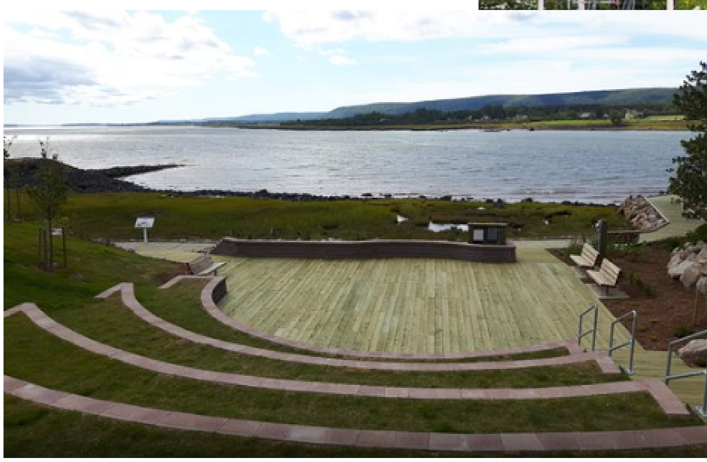

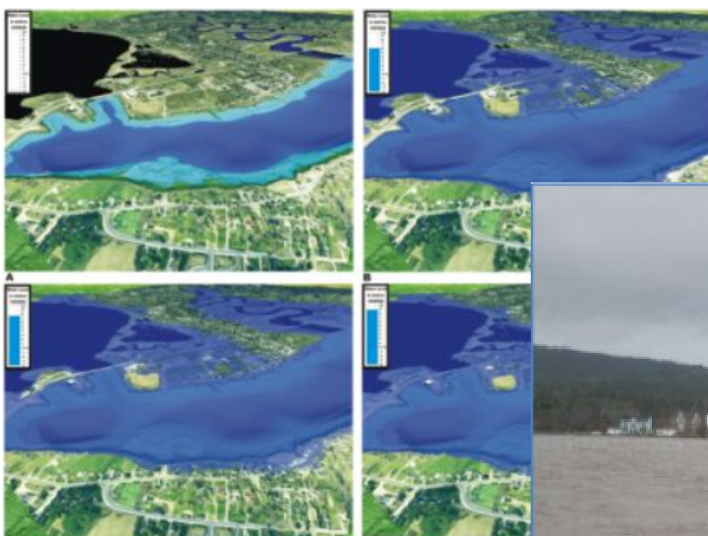

Town of Annapolis Royal

Flood Risk Assessment and Adaptation Concepts

Final Report Prepared: April22nd, 2024

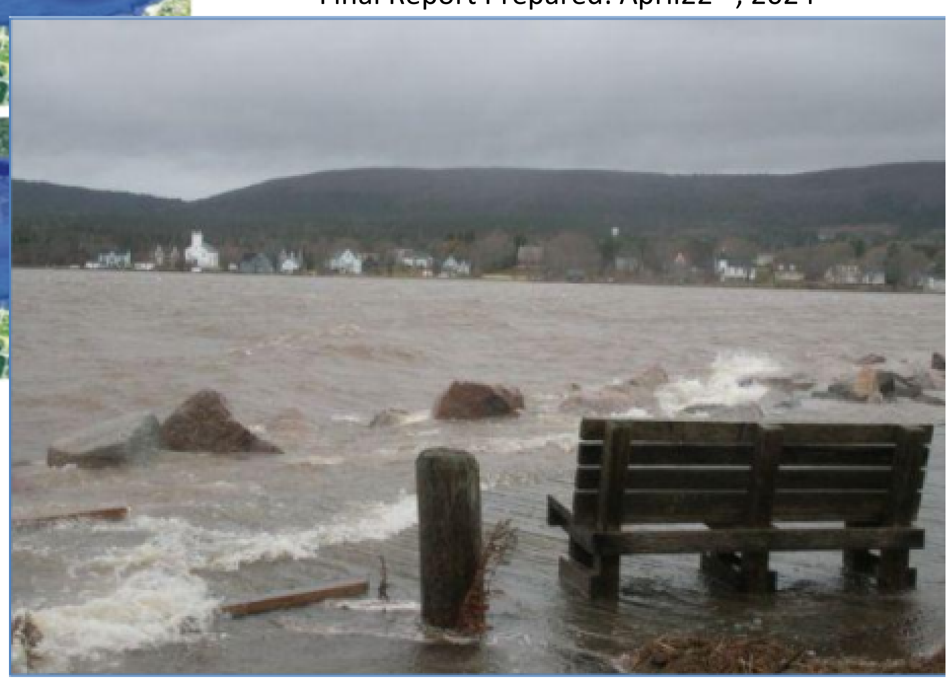

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Table of Contents

Executive Summary

The Town of Annapolis Royal commissioned this report to investigate adaptation measures to protect the Town from coastal flooding of the Annapolis River. Numerous reports have been completed in the past to study the impact of coastal flooding on the Town's infrastructure and how this flood risk will change as a result of climate change. This report is intended to:

a) Incorporate the results of these previous reports,
b) Supplement prior climate change assumptions with a risk management approach that considers uncertainty in forecasts and multiple scenarios from the Intergovernmental Panel on Climate Change (IPCC) sixth assessment report (AR6),
c) Investigate climate adaptation options that can provide a flexible adaptation pathway for impacts of climate change over the next eighty years,
d) Provide advice on risk decisions to assist Annapolis Royal in taking immediate action toward adaptation, and
e) Provide cost estimates to allow capital financing strategies to be put into place.

The level of risk is established by looking at the likelihood that something will occur and the impact if it does occur. These two elements, the likelihood or probability, and the impact or consequence, together form the risk of an event. For example, something that happens often with low, but not inconsequential, impacts could be considered a similar risk as something that has an extremely low chance of occurring but a greater impact.

Annapolis Royal is currently at moderate risk of flooding from a major storm surge event coinciding with high tide levels in the Bay of Fundy, with this risk increasing in the future. In the near-term (five to twenty years), the increased risk of higher water levels is from larger storm surges resulting from increased wind energy in storms. In the longer term (thirty to one hundred years), risk increases from both increased wind-driven storm surge and predicted sea-level rise.

A small portion of the central core and large extent of the eastern lowlands will flood during current projections of the 100-year (one percent chance of occurring annually) flood event. Currently the eastern extents of the Town are protected by water management at the tidal plant. Any solution selected must include a plan to maintain flood control measures at the causeway to be effective.

