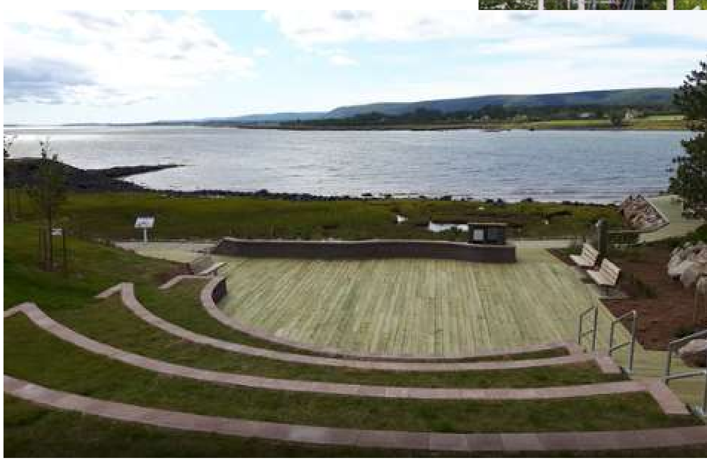
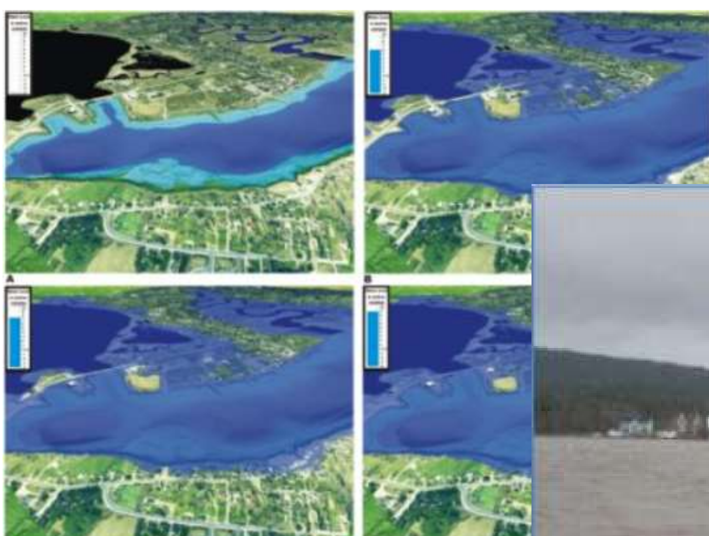


Town of Annapolis Royal

Flood Risk Assessment and Adaptation Concepts

MARCH 2023



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Appendix A: Flood Risk Assessment, Town of Annapolis Royal – John Bottomley, BA, MA, Ph.D.

Appendix B: Risk Assessment

Appendix C: Flood Extent Mapping

Appendix D: General Arrangement Drawing

1 Executive Summary

The Town of Annapolis Royal (Annapolis Royal) has commissioned this report to propose adaptation measures to protect the Town from inland flooding of the Annapolis River. Several reports have been completed in the past to study the effects of inland flooding and effects of climate change on the Town's infrastructure. This report proposes a clear path forward to mitigate risk at this National Historic Site from catastrophic floodwaters and proposes solutions that are adaptable to the uncertain impacts of climate change over the next eighty years.

Immediate action is required to protect the Town. The central core and eastern lowlands of Annapolis Royal are not only at risk from future increases in sea-level rise and storm surges from climate change and rising sea levels but are at risk currently from storm surges caused by increased wind. Despite the urgency of action, with a calculated risk approach, the costs related to this adaptation can be managed by considering the probabilities of catastrophic events occurring simultaneously.

Canada has experienced dramatically rising costs from weather related damage in the last twenty-years. This trend is going to continue, as climate change increases the frequency and severity of extreme weather events. Adaptation measures can save five to six dollars in damage for every dollar spent, or up to fifteen dollars for every dollar spent if economic and social costs are considered as well[1].

The lower population density of Annapolis Royal and length of coastline to be protected per capita results in a lower benefit to cost ratio than the national estimates, the cost-benefit analysis demonstrates clearly that action now will cost less than waiting for the next major flooding event and repairing the damage.

This report discusses several options: doing nothing and repairing damage as it occurs, managed retreat to relocate people and services from at-risk areas, construction of a seawall along the existing boardwalk location with a flood gate at the existing causeway, construction of a flood barrier at Goat Island in the Annapolis River Basin, and construction of a storm gate at Digby Gut that would protect the entire river valley.

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[1] Damage Control: Reducing the Costs of Climate Impact in Canada, Canadian Climate Institute. September 2022.

The combination of a new seawall and flood gate is the most resilient, cost-effective and practical option that will maintain the character and heart of this historic site.

Finally, the report provides cost estimates and a roadmap to build the needed protection, including recommendations on interactions with permitting agencies, First Nations and the local community to make the project a success for future generations.

2 Introduction

Annapolis Royal is located on the banks of the Annapolis River on the northwest coast of Nova Scotia. The Annapolis River is a 120-kilometer-long river, conveyed from its headwaters near Aylesford, Nova Scotia to its outlet to the Bay of Fundy at Digby Gut. The outlet is 20 kilometers west of Annapolis Royal. The western part of the Annapolis River is located near the tailwater end of the estuarine part of the river, which runs from Bridgetown to Digby Gut.

River levels vary because of changing tide levels in the Bay of Fundy, which has a 9.7 metre variance between lowest and highest tides. This analysis will look at risk factors for inland flooding at Annapolis Royal from high tides, storm surges and high river flows during spring melt or following a major storm event.

Reviewing background information for this report made it clear that there is no lack of data or study on the Annapolis River. There have been many studies done in the past, and the authors of this report would like to acknowledge the work of John Bottomley for his summary of past reports[2] and CLIMAtlantic for assistance in defining the most relevant climate data in this report.

Despite data and evidence that Annapolis Royal is indeed at risk from climate-change related extreme weather events produced since 1998, the Town has not had the opportunity to construct adaptation or protection measures in the last decade. In discussing this with stakeholders from Annapolis Royal and reviewing the past body of work, there are two main barriers.

First, Annapolis Royal is a small community with limited revenue from municipal sources. Even if funding for adaptation work heavily subsidizes the cost of a major project, it will be challenging for Annapolis Royal to fund the remaining contribution to support the project, even if a new reserve fund is created immediately. Further, any dedicated reserve fund will divert infrastructure spending from needed upgrades to core service infrastructure, risking failure from aging and lack of maintenance rather than weather events.

Secondly, while there has been substantial work in recent years toward climate mitigation, there has been little funding available for climate adaptation action, and disaster mitigation funding has typically only followed a disaster event.

To address the first barrier, the conclusions of this report will provide a roadmap to adaptation that will include novel approaches to funding but will still rely heavily on contributions from

[2] Bottomley, John (2022) Flood Risk Assessment, Town of Annapolis Royal, Annapolis Royal

federal and provincial sources. The roadmap will consider constraints on municipal funding based on Annapolis Royal's asset management program to maintain the existing asset base.

For the second barrier, this report uses the Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol to assess the current risk of infrastructure service failure along with assessing the increase in risk from future climate change. This approach will suggest an appropriate timeline for action on the understanding that if adaptation measures cannot be constructed, there will still be costs associated with reconstruction of public and private infrastructure on an emergency basis.

The risk management discussion will examine the time-based changes in this risk of the public bearing this cost. Triple bottom line cost analysis was outside of the scope of this report, but an overview social and environmental impacts will be discussed as they may be significant considerations in decision making.

3 Project Definition

The outcomes of this report will be a risk assessment, conceptual design solutions to address riverine or storm surge flooding in Annapolis Royal from the Annapolis River, and recommendations for a roadmap to adaptation. The solutions and roadmap are to be used to engage permitting agencies, public consultation, funding organizations and First Nations stakeholders. The intent is that findings and recommendations from this assessment will inform decision-making throughout the detailed design and construction of a funded project.

3.1 Scope

This report uses Engineers Canada's PIEVC model for risk assessment and draws on the recommended risk evaluation and treatment analysis methodologies outlined in Infrastructure Canada's Climate Lens Guideline and will strive to keep recommendations in accordance with Canada's National Adaptation Strategy. The assessment was completed using the Practitioner Risk Assessment approach rather than a fully facilitated approach. The risk assessment has drawn on failure modes described in the document *Flood Risk Assessment; Town of Annapolis Royal* published by John Bottomley in March of 2022. Because the Bottomley report contains numerous references to a comprehensive body of past work on flood risk in Annapolis Royal, it has been included as **Appendix A** of this report. Consequence of failure (CoF) rankings are based on a CoF matrix developed in a workshop with Annapolis Royal staff during their asset management program development.

The risk assessment is limited to the impacts of rainfall, riverine and coastal driven flooding and does not contemplate impacts of other climate events such as increased wind damage to structures, fire risk, temperature or others not explicitly mentioned.

Figure 3-1 is an excerpt from Infrastructure Canada's Climate Lens – General Guidance. Based on:

a) historical reports of catastrophic coastal flooding (Saxby Gale, 1869 and Groundhog Day Storm, 1976) within the last 150 years, and
b) the vast body of literature demonstrating risk to low-lying areas from coastal flooding,

The coastline of Annapolis Royal is considered high risk and calls for more detailed analysis and action if following this guidance. This report adds to the previous body of work by defining clear probabilities for a wider range of events and conducting a detailed cost analysis of current and climate change scenarios to determine appropriate adaptation measures to pursue immediately and when further funding can be secured.

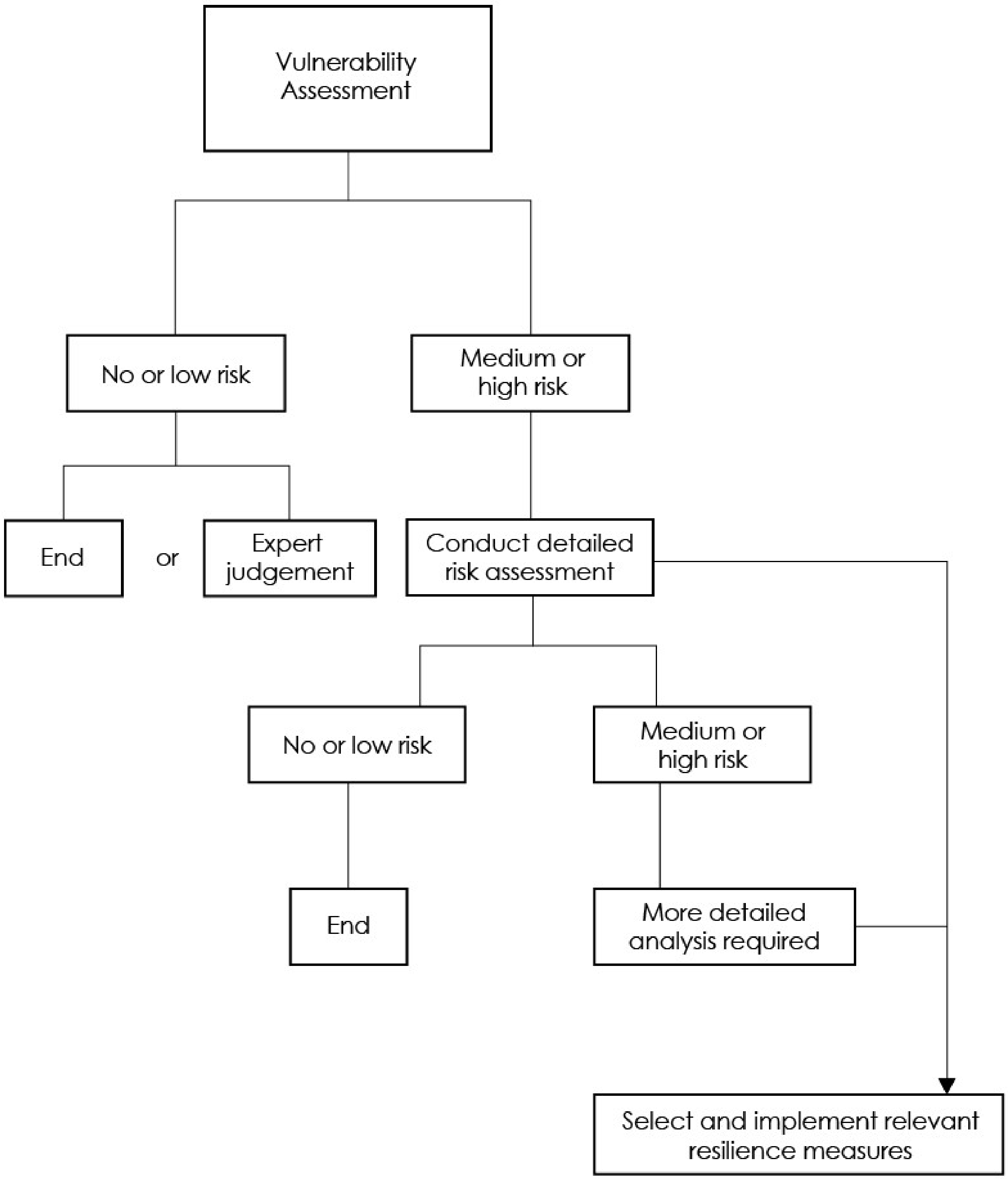

Figure 3-1 Flowchart of Resilience Assessment

3.2 Analysis Context

The results of this risk assessment are focused on identifying climate adaptation action for Annapolis Royal that can be integrated with work currently underway to develop an asset management plan for long-term sustainable service delivery. The analysis concludes with recommendations in **Section 7**. The report expands on these recommendations to provide a roadmap for adaptation with actions that can be taken immediately. These actions recognize that large scale adaptation is not possible using only the Town's financial resources and existing funding structures from other levels of government. The adaptation plan will focus not on what "should" be done, as risks have been clear from numerous past reports over the last decade, but will focus on what can be done, including activities to remove the barriers to proper adaptation that currently exist.

3.3 Risk Definition

The risk appetite and risk tolerance developed with Annapolis Royal for the asset management plan were used to define the relevant criteria for the risk assessment.

Risk cannot be eliminated from any system; risks can only be managed to an acceptable level. The acceptable level is determined by balancing the costs and benefits of risk management activities. Risk appetite is the amount of risk that Annapolis Royal is willing to accept at an organizational level, and risk tolerance is the willingness of the organization to deviate from that risk profile. Risk is the combination of the probability, or likelihood of an event and the consequences of such an event. Probability of Failure is defined for the purposes of infrastructure planning as shown in **Table 3-1**:

Typically, these probabilities are considered in asset management risk assessments over the five-year, near-term planning period. With longer range climate impacts as those considered in this assessment, it is necessary to consider both short and long-term probabilities to make decisions.

The probability of failure (PoF) percentages are defined as the percentage change of a specific service failure during a specific period. In the case of this study, the defined time periods are medium-term planning to 2053 (a thirty-year horizon) and long-term planning to 2103 (an eighty-year horizon). Probabilities that the infrastructure will fail to protect the downtown area from flooding are different for each period. The longer period has a higher chance of experiencing a catastrophic event because of climate change impacts and because there are a greater number of years in the period that may experience a flooding event.

Table 3-1 Probability of Failure

Probability of Failure (PoF)	Likelihood of Failure during the planning period	
	Description	Representative Percentage Chance of Failure
1	Negligible – little chance of failure	0% to 10%
2	Low – more unlikely than likely	11% to 40%
3	Moderate – equally likely as unlikely	41% to 60%
4	High – more likely than unlikely	61% to 80%
5	Very High – probable failure	81% to 90%
6	Effectively failed, or near certain to fail	91% to 100%

Consequences of failure are defined in **Table 3-2**.

Annapolis Royal's risk tolerance is represented in the risk tolerance matrix developed in the risk workshop during asset management plan development, shown in **Figure 3-2**.

	Consequence				
Probability	1	2	3	4	5
1	1	3	6	10	15
2	2	5	9	14	19
3	4	8	13	18	22
4	7	12	17	21	24
5	11	16	20	23	25

	Risk Tolerance	
Risk Class	Low	High
Lowest	1	8
Low	9	15
Medium	16	19
High	20	22
Extreme	23	25

Figure 3-2 Risk Tolerance

In developing a strategy to address risks from an asset management perspective, the Town has adopted an approach that seeks to eliminate (by infrastructure management or risk mitigation) Extreme risks immediately, High risks within five years of identifying them and to develop longer-term plans to address medium risks so they can be addressed when they become High risk or when all higher risks have been addressed.

Table 3-2 Consequence of Failure Matrix

CONSE-QUENCE LEVEL	RANK	SOCIAL / CULTURAL / POLITICAL	ECONOMIC	LEGAL	SAFETY	ENVIRONMENTAL
INSIG-NIFICANT	1	Public will not notice. No impact to cultural resources or groups. No impact to relations with other levels of government.	Costs are minor and expected within ongoing operational budget.	No regulatory or legal impacts.	No risk to safety above baseline conditions.	No impact to the environment.
MINOR	2	Minor public notice, public contacts staff - single point of contact. Municipality can alert the public with only minimal social media commentary on the incident. No impact to cultural resources or cultural groups. No impact to relations with other levels of government.	Unexpected operational cost can be accommodated by redistribution of yearly budget. Grant can offset the unexpected cost.	Failure may result in small claims.	Risk of "near miss" incidents, low risk of injury.	Short term effects to the environment requiring one time remediation of mitigation to restore the system to its original state. Notification to NSE.
MODERATE	3	Moderate public notice - multiple single points of contact, elected officials are contacted. Social media has a significant presence with pictures or video. Interruption of service is characterized as unusual. Coverage in local news, requires official municipal response. Impact to cultural groups limited. Potential for insurable damage more than $10,000.	Unexpected operational cost requires cancellation of minor planned activities accommodate. No long-term financial impacts. Minor impact to tourism. Grant cannot offset unexpected cost.	Failure may result in litigation and informal inquiry.	More unlikely than likely to cause short- or long-term injury, no risk of loss of life.	Short term effects to the environment requiring temporary remediation or mitigation which restore the system to its original state. Submit plans for approval to NSE.
MAJOR	4	Potential for injury. Mayor / CAO is notified. Public notice is widespread, large volume of multiple contacts. Social media has a strong awareness in terms of pictures or video. Coverage in local news, requires multiple official municipal responses. Interruption of service is characterized as very unusual. Coverage in provincial news. Impact to cultural groups widespread. Potential for insurable loss greater than $100,000	Unexpected operational cost requires cancellation of major planned activities to accommodate. Long term financing required to accommodate. Loss of commercial or tourism service greater than 5 days.	Failure may result in class action litigation and formal inquiry.	More likely than not to cause short- or long-term injury, low potential for loss of life.	Long term effects to the environment requiring sustained remediation or mitigation. System may not ultimately reach its original state. NSE issues a directive to the Town.
CATASTROPHIC	5	Potential for loss of life or damage. Coverage in national news. Public life is disrupted for an extended period. Interruption of service is "once in a lifetime". Potential for insurable loss greater than $1,000,000	Property damage that the Town is liable for. Loss commercial or tourism service greater than a season. Financing requirements may render the municipality insolvent.	Failure results in contravention of laws, significant litigation, court action and multiple litigations.	More likely than not to cause short- or long-term injury, potential for loss of life.	Permanent or long-term environmental effects that cannot be remediated or mitigated. Failure to comply results in legal action.

3.4 Climate Events

Four weather events were considered relevant to the assessment: sea-level rise, storm surge magnitude, wave runup magnitude and higher riverine flooding from increased flow. Discussion of these events and potential changes because of climate change are discussed in detail in **Section 5** of this report.

3.5 Time Horizon

The assessment considered how current weather events may affect infrastructure in Annapolis Royal and how a changing climate will change infrastructure performance before and after construction. The time horizons considered are current to 2023, thirty-years into design life to 2053 and the end of proposed design life in eighty-years to 2103.

3.6 Infrastructure

Flooding from the Annapolis River has the potential to inundate the downtown core and surrounding areas for an extended period. The scope of this assessment looks at the impact of inland flooding on the buildings, roads and underground utilities in the flood zone.

The focus of the engineering analysis in **Section 5** of this report will be potential damage and disaster repair costs from these events. However, the risk assessment considers broader reaching impacts such as environmental and socio-political consequences that may not be captured fully in the financial analysis of adaptation options. It is important to consider that while triple bottom line accounting (that considers financial, social and economic costs) of risk is outside the scope of this report, actual impacts will be greater than those captured in the conventional engineering cost analysis presented here.

3.7 Geographic Setting

The study includes the geographic area bounded by the Town of Annapolis Royal jurisdictional boundary, shown as a black dashed line in **Figure 3-3**.

3.8 Applicable Jurisdictions

Most potential impacts from flooding are on private infrastructure within the Annapolis Royal jurisdictional boundary. The Parks Canada National Historic Site of Fort Anne lies within the study boundaries, so it will be considered as well. In addition to the Town jurisdiction, the land lies within the Mi’kmaw district of Kespukwitk, and consultation with Bear River First Nation will be required for any potential adaptation work. Land along the Annapolis River waterfront below the

Ordinary High-Water Mark (OHWM) falls under jurisdiction of the provincial Department of Natural Resources, and any impact may be referred by Nova Scotia environment for review by the federal department of Fisheries and Oceans Canada.

3.9 Participating Stakeholders

This report has been developed using input from a variety of consultants, NGOs, local government authorities, provincial reporting and academic studies. The report is produced through consultation with the Annapolis Royal Environment Advisory Committee, CAO and public works staff.

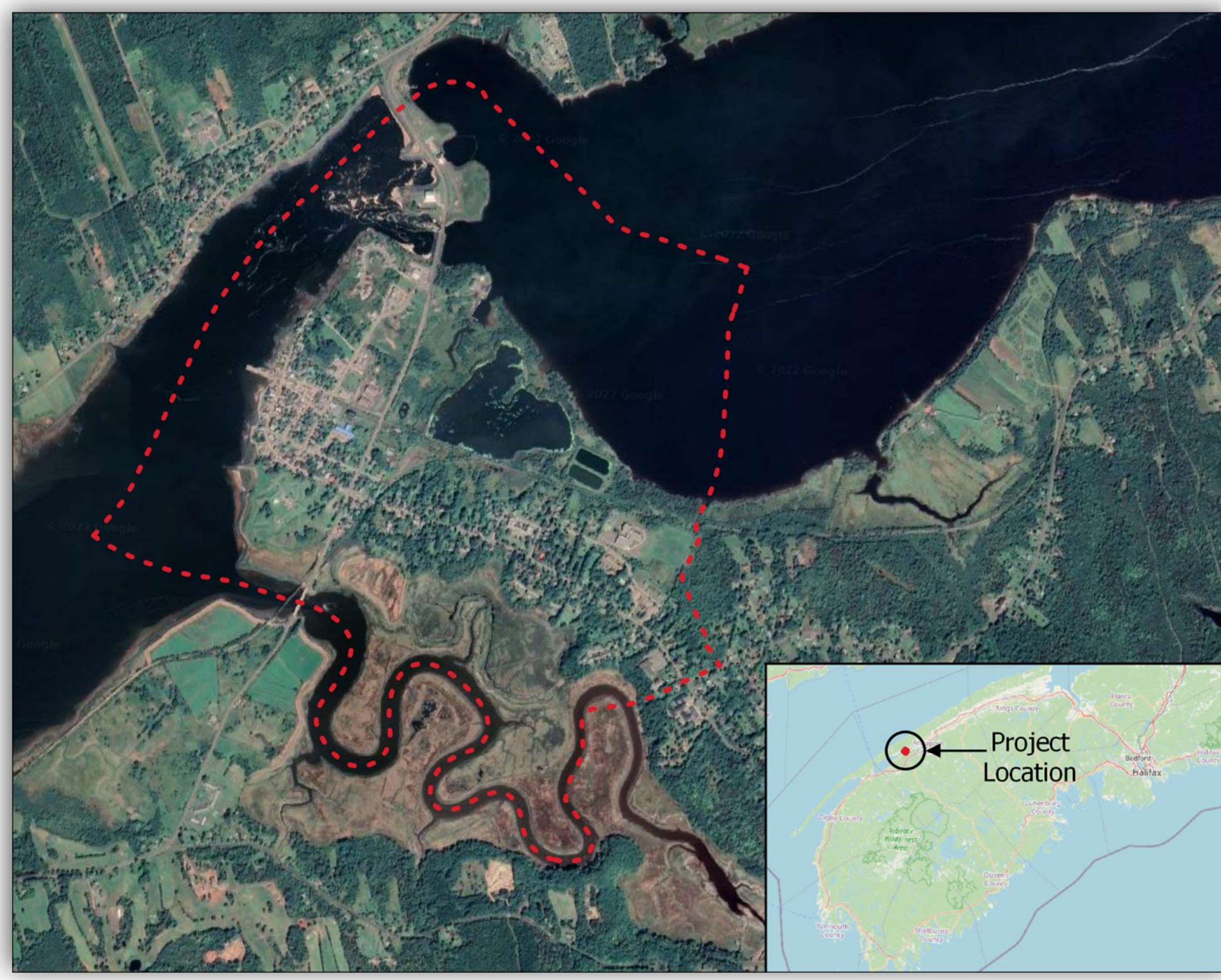

Figure 3-3 Geographic Setting

4 Data Gathering

The historical review of climate impacts, event likelihood and potential impacts was supplemented by an independent analysis of various climate projections and likelihoods. This independent review provided the final assessment in this report used to produce the time bound risk assessments.

Data used in this report were gathered from available reference material, most notably from reference sources quoted in the Bottomley report, independent collection of climate data in consultation with CLIMAtlantic on the most relevant current climate data, hydrotechnical information developed by subject matter experts on the project team, past infrastructure projects with Annapolis Royal, asset inventories from Annapolis Royal's asset management program and provincial digital elevation model (DEM) data from LiDAR collection for GIS mapping. This section summarizes the outcomes of the data collection and modelling.

4.1 Baseline Data and Climate Change

Benchmark tide elevations for the tide station at Digby are shown in **Table 4-1**. Peak water levels for current climate conditions and various climate scenarios are shown in **Table 4-2**. Maximum water levels can arise from four factors:

a) astronomical tide elevations in the Bay of Fundy,
b) storm surge from sustained winds during a hurricane or post-tropical storm, with lesser contribution from pressure differential over the water surface,
c) wave runup from wind gusts during a storm, and
d) increased water level from outward flow of the Annapolis River

4.1.1 Astronomical Tide Elevations

Tide elevations are consistent and predictable but do experience variations in magnitude. High tides are the critical risk factor, but even these have variations in maximum level. It is important for this analysis to differentiate the different high tides. High tides occur twice a day with differing elevations. High tide levels vary throughout the year depending on the relative position of the earth, sun and moon. Once or twice a year, high tide occurs at its maximum level, often referred to as a king tide, or highest astronomical tide (HAT). For this analysis, the critical tide elevation is the **higher high water mean tide** (HHWMT), or the average elevation of the higher high tide range.

Storm surges can last several hours to near a day, so it is probable that a storm surge will be coincident with a level at, or greater than the HHMT. For greater tides, such as a king tides, the frequency of occurrence is less than that of the HHMT. Occurrence of these higher tide levels is independent of the probability of a given storm surge elevation. Combining a king tide with a given return period of a storm surge would require adjusting the probability to a lower frequency to reflect the likelihood of coincidence of the two events.

Table 4-1 Digby Tide Elevation - Relative to Geodetic datum

Name		Description	Elevation (m)
Highest Astronomical Tide	HAT	The highest predicted tide expected over the period of 40 years.	4.951
Higher High Water Large Tide	HHWLT	The average of the highest high waters, 1 from each of 19 years of predictions.	4.741
Higher High Water Mean Tide	HHWMT	The average from all the higher high waters from 19 years of predictions.	3.511
High Water Level	HWL	The highest level reached at a place by the water surface in 1 oscillation.	3.371
Mean Water Level	MWL	The average of all hourly water levels over the available period of record.	0.111
Low Water Level	LWL	The lowest level reached at a place by the water surface in 1 oscillation.	-3.179
Lower Low Water Mean Tide	LLWMT	The average of the lowest low waters, 1 from each of 19 years of predictions.	-3.299
Lower Low Water Large Tide	LLWLT	The average of all the lower low waters from 19 years of predictions.	-4.589
Lowest Astronomical Tide	LAT	The lowest predicted tide expected over the period of 40 years.	-4.779

Mean high tide, adjusted to geodetic elevation has been derived from historic tide charts provided by Fisheries and Oceans Canada.

4.1.2 Sea Level Rise

Climate models for sea level rise are inherently uncertain. First, all models rely on calculations of complex systems. Such modelling has potential for error, represented by how confident we are that the future condition will **exceed** a given result. Projected sea level rise is typically shown as a mean projection with increasing potential for error as we project further into the future. **Figure 4-1** demonstrates this for one climate case.

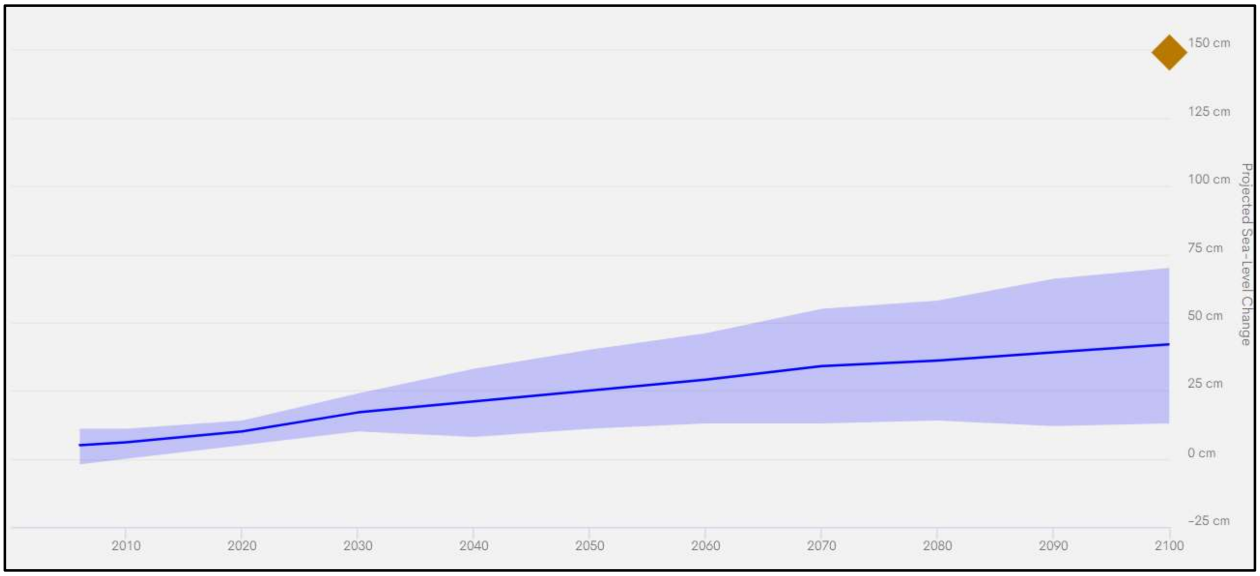

Figure 4-1 Sea Level Rise Projection for RCP 2.6[3]

Figure 4-1 shows that for a given year, all predictions will be **higher** than the lowest band of the error (bottom of the shaded part) and all predictions will be lower than the **highest** band of the error. The mean sea level rise is the line with half predictions higher and half predictions lower than that value.

Referring to the "5th percentile" for sea level rise means that 95% of the results exceed the given value, that is, we have a high level of confidence that this increase will be exceeded in the given period. So,

The "95th percentile" in contrast, is only exceeded by 5% of the values, therefore, while it is possible that the increase will be this much, we have a lower level of confidence that it will occur.

[3] https://climatedata.ca/

More plainly, it is almost certain that sea level rise will be higher than the 5th percentile, and unlikely that it will be higher than the 95th percentile.

The second uncertainty affecting the magnitude of sea-level rise is human mitigation actions. Climate change impacts are lessened over the next century if, globally, aggressive measures are taken to reduce greenhouse gas emissions. One way of measuring this, used by the Intergovernmental Panel on Climate Change (IPCC) is the representative concentration pathway (RCP). A lower RCP indicates more effective reduction of greenhouse gas emissions, and a higher RCP represents less mitigation. Consider the chart in **Figure 4-1**. This is a best-case mitigation scenario, with a median sea level rise of 380 millimetres and maximum projection of 700 millimeters increase.

Figure 4-2 shows the relative greenhouse gas emissions and mean worldwide temperature increase for different RCPs.

In contrast, RCP 8.5 is a projection that assumes there are no aggressive climate policies adopted worldwide. This assumes that our past increases in fossil fuel use continue unabated or put differently, that recent mitigation efforts and policy changes are abandoned in the future. Consider the difference between the projections shown in **Figure 4-1** and those shown for RCP 8.5, shown in **Figure 4-3**.

The median sea level rise under this projection is 750 millimetres, almost double that of the RCP 2.6 scenario. The maximum projection is 112 millimetres, a 60% increase over the RCP 2.6 scenario.

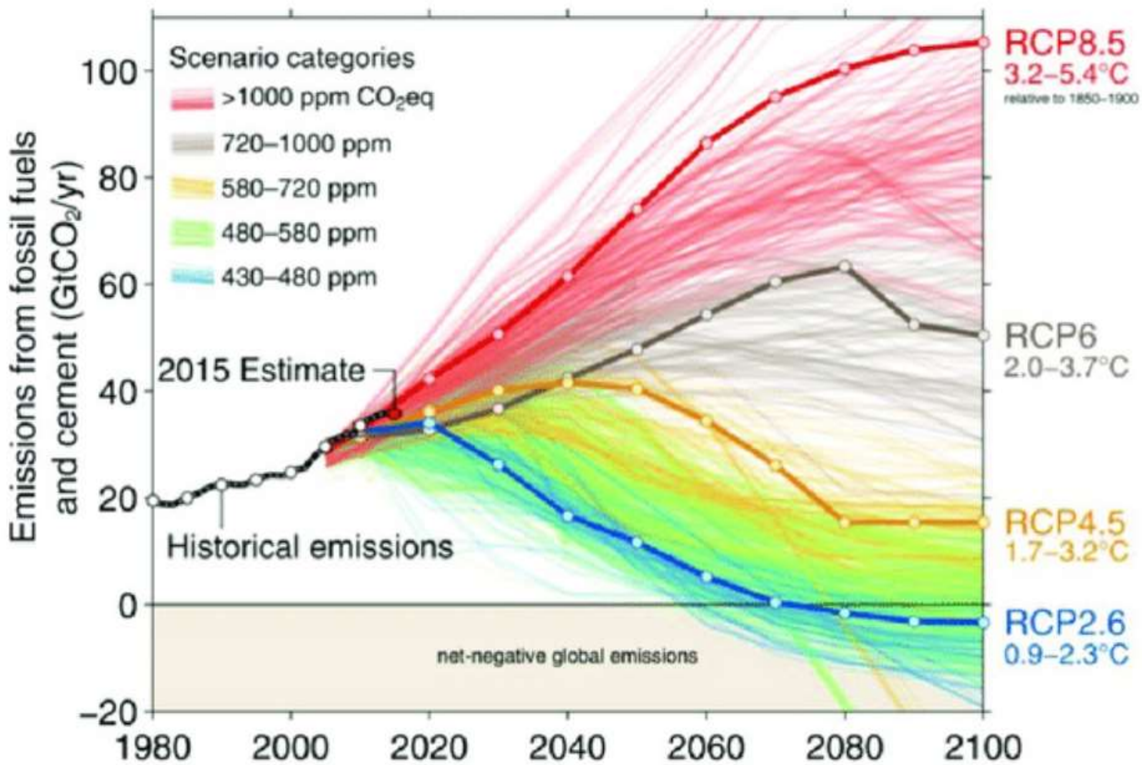

Figure 4-2 RCP Pathways and Mean Global Temperature Increase[4]

In summary, it is important to consider that there is no "right" prediction for climate change impacts, only more or less likely possibilities. Adaptation measures that consider smaller, more likely scenarios are less costly and more accessible. Adaptation measures that consider worse case scenarios are more robust, but also more costly and prohibitive. This basis allows a risk managed approach to developing climate change adaptation measures.

[4] Image Credit: Neil Craik, University of Waterloo

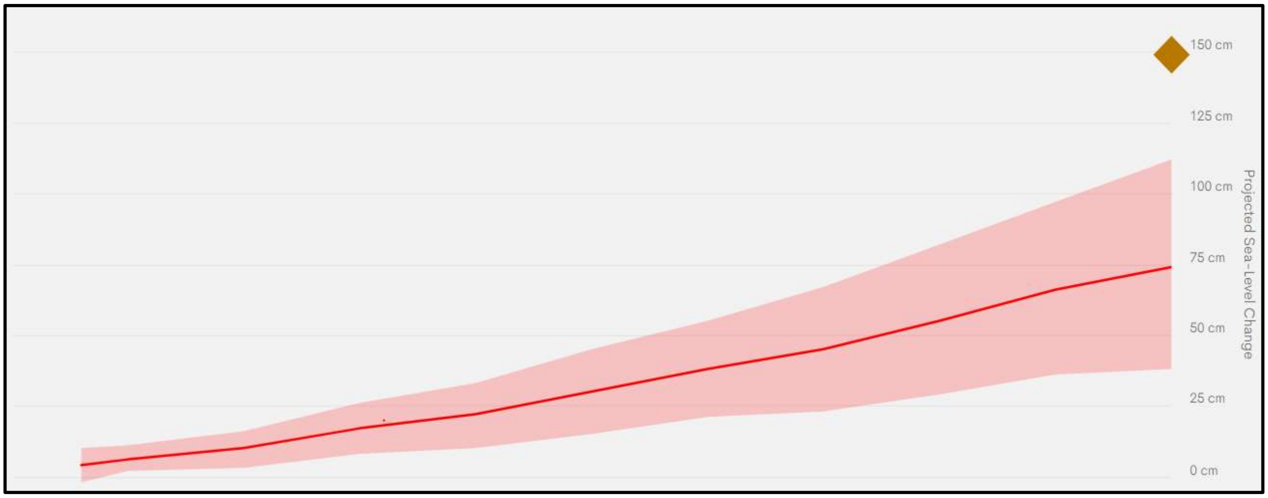

Figure 4-3 Sea Level Rise Projection for RCP 8.5[5]

The sea level rise projections also include a factor for land subsidence. Nova Scotia is sinking in elevation at a rate of approximately 1 millimetre per year, which causes an apparent rise in sea level of the same amount.

4.1.3 Storm Surge and Wave Runup

Storm surge and wave runup are increases in water elevation resulting from wind action on water bodies. The difference between them is that storm surge is a sustained increase in water level over a large area lasting several hours, while wave runup is a localized change in water level from waves. In the Annapolis Basin, storm surge from the Bay of Fundy has a much greater impact than wave runup. The largest wave height is limited by the short wind reach across the Annapolis River, while the larger geographic impact of storm surge originates in water levels at the Bay of Fundy, which has a much longer wind reach. Data collected at tide gauges does not differentiate between water level increases from storm surge or wind action, so they have been combined for this assessment.

There is limited literature available for the relationship between climate change and increased storm surge potential from greater wind energy in storms. However, there is consensus that climate change will result in more energetic storms and greater potential for sea-level rise, with an increase in storm intensity of between one percent and ten percent for a two-degree Celsius warming. With reference to Figure 4-2, warming could be up to four to five degrees above the global mean under the RCP 8.5 scenario, which would increase the energy in the atmosphere and

[5] https://climatedata.ca/

wind energy. Based on available data, this study has adopted potential wind speed increases above baseline between 5% and 20% for the high confidence and low confidence values over the next eighty years. Increase over time has been assumed to be approximately linear.

To predict the increase in water levels from increased storm energy, the project team used a plot of storm surge versus wind speed for the Bay of Fundy developed using method from the *Guide to Storm Surge Forecasting*, World Meteorological Association. 2011. The projected curve is shown in **Figure 4-4**.

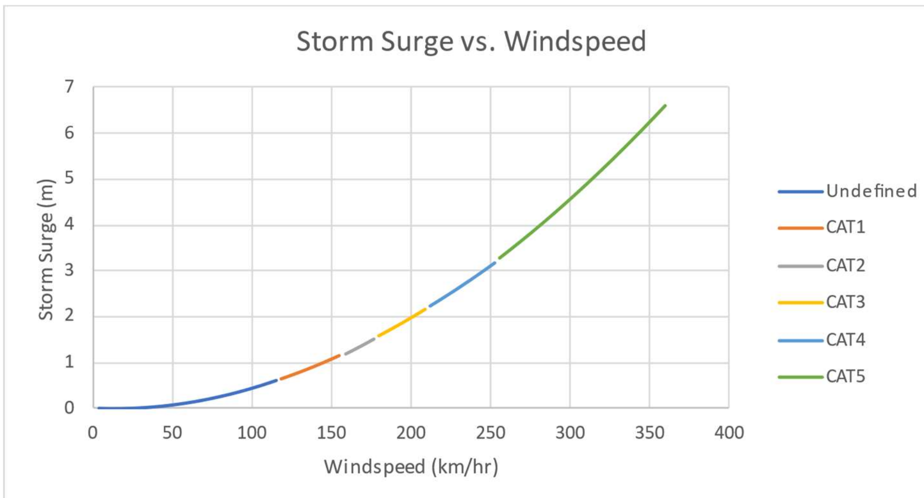

Figure 4-4 Storm Surge vs Wind Speed

The Saxby Gale of 1869 was estimated to have water levels 1.5 meters above tide elevation, corresponding to a 1:100-year return period (1% chance of occurrence each year) storm surge[6]. Combined with a HHMT elevation of 3.51 metres, this would result in a flood water elevation of 5.01 metres, which is close to the predicted 1:100-year storm surge elevation presented in *Flood Risk Mapping Using LiDAR for Annapolis Royal, Nova Scotia, Canada*, Tim L. Webster, Applied Geomatics Research Group, Nova Scotia Community College. 2010.

Based on the wind speed analysis, this would correspond to a post-tropical storm with sustained wind velocities of approximately 170 kilometres per hour. This would result in a future 1:100 return period storm surge resulting from wind speeds between 179 kilometres per hour and 204 kilometres per hour, with resultant storm surge increases of 1.6 metres and 2.0 metres,

[6] An Evaluation of Flood Risk to Infrastructure Across the Chignecto Isthmus, Atlantic Climate Adaptation Solutions Association. 2012

respectively. For reference, a 200 kilometre per hour wind speed is the boundary between a Category 3 and Category 4 hurricane, more typically seen in the tropics.

From this assessment, this report has adopted the following estimates for surge with intermediate estimates for interim time periods and probabilities:

a) 1.5 metres as the estimate for the current 1:100-year return period event,
b) 1.6 metres as the high likelihood 1:100-year return period event in 2100, and
c) 2.0 metres as the low likelihood, or worst-case, 1:100-year return period event in the year 2100,

4.1.4 Increased Riverine Flooding from Increased Precipitation

The final mechanism to cause flooding along the Annapolis River is elevated water levels from increased flow from precipitation. Flow in the Annapolis River is caused by short duration storms and periodic snowpack melting through the winter and in the spring.

In support of this study to find the risk caused by riverine flooding, the project team assessed flow records for the Annapolis River gauge at Lawrencetown and corresponding flood reports at Annapolis Royal. Through the historical record, from 1983 to 2020, there were several significant flood events noted at Lawrencetown. The majority corresponded to a mid-winter warming combined with rainfall, combining stormwater flow with significant snowmelt. Discharges on record were up to 402 cubic metres per second, more than four times the mean flow levels. Water elevation is affected by downstream tide levels, and high flows with high tide resulted in water elevations of 9.0 meters, which is over 2 metres higher than mean water elevations.

During these substantial flooding events at the Lawrencetown gauge station, there were no reports of flooding at Annapolis Royal. The conclusion from this assessment is that increased flow at Annapolis Royal does not have a significant impact on water levels compared to the height of storm surge and wave runup. Hydraulically, this can be explained by the cross section of the river being larger at Annapolis Royal. The width of the river is 420 metres, compared to approximately 30 metres at Lawrencetown. The large cross section as the river expands into the Annapolis Basin results in low sensitivity to increased flows.

No further analysis was necessary on peak flow water elevations because the critical events are storm surges during summer and fall storms. These are unlikely to coincide with winter and spring flood events which contribute to increased rainfall and snowmelt flow.

4.1.5 Increased Stormwater Flow from Increased Rainfall Intensity

The scope of this project is focused on flooding from the Annapolis River overtopping its banks, however, increased rainfall during a storm event can cause flooding in the stormwater system upstream of the storm system outfalls. Water levels in the storm conveyance system (both the minor piped system and major overland flow system) can be affected by increased rainfall.

A combination of events, with high tide and storm surge combined with an extreme precipitation event can cause unexpected failure of the storm system from increased tailwater at the river.

This analysis included an assessment of the performance of the Annapolis Royal stormwater conveyance system using a PCSWMM model to develop hydraulic gradelines through the system under different conditions. PCSWMM is a hydrologic and hydraulic modelling tool that models 2-dimensional, unsteady flow.

Rainfall intensity-duration-frequencies have been obtained from the IDF_CC tool from the University of Western Ontario[7]. Current peak rainfall is based on a 1:100 (two percent per year chance of occurrence), twenty-four-hour rain event with 109.3 millimetres of total rainfall. The climate adjusted rainfall, based on projections to the year 2100 is 129.0 millimetres of total rainfall. This is an 18 percent increase, which corresponds to 2.5 degrees of mean global temperature increase[8].

If a new seawall is constructed to prevent flooding, a new stormwater pump station with a floodbox will be required to expel stormwater from the Town system during periods of high river water level.

4.1.6 Threshold Values

Threshold values are the load at which an infrastructure element may experience impacts from a weather event. These are not the same as the design event and typically results in lower impacts with more frequent occurrence.

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[7] Simonovic, S.P., A. Schardong, R. Srivastav, and D. Sandink (2015), *IDF_CC Web-based Tool for Updating Intensity-Duration-Frequency Curves to Changing Climate – ver 6.0*, Western University Facility for Intelligent Decision Support and Institute for Catastrophic Loss Reduction, open access https://www.idf-cc-uwo.ca.

8 Westra, S., Alexander, L.V. and Zwiers, F.W. (2013): Global increasing trends in annual maximum daily precipitation; Journal of Climate, v. 26, p. 3904–3918. doi:10.1175/JCLI-D-12-00502.1

Flooding at the waterfront of Annapolis Royal could potentially damage infrastructure at an elevation of 4.8 metres. Impacts will be minimal, with overtopping of the lower portions of the boardwalk, wharf and St. George Street. As water levels increase above this elevation, the impact becomes greater as the extents of flooding become larger and impact greater areas of the Town.

A series of flood maps showing the extents of flooding in 0.5-meter intervals of elevation are included as **Appendix B**.

4.1.7 Design Values

Based on the analysis above, Table 4-2 shows the range of peak water elevations in the Annapolis River for RCP 2.5 and RCP 8.5 currently and in the future.

Table 4-2 Peak Water Elevations

RCP	Year	100 yr. Flood Elevation (m)	Higher High Mean Tide (HHMT) Elevation, 2023 (m)	Sea Level Rise (m)	100 yr. Storm Surge (m)	Subsidence (m)
RCP2.6 High confidence	2023	5.01	3.51	0.00	1.5	0.00
	2053	5.15	3.51	0.11	1.5	0.03
	2103	5.32	3.51	0.13	1.6	0.08
RCP8.5 Low confidence	2023	5.01	3.51	0.00	1.5	0.00
	2053	5.79	3.51	0.45	1.8	0.03
	2103	6.71	3.51	1.12	2.0	0.08

Table 4-2 shows that under various climate scenarios, a 1:100-year return event, otherwise stated as that event that has a one percent chance of occurrence each year, increases in magnitude under the effects of climate change. This increase results from increasing sea level in the Bay of Fundy and an increase in maximum wind speed causing larger storm surges.

This impact can be interpreted in two ways:

a) The damage and cost impact for a given return period event (e.g., the 1:100-year return period) will increase in the future, or

b) The threshold flood elevation and the **current** 1:100-year return event will have a greater chance of occurrence in the future.

The cost analysis in this report will be based on the former interpretation.

4.2 Infrastructure Elements

The impact of weather events, and climate change on those weather events

4.3 Indigenous Consultation

One of the guiding principles of Canada's National Adaptation Strategy is to respect jurisdictions and uphold Indigenous rights[9]. With respect to jurisdiction, all land in Nova Scotia is considered unceded Mi'kmaw territory[10]. In this regard, any impact from storm surge or riverine flooding, as well as the potential impacts of adaptation works discussed in this report fall under the duty to consult with First Nations. This report has been developed in part to open a collaborative effort in exploring risk mitigation and climate adaptation efforts with local First Nations as part of the climate adaptation roadmap.

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[9] Canada's National Adaptation Strategy: Building Resilient Communities and a Strong Economy, Environment and Climate Change Canada. 2022

[10] Supreme Court Ruling, R v. Simon. 1985, s50.

5 Technical Analysis

The engineering analysis centred around finding the likelihood of catastrophic events occurring, possibly more than once in the period of concern. Based on the risk analysis, there is potential for significant damage to municipal and private infrastructure from flooding.

5.1 Probability Analysis

Section 4.1.7 discussed the change in likelihood and effects of a 1:100-year return period event under the effects of climate change. A fundamental characteristic of this statistical approach is that there is an equal chance, one percent, each year of this storm occurring. This leads to a conclusion that there is a possibility of the design event occurring more than once in the period of concern. To establish the percentage likelihood of a design event occurring once, more than once or not at all, a statistical method called a Monte Carlo simulation was developed for the 1:100-year return period event. This method runs a randomized simulation of the period(s) of concern; in this case, the 30-year period to 2053 and the 80-year period to 2103 and determines how many times the design event occurs in the period. This is repeated thousands of times to determine the average percentage chance of occurrence for each frequency of occurrence. **Table 5-1** shows the results of this simulation.

Table 5-1 Probability of Storm Occurrence

Number of 1:100-Year Events	To 2053	To 2103
None	73.6%	43.3%
One	22.6%	36.4%
Two	3.3%	15.1%
Three	0.3%	4.1%
Four	Negligible	0.8%
Five	Negligible	Negligible

5.2 Cost Analysis

The Federal Flood Damage Estimation Guidelines for Buildings and Infrastructure, Version 1.0[11] has been used to develop a stage / damage curve for different levels of flooding in Annapolis Royal, shown in **Table 5-2**. Costs are based on 2014 data from Alberta, so costs have been adjusted for regional differences (a reduction of 18%) and inflation from 2014 to 2022 (an increase of 36% for non-residential buildings).

Table 5-2 Estimated Damage by Flood Depth

Flood Depth	Affected Structures (Cumulative)	Footprint (Cumulative m^2)	Estimated Damage (Cumulative)
0	6	1213	$721,450.82
0.1	21	3826	$2,957,048.14
0.3	43	8547	$7,914,744.98
0.6[1]	58	10786	$10,382,159.20
0.9[2]	67	13214	$13,235,513.66
1.3[3]	69	14237	$14,440,368.00
1.5	70	14376	$14,604,614.56
1.8	71	14487	$14,735,500.16
2.1	74	16580	$17,202,279.54
2.4[4]	78	17833	$18,679,855.48

1. Current 1:100-year return period
2. RCP2.6, Projection to 2103
3. RCP8.5, Projection to 2053
4. RCP8.5, Projection to 2103

5.3 Economic Consequence of Failure

Combining **Table 5-1** and **Table 5-2** yields a percentage weighted cost impact of storm surge flooding, shown in **Table 5-3**. Because all years are equally likely to experience a given magnitude

[11] Federal Flood Damage Estimation Guidelines for Buildings and Infrastructure Version 1.0, Natural Resources Canada. 2021

storm, the default cost for each period and climate scenario is the average of the current loss estimate and the future loss estimate. The total cost representation is calculated by:

$$Cost(2022\$) = Sum\ of\ \mathrm{n\ x}\ C_A x P_n$$

where n is the number of occurrences, CA is the period cost average and Pn is the probability of occurrence for n storms in the period.

Table 5-3 Estimated Damage by Flood Depth

Scenario	Average Cost Impact per Event	Cumulative Percentage Weighted Cost
2053 RCP8.5	$11,808,836.43	$3,735,790.34
2103 RCP2.6	$12,411,263.60	$9,695,054.71
2103 RCP8.5	$14,531,007.34	$11,929,957.03

6 Options Assessment

Several options are available to address the climate risk, and in this section each option is discussed as it relates to timeframe, feasibility, economic considerations and socio-environmental concerns.

6.1 Managed Retreat

Managed retreat is a strategy that seeks to adapt to changes in weather patterns from climate change by abandoning properties at risk. Typically, properties are purchased by a level of government and converted into green space or recreational use parks or green space that is not at risk from major damage from a weather event.

Managed retreat strategies are best used in locations where there is readily available land for relocation and where relocation does not carry costs greater than other adaptation options. Neither of these ideal conditions is present in Annapolis Royal. In determining the feasibility of this strategy, Town management and the project team considered that:

a) The Annapolis Royal Historic District which encompasses the downtown area, was designated a national historic site in Canada in 1994 because of its mix of 18th, 19th and early 20th century architecture and its distinctive sense of history and place as former colonial capital and significant Acadian history,
b) There are a substantial number of medium density commercial and mixed-use properties that cannot be readily relocated to elsewhere within the area,
c) There is little remaining area within the Town limits to relocate the downtown core
d) The cost of relocating service infrastructure and reconstructing buildings would be far greater than other adaptation measures available.

Based on this high-level screening of this option, managed retreat is not a feasible option.

6.2 Emergency Response Measures

Annapolis Royal participates in a Regional Emergency Management Organisation (REMO) with neighboring municipal units. The goal of this organization is to plan for response to potential disasters, one of which is catastrophic flooding of the downtown core. The engineering analysis has demonstrated that the downtown core is at risk of flooding not only from future events related to climate change but is also at risk from a current 1:100-year storm surge event.

Developing constructed adaptation measures will require significant capital investment and multiple years of planning. During this time there is a small, but not statistically insignificant chance that a catastrophic flood event could occur. Annapolis Royal should prepare the emergency response measures for such an event, including:

1. Developing a communication plan for residents in at risk areas when there is a forecast of a major storm / wind event that can coincide with high tide
2. Developing an evacuation plan that considers floodwater interruption to the road network. Evacuation plan should consider mobilizing people and goods before, during and after floodwaters, when streets may not be passable due to debris.
3. Establishing default lines of communication to provincial and federal disaster relief departments for potential damage more than $10,000,000
4. Identifying process to engage insurance companies and aiding residents in navigating the process
5. Identifying temporary residences for displaced residents immediately following an event and longer-term residence for residents with uninhabitable homes
6. Identifying programs for assistance to businesses with lost revenue during reconstruction periods
7. Identifying challenges and solutions if a surge event is followed by freezing weather
8. Developing a plan to address sewage overflow and ingress into buildings

6.3 Adaptive Building

Adaptive building seeks to build flood resilient infrastructure that minimizes the reconstruction required after a flood event. This typically includes using building materials for structures and exterior cladding that is resistant to water damage and can be more easily cleaned following sewage overflow from the collection system. Electrical and mechanical infrastructure is installed on higher floors, above the predicted flood elevation.

These measures are most effective in new buildings where they can be designed to purpose. Retrofitting such measures is possible, but costly, and the relative savings in damage do not always offset the cost of design and construction. Also, Annapolis Royal, as a national heritage site, needs to retain the character and architecture of its buildings.

Because of the technical difficulty and cost to retrofit older buildings and the inevitable impact on the character of the Town, this option is not feasible in this location.

6.4 Goat Island Barrier

The option to construct a flood protection barrier and gate at Goat Island was discussed during preliminary public consultation meetings. This option was determined to be undesirable when compared to the proposed solution of a seawall discussed in **Section 6.6**. The overall length of the wall would be comparable to the seawall discussed in **Section 6.6**, with increased costs of due to the depth of the river reaching 15m in the construction site, complications if maintaining navigable waters, impacts to aquatic habitat, and unknow impacts on erosion & sediment transportation. These increased risks and costs provide a limited increase to properties protected from the project.

6.5 Digby Gut Storm Gate

Annapolis Royal is not the only municipality at risk from elevated flood levels in the Annapolis Valley. Impact of this type of event can extend to Bridgetown. In Holland, they have adopted a solution to install a massive tide gate that can be closed when storms are predicted to cause high storm surges.

An estimate of the current cost of such a barrier in Nova Scotia would be optimistically estimated at $1.5 billion, not considering the significant technical, material procurement and construction expertise that would need to be obtained for such a project.

With anticipated maximum flood damages throughout the Annapolis Valley on the order of $100 million, this project would not be feasible from a cost-benefit perspective.

6.6 Seawall

Appendix D contains concept drawings of a 1.3-kilometre seawall along the river shoreline, a new automatic tide gate at the current NSPI tidal station causeway and a new storm system and pumping station within the Town limits to allow stormwater to be pumped to the river during high tides. The proposed design will also need to accommodate access at the boat launch adjacent to the community wharf, which will be outside the wall protection limits.

The wall will consist of a mechanically stabilized earth (MSE) wall along the shore where the current boardwalk and riverfront trails are. The top of the structure will be approximately 7 metres wide to permit future raising of the wall with an earthen berm construction on top. Subject to a geotechnical analysis, this wall may need to have piled foundations to support not only the current structure weight, but also possible future weight of a wall extension. This approach allows future adaptation without reconstructing the wall.

Wharf upgrades are excluded from the present analysis because the Town is assessing options to address structural issues at the wharf. Wharf upgrades and an option for a smaller wall will be included in a subsequent version of this report.

The estimated cost of constructing the works is approximately $4.2 million. This is more than the cost-weighted impacts forecast to 2053, but lower than the cost-weighted impacts of any scenario to 2103.

It is recommended to explore a further option for protection with a gravity wall that will protect the Town to projected 2053 levels as well as to the lower extent of 2103 levels. The wall will be less able to be adapted to the worst case 2103 levels than the wall contemplated in this report, but cost will be considerably less. The trade-off is that there is justification for constructing the wall in the medium-term with a relatively high probably of protecting the Town for eighty-years. The risk is that evidence of sea level rise and storm surge in the coming thirty years may indicate that a more expensive increase in protection elevation may be required.

Alternately, the Town may develop adequate contingencies for a single catastrophic event and begin planning to fund the larger project with a longer time frame for development, in the range of twenty years. At this time, there will be more data available on actual trends in sea level rise and better data on storm surges to set a wall height sufficient for long-term protection.

7 Conclusions and Recommendations

Based on this analysis, there is a current risk to infrastructure in the Town Centre, with increasing risks over the coming decades with the impacts of climate change. Risk of catastrophic flooding is possible, but low probability under current conditions. Many previous reports have identified these risks, but they have not been quantified in a way to permit successful funding of the projects.

There is substantial future risk of catastrophic flooding, even based on current sea level and storm surge magnitudes. This risk increases the longer adaptation activities are delayed. None of the potential options are viable, save for construction of a structural barrier along the waterfront to protect from high storm surge. Construction of this barrier should include adequate freeboard to protect, at a minimum to the worst-case RCP 2.6 scenario for 2013, which is elevation 5.3 metres geodetic plus 900 millimetres freeboard, or a top elevation of 6.2 meters.

If adequate funding can be secured, the Town should consider measures that allow the wall to be extended for future sea level rise to a minimum elevation of 6.7 metres geodetic plus 600 millimetres freeboard, or elevation 7.3 metres. Note that this proposed worst-case elevation is:

a) potentially 1.5 metres higher than required if climate scenarios occur closer to the worst cast RCP 2.5 predication rather than the best-case RCP 8.5 prediction.
b) 2.5 metres above the street elevation at the wharf, which would cause a significant aesthetic impact to the character of the Town, and
c) Would significantly increase the cost of construction and pose a barrier to the Town's business case for the adaptation as well as the Town's ability to finance the project.

The following list of recommendations will provide various levels of protection against current and future risk:

a) Develop an emergency response plan immediately that contains at minimum, the following elements:
    i. a communication plan for residents in at risk areas when there is a forecast of a major storm / wind event that can coincide with high tide
    ii. an evacuation plan that considers floodwater interruption to the road network. Evacuation plan should consider mobilizing people and goods before, during and after floodwaters, when streets may not be passable due to debris.
    iii. default lines of communication to provincial and federal disaster relief departments for potential damage more than $10,000,000

iv. process to engage insurance companies and aiding residents in navigating the process
v. identification of temporary residences for displaced residents immediately following an event and longer-term residence for residents with uninhabitable homes
vi. identification of programs for assistance to businesses with lost revenue during reconstruction periods
vii. process to address challenges and solutions if a surge event is followed by freezing weather
viii. contingency planning to address sewage overflow and ingress into buildings

b) Engage with sponsors / potential contributors through businesses or large industry to begin getting commitments to raise a potential 33% contribution to the works, or $1.4 million

c) Consider a special levy for impacted businesses and residents to support some or all of the municipal contribution. This will need to be presented with substantial public engagement that considers the potential risk-weighted cost to residents from lost property and business revenue versus the potential cost of a special levy

d) Start a reserve fund in the asset management plan to support construction of potential adaptation measures. This reserve fund should not take precedence over maintenance of critical infrastructure systems but can take precedence over non-essential development activities.

e) Engage provincial and federal elected officials to determine proposed courses of action for funding needed adaptation projects for small coastal communities in Nova Scotia

f) Commence geotechnical investigation and preliminary structural design to refine cost estimates to augment the information in this report. The selected wall parameters should consider the limitation on funding (both internal and external), impacts to the Town's waterfront for resident and tourist enjoyment and finally, the ability to adapt the wall further in the future.

8 Closure

This report (including any enclosures and attachments) has been prepared for the exclusive use and benefit of the Town of Annapolis Royal and solely for the purpose for which it is provided. The report is not intended nor are to be used as a guarantee or warranty, expressed or implied, regarding the future adequacy, performance or condition of any inspected structure, item or system. The inspector is not an insurer of any inspected conditions. Unless we provide express prior written consent, no part of this report should be reproduced, distributed or communicated to any third party. We do not accept any liability if this report is used for an alternative purpose from which it is intended, nor to any third party in respect of this report.

Matt Delorme, P.Eng.

Affix Professional Seal

Appendix A

Flood Risk Assessment, Town of Annapolis Royal – John Bottomley, BA, MA, Ph.D.

Appendix B

Risk Assessment

Appendix C

Flood Extent Mapping

Appendix D

General Arrangement Drawing