptation Solutions Association

January, 2012

Letter of Transmittal

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January 15, 2012

I am pleased to submit the following report to New Brunswick Environment in fulfilment of the contract between R. J. Daigle Enviro and the Atlantic Climate Change Adaptation Solutions Association.

This report contains sea-level rise and flooding scenarios for the coastlines of the Province of New Brunswick. This complements previous work prepared for New Brunswick municipalities to develop effective climate change adaptation plans.

I thank you for the opportunity to offer my expertise in sea-level rise toward addressing the complex issues being tackled by the Atlantic Regional Adaptation Collaborative. I hope that it will facilitate informed decision-making and planning on climate change adaptation leading to sustainable communities.

Sincerely,

Réal Daigle

R. J. Daigle Enviro

Acknowledgements

This report would not have been possible without the kind contributions of:

a) Phillip MacAulay and Mike McMahon (Canadian Hydrographic Service/Fisheries and Oceans Canada) who provided Higher High Water at Large Tide (HHWLT) baseline data and Chart Datum to Geodetic elevation differences for New Brunswick tidal prediction sites, and

b) Dominique Bérubé and Marc Desrosiers (New Brunswick Natural Resources) who provided high precision baseline water level and Chart Datum to Geodetic elevation survey data for some key coastal locations.

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1 Executive Summary

1.1 Overview

The coasts of Atlantic Canada have been shown to have significant sensitivity to sea-level rise and associated storm impacts. Areas with the highest sensitivity include most of the Gulf of St. Lawrence coast of New Brunswick, the north shore of Prince Edward Island, the south coast of Nova Scotia and the southwest coast and Burin Peninsula regions of Newfoundland & Labrador. Accelerated sea-level rise under greenhouse warming is expected to aggravate these impacts, increasing the need for adaptation in order to minimize damage and costs. Threats in these areas come primarily from impacts of greater coastal flooding and erosion. To further complicate matters, there has been a modern society trend to build homes and cottages (usually very expensive) often within tens of metres of coastlines, directly in harm's way of damaging coastal storms.

Coastal flooding normally occurs during the late Fall to early Spring period of the year when fierce storms develop during periods of high tides, which naturally occur near the full and new moon cycles. At times, the flooding impacts in New Brunswick can be catastrophic, as was the case at the height of the record storm surge event of January 21, 2000, and then again ten years later, with the December 21, 2010 storm. The impacts from such storms range from the destruction of natural habitats such as protective sand dunes, of built-up coastal infrastructure such as roadways, fishing wharves and erosion protection structures, and in some cases homes and cottages.

1.2 Storm Surge Flooding

A storm surge can be defined at the coast as the difference between the observed water levels and the predicted tides. Tides result from the rise and fall of sea levels caused by the combined effects of the gravitational forces exerted by the moon and the sun and the rotation of the Earth. In reality, observed tide levels are rarely as predicted for the simple fact that their predicted levels are based on standard atmospheric conditions. When the atmospheric pressure is lower than the standard, observed tides are higher than predicted and the opposite is true for higher atmospheric pressure. Additionally, onshore and offshore winds will respectively increase and diminish the tide level.

Storm surges can be positive or negative and may therefore raise or lower sea level from its predicted value. Storm surges occur everywhere along our coastlines, can occur anywhere in the tidal cycle and may last over several tidal cycles. Large positive storm surges at times of high tide are events that lead to coastal flooding, whereas when they coincide with low tides, flooding problems are not expected.

1.3 Impacts of Climate Change on Coastal Flooding

Climate change is expected to further increase ocean temperatures and accelerate the melting of land glaciers and polar ice sheets (Greenland and Antarctica) resulting in further rise in global sea levels of nearly one metre by year 2100. Regionally, as ocean temperatures increase it is expected that the winter sea ice season in the Gulf of St. Lawrence will continue to shorten and that by the period 2040-2050 winter ice will no longer develop in this region. Until then, due to climate variability, abnormal relatively ice-free seasons such as those which occurred in 2010 and 2011 will become more frequent. With less or no ice to help buffer ocean wave action during intense storms, coastal erosion rates will likely increase resulting in more extensive damage to ecosystems (such as wetlands and sand dunes) and coastal infrastructure (such as wharves and erosion protection structures). Coastal flooding will become more frequent due to sea-level rise because in the future, even weaker storm systems will produce flooding impacts similar to the most extreme storms of the past. By way of example, given a one-metre sea-level rise scenario, which is expected to occur by 2100, the flooding levels reached with the record event of January 21, 2000 along the southeast coastline of New Brunswick (then close to a 1 in 100 year event), could statistically occur every year.

The coastlines of Atlantic Canada, due to their proximity to storm tracks, have been exposed to destructive flooding events over the years. When the timing of the most extreme storms coincides with high tide cycles, the associated impacts can be catastrophic. After the benchmark flooding event of January 21, 2000 in the southern Gulf of St. Lawrence a research project was launched to evaluate the impact of the flooding event at Charlottetown in the context of both year 2000 and future elevated sea levels due to climate change. In that research project and a follow-up larger project focussed on coastal areas of southeastern New Brunswick, an innovative mapping approach was used using Light Detection and Ranging (LiDAR), thereby providing a highly effective visual tool to display flood zones and to conduct socio-economic impact analyses (see Figure 1 for example of LiDAR mapping scenario in the Shediac Bay coastal zone).

Figure 1. LiDAR-derived maps showing the January 21, 2000 flooding event (left) and the same event (right) given a sea-level rise scenario of one metre on an orthophoto (geometrically corrected aerial photo) background map.

The shaded light blue area represents the flooding that would result if the water level reached at the peak of the January 21, 2000 flooding event (left image) was raised by one metre, the estimated sea-level rise scenario by year 2100 (right image). (Background aerial photo courtesy of Service New Brunswick)

1.4 Flooding Scenarios

The flooding levels (scenarios) presented in this report (see Appendix A) are representative of the impact of storm surge flooding on runs of higher tides that normally occur near Full Moon and New Moon cycles. The scenarios have been built around the higher annual tidal cycles, referred to as the Higher High Water at Large Tides (HHWLT). The HHWLT value is calculated over a 19 year cycle and represents the average of the highest annual high water, one for each of the 19 years of prediction.

The HHWLT value was then added to sea-level estimates and then to documented storm-surge return period climatology to come up with flooding scenarios for future milestones of 2025, 2055, 2085 and 2100. It should be noted that with a 1-metre sea level rise scenario, the flooding levels reached at the height of the January 21, 2000 along the southeast coastline of New Brunswick (then close to a 1 in 100 year event), could statistically occur every year.

2 Context

The objective of this report is to provide estimates of relative sea-level rise over the coming century, including the storm surge component for return periods of 1, 2, 5, 10, 25, 50 and 100 years, for the coastline of New Brunswick, based on the availability of tidal data information. This work will complement the information provided in *Sea-Level Rise Estimates for NB Municipalities, March 2011 (R.J. Daigle Enviro),* in which statistically derived extreme flooding scenarios (for return periods of 10, 25, 50 and 100 years) were derived.

3 Methodology

3.1 Global Sea-Level Rise Trends

The Intergovernmental Panel on Climate Change (IPCC), a scientific intergovernmental body with participation from more than 130 countries, provides the world with a consensus-based policy advice and scientific review of climate change information in the form of assessment reports, produced every seven years. IPCC is considered to be the authoritative voice for climate change information at the international level.

The IPCC Fourth Assessment Report (AR4) cites updated information on global sea-level rise over the past 50-100 years and provides estimates of the potential rise in mean sea level over the coming 100 years. For the global ocean as a whole, the latest literature assessed in AR4 indicates that sea level rose 0.17±0.05 m during the 20th century, an increase over the rate in the 19th century, and slightly less than the mean rate of 1.8±0.5 mm/year observed from 1961 to 2003. Climate model projections (Table 1) of global mean sea-level rise (mean for 2090-2099 relative to 1980-1999) are shown for a range of scenarios ranging from 0.18 - 0.26 m for the B1 scenario (lowest greenhouse gas emissions) to 0.26 - 0.59 m (central value of 0.43 m) for A1FI (“fossil intensive”).

Table 1. Sea-level rise projections from AR4. (IPCC, 2007)

Scenario	Temperature change (°C at 2090-2099 relative to 1980-1999)		Sea-level rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	Likely range	Model-based range Excluding future rapid dynamic changes in ice flow
Constant year 2000 concentrations	0.6	0.3 – 0.9	Not available
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 2.9	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI	4.0	2.4 – 6.4	0.26 – 0.59

At the low end, this is equivalent to (or possibly less than) the present rate of rise. At the high end, it is less than projected in the 2001 IPCC Third Assessment (range up to 0.88 m), but still represents more than three times the rise observed during the 20th century. Furthermore, these estimates exclude the effects of any future acceleration in the flow rates of glaciers draining the Greenland and Antarctic ice sheets. For Atlantic Canada, AR4 indicates that the regional sea-level rise related to thermal expansion (the increase due to the warming of the oceans) may be very close to the global mean.

There has been much discussion since the release of AR4 by the scientific community regarding the effects of a potential acceleration in the flow rates of glaciers, particularly with regards to the Greenland Ice Sheet, which if entirely melted, would result in a global sea-level rise the order of seven metres. The rise in sea levels would however not be uniform around the globe due the changes in the gravitational field associated with the changing mass distribution on the earth.

The contribution of Antarctica to global sea-level rise which had been previously estimated to be negligible, has also been the topic of new research and there is now widespread concern that the West Antarctica Ice Sheet (WAIS) may collapse entirely due to climate change (Bamber, Riva, Vermeersen, & LeBrocq, 2009). The contribution to global sea-level rise from WAIS would be approximately five metres, but the rise in sea levels would however not be uniform around the globe (Mitrovica, Gomez, & Clark, 2009) due to changes in the gravitational field associated with the changing mass distribution on the earth (referred to as sea-level fingerprinting), and would in fact be more pronounced over the northern hemisphere. Conversely, contributions to sea-level rise from the Greenland Ice Sheet would be more pronounced over the southern hemisphere. The net balance from these changes in gravitational fields will however depend on the melting rates of the respective glaciers and noticeable impacts would not likely be evident within the next century. **The sea-level rise estimates in this report will therefore not reflect any finger-printing considerations.**

A reputable and highly-regarded sea-level rise expert and contributor to the IPCC process, Professor Stefan Rahmstorf of Potsdam University, Germany, has developed a simple semi-empirical correlation between mean globally averaged surface air temperature and global sea-level rise trends. He has then applied this correlation to predicted climate change warming over the next century to come up with new estimates of sea-level rise in the range of approximately 50-130 cm with a median value of 90 cm (Rahmstorf, 2007). The global sea-level rise estimates for this report were derived from the Professor Rahmstorf median A2 projections (red dashed line) as depicted in Figure 2. The yellow line is representative of a B1 scenario and the light blue represents the A1FI scenario. The gray uncertainty area spans the range of global temperature rise of 1.4°C to 5.8°C.

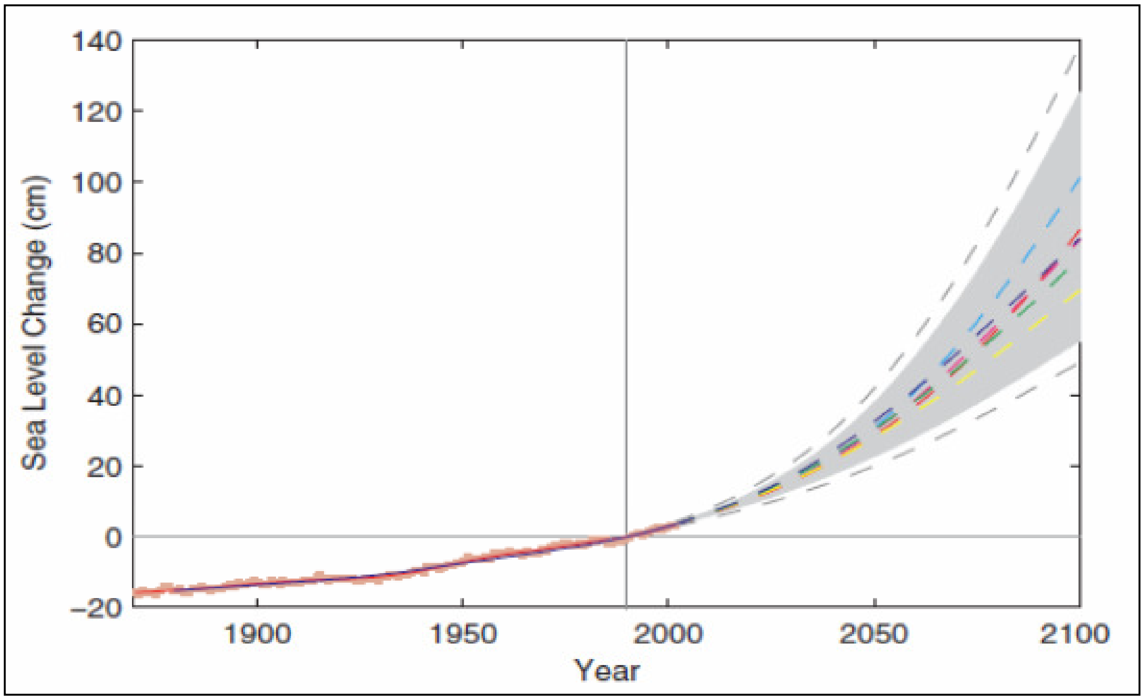

Figure 2: Sea-level rise based on simple relationship between rate of sea-level rise and global average temperature. (Rahmstorf, 2007).

3.2 Local Crustal Subsidence

In addition to sea level rise due to a) thermal expansion of the oceans , b) melting of nonpolar glaciers and c) changes in the volume of the ice sheets of West Antarctica and Greenland, sea levels along most coasts of Atlantic Canada are rising due to the fact that these coastlines are very slowly subsiding (up to a few tenths of meters per century). This relates to a post-glacial adjustment of the earth's crust. The rebound (maximum in the Hudson Bay area) and a corresponding subsidence along coastlines is in response to a depression of the earth's crust caused by the immense weight of continental ice sheets during the last Ice Age (Henton, Craymer, Ferland, Dragert, Mazzotti, & Forbes, 2006). Figure 3 (left) shows a schematic drawing of crustal motion both during a glacial maximum and after glaciations (the present scenario). Figure 3 (right) shows preliminary results of the earth's crust vertical motion in mm/year obtained from Natural Resources Canada's network of the Canadian Base Network (CBN) (Henton, Craymer, Ferland, Dragert, Mazzotti, & Forbes, 2006). These results are in agreement with north-south slopes calculated in Daigle (2006) and derived partially from previous research (Koohzare, Vanicek, & Santos, 2005) as depicted in Figure 4. A detailed analysis of tide gauge data from Charlottetown, Shediac (Pointe-du-Chêne) and Escuminac (Daigle, 2006) led to the conclusion that the zero-line as depicted in Figure 4 should be displaced further north towards the Gaspé peninsula.

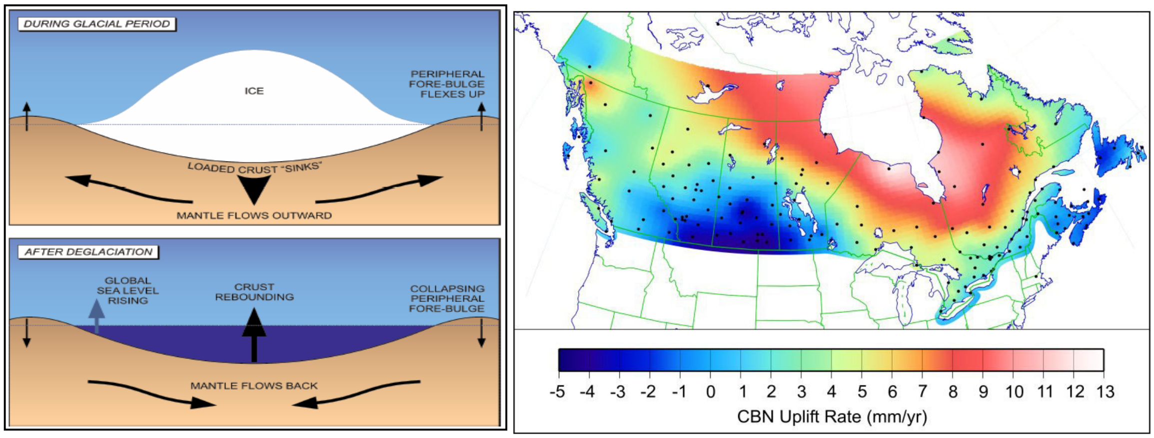

Figure 3: Crustal motion due to ice sheet loadings

Schematic drawing at left illustrates how the earth's crust reacts to changes in ice sheet loadings. Map at right depicts preliminary results of the earth's crust vertical motion in mm/year obtained from Natural Resources Canada's network of the CBN. Source: (Henton, Craymer, Ferland, Dragert, Mazzotti, & Forbes, 2006)

Some more recent research results (Koohzare, Vanicek, & Santos, 2007) with results depicted in mm/year in Figure 5 show a significant shift of the zero-line northward over the Gaspé peninsula, in agreement with findings in Daigle (2006). These results also show some similarities with the CBN data as depicted in Figure 3, but also a significant departure from earlier work in Daigle (2006) over New Brunswick.

The "take-home message" from the preceding is that there are some significant gaps in understanding the vertical crustal movement field over eastern Canada other than at Halifax and Charlottetown (Pers. Comm., D. Forbes, NRCan) where estimates are correlated with precise GPS determinations of vertical motion and water level measurements from tide gauges. It is expected that within the next few years (Pers. Comm., D. Forbes, NRCan), similar vertical crustal movement assessments will be conducted at all continuous tide gauges in the region using a Precision Point Positioning (PPP) technique.

Estimates of crustal subsidence for the New Brunswick coastal sections being considered in this report have been estimated using the best understanding of the data available at this time, and are listed in Appendix A, Table 2. These estimates will need to be refined pending the availability of more up-to-date data such as PPP.

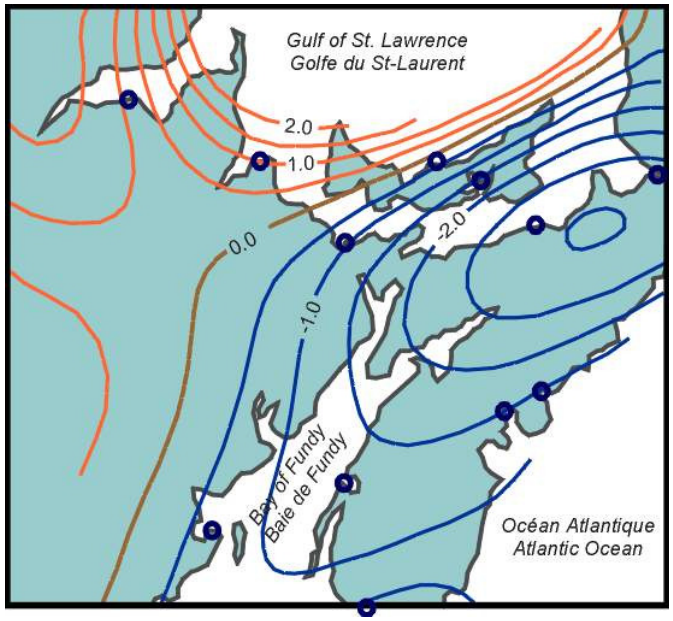

Figure 4: Vertical crustal motion in the Maritime Provinces (mm/yr) from published research (Koohzare, Vanicek, & Santos, 2005)

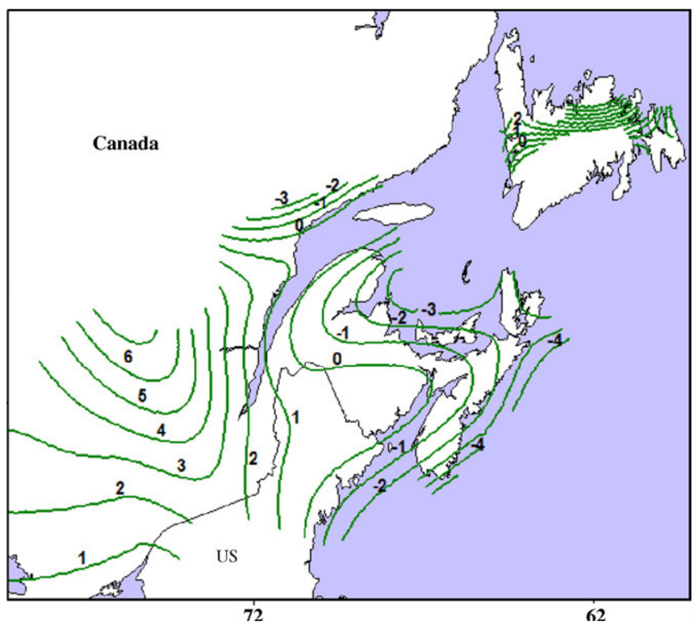

Figure 5: More recent research results on vertical crustal movement from (Koohzare, Vanicek, & Santos, 2007)

3.3 Storm-Surge Flooding Return Periods

A storm surge can be defined at the coast as the difference between the observed water level and the predicted astronomical tide. Tides result from the rise and fall of sea levels caused by the combined effects of the gravitational forces exerted by the moon and the sun and the rotation of the Earth. In reality, observed tide levels are rarely as predicted for the simple fact that their predicted levels are based on standard atmospheric pressure conditions, that being a mean sea level pressure of 101.33 kilopascals (1013.3 millibars). When the atmospheric pressure is lower than the standard, observed tides are higher than predicted and the opposite is true for higher atmospheric pressure. Additionally, onshore and offshore winds will respectively increase and diminish the sea level.

Storm surges can be positive or negative and may therefore raise or lower sea level from its predicted value. Storm surges occur everywhere along our coastlines and can occur anywhere in the tidal cycle or may last over several tidal cycles. Large positive storm surges at times of high tide are events that lead to coastal flooding, whereas when they coincide with low tides, flooding problems are not expected. The storm surge return periods presented in this report were calculated using the Bernier (2005) method as the probability that a given storm surge event would coincide with a run of high tides.

Elevated sea levels also enhance wave attack and coastal erosion and in the presence of ice and ice pressure can lead to ice ride-up and pile-up. The magnitude of storm surges depends on the nature of the meteorological event responsible for the reduced atmospheric pressure and the strength, duration and direction of the winds associated with a particular event. Atlantic Canada has seen extreme cases of coastal flooding, and the frequency of these events seems to have been increasing over the past ten years. The most common devastating storms are the synoptic scale (meaning a horizontal scale of the order of 1000 km) events that typically intensify or re-form off the US east coast. The centre of these storms typically crosses Nova Scotia and tracks through the Gulf of Saint Lawrence.

Estimates of extreme total sea levels and associated levels of risk for this report were extracted from published results (Bernier, 2005), as displayed on the Environment Canada Atmospheric Hazards Web Site – Atlantic at the following link: http://atlantic.hazards.ca/search/search-e.html?user=H&who=A&class[]=427.

Figure 6, extracted from the above website, shows the statistically-derived total sea levels and storm surge residuals from the Shediac tide gauge database (Bernier, 2005). The storm surge residual is defined as the difference between the predicted astronomical tide and the actual water level as measured, in this case, by a tide gauge.

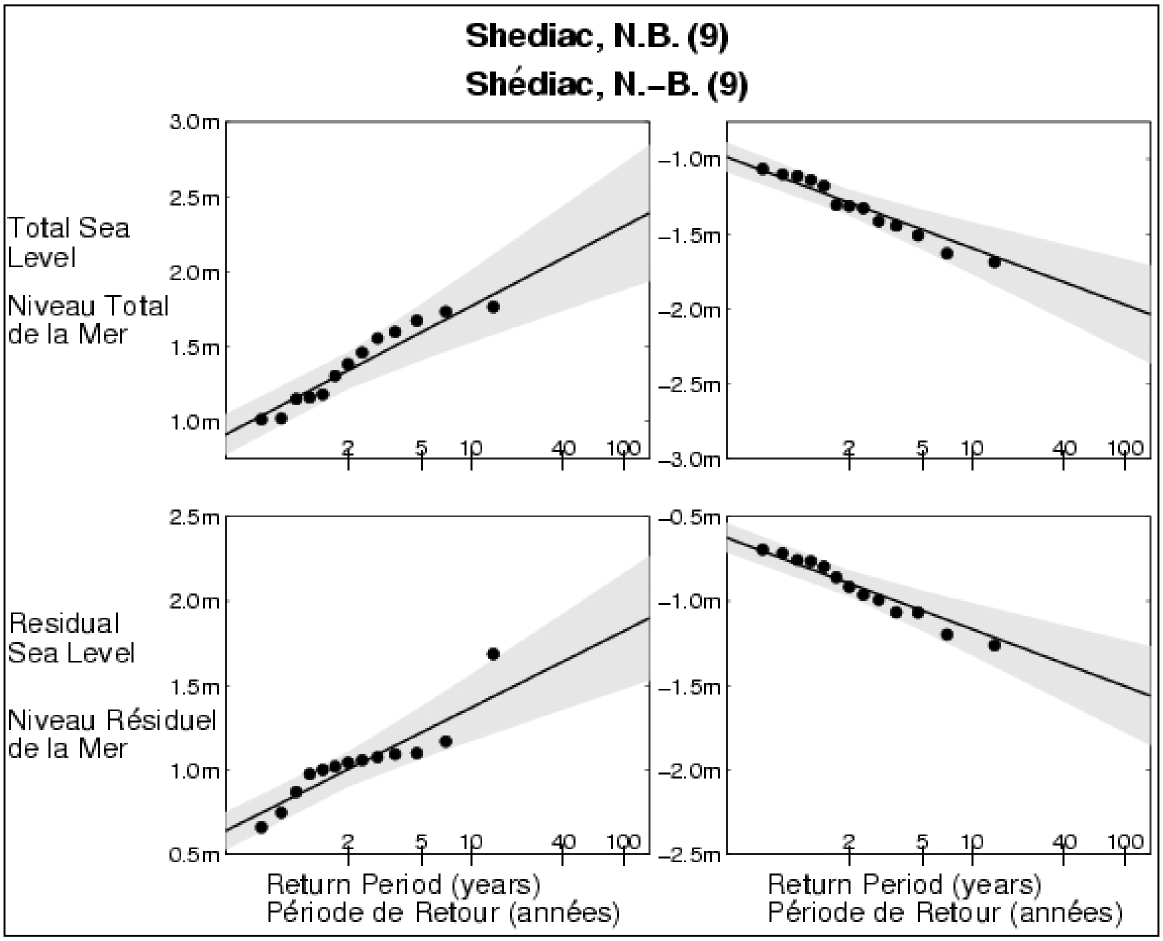

Figure 6: Total sea levels (upper left) and storm surge residual plots (lower left) for Shediac from Bernier, N.B. (2005).

Plots at right show negative surges which occur when the atmospheric pressure is higher than normal. Close inspection of the published residual graphs (difference between the observed sea level and the anticipated tides) reveals that a significant number of recorded extreme storm surge events (represented by black dots) fall within range of the upper 95% confidence limit. Note: the maximum water level recorded in Shediac Bay (21 Jan 2000, 3.62 m above CD including a residual storm surge component of 2.0 m) is not plotted on the graphs because the Bernier (2005) analysis covers only the storms that occurred during period 1960-1999.

A return period represents the average time between occurrences of an event exceeding a given level. Another way of interpreting a level with a given return period (T) is that in any year there is a 1/T chance that the return level will be exceeded. For example, in any given year there is a 10% chance that 10 year return period value will be exceeded. Similarly, in any given year there is a 1% chance that a 100 year return period will be exceeded. An example of a 100-year storm surge return period map can be seen in Figure 7.

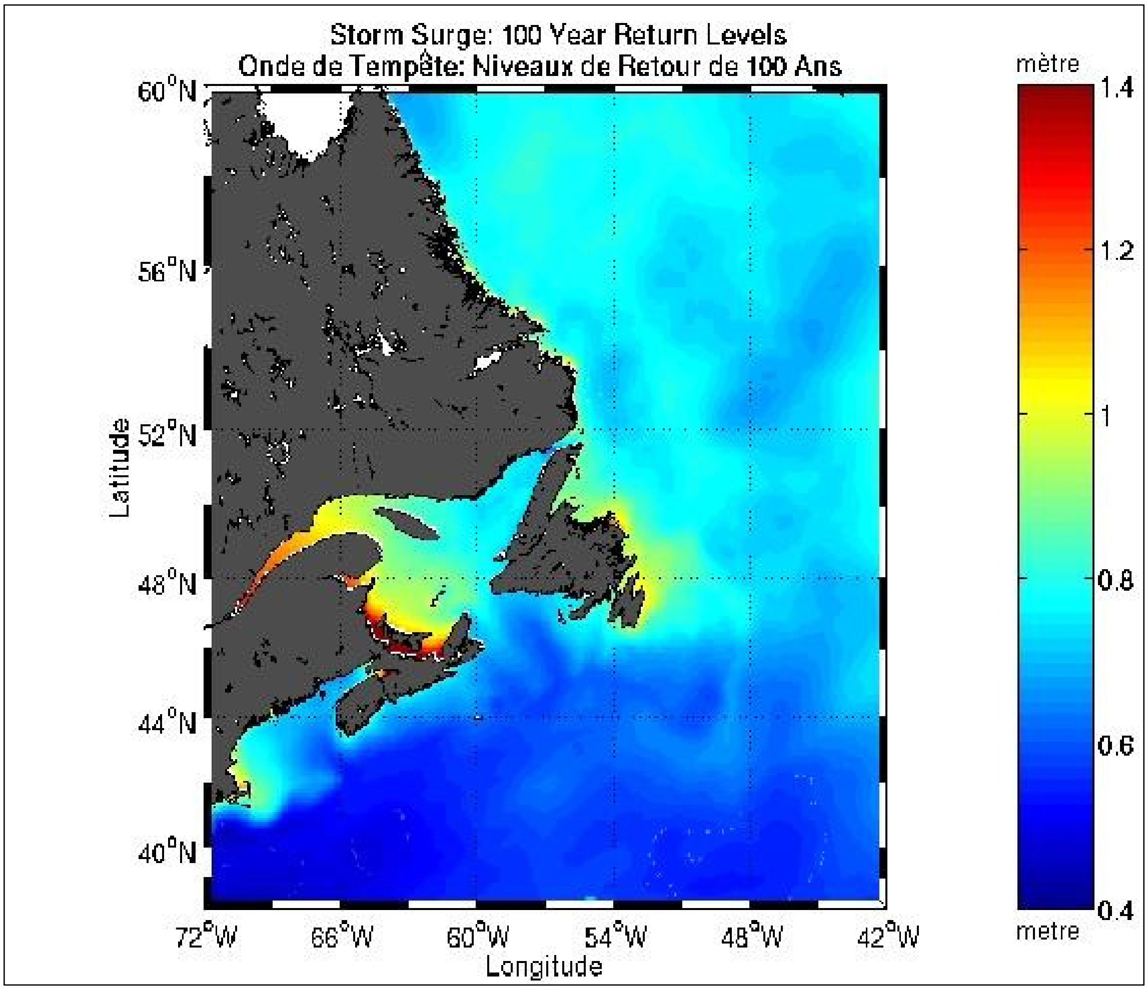

Figure 7: Storm surge 100-year return period map. (Bernier, 2005)

The data used to estimate the extreme total sea-level return periods was extracted from the upper boundary of the shaded area on the representative graphs. The procedure used was as follows:

Residual sea-level values for the 1-,2-, 5-,10-, 25-, 40- and 100-year return periods, mined from the published semi-logarithmic graphs, were subsequently plotted on a linear graph and fitted to a natural logarithm (LN) regression curve; values were then calculated from the regression equation for the 1-,2-, 5-,10-, 25-, 40- and 100-year return periods. See Figures 8 and 9 for Saint John example. Total estimated return-period sea levels (storm surge + tide levels) for the years 2025, 2055, 2085 and 2100 were then calculated as the sum of the relevant incremental values (estimated sea-level rise + storm surge) and the current Higher High Water at Large Tide (HHWLT) values (see Appendix A, Tables

3- 16). The HHWLT values were provided the Canadian Hydrographic Service (CHS) of Fisheries and Oceans Canada (Pers. Comm., P. MacAulay, CHS). The HHWLT value is calculated over a 19 year cycle and represents the average of the highest annual high water, one for each of the 19 years of prediction.

In more practical terms, the HHWLT value is representative of the highest astronomical tides possible for a given location; the Chart Datum (CD)-zero value is representative of the lowest possible tide for a given location; the Mean Water Level (MWL) value is representative of the average of HHWLT and CD-zero; and the CGVD28-zero value represents approximately the MWL value, but there are varying differences depending on the location (normally within 10-25 cm).

It is to be noted that HHWLT and Extreme Total Sea Levels (defined as the sum of HHWLT, sea-level rise and storm surge return-period values) presented in this report are referenced to the geodetic reference level CGVD28. These values were calculated, requiring a conversion between CD and CGVD28 reference levels that are specific to each location, as provided by the CHS where available. Where the conversion was not available from the CHS, the New Brunswick Department of Natural Resources (D. Bérubé and M. Desrosiers) calculated the values through precise GPS surveys at the location in question. Results from previous research were used for HHWLT values in the Tantramar area (Ollerhead, J., 2011).

Storm-surge residual values for locations without tide gauge statistics were estimated from the Bernier (2005) color-coded return-period maps (Figure 7 shows 100-year return period map) and from the author’s understanding of the behaviour of synoptic storms in the region. Estimates of sea-level rise components (global sea-level rise + crustal subsidence) for each Coastal Zone are detailed in Appendix A (Table 2).

Estimates of the anticipated changes in Total Sea Levels (HHWLT + sea-level rise + storm surge flooding) for the future times frames of 2025, 2055, 2085 and 2100, represented in Appendix A (Tables 3 - 16) are meant to represent the worst case flooding scenario resulting from the simultaneous occurrence of a significant storm-surge event for the respective return-periods and a high astronomical tide at a given location (the HHWLT).

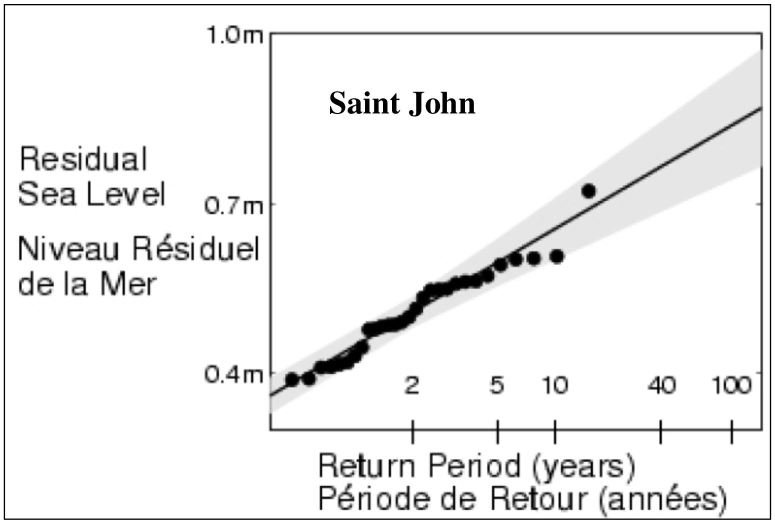

Figure 8: Residual sea levels (with 95% confidence levels in grey) and associated return periods for Saint John, with x-axis values on logarithmic scale (Bernier, 2005).

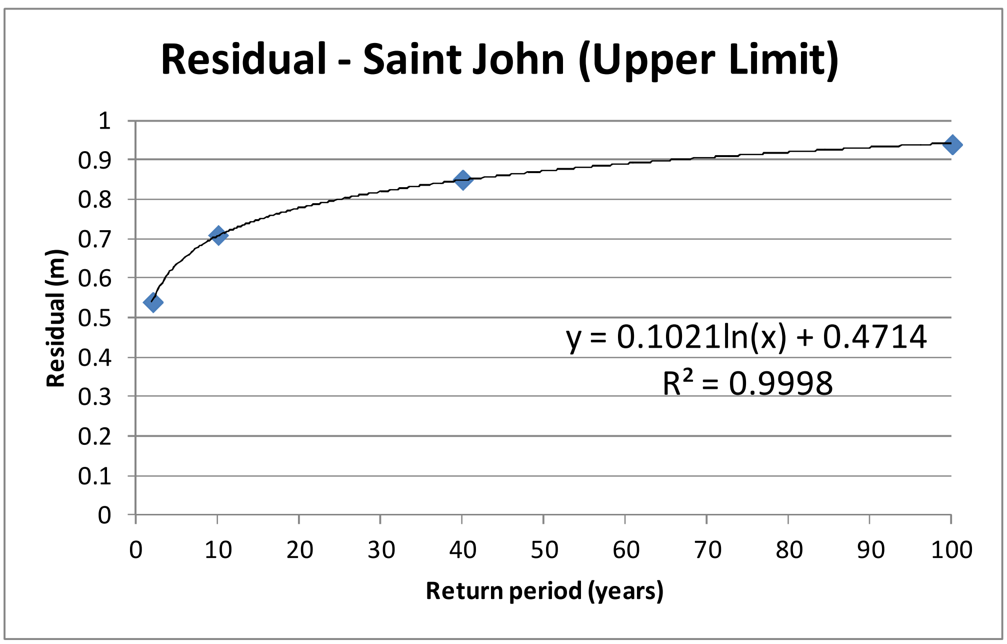

Figure 9: Saint John residuals showing the same data as in Figure 8, but with x-axis values on a linear scale and the associated regression equation used to calculate residual values for 1-, 2-, 5-, 10-, 25-, 50- and 100-year return periods.

3.4 Coastal Section Selection

The Coastal Section flooding scenarios were developed on the basis of combined quasi-homogeneous HHWLT elevations and storm-surge flooding climatology. The resulting HHWLT values (in geodetic reference frame CGVD28), were calculated as the difference between the HHWLT (CD) and the difference between CD and CGVD28 (as provided by

CHS where available or surveyed by NB Natural Resources). The resulting HHWLT values are displayed on the map in Figure 10. Based on the above-noted rationale, a total of 14 coastal section segments, identified as Zones 1-14, are shown in Figure 11 and presented in the various Tables of Appendix A .

There was one location, (Tracadie Sheila) where the above-mentioned calculations produced much lower HHWLT results than the surrounding coastal segment, due most likely to the sheltered nature of Tracadie Bay. A separate Zone was hence produced for that location.

The Bay of Fundy was problematic due to the lack of CHS tidal prediction points between Saint Martins and Alma. Since there was not a CD to CGVD28 conversion available for Saint Martins, estimates of future sea level for the Bay of Fundy coastline between Cape Spencer and Alma are not provided in this report.

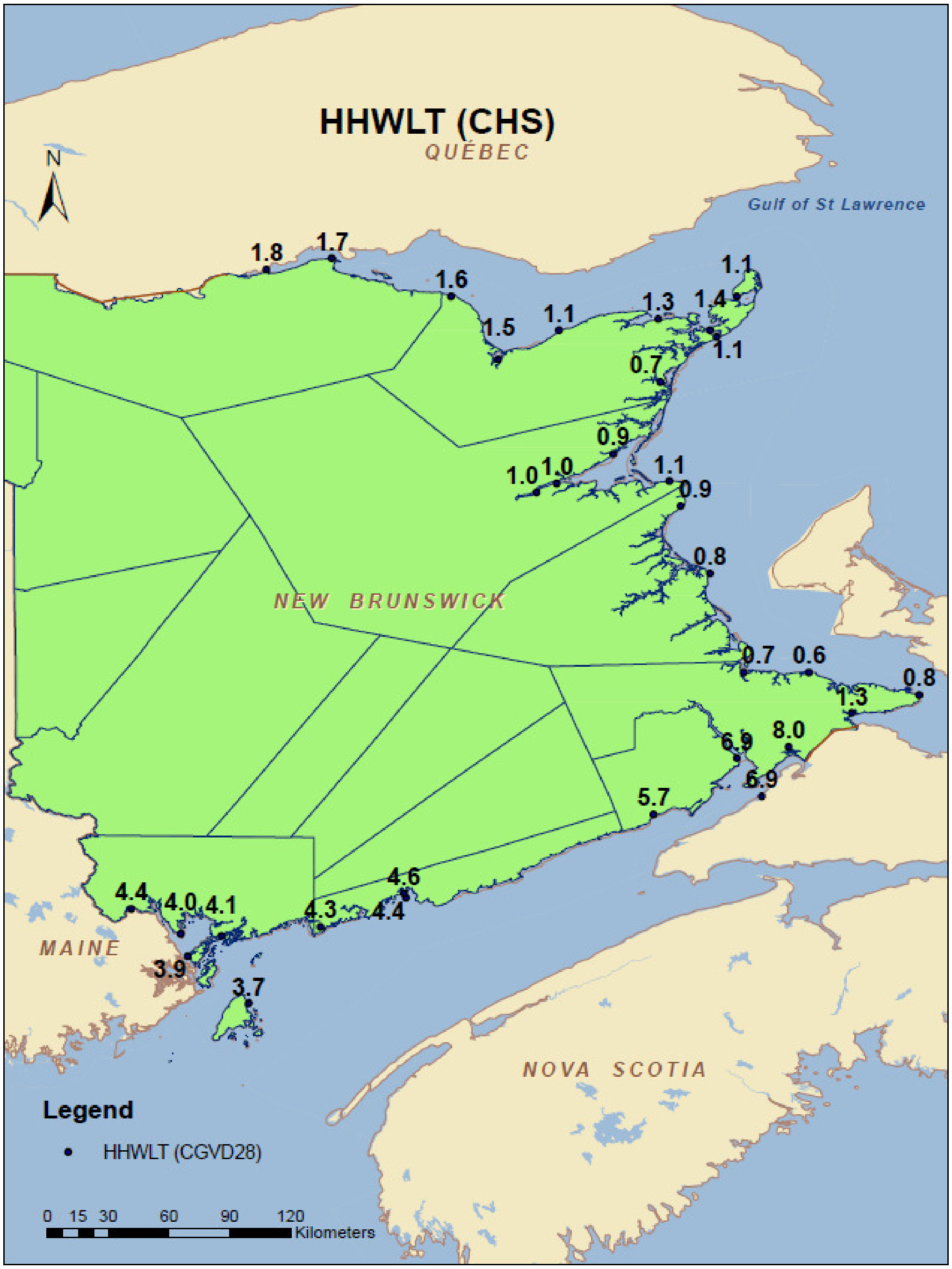

Figure 10: Map showing HHWLT values (metres above CGVD28) used as a guideline for Coastal Zone selection. (Data source, CHS)

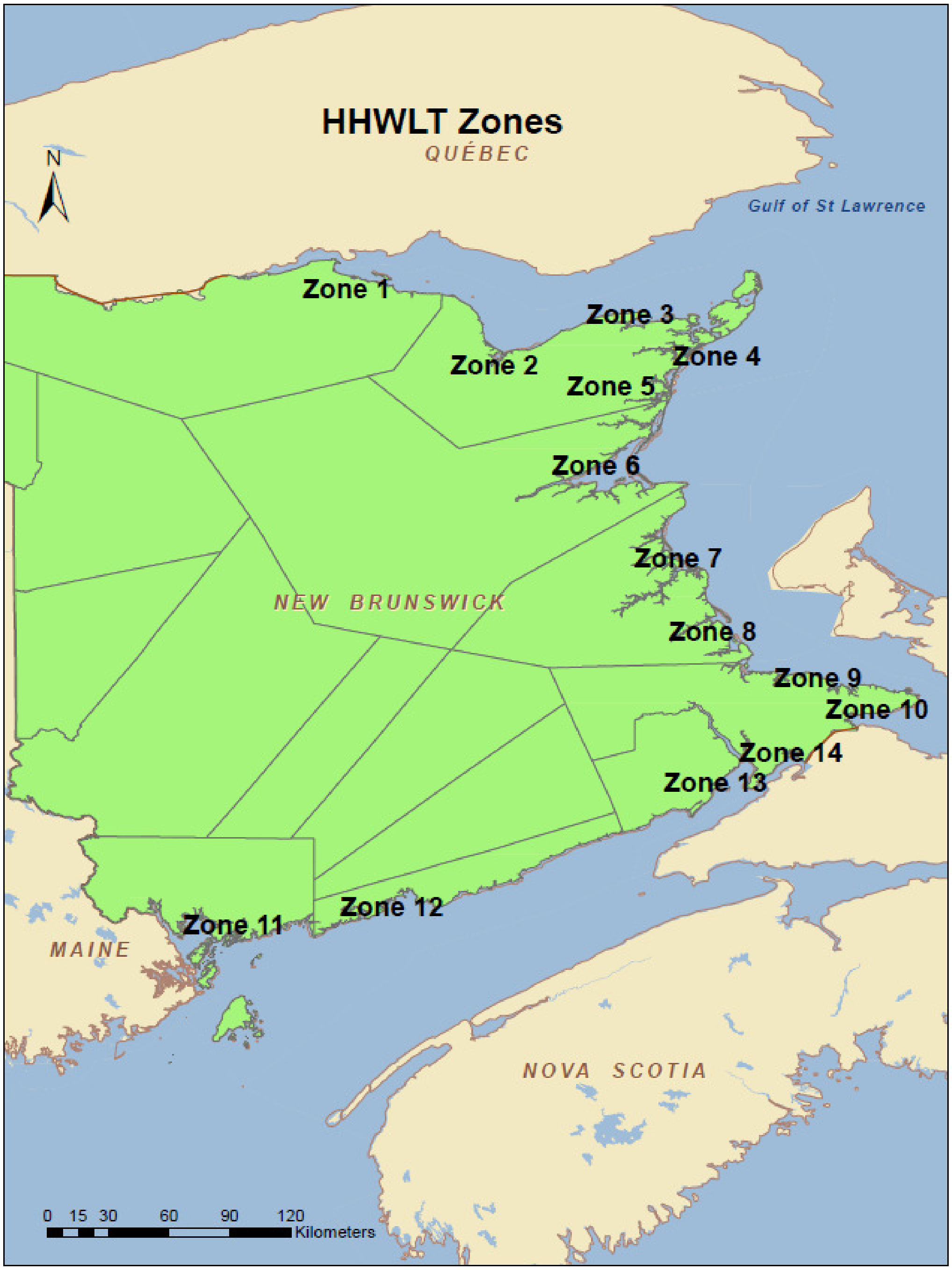

Figure 11. Map showing Coastal Zones based on quasi-homogeneous HHWLT and storm surge flooding climatology

4 Summary and Recommendations

The scientific community has concluded that global sea-level rise estimates presented in the IPCC AR4 report (IPCC, 2007) were too low because the impact of the potential acceleration of the flow rates of the Greenland and Antarctic ice sheets were purposely excluded from the calculations.

This report is based on the higher estimates of global sea-level rise using a new approach based on a simple correlation (semi-empirical) between mean globally averaged surface air temperature and global sea-level rise trends. The correlation is then applied to predicted climate change warming scenarios over the next century to come up with new global estimates of sea-level rise in the range of approximately 60-120 cm (Rahmstorf, S., 2007).

The estimates of global sea-level rise were used, in conjunction with the best estimates of local vertical motion (crustal subsidence) to calculate total sea-level rise estimates over the next century for the coastlines of New Brunswick of 0.9 to 1.05 metres. These estimates were then combined with documented storm-surge return period climatology to develop flooding scenarios for future milestones of 2025, 2055, 2085 and 2100. It should be noted that with a 1-metre sea level rise scenario, the flooding levels reached at the height of the January 21, 2000 along the southeast coastline of New Brunswick (then close to a 1 in 100-year event), could statistically occur every year.

It is recommended that the main value of the sea-level rise estimates for the selected return-period and year (Appendix A, Tables 3-16) be used as a tool for sea-level rise adaptation planning. As a further precaution, contingencies should be planned to account for the potential impact of the upper limits (main values + error bars), in the context of risk management. These upper limits, named Plausible Upper Bound Water Levels in this report, are listed in Appendix A (Table 18) with an estimated value for each Coastal Zone. Planners should also keep in mind that sea levels will continue to increase past the year 2100.

Users of the Flooding Estimates presented in the report should be cognisant that the baseline HHWLT tidal levels used as representative of Coastal Zones are based on available CHS prediction points; hence, care needs to be given to the application of the stated Zone HHWLT error bars to best suit the specific HHWLT of a location of interest.

5 Bibliography

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Appendix A

Estimate of Anticipated Change in Total Sea Levels for the Years 2025, 2055, 2085 and 2100

Table 2. Anticipated change in relative sea level (metres)

Coastal Section	**Global Sea-Level Rise (2100)** [1]	**Vertical Motion (2100)**	**Total Change (2025)** [2]	**Total Change (2055)** [3]	**Total Change (2085)**[4]	**Total Change (2100)**
Zone 1: Restigouche County	0.90 ± 0.43	0.10 ± 0.05	0.14 ± 0.03	0.40 ± 0.15	0.78 ± 0.36	1.00 ± 0.48
Zone 2: Gloucester County - County Line to Grande-Anse (inclusive)	0.90 ± 0.43	0.10 ± 0.05	0.14 ± 0.03	0.40 ± 0.15	0.78 ± 0.36	1.00 ± 0.48
Zone 3: Gloucester County - Grande-Anse to Pointe-Sauvage	0.90 ± 0.43	0.10 ± 0.05	0.14 ± 0.03	0.40 ± 0.15	0.78 ± 0.36	1.00 ± 0.48
Zone 4: Gloucester County - Pointe-Sauvage to Northumberland County Line	0.90 ± 0.43	0.10 ± 0.05	0.14 ± 0.03	0.40 ± 0.15	0.78 ± 0.36	1.00 ± 0.48
Zone 5: Gloucester County - Tracadie-Sheila (Tracadie Bay)	0.90 ± 0.43	0.10 ± 0.05	0.14 ± 0.03	0.40 ± 0.15	0.78 ± 0.36	1.00 ± 0.48

[1] The value of 90 cm is the central value for the Rahmstorf year 2100 estimates (Figure 2) and the ±43 cm error bar (calculated from range of global temperature rise of 1.4°C to 5.8°C) represents the associated range.
[2] Total includes linear increase of vertical motion (25%) + prorated non-linear increase of 100-year global sea-level rise.
[3] Total includes linear increase of vertical motion (55%) + prorated non-linear increase of 100-year global sea-level rise.
[4] includes linear increase of vertical motion (85%) + prorated non-linear increase of 100-year global sea-level rise.

Table 2 continued

Coastal Section	**Global Sea-Level Rise (2100)**	**Vertical Motion (2100)**	**Total Change (2025)**	**Total Change (2055)**	**Total Change (2085)**	**Total Change (2100)**
Zone 6: Northumberland County (Miramichi Bay)	0.90 ± 0.43	0.10 ± 0.05	0.14 ± 0.03	0.40 ± 0.15	0.78 ± 0.36	1.00 ± 0.48
Zone 7: Kent County - County Line to Saint Édouard-de-Kent (inclusive)	0.90 ± 0.43	0.10 ± 0.05	0.14 ± 0.03	0.40 ± 0.15	0.78 ± 0.36	1.00 ± 0.48
Zone 8: Kent County - Saint-Édouard-de-Kent to Westmorland County Line	0.90 ± 0.43	0.12 ± 0.05	0.14 ± 0.03	0.41 ± 0.15	0.79 ± 0.36	1.02 ± 0.48
Zone 9: Westmorland County - County Line to Cape Spear	0.90 ± 0.43	0.15 ± 0.05	0.15 ± 0.03	0.42 ± 0.15	0.82 ± 0.36	1.05 ± 0.48
Zone 10: Westmorland County - Cape Spear to Port Elgin	0.90 ± 0.43	0.15 ± 0.05	0.15 ± 0.03	0.42 ± 0.15	0.82 ± 0.36	1.05 ± 0.48
Zone 11: Charlotte County (including Grand Manan)	0.90 ± 0.43	0.10 ± 0.05	0.14 ± 0.03	0.40 ± 0.15	0.78 ± 0.36	1.00 ± 0.48
Zone 12: Saint John County - County Line to Cape Spencer	0.90 ± 0.43	0.10 ± 0.05	0.14 ± 0.03	0.40 ± 0.15	0.78 ± 0.36	1.00 ± 0.48
Zone 13: Albert County - Alma to Hopewell (Shepody Bay)	0.90 ± 0.43	0.12 ± 0.05	0.14 ± 0.03	0.41 ± 0.15	0.79 ± 0.36	1.02 ± 0.48
Zone 14: Westmorland County - Rockport to Sackville	0.90 ± 0.43	0.15 ± 0.05	0.15 ± 0.03	0.42 ± 0.15	0.82 ± 0.36	1.05 ± 0.48

Estimated Extreme Total Sea Levels for Years 2000, 2025, 2050, 2085 and 2100[5][6][7]

Table 3. Zone 1: Restigouche County

Zone 1: Restigouche County, HHWLT 1.6 m ± 0.2 (CGVD28)[8]						
Return Period	**Surge Residual** [9]	**Level 2000**	**Level 2025**	**Level 2055**	**Level 2085**	**Level 2100**
1-Year	0.60 ± 0.20	2.20 ± 0.40	2.34 ± 0.43	2.60 ± 0.55	2.98 ± 0.76	3.20 ± 0.88
2-Year	0.74 ± 0.20	2.34 ± 0.40	2.48 ± 0.43	2.74 ± 0.55	3.12 ± 0.76	3.34 ± 0.88
5-Year	0.92 ± 0.20	2.52 ± 0.40	2.66 ± 0.43	2.92 ± 0.55	3.30 ± 0.76	3.52 ± 0.88
10-Year	1.06 ± 0.20	2.66 ± 0.40	2.80 ± 0.43	3.06 ± 0.55	3.44 ± 0.76	3.66 ± 0.88
25-Year	1.24 ± 0.20	2.84 ± 0.40	2.98 ± 0.43	3.24 ± 0.55	3.62 ± 0.76	3.84 ± 0.88
50-Year	1.38 ± 0.20	2.98 ± 0.40	3.12 ± 0.43	3.38 ± 0.55	3.76 ± 0.76	3.98 ± 0.88
100-Year	1.52 ± 0.20	3.12 ± 0.40	3.26 ± 0.43	3.52 ± 0.55	3.90 ± 0.76	4.12 ± 0.88

[5] Total Sea Level is defined as the sum of HHWLT, sea-level rise and storm surge return-period values for each return-period and for each of the years 2000, 2025, 2055, 2085 and 2100.
[6] Surge Residual error bar of 0.2 m includes the 0.08 m from *Storm Surge Extremal Analysis (Bernier, 2005)* and a further arbitrary value of 0.12 m linked to the application of tide gauge-specific storm surge statistics to a wider coastal zone.
[7] Error bars for the Level 2000, 2025, 2055, 2085 and 2100 Extreme Total Sea Levels are the sum of the error bars for the HHWLT, Surge Residual and the respective Total Sea Level Changes from Table 2.
[8] Error bars represent the difference between the selected HHWLT value for Zone and the range of HHWLT values for Zone.
[9] Storm surge residual estimated as average between Rivière-au-Renard and Escuminac tide gauge statistics (upper 95% confidence value).

Table 4. Zone 2: Gloucester County - County Line to Grande-Anse (inclusive)

Zone 2: Gloucester County – County Line to Grande-Anse (Inclusive), HHWLT 1.5 m ± 0.1 (CGVD28)[10]						
Return Period	**Surge Residual [11]**	**Level 2000**	**Level 2025**	**Level 2055**	**Level 2085**	**Level 2100**
1-Year	0.60 ± 0.20	2.10 ± 0.30	2.24 ± 0.33	2.50 ± 0.45	2.88 ± 0.66	3.10 ± 0.78
2-Year	0.74 ± 0.20	2.24 ± 0.30	2.38 ± 0.33	2.64 ± 0.45	3.02 ± 0.66	3.24 ± 0.78
5-Year	0.92 ± 0.20	2.42 ± 0.30	2.56 ± 0.33	2.82 ± 0.45	3.20 ± 0.66	3.42 ± 0.78
10-Year	1.06 ± 0.20	2.56 ± 0.30	2.70 ± 0.33	2.96 ± 0.45	3.34 ± 0.66	3.56 ± 0.78
25-Year	1.24 ± 0.20	2.74 ± 0.30	2.88 ± 0.33	3.14 ± 0.45	3.52 ± 0.66	3.74 ± 0.78
50-Year	1.38 ± 0.20	2.88 ± 0.30	3.02 ± 0.33	3.28 ± 0.45	3.66 ± 0.66	3.88 ± 0.78
100-Year	1.52 ± 0.20	3.02 ± 0.30	3.16 ± 0.33	3.42 ± 0.45	3.80 ± 0.66	4.02 ± 0.78

[10] Error bars represent the difference between the selected HHWLT value for Zone and the range of HHWLT values for Zone.
[11] Storm surge residual estimated as average between Rivière-au-Renard and Escuminac tide gauge statistics (upper 95% confidence value).

Table 5. Zone 3: Gloucester County - Grande-Anse to Pointe-Sauvage (inclusive)

Zone 3: Gloucester County - Grande-Anse to Pointe-Sauvage (inclusive), HHWLT 1.2 m ± 0.2 (CGVD28)[12]						
Return Period	**Surge Residual [13]**	**Level 2000**	**Level 2025**	**Level 2055**	**Level 2085**	**Level 2100**
1-Year	0.59 ± 0.20	1.79 ± 0.40	1.93 ± 0.43	2.19 ± 0.55	2.57 ± 0.76	2.79 ± 0.88
2-Year	0.67 ± 0.20	1.87 ± 0.40	2.01 ± 0.43	2.27 ± 0.55	2.65 ± 0.76	2.87 ± 0.88
5-Year	0.79 ± 0.20	1.99 ± 0.40	2.13 ± 0.43	2.39 ± 0.55	2.77 ± 0.76	2.99 ± 0.88
10-Year	0.97 ± 0.20	2.17 ± 0.40	2.31 ± 0.43	2.57 ± 0.55	2.95 ± 0.76	3.17 ± 0.88
25-Year	1.11 ± 0.20	2.31 ± 0.40	2.45 ± 0.43	2.71 ± 0.55	3.09 ± 0.76	3.31 ± 0.88
50-Year	1.23 ± 0.20	2.43 ± 0.40	2.57 ± 0.43	2.83 ± 0.55	3.21 ± 0.76	3.43 ± 0.88
100-Year	1.34 ± 0.20	2.54 ± 0.40	2.68 ± 0.43	2.94 ± 0.55	3.32 ± 0.76	3.54 ± 0.88

[12] Error bars represent the difference between the selected HHWLT value for Zone and the range of HHWLT values for Zone.
[13] Storm surge residual estimated as average between Rivière-au-Renard and Escuminac tide gauge statistics (mean value).

Table 6. Zone 4: Gloucester County - Pointe-Sauvage to Northumberland County Line

Zone 4: Gloucester County - Pointe-Sauvage to Northumberland County Line, HHWLT 1.0 m ± 0.1 (CGVD28)[14]						
Return Period	**Surge Residual [15]**	**Level 2000**	**Level 2025**	**Level 2055**	**Level 2085**	**Level 2100**
1-Year	0.59 ± 0.20	1.59 ± 0.30	1.73 ± 0.33	1.99 ± 0.45	2.37 ± 0.66	2.59 ± 0.78
2-Year	0.67 ± 0.20	1.67 ± 0.30	1.81 ± 0.33	2.07 ± 0.45	2.45 ± 0.66	2.67 ± 0.78
5-Year	0.79 ± 0.20	1.79 ± 0.30	1.93 ± 0.33	2.19 ± 0.45	2.57 ± 0.66	2.79 ± 0.78
10-Year	0.97 ± 0.20	1.97 ± 0.30	2.11 ± 0.33	2.37 ± 0.45	2.75 ± 0.66	2.97 ± 0.78
25-Year	1.11 ± 0.20	2.11 ± 0.30	2.25 ± 0.33	2.51 ± 0.45	2.89 ± 0.66	3.11 ± 0.78
50-Year	1.23 ± 0.20	2.23 ± 0.30	2.37 ± 0.33	2.63 ± 0.45	3.01 ± 0.66	3.23 ± 0.78
100-Year	1.34 ± 0.20	2.34 ± 0.30	2.48 ± 0.33	2.74 ± 0.45	3.12 ± 0.66	3.34 ± 0.78

[14] Error bars represent the difference between the selected HHWLT value for Zone and the range of HHWLT values for Zone.
[15] Storm surge residual estimated as average between Rivière-au-Renard and Escuminac tide gauge statistics (mean value).

Table 7. Zone 5: Gloucester County - Tracadie-Sheila (Tracadie Bay)

Zone 5: Gloucester County - Tracadie-Sheila (Tracadie Bay), HHWLT 0.7 m ± 0.1 (CGVD28)[16]						
Return Period	**Surge Residual [17]**	**Level 2000**	**Level 2025**	**Level 2055**	**Level 2085**	**Level 2100**
1-Year	0.59 ± 0.20	1.29 ± 0.30	1.43 ± 0.33	1.69 ± 0.45	2.07 ± 0.66	2.29 ± 0.78
2-Year	0.67 ± 0.20	1.37 ± 0.30	1.51 ± 0.33	1.77 ± 0.45	2.15 ± 0.66	2.37 ± 0.78
5-Year	0.79 ± 0.20	1.49 ± 0.30	1.63 ± 0.33	1.89 ± 0.45	2.27 ± 0.66	2.49 ± 0.78
10-Year	0.97 ± 0.20	1.67 ± 0.30	1.81 ± 0.33	2.07 ± 0.45	2.45 ± 0.66	2.67 ± 0.78
25-Year	1.11 ± 0.20	1.81 ± 0.30	1.95 ± 0.33	2.21 ± 0.45	2.59 ± 0.66	2.81 ± 0.78
50-Year	1.23 ± 0.20	1.93 ± 0.30	2.07 ± 0.33	2.33 ± 0.45	2.71 ± 0.66	2.93 ± 0.78
100-Year	1.34 ± 0.20	2.04 ± 0.30	2.18 ± 0.33	2.44 ± 0.45	2.82 ± 0.66	3.04 ± 0.78

[16] Error bars represent the difference between the selected HHWLT value for Zone and the range of HHWLT values for Zone.
[17] Storm surge residual estimated as average between Rivière-au-Renard and Escuminac tide gauge statistics (mean value).

Table 8. Zone 6: Northumberland County (Miramichi Bay)

Zone 6: Northumberland County (Miramichi Bay), HHWLT 1.0 m ± 0.1 (CGVD28)[18]						
Return Period	**Surge Residual [19]**	**Level 2000**	**Level 2025**	**Level 2055**	**Level 2085**	**Level 2100**
1-Year	0.63 ± 0.20	1.63 ± 0.30	1.77 ± 0.33	2.03 ± 0.45	2.41 ± 0.66	2.63 ± 0.78
2-Year	0.79 ± 0.20	1.79 ± 0.30	1.93 ± 0.33	2.19 ± 0.45	2.57 ± 0.66	2.79 ± 0.78
5-Year	1.00 ± 0.20	2.00 ± 0.30	2.14 ± 0.33	2.40 ± 0.45	2.78 ± 0.66	3.00 ± 0.78
10-Year	1.16 ± 0.20	2.16 ± 0.30	2.30 ± 0.33	2.56 ± 0.45	2.94 ± 0.66	3.16 ± 0.78
25-Year	1.37 ± 0.20	2.37 ± 0.30	2.51 ± 0.33	2.77 ± 0.45	3.15 ± 0.66	3.37 ± 0.78
50-Year	1.53 ± 0.20	2.53 ± 0.30	2.67 ± 0.33	2.93 ± 0.45	3.31 ± 0.66	3.53 ± 0.78
100-Year	1.69 ± 0.20	2.69 ± 0.30	2.83 ± 0.33	3.09 ± 0.45	3.47 ± 0.66	3.69 ± 0.78

[18] Error bars represent the difference between the selected HHWLT value for Zone and the range of HHWLT values for Zone.
[19] Storm surge residual estimated as Escuminac tide gauge statistics (upper 95% confidence value).

Table 9. Zone 7: Kent County - County Line to Saint Édouard-de-Kent (inclusive)

Zone 7: Kent County - County Line to Saint Édouard-de-Kent (inclusive), HHWLT 0.9 m ± 0.1 (CGVD28)[20]						
Return Period	**Surge Residual [21]**	**Level 2000**	**Level 2025**	**Level 2055**	**Level 2085**	**Level 2100**
1-Year	0.78 ± 0.20	1.68 ± 0.30	1.82 ± 0.33	2.08 ± 0.45	2.46 ± 0.66	2.68 ± 0.78
2-Year	0.95 ± 0.20	1.85 ± 0.30	1.99 ± 0.33	2.25 ± 0.45	2.63 ± 0.66	2.85 ± 0.78
5-Year	1.18 ± 0.20	2.08 ± 0.30	2.22 ± 0.33	2.48 ± 0.45	2.86 ± 0.66	3.08 ± 0.78
10-Year	1.35 ± 0.20	2.25 ± 0.30	2.39 ± 0.33	2.65 ± 0.45	3.03 ± 0.66	3.25 ± 0.78
25-Year	1.58 ± 0.20	2.48 ± 0.30	2.62 ± 0.33	2.88 ± 0.45	3.26 ± 0.66	3.48 ± 0.78
50-Year	1.75 ± 0.20	2.65 ± 0.30	2.79 ± 0.33	3.05 ± 0.45	3.43 ± 0.66	3.65 ± 0.78
100-Year	1.93 ± 0.20	2.83 ± 0.30	2.97 ± 0.33	3.23 ± 0.45	3.61 ± 0.66	3.83 ± 0.78

[20] Error bars represent the difference between the selected HHWLT value for Zone and the range of HHWLT values for Zone.
[21] Storm surge residual estimated as average between Escuminac and Shediac tide gauge statistics (upper 95% confidence value).

Table 10. Zone 8: Kent County - Saint-Édouard-de-Kent to Westmorland County Line

Zone 8: Kent County - Saint-Édouard-de-Kent to Westmorland County Line, HHWLT 0.8 m ± 0.1 (CGVD28)[22]						
Return Period	**Surge Residual [23]**	**Level 2000**	**Level 2025**	**Level 2055**	**Level 2085**	**Level 2100**
1-Year	0.92 ± 0.20	1.72 ± 0.30	1.86 ± 0.33	2.13 ± 0.45	2.51 ± 0.66	2.74 ± 0.78
2-Year	1.11 ± 0.20	1.91 ± 0.30	2.05 ± 0.33	2.32 ± 0.45	2.70 ± 0.66	2.93 ± 0.78
5-Year	1.36 ± 0.20	2.16 ± 0.30	2.30 ± 0.33	2.57 ± 0.45	2.95 ± 0.66	3.18 ± 0.78
10-Year	1.54 ± 0.20	2.34 ± 0.30	2.48 ± 0.33	2.75 ± 0.45	3.13 ± 0.66	3.36 ± 0.78
25-Year	1.79 ± 0.20	2.59 ± 0.30	2.73 ± 0.33	3.00 ± 0.45	3.38 ± 0.66	3.61 ± 0.78
50-Year	1.98 ± 0.20	2.78 ± 0.30	2.92 ± 0.33	3.19 ± 0.45	3.57 ± 0.66	3.80 ± 0.78
100-Year	2.17 ± 0.20	2.97 ± 0.30	3.11 ± 0.33	3.38 ± 0.45	3.76 ± 0.66	3.99 ± 0.78

[22] Error bars represent the difference between the selected HHWLT value for Zone and the range of HHWLT values for Zone.
[23] Storm surge residual estimated as Shediac tide gauge statistics (upper 95% confidence value).

Table 11. Zone 9: Westmorland County - County Line to Cape Spear

Zone 9: Westmorland County - County Line to Cape Spear, HHWLT 0.7 m ± 0.1 (CGVD28)[24]						
Return Period	**Surge Residual [25]**	**Level 2000**	**Level 2025**	**Level 2055**	**Level 2085**	**Level 2100**
1-Year	0.92 ± 0.20	1.62 ± 0.30	1.77 ± 0.33	2.04 ± 0.45	2.44 ± 0.66	2.67 ± 0.78
2-Year	1.11 ± 0.20	1.81 ± 0.30	1.96 ± 0.33	2.23 ± 0.45	2.63 ± 0.66	2.86 ± 0.78
5-Year	1.36 ± 0.20	2.06 ± 0.30	2.21 ± 0.33	2.48 ± 0.45	2.88 ± 0.66	3.11 ± 0.78
10-Year	1.54 ± 0.20	2.24 ± 0.30	2.39 ± 0.33	2.66 ± 0.45	3.06 ± 0.66	3.29 ± 0.78
25-Year	1.79 ± 0.20	2.49 ± 0.30	2.64 ± 0.33	2.91 ± 0.45	3.31 ± 0.66	3.54 ± 0.78
50-Year	1.98 ± 0.20	2.68 ± 0.30	2.83 ± 0.33	3.10 ± 0.45	3.50 ± 0.66	3.73 ± 0.78
100-Year	2.17 ± 0.20	2.87 ± 0.30	3.02 ± 0.33	3.29 ± 0.45	3.69 ± 0.66	3.92 ± 0.78

[24] Error bars represent the difference between the selected HHWLT value for Zone and the range of HHWLT values for Zone.
[25] Storm surge residual estimated as Shediac tide gauge statistics (upper 95% confidence value).

Table 12. Zone 10: Westmorland County - Cape Spear to Port Elgin

Zone 10: Westmorland County - Cape Spear to Port Elgin, HHWLT 1.2 m ± 0.1 (CGVD28)[26]						
Return Period	**Surge Residual [27]**	**Level 2000**	**Level 2025**	**Level 2055**	**Level 2085**	**Level 2100**
1-Year	0.92 ± 0.20	2.12 ± 0.30	2.27 ± 0.33	2.54 ± 0.45	2.94 ± 0.66	3.17 ± 0.78
2-Year	1.11 ± 0.20	2.31 ± 0.30	2.46 ± 0.33	2.73 ± 0.45	3.13 ± 0.66	3.36 ± 0.78
5-Year	1.36 ± 0.20	2.56 ± 0.30	2.71 ± 0.33	2.98 ± 0.45	3.38 ± 0.66	3.61 ± 0.78
10-Year	1.54 ± 0.20	2.74 ± 0.30	2.89 ± 0.33	3.16 ± 0.45	3.56 ± 0.66	3.79 ± 0.78
25-Year	1.79 ± 0.20	2.99 ± 0.30	3.14 ± 0.33	3.41 ± 0.45	3.81 ± 0.66	4.04 ± 0.78
50-Year	1.98 ± 0.20	3.18 ± 0.30	3.33 ± 0.33	3.60 ± 0.45	4.00 ± 0.66	4.23 ± 0.78
100-Year	2.17 ± 0.20	3.37 ± 0.30	3.52 ± 0.33	3.79 ± 0.45	4.19 ± 0.66	4.42 ± 0.78

[26] Error bars represent the difference between the selected HHWLT value for Zone and the range of HHWLT values for Zone.
[27] Storm surge residual estimated as Shediac tide gauge statistics (upper 95% confidence value).

Table 13. Zone 11: Charlotte County (including Grand Manan)

Zone 11: Charlotte County (including Grand Manan), HHWLT 4.0 m ± 0.3 (CGVD28)[28]						
Return Period	**Surge Residual** [29]	**Level 2000**	**Level 2025**	**Level 2055**	**Level 2085**	**Level 2100**
1-Year	0.47 ± 0.20	4.47 ± 0.50	4.61 ± 0.53	4.87 ± 0.65	5.25 ± 0.86	5.47 ± 0.98
2-Year	0.54 ± 0.20	4.54 ± 0.50	4.68 ± 0.53	4.94 ± 0.65	5.32 ± 0.86	5.54 ± 0.98
5-Year	0.64 ± 0.20	4.64 ± 0.50	4.78 ± 0.53	5.04 ± 0.65	5.42 ± 0.86	5.64 ± 0.98
10-Year	0.71 ± 0.20	4.71 ± 0.50	4.85 ± 0.53	5.11 ± 0.65	5.49 ± 0.86	5.71 ± 0.98
25-Year	0.80 ± 0.20	4.80 ± 0.50	4.94 ± 0.53	5.20 ± 0.65	5.58 ± 0.86	5.80 ± 0.98
50-Year	0.87 ± 0.20	4.87 ± 0.50	5.01 ± 0.53	5.27 ± 0.65	5.65 ± 0.86	5.87 ± 0.98
100-Year	0.94 ± 0.20	4.94 ± 0.50	5.08 ± 0.53	5.34 ± 0.65	5.72 ± 0.86	5.94 ± 0.98

[28] Error bars represent the difference between the selected HHWLT value for Zone and the range of HHWLT values for Zone.
[29] Storm surge residual estimated as Saint John tide gauge statistics (upper 95% confidence value).

Table 14. Zone 12: Saint John County - County Line to Cape Spencer

Zone 12: Saint John County - County Line to Cape Spencer, HHWLT 4.4 m ± 0.2 (CGVD28)[30]						
Return Period	**Surge Residual [31]**	**Level 2000**	**Level 2025**	**Level 2055**	**Level 2085**	**Level 2100**
1-Year	0.47 ± 0.20	4.87 ± 0.40	5.01 ± 0.43	5.27 ± 0.55	5.65 ± 0.76	5.87 ± 0.88
2-Year	0.54 ± 0.20	4.94 ± 0.40	5.08 ± 0.43	5.34 ± 0.55	5.72 ± 0.76	5.94 ± 0.88
5-Year	0.64 ± 0.20	5.04 ± 0.40	5.18 ± 0.43	5.44 ± 0.55	5.82 ± 0.76	6.04 ± 0.88
10-Year	0.71 ± 0.20	5.11 ± 0.40	5.25 ± 0.43	5.51 ± 0.55	5.89 ± 0.76	6.11 ± 0.88
25-Year	0.80 ± 0.20	5.20 ± 0.40	5.34 ± 0.43	5.60 ± 0.55	5.98 ± 0.76	6.20 ± 0.88
50-Year	0.87 ± 0.20	5.27 ± 0.40	5.41 ± 0.43	5.67 ± 0.55	6.05 ± 0.76	6.27 ± 0.88
100-Year	0.94 ± 0.20	5.34 ± 0.40	5.48 ± 0.43	5.74 ± 0.55	6.12 ± 0.76	6.34 ± 0.88

[30] Error bars represent the difference between the selected HHWLT value for Zone and the range of HHWLT values for Zone.
[31] Storm surge residual estimated as Saint John tide gauge statistics (upper 95% confidence value).

Table 15. Zone 13: Albert County - Alma to Hopewell (Shepody Bay)

Zone 13: Albert County - Alma to Hopewell (Shepody Bay), HHWLT 6.5 m ± 0.5 (CGVD28)[32]						
Return Period	**Surge Residual [33]**	**Level 2000**	**Level 2025**	**Level 2055**	**Level 2085**	**Level 2100**
1-Year	0.54 ± 0.20	7.04 ± 0.70	7.18 ± 0.73	7.45 ± 0.85	7.83 ± 1.06	8.06 ± 1.18
2-Year	0.62 ± 0.20	7.12 ± 0.70	7.26 ± 0.73	7.53 ± 0.85	7.91 ± 1.06	8.14 ± 1.18
5-Year	0.73 ± 0.20	7.23 ± 0.70	7.37 ± 0.73	7.64 ± 0.85	8.02 ± 1.06	8.25 ± 1.18
10-Year	0.81 ± 0.20	7.31 ± 0.70	7.45 ± 0.73	7.72 ± 0.85	8.10 ± 1.06	8.33 ± 1.18
25-Year	0.92 ± 0.20	7.42 ± 0.70	7.56 ± 0.73	7.83 ± 0.85	8.21 ± 1.06	8.44 ± 1.18
50-Year	1.00 ± 0.20	7.50 ± 0.70	7.64 ± 0.73	7.91 ± 0.85	8.29 ± 1.06	8.52 ± 1.18
100-Year	1.08 ± 0.20	7.58 ± 0.70	7.72 ± 0.73	7.99 ± 0.85	8.37 ± 1.06	8.60 ± 1.18

[32] Error bars represent the difference between the selected HHWLT value for Zone and the range of HHWLT values for Zone.
[33] Storm surge residual estimated as Saint John tide gauge statistics (upper 95% confidence value) + 15%.

Table 16. Zone 14: Westmorland County - Rockport to Sackville

Zone 14: Westmorland County - Rockport to Sackville, HHWLT 7.5m ± 0.5 (CGVD28)[34]						
Return Period	**Surge Residual [35]**	**Level 2000**	**Level 2025**	**Level 2055**	**Level 2085**	**Level 2100**
1-Year	0.57 ± 0.20	8.07 ± 0.70	8.22 ± 0.73	8.49 ± 0.85	8.89 ± 1.06	9.12 ± 1.18
2-Year	0.65 ± 0.20	8.15 ± 0.70	8.30 ± 0.73	8.57 ± 0.85	8.97 ± 1.06	9.20 ± 1.18
5-Year	0.76 ± 0.20	8.26 ± 0.70	8.41 ± 0.73	8.68 ± 0.85	9.08 ± 1.06	9.31 ± 1.18
10-Year	0.85 ± 0.20	8.35 ± 0.70	8.50 ± 0.73	8.77 ± 0.85	9.17 ± 1.06	9.40 ± 1.18
25-Year	0.96 ± 0.20	8.46 ± 0.70	8.61 ± 0.73	8.88 ± 0.85	9.28 ± 1.06	9.51 ± 1.18
50-Year	1.04 ± 0.20	8.54 ± 0.70	8.69 ± 0.73	8.96 ± 0.85	9.36 ± 1.06	9.59 ± 1.18
100-Year	1.13 ± 0.20	8.63 ± 0.70	8.78 ± 0.73	9.05 ± 0.85	9.45 ± 1.06	9.68 ± 1.18

NOTE: The Surge Residual values listed in Tables 3 -16 exclude the incremental value of any wave run-up (defined as the uprush of water from wave action on a shore barrier) that could potentially accompany a storm surge event. The wave run-up factor will be particularly enhanced by the strength and duration of onshore winds. This factor was documented in an extreme recent storm surge event (6 Dec 2010) in the Eel River Bar First Nation Community. In this case, the extended period of strong easterly winds blowing into the Bay of Chaleur contributed a wave run-up factor of approximately one metre along the exposed coastlines of the northern portion of the Eel River Bar community; the southern part of the community did not experience this higher wave run-up factor due to the protection by Eel River Bar (Route 134).

[34] Error bars represent the difference between the selected HHWLT value for Zone and the range of HHWLT values for Zone.
[35] Storm surge residual estimated as Saint John tide gauge statistics (upper 95% confidence value) + 20%.

Plausible Upper Bound Water Levels

Table 17. Plausible upper bound water (metres above CGVD28). [36]

Coastal Section	HHWLT (m) + Error Bar (CGVD28)	Sea-Level Rise (2100) + Error Bar (m)	100-Year Return Period Storm Surge + Error Bar (m)	Plausible Upper Bound Water Level (m) (CGVD28) by Year 2100
Zone 1: Restigouche County	1.8	1.48	1.72	5.00
Zone 2: Gloucester County - County Line to Grande-Anse (inclusive)	1.6	1.48	1.72	4.80
Zone 3: Gloucester County - Grande-Anse to Pointe-Sauvage	1.4	1.48	1.54	4.42
Zone 4: Gloucester County - Pointe-Sauvage to Northumberland County Line	1.1	1.48	1.54	4.12
Zone 5: Gloucester County - Tracadie-Sheila (Tracadie Bay)	0.8	1.48	1.54	3.82
Zone 6: Northumberland County (Miramichi Bay)	1.1	1.48	1.89	4.47
Zone 7: Kent County - County Line to Saint Édouard-de-Kent (inclusive)	1.0	1.48	2.13	4.61
Zone 8: Kent County - Saint-Édouard-de-Kent to Westmorland County Line	0.9	1.50	2.37	4.77

[36] The Plausible Upper Bound Water Level is calculated as the sum of each of the components' value plus respective upper error bars of; HHWLT, sea-level rise to year 2100 and 100-year storm surge residual.

Table 18 (continued)

Coastal Section	HHWLT (m) + Error Bar (CGVD28)	Sea-Level Rise (2100) + Error Bar (m)	100-Year Return Period Storm Surge + Error Bar (m)	Plausible Upper Bound Water Level (m) (CGVD28) by Year 2100
Zone 9: Westmorland County - County Line to Cape Spear	0.8	1.53	2.37	4.70
Zone 10: Westmorland County - Cape Spear to Port Elgin	1.3	1.53	2.37	5.20
Zone 11: Charlotte County	4.3	1.48	1.14	6.92
Zone 12: Saint John County - County Line to Cape Spencer	4.6	1.48	1.14	7.22
Zone 13: Albert County - Alma to Hopewell (Shepody Bay)	7.0	1.50	1.28	9.78
Zone 14: Westmorland County - Rockport to Sackville	8.0	1.53	1.33	10.86