Climate change increases the predicted occurrence of these large events, or to think of it another way, increases the amount of flooding expected from that one-percent change per year event. This makes risk increase over time, so it becomes high- to very high-risk once climate impacts are considered. By considering the possible future occurrences, a risk management approach can minimize the potential loss of services, damage to properties, disruption to businesses and displacement of people with climate adaptation measures.

Canada has experienced dramatically rising costs from weather related damage in the last forty-years. There is a staggering amount of infrastructure at risk, and we as a Canadian society bear those costs through the cost of national emergency relief for catastrophic events, uninsured loss of property, decreased economic activity or increasing costs of insurance, particularly in high-risk zones. This has prompted a call for action through the National Adaptation Strategy (NAS) for everyone to understand that we share many of these costs whether the disaster occurs in our backyard or across the country. The NAS encourages all residents and communities to think about adaptation in this respect so we can make sensible decisions nationally about investing in adaptation work and minimize the risk of future costs and community disruption. 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].

Adaptation pathways are a key concept in today's climate field. An adaptation pathway is a decision-making approach that allows infrastructure owners to maintain resilient infrastructure through the large amount of uncertainty inherent in climate predictions. This uncertainty comes both from the possible variation in how aggressively the global community reduces greenhouse gas production over the next thirty-years, as well as from uncertainty in the modelling used to predict climate impacts. This reality of climate forecasting means that there are models of low emission futures, with lower impacts, and higher emission futures, with higher impacts. Within each of these models, there is uncertainty that results in a range of impacts that gets wider the further into the future the modelling seeks to predict. Adaptation pathways allow us to construct cost-effective protection now to be resilient to more moderate impacts, while allowing future expansion if evidence demonstrates we are on a more catastrophic path.

Climate change is increasing the severity of weather events. The cost-benefit analysis presented here demonstrates that action now will cost less than the "do-nothing" option. The probabilistic analysis in this report shows that there is expected to be an increasing cost risk from flood events as a result of climate change, and that considered over the next eighty years, adaptation is a more cost-effective option than responding to a disaster through emergency funding or insurance.

Risk related to coastal flooding in Annapolis Royal is mostly related to flooding of private properties on St. George Street and inundation of the wastewater treatment plant on the east side of the Town. To a lesser extent, there is minor or moderate risk to other municipal infrastructure such as streets and underground utilities from these flood events.

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

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

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.

The combination of a new seawall and managing upstream impacts at the Highway 1 causeway is the most resilient, cost-effective and practical option to maintain the character and heart of this historic site while protecting it from coastal flood risk. It is also able to be constructed in a way that allows flexibility to protect Annapolis Royal over the life of the infrastructure while avoiding major impacts to the existing waterfront and view across the river.

The conceptual design of the new seawall can accommodate expansion if required in thirty to forty years without having to remove any of the wall structure. The design is based on climate forecasts based on the eighty-year impacts from the IPCC. The IPCC sixth assessment report (AR6) identifies forecasts based on shared socio-economic pathway (SSP) scenarios that represent how aggressively we, as a global society, will reduce greenhouse gas emissions in the coming decades[2]. The design proposed in this report uses forecasts from models based on SSP2-4.5, the intermediate emissions scenario. Adaptation pathways are planned considering SSP5-8.5, the very-high emissions, or worst-case scenario. The lower estimate assumes that globally, there is sustained action to reduce reliance on fossil fuels; and the higher estimate assumes greenhouse gas production continues with existing trends. This results in a lower cost of construction for the project and reduces the likelihood of over-adapting and spending scarce infrastructure funding on over-built infrastructure, while accommodating future expansion should we find ourselves on the more catastrophic climate impact path.

In simpler terms, despite worldwide efforts and current policy it is almost certain that flood levels predicted in the intermediate scenario will occur, while it is less likely – though still possible – that the greater flood levels predicted in the very high emissions scenario will occur, and these only after several decades have passed. The design plans for the very likely scenario and allows for an adaptation pathway to adjust in the future for the less likely scenario weather patterns and sea-level data monitoring confirms it is occurring.

Finally, the proposed solution seeks opportunity in crisis. With a major infrastructure project like the one needed here, there is an opportunity to enhance the waterfront with natural, artistic, cultural and heritage features that will increase the attraction to this already popular destination. There is also opportunity to restore marine habitat that has been impacted by development, restore natural species, build shoreline habitat and increase biodiversity in the Annapolis River.

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[2] IPCC, 2023: Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001

The total cost estimate of the seawall concept is **$4.65 million**, including detail design, construction management, project management and construction. The report also provides conceptual cost estimates of additional work that may be interrelated with the seawall construction: rehabilitation of the Town Wharf and shoreline salt marsh restoration. Any infrastructure adaptation project must be accompanied by a floodwater management plan at the Highway 1 causeway to replace the flood control inherent in the tidal plant operation.

The cost of adaptation is lower than the likely cost of major coastal flooding risk over the next eighty years. However, the municipal contribution to support this project is significant. The project will primarily protect function of the downtown core and private properties along the waterfront. Private property flood risk is higher closer to the wharf. The Town will need to consider novel financing strategies such as aggressive reserve funding, alternative revenue sources, contributions from industry and additional contributions from the community.

Damage estimates include both private and public property. Potential damage to municipal property includes the wastewater treatment plant, King's Theatre and damage to roadways, but do not include environmental damages from flooding of the wastewater lagoons. The damage to municipal property is a smaller fraction of anticipated damage than that to private property, and the wastewater treatment facility can be protected by non-structural means by developing a flood management plan at the former tidal plant causeway crossing. The Town is recommended to review their obligations with respect to flooding of private property found in the document ***Climate Risk, Responsibility, and Liability for Municipalities: Exploring Municipalities' Responsibilities to Consider, Manage, and Disclose Climate Change Flood Risks*** **(CLIMAtlantic, 2022)** prior to deciding to invest in high-cost hard infrastructure. Diversion of municipal funds to flood protection measures must be balanced with municipal obligations to maintain infrastructure for core services. Without contributions from private sources such as insurance organizations or impacted property owners, the Town may consider other pathways to risk mitigation through its duty to inform and robust emergency response measures.

Impacts of catastrophic events are more than damage to infrastructure. Major flood events impact the social fabric of the community, physical and mental health of its residents and long-term sustainability of this historic location. This report discusses in detail the assumptions, uncertainties, risks, cost estimates and recommended activities for climate adaptation in Annapolis Royal to allow the Town and its residents to make well-informed decisions, discuss activities with permitting agencies, consult with First Nations and inform the local community to plan for success of future generations.

1 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. Annapolis Royal is located near the end of the estuarine section of the river, which runs from Bridgetown to Digby Gut. Tidal mixing occurs here as high tides in the Bay of Fundy push ocean water into the freshwater stream of the river.

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 considers risk factors for coastal 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[3] and CLIMAtlantic for assistance in defining the most relevant climate data in this report. The summary of past reports is included as **Appendix A**.

Despite data and evidence contained in reports produced since 1998 that Annapolis Royal is indeed at risk from climate-change related extreme weather events, 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 municipal revenue. Even if funding for adaptation work heavily subsidizes the cost of a major project, it is challenging for Annapolis Royal to support the municipal contribution with current revenue and cash reserves. This financing gap is made more acute with a loss of approximately 16% of past revenue with the closure of the Annapolis Tidal Plant. Further, any use of revenue and reserves diverts infrastructure spending from needed upgrades to core service infrastructure, risking failure from aging and lack of maintenance.

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 catastrophic event.

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

To address the first barrier, the Town will need to consider novel approaches to financing the infrastructure project. Without unconventional funding strategies – including investigating overland flood insurance for impacted properties, contributions from the insurance industry and contributions from impacted property owners – funding the project will impact the Town's ability to support capital renewal of existing infrastructure like roads, water lines, sewer lines and facilities. It could also result in heavy debt loads that, with recent high interest rate variability, could cause the Town financial risk. Annapolis Royal is not alone in these challenges. Across the country, all levels of government and private sector are coming to realize that we will be unable to delver all the needed adaptation work at the speed and scale needed with conventional infrastructure funding models[4].

The second barrier has been addressed through policy and funding changes at a federal level. Along with the National Adaptation Strategy, the Canadian government announced new funding streams to support major capital projects with the goal of climate adaptation. This report is intended to support application(s) for funding under these streams.

The risk assessment in **Appendix B** and detailed technical discussion in **Appendix C** are based on the Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol. The PIEVC Protocol was developed by Engineers Canada to assess the change in risk of infrastructure service failure from future climate change and is currently under the oversight of the Climate Risk Institute (CRI) and Institute for Catastrophic Loss Reduction (ICLR). The assessment considers the increasing cost risk of delaying action (the "do-nothing" option) against the cost of a proposed adaptation solution. Because there is no certainty in if, when or how often disaster-scale events would occur, the Town should use this information to make strategic risk management decisions, and plan for emergency measures if adaptation work is deferred or not constructed.

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

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[4] Canadian Climate Institute, 2023: Mobilizing Private Capital For Climate Adaptation Infrastructure [Ewart, T., Coffee, J. and Miller, S.], https://climateinstitute.ca/wp-content/uploads/2023/05/mobilizing-private-capital-climate-adaptation-infrastructure.pdf

2 Risk Assessment Overview

Appendix B contains the results of the climate risk analysis for coastal flooding. Risk is defined as a combination of:

a) the probability, or likelihood, of infrastructure being exposed to a severe weather event, and
b) the potential consequence of exposure of infrastructure to that severe weather event.

A complete explanation of the risk analysis process is in **Appendix C, Section C4**. Infrastructure elements at greatest risk are the wastewater treatment plant, Town Wharf, and private properties along the waterfront.

The wastewater treatment plant lies on the eastern side of Town, with coastline behind the causeway and tidal plant flow control system. Recommendations for ongoing water management at the tidal plant site is presented in more detail in **Section 3.6.2**.

The Town Wharf is already at risk from structural failure because the aging sheet pile encasement, which was installed to rehabilitate the original wooden wharf, is reaching its end of life. The steel panels exhibit significant rust and narrowing of the steel section, with some locations perforated through. It is at risk from structural damage during current high-water events, and this risk will increase with time. A detailed wharf structural report was issued by Able Engineering on September 22, 2022, along with the conclusion that rehabilitation or replacement is necessary in the next five years. **Section 4** of this report discusses possible integration of the wharf rehabilitation with this project. Because this project is already viewed as a priority because of the risk of structural failure in the near-term, costs of wharf reinstatement are not included in the damage estimates in **Appendix C**.

The other major impact is to private buildings within the Town boundaries. **Appendix D** contains flood maps that show the extent of the various 100-year storm surge scenarios discussed in **Appendix C**. The mapping demonstrates that aside from the wharf and water treatment plant, a proposed seawall and flow management strategy at the causeway would be supported by a need to protect public and private properties - many with historical significance - within the Town.

There would also be some minor potential impacts to the pavement structure, sanitary sewer system and stormwater system. These costs would be minor compared to potential structural damage, insurance costs, uninsurable building damage, loss of commercial activity and loss of habitable space both near and long-term. Transportation corridors, particularly along St. George Street will be impacted during flooding, but would be reinstated following cleanup of debris.

There are also wind-related risks to telecommunication and power infrastructure as stronger extreme gusts are expected with climate change. However, this has not been assessed in **Appendix C** as it is not under Town jurisdiction and is outside the scope of this report.

3 Options Assessment

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

3.1 Managed Retreat

Managed retreat is a strategy that seeks to adapt to changes in weather patterns from climate change by protecting (through regulation) or abandoning properties at risk. Typically, properties are acquired by a level of government and converted into green space or recreational use parks that are not at risk from major damage from a weather event. Restricting development on at-risk land and planning for relocation after a catastrophic event occurs are considered low-monetary cost measures of dealing with climate risk. Where these measures involve private property, there is a lengthy process of consultation and consensus building.

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, its distinctive sense of history and place as former colonial capital and significant Acadian history, and early roots in contact between the first settlers and Indigenous populations,
b) There are a substantial number of medium density commercial and mixed-use properties that cannot be readily relocated elsewhere within the area,
c) There is no nearby urban centre to relocate the commercial heart of the Town,
d) There is little remaining area within the Town limits to relocate the downtown core, and
e) 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.

3.2 Emergency Response Measures

Annapolis Royal participates in a Regional Emergency Management Organisation (REMO) with neighboring municipal units. The goal of the REMO 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 moderate risk of flooding currently, with increasing risk over time from a 1:100-year storm surge event. The increasing risk is because the flood depth of a 1:100-year flood event (with a one percent per year likelihood based on historic data) will become greater as average and peak wind velocities increase and sea-level rises, generating higher storm surge water levels for a given storm recurrence.

The analysis in **Appendix C** takes an approach of assessing increasing cost impacts of a standard weather event over time, in this case the 1:100-year storm surge. That is, the event with one percent chance per year of occurring will have greater flood extents and greater damage costs in the future. This convention is adopted because climate projections are well suited to this approach.

However, note that it also true that the current 1:100-year flood event would be expected to become more likely in the future. That is, another way of looking at the climate impacts is that more frequent, smaller flood events are predicted from climate change projections along with more impactful infrequent events.

Developing constructed adaptation measures requires 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. Also, if the Town determines that constructing a large, engineered structure is not a viable option, a robust emergency response plan can provide sufficient risk mitigation for catastrophic flooding events. Regardless of the chosen action, Annapolis Royal should prepare the emergency response measures for such an event, including:

a) 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, and in particular with higher astronomical, or king tides,
b) Developing an evacuation plan that considers floodwater interruption to the road network, especially in low areas by the Town Wharf. The evacuation plan should consider how to mobilize people and goods before, during and after floodwaters, when streets may not be passable due to water and debris,
c) Establishing default lines of communication to provincial and federal disaster relief departments,
d) Identifying processes and resources to make it easier to engage insurance companies and aiding residents in navigating the process,
e) Educating residents about the risk of overland flooding and that default insurance policies do not typically cover damage from water running over the ground,
f) Identifying temporary residences for displaced residents immediately following an event and longer-term residence for residents with uninhabitable homes,
g) Identifying programs for assistance to businesses with lost revenue during reconstruction periods,

h) Identifying challenges and solutions if freezing weather follows a flood event, and
i) Identifying responsibilities and a plan to address sewage overflow and ingress into buildings.

Planning early and establishing the protocols to update plans, the Town will be able to mitigate consequences of a disaster event such as those seen throughout Nova Scotia in recent years.

3.3 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. It can be costly, and difficult to enforce without updates to national and local building codes.

These measures are most effective in new buildings where they can be designed to purpose. While retrofitting these measures is possible, the relative savings in damage do not always offset the cost of design and construction, and the changes can reduce usable area for commercial or residential purposes in the building. Also, Annapolis Royal, as a national heritage site, needs to retain the character and architecture of its buildings.

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

3.4 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 3.6**. The overall length of the wall would be comparable to the seawall discussed in **Section 3.6**, with increased costs of due to the depth of the river reaching 15 meters in the project site, complications with maintaining navigable waters, impacts to aquatic habitat and biological function, and unknown impacts on erosion and sediment transportation. Based on the potentially high cost, unknown risks and technical challenges with such an installation, this protection measure is not feasible to pursue.

3.5 Digby Gut Storm Gate

Annapolis Royal is not the only municipality at risk from elevated flood levels in the Annapolis Valley. Impact of major storm surge events can extend to Bridgetown. In the Netherlands, where there is a similar tidally influenced river that impacts far inland, they constructed the Maeslant structure, a massive tide gate at the ocean outfall that can be closed when storms are predicted to cause high surges. Built in the 1990’s, the structure protects Rotterdam and nearby coastal communities from storm surges up to three metres. It was first put into effect in 2007 during a large storm event and has proven to be effective in controlling inland flooding.

However, 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. While the construction would be an economic boon to the area, and the gate itself would be a world class attraction, the economic benefits would not outweigh the cost to communities to support the project and return on investment would be long after there were irreparable effects on capital renewal of existing infrastructure and financial stability of the communities.

With anticipated flood damage from a single flood event throughout the Annapolis Valley on the order of $100 million in current dollars, this project would not be feasible from a cost-benefit perspective.

3.6 Seawall

Because other structural and regulatory management measures are not feasible, a waterfront seawall is the preferred adaptation option to protect the Town from current and future flood risk. A schematic of the wall location and key infrastructure is shown in **Figure 3-1**.

Figure 3-1: Schematic of Proposed Seawall

3.6.1 Proposed Seawall

The elevations given in this section are heights relative to the Canadian Geodetic Vertical Datum of 2013 (CGVD2013).

The cost and detailed technical analysis of a seawall design concept, included in **Appendix C**, should be measured against the increasing likelihood of need for emergency measures discussed in **Section 3.2 and** emergency response costs when considering risk management strategies to build resilience against climate change impacts. **Table 3-1** summarizes key flood elevations, shown in bold, used in the seawall concept design, with reference to how likely they will occur based on current climate change forecasts. Details on how the flood elevations were developed are in **Appendix C, Section C13.**

Table 3-1 Peak Water Elevations

Likelihood	Year	100 yr. Flood Elevation (m)
More Likely to Occur (RCP4.5 Moderate Case)	2023	4.37
	2053	4.64
	2103	**4.96**
Less Likely to Occur (RCP8.5 Worst Case)	2023	4.37
	2053	**5.04**
	2103	**6.06**
Model Extreme	2103	**6.43**

The proposed wall is a cantilevered concrete wall along the shore along the current boardwalk and riverfront trail. **Appendix E** contains general arrangement and concept wall sections that were used to generate the cost estimates. Detailed cost estimates are included in **Appendix F**. The top of wall in the concept design has been set at elevation **5.34 metres**. This top of wall elevation results in a maximum wall height of **780 millimetres** above existing ground, near the lighthouse.

The wall elevation provides approximately **500 millimetres** of freeboard for the moderate climate change prediction to year **2103**, or **300 millimetres** of freeboard for the worst-case predictions in **2053**.

The concept has also been designed to resist overturning sliding or uplift failure for the worst-case elevation of **6.06 metres** in **2103**. This means that the wall will be stable if the barrier is extended in the future should data demonstrate that we are tracking closer to the worst-case scenario by **2053**, at which time there will be less uncertainty in the rate of climate change impacts. This approach allows future expansion without reconstructing the wall foundations or face. The last line item is the modelling extreme prediction, with 1.5 metres of sea level rise by 2100.

3.6.2 Causeway Flood Control

For the seawall to be effective, flood control at the tidal station causeway crossing will be required. If water levels are not managed through the causeway, there is a high likelihood that flooding will occur on the eastern side of the Town, which can reach the western side through the system of channels and culverts to the French Basin.

The flood mapping in **Appendix D** assumes equal water levels on either side of the causeway river crossing. In reality, the narrow passage at the causeway could restrict flow to the north side of the causeway. This would prevent the peak level of the storm surge from fully developing on the north side of the causeway, and by extension, on the east side of town. This would mitigate, but not prevent, flooding on the east side of Town. Hydraulic modelling of these flow dynamics is outside the scope of this report but should be undertaken as part of the long-term management strategy of the causeway flow.

We strongly recommend that if any flood mitigation measures are put in place to protect the downtown and waterfront on the west side of town, that it be accompanied by an agreement with the authority having jurisdiction over the causeway river crossing to ensure that there are adequate measures in place to prevent high tide and storm surge water levels from fully developing across the causeway. This could be done by maintaining a controlled gate system similar to the one used during operation of the tidal generating plant, or it could be a detailed hydraulic study to confirm expected water levels on the north side of the causeway during various tide and storm surge events. Note that the latter option is very likely to trigger the need for various flood control measures on the east side of town, which could range from simple installations like tide gates on culverts, to more major interventions such as seawalls or raising the Highway 1 embankment to protect against longer term scenarios with more pronounced climate change effects.

3.6.3 Proposed Storm Sewer System

The proposed concept also includes new catch basins and a new storm sewer behind the wall to collect runoff from properties. This runoff would no longer be able to run over the boardwalk into the river and must be collected to an outfall.

Flow from this system is conveyed to a proposed stormwater pump station near the existing sewage lift station at the boat works. This pump station will collect runoff from the waterfront, seepage from behind and under the proposed wall, and stormwater from the existing outfall. When Annapolis River levels are lower than approximately the level of the boardwalk, stormwater will flow by gravity through a pipe similar to the existing concrete outfall beside Town Wharf and pumping will not be required.

When river levels are higher than the water in the stormwater pipe system, a flap gate on the gravity pipe will close, preventing backflow from the river into the storm system. Provided water levels do not reach a critical level where they will flood streets or properties, stormwater will collect in the underground storm sewers until the river levels are low enough to discharge by gravity. If water levels reach a critical level that risk flooding streets or properties, the pumps will activate and drain the system to safe levels until the river recedes sufficiently to drain without pumping. In effect, this pump system will only be required during extreme events of heavy rainfall combined with high tide and storm surge conditions and is not expected to incur large ongoing energy expenses for operation. Cost of the pump station will be the initial capital costs, plus routine pump maintenance costs. With proper routine maintenance the life of the pumps is expected to exceed thirty years because of the low run-time expected.

3.6.4 Access to Town Wharf and Annapolis Royal Haul Up Association

The proposed design needs to accommodate access to the Town Wharf and to the Annapolis Royal Haul Up Association (ARHUA) property. This is challenging, as during design storm surge events, both of these areas are under flood waters. During development of the protection concept, the design team considered permanent flood protection for these areas – in effect, extending the wall to provide permanent protection.

At the wharf, this would require raising the elevation of the wharf approximately 600 millimetres in the base scenario, and over one metre in the worst-case scenario. This would not be possible without reconstructing the entire wharf because, as discussed in more detail in **Section 3.8**, the existing wharf is experiencing critical structural degradation and cannot support any extension.

Secondly, the ARHUA needs to maintain access to the river beside the wharf as well as to land access at St. George Street. A permanent barrier would interfere with one or the other of these requirements.

Lastly, major changes in grade at the wharf or the ARHUA would create changes in grade, or slopes from the road to the wharf / ARHUA that were not traversable by vehicles. There is insufficient distance between the areas that would need to be raised and the street to maintain a maximum eight percent (or lower in the case of the wharf) desirable grade for vehicle traffic.

Because of these functional and geometric restrictions, a permanent barrier at this location is not feasible. To maintain access to these locations while providing adequate flood protection, the concept design proposes a section of temporary flood protection as shown in **Figure 3-1**.

3.6.5 Temporary Flood Protection

Temporary flood protection refers to protection measures that are not permanently in place. Instead, they are deployed by Public Works only when there is a possibility of flood risk. This type of emergency measure is used to protect urban areas that experience frequent street flooding from undersized storm sewers to prevent flow into underground parkades or other at-risk, low-elevation areas. The samples shown here are intended to be indicative of how the flood barriers work and are not intended to endorse or warrant the performance of any particular temporary flood barrier.

The proposed design leaves a gap in the seawall from the south side of the Town Wharf to the park north of the ARHUA. The final wall design will have keyways where the wall terminates for the temporary flood barrier to abut the wall structure. When deployment is required, that is, when there is a forecast of a large post-tropical storm event that could coincide with high tide, the flood barriers will be laid between the ends of the wall. **Figure 3-2** shows a picture of temporary flood barriers deployed before a flood event.

Figure 3-2: Temporary Flood Barrier - Deployment

Once the flood barrier has been laid out, it can be driven over, and will not impact operation of the wharf or ARHUA while it is in place. Once flood waters begin to rise in front of the barrier, the water pressure starts to lift the leading edge of the barrier, as seen in **Figure 3-3**.

Figure 3-3: Temporary Flood Barrier – Rising Flood Water

The barrier will effectively extend the seawall, providing temporary flood protection for the duration of the storm event, shown in **Figure 3-4**. These barriers are expected to have some seepage below and around the edges that will be captured in the Town stormwater system, conveyed to the lift station and pumped out with the rest of the stormwater. The seepage will be a much lower rate than the stormwater inflow that the system is designed to accommodate.

Figure 3-4: Flood Barrier in Place

In considering whether temporary flood measures could be appropriate for the full extent of the waterfront, rather than constructing the seawall, the following considerations are relevant:

a) The barriers are available with heights up to 1.5 metres. This would provide protection to elevation 5.7 metres, higher than the best-case scenario, but 300 millimetres lower than the worst-case scenario.
b) Because it is lower than the worst-case scenario, this option is insufficient to provide an adaptation pathway to long-term protection if climate change impacts follow the worst-case predictions in the future.
c) Despite being available with heights up to 1.5 metres, common use of these flood barriers is up to a height of 675 millimetres. 675 millimetres is sufficient to provide protection to the 2053 worst-case flood elevation of 5.04 metres at the wharf, but no higher. If the Town elects to pursue an option with greater heights, we recommend working with suppliers to field proof effectiveness and stability under the higher water levels prior to proceeding.
d) The maximum length of continuous flood protection required is 580 metres, or 1900 feet. The barriers are sold in 15 metres, or 50-foot lengths. The wharf temporary protection would require four lengths of flood barriers, whereas the maximum length would require thirty-eight lengths of flood barriers. The Town should confirm stability of barriers without interim support with suppliers to confirm if there is a need for interim support such as concrete keyways at intervals through the installation.
e) The temporary barrier sits on the ground surface. This increases the risk of high floodwaters undermining the ground during a flood event. The barrier would likely need a concrete pad over much of the length to provide a consistent base for the barrier.

f) Deployment of the 38 lengths of flood barrier could be a multi-day process for public works, which will would require earlier preparation and more frequent response to forecasted extreme events.
g) The subdrain, storm sewer and pump station will still be required to deal with runoff behind the barrier, seepage through the ground under the barrier and seepage through the barrier joints and under the barrier.

Based on the additional risk inherent in using a surface based temporary flood barrier and lack of adaptation pathways for future worst-case scenarios, the temporary flood barrier is not selected as the preferred option. However, it can be pursued as a lower-cost alternative if funding cannot be secured for the seawall, provided additional investigation for proof of concept is undertaken prior to construction of concrete pads, the stormwater collection system and interim support columns if needed.

3.6.6 Estimated Cost

The estimated cost of the concept seawall design, including the storm sewer system is $4.42 million, which includes a 25% contingency for unknown factors in the detail design phase. **Appendix E** contains concept drawings of the seawall along the river shoreline for a combined distance of **570-metres**. The temporary flood protection barriers would be required for the **60-metre** gap at the wharf and ARHUA with an estimated cost of $53,000. Detailed engineering, site inspection and project management are anticipated to be an additional $180,000. The total estimated cost to deliver the concept design through construction is **$4.65 million**. A detailed breakdown of cost estimate items can be found in **Appendix F**.

A detailed cost estimate of work to prepare a working platform and install intermittent supports for a temporary flood barrier instead of a permanent wall was outside of the scope of this report, which was intended identify and provide costs for one preferred option. However, to assist the Town in decision making, the opinion of probable cost (order of magnitude costing) for the temporary barrier solution, provided that it is validated by proof of concept, is $1.5 million for site preparation and concrete, plus $456,000 for the flood barriers for a total of **$1.96 million**.

3.7 Shoreline Restoration

The existing waterfront has been impacted with over two hundred years of development which has altered the riverbanks and salt marshes that originally thrived in the inter-tidal zone. With this work along the waterfront, there is an opportunity to incorporate shoreline restoration to reinstate aquatic habitat and biodiversity within the intertidal zone. The section at the lighthouse, shown in **Figure 3-5**, shows conceptually how the shoreline could be adjusted by rearranging the existing boulders shore protection to create a biodiversity rich salt marsh habitat.

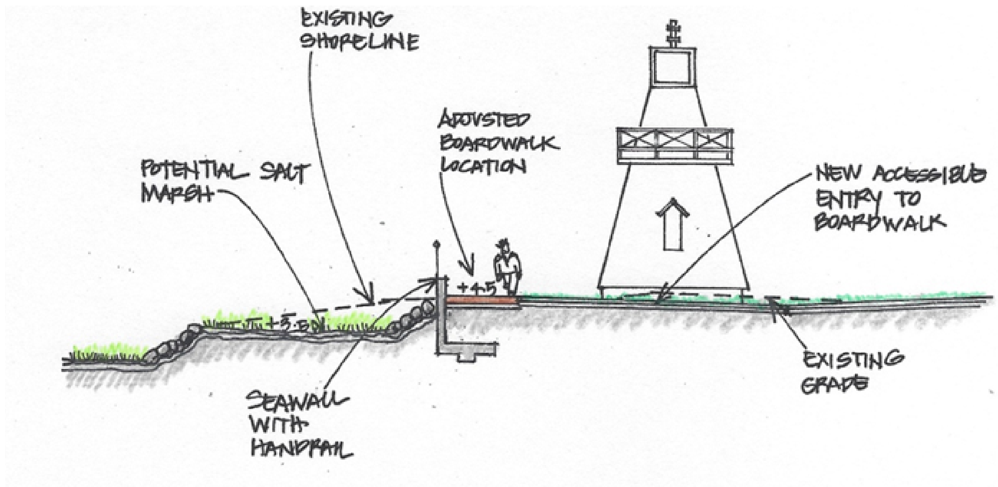

Figure 3-5: Section at the Lighthouse

The area between the Town Wharf and the King's Theatre has been protected with a mix of large stone and driven sheet pile walls, shown in **Figure 3-6**.

Figure 3-6: Existing Condition at Town Wharf

It is proposed that the area be infilled in levels to match aquatic environments that sustain life and create biodiversity. This work will correspond to proposed wharf retention measures to protect Town Wharf. The photos in **Figure 3-7** are examples of built intertidal green spaces – a diverse salt marsh habitat which offers shoreline erosion protection as well.

The section and plan view in **Figure 3-8** shows a conceptual idea of what shoreline restoration could look like between the wharf and the King's Theatre. Refer as well to report **Section 3.8** for a detail through the wharf showing how intertidal terracing can be used as part of a wharf rehabilitation strategy.

The cost of the shoreline restoration is highly variable depending on the extent, length and breadth of construction. The estimated cost of this restoration work is $750,000 based on the extents shown on the drawing in **Appendix E**. Detail design, specifications, project management, site inspection and monitoring are expected to be approximately $95,000 for a total of **$845,000.**

The shoreline restoration is not required for stability of the seawall because the seawall cost estimate includes an accommodation for moving and importing armour stone to protect the toe of the wall against erosion and debris. The shoreline restoration is an additional environmental enhancement that may open access to special-purpose funding if incorporated into the project, as well as improve the look, useability and tourism benefit of the waterfront.

Figure 3-7: Shoreline Restoration

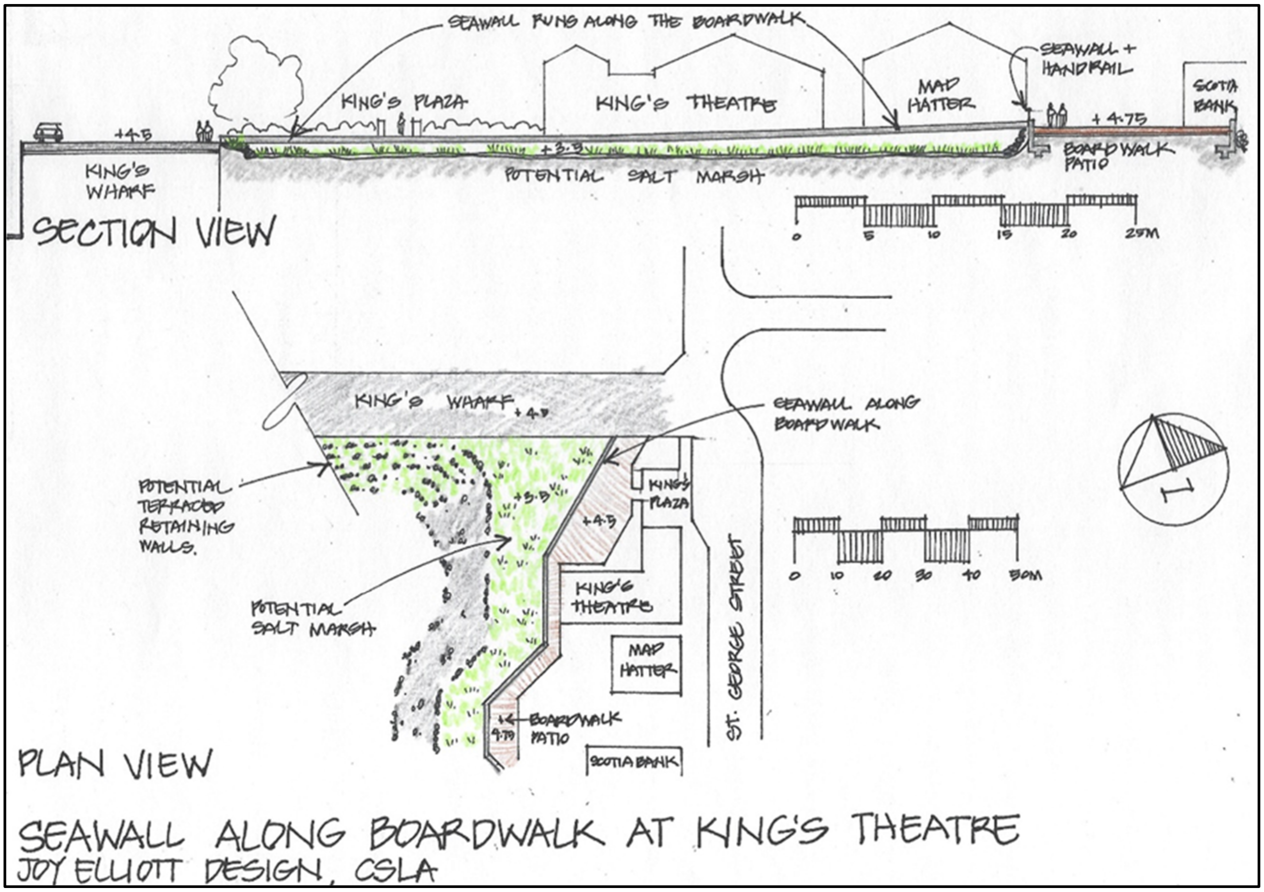

Figure 3-8 Terracing and Shoreline Restoration at King's Theatre

3.8 Wharf Replacement

The Town is assessing options to address structural issues at the Town Wharf, following a structural report issued by Able Engineering on September 22, 2022, with the conclusion that rehabilitation or replacement is necessary in the next five years. On the understanding that this is a priority for the Town, this report has incorporated this section to discuss how the wharf rehabilitation could be incorporated into the waterfront construction and shoreline rehabilitation.

The original wharf was timber construction and the current corrugated sheet piles were installed as a rehabilitation of the original wharf. Rather than reconstruct a new wharf, the Town could construct a new shell around the wharf to retain the existing fill as the existing sheet piles continue to degrade and perforate. **Figure 3-9** shows a plan view of the concept for rehabilitation of the wharf. The concept incorporates a terraced fill embankment as part of the coastal restoration on the south side of the wharf, which reduces the amount of wall required for rehabilitation.

It is not intended here to provide a design of the wharf rehabilitation, as this is outside the scope of this report. However, the Town has requested an order of magnitude cost estimate for rehabilitation that includes an embankment fill on the south side and potential to tie into shoreline restoration that will contribute to habitat restoration and beautification of the waterfront by the King's Theatre. The cost estimate provided here is based on the following assumptions should this be adopted as a preferred approach, subject to validation through detailed structural design. Note that cost estimates do not include cost of design, construction support and project management.

a) The existing wharf will be retained, with the exception of the concrete cap which will be demolished and replaced,
b) Steel H-Piles will be driven around the wharf at 1.8 metre spacing,
c) Facing for the new walls will be 75 millimeter thick, 300-millimetre x 1.8 metre long treated and marine painted timber or stainless-steel structural mesh,
d) As shown in Section A-A in **Figure 3-10**, the embankment can be used as a tie-back to support the opposite H-Piles and reduce the depth required for piling,
e) On the west end of the wharf, the embankment is not possible to construct because the river bottom drops off steeply. In this area, two options are available:
    a. Drive the H-Piles deeper to get the required stability. This will require additional cost in pile length and installation time, as well as increase the risk of hitting obstructions or rock during piling, but saves cost in steel fabrication, or
    b. Fabricate a steel structure by connecting the H-Piles with cross beams and stiffening plates to provide global stability, which incurs less piling cost but more structural fabrication cost.

Once the shell has been constructed, the wharf cap can be repoured.

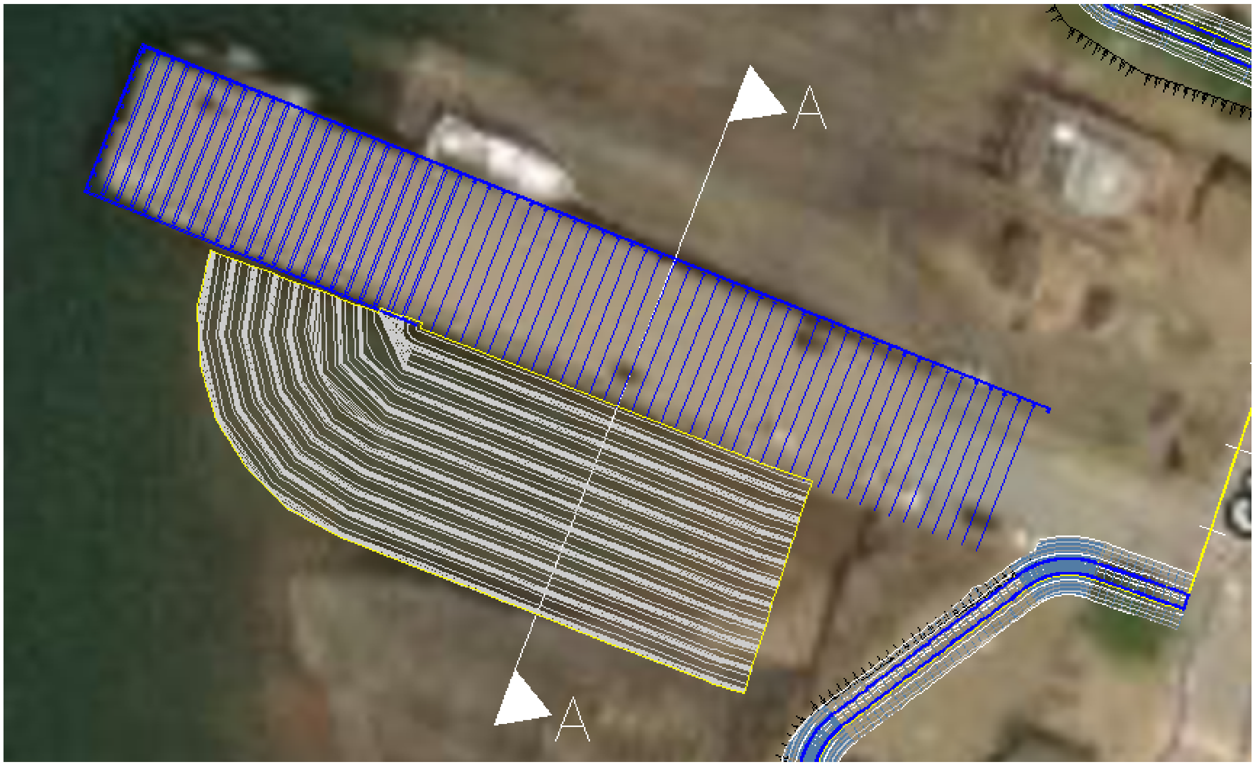

Figure 3-9: Wharf Rehabilitation Plan View

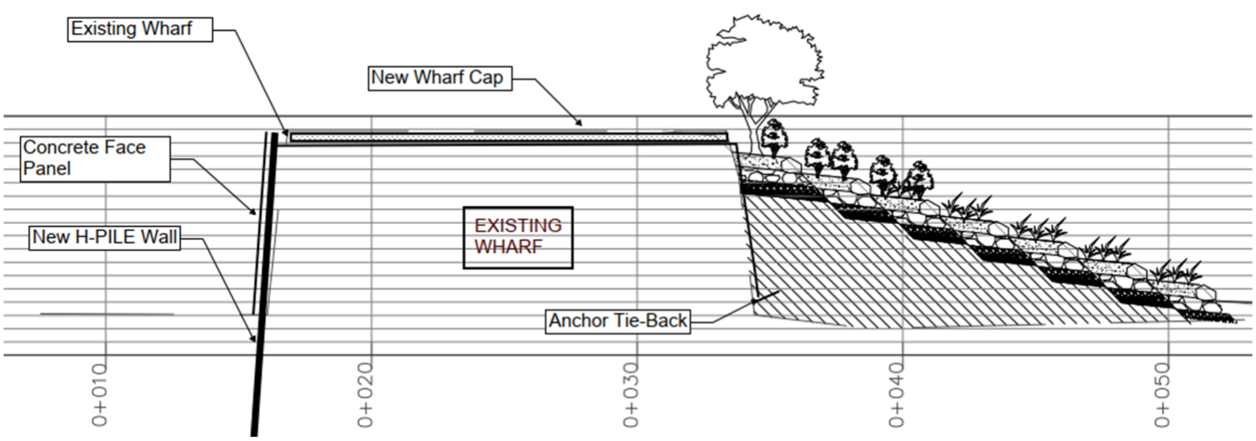

Figure 3-10: Wharf Rehabilitation Concept Section A-A

The opinion of probable cost for this construction is shown in **Table 3-2**. During discussions with town stakeholders, there has been an opportunity identified to include precast facing panels on the outside of the wall. The architectural pre-cast panels would allow for cultural and artistic elements to be incorporated into the wall; however, this carries significant extra cost because the precast facing panels are not used as structural elements to retain fill to the heights required for the wharf. Costs are presented in tabular format to show an overview of cost elements in the concept.

Table 3-2 Wharf Rehabilitation Opinion of Probable Cost

Element	Approximate Cost (2023$)
Steel Piling and Wall Face	$ 630,000
Structural Steel Work	$ 325,680
Tie-Back System	$ 87,000
Embankment fill, rock placement and geotextile	$ 726,200
Vegetation and Planting	$ 56,000
Concrete capping	$ 140,875
Miscellaneous Staging and Other Elements	$ 38,245
Subtotal	**$ 2,004,000**
Geotechnical Investigation and Detail Design	**$ 162,500**
25% Contingency for unknowns (includes contingency on design)	$ 541,625
Total without architectural panels	**$ 2,545,625**
Architectural Pre-Cast Panels	$ 1,128,000
25% Contingency for unknowns	$ 282,000
Total with architectural panels	**$ 3,955,625**

4 Seawall Design Basis

This section provides the basis of the concept design of the seawall that should be considered if the Town proceeds to detail design and construction. All elevations are given in Canadian Vertical Geodetic Datum (CGVD) 2013.

- Design life of the wall shall be 100 years.
- Concrete mix shall be developed considering the possibility of saltwater exposure from estuarine conditions, which will become more pronounced with sea level rise.
- Drilling logs and an interpretive report are included as **Appendix G** of this report. The dominant substrate is a firm clay material overlain with some areas of imported fill. Based on the drill logs, it is expected that most of the wall foundation will be on native clay material, but the cost estimate includes a provision to remove and replace pockets of material where unsuitable fill is encountered.

- Maximum bearing pressure of the firm clay has been assumed to be 75 kPa with a maximum design wall bearing pressure of 45 kPa.
- Minimum factor of safety against overturning shall be 1.5.
- Top of wall is set at elevation 5.34 metres with a design water level of 5.04 metres.
- Minimum frost depth to bottom of wall is 1.2 metres.
- Handrail height is 450 millimetres with top of rail at elevation 5.78 metres.
- Maximum water level in the worst-case climate forecast is 6.05 metres.
- Handrail design should accommodate bending moments from a water level to top of rail at its lowest elevation in the event it is integrated as part of the barrier in the future.
- Handrail heights should be set to meet code while minimizing the impact to the visual line across the river. Height may vary depending on the height of wall above the boardwalk.
- Wall overturning and sliding should consider current conditions, design conditions and worst-case water elevations, as well as low tide conditions.
- The toe of the wall will need to be protected from erosion and undermining by armour stone or living shoreline.
- Elevations of the existing boardwalk shall be retained.
- Access to the existing boardwalk shall be retained at all current locations. At the lighthouse, the boardwalk and wall shall be stepped out toward the river to straighten this section of walkway.
- Existing stair access from the deck behind the King's Theatre to the waterside shall be reinstated with steps over the wall from the boardwalk side.
- Wall design should include considerations that the wall may need to be extended up to 900 millimetres in the future, so rebar design and upstand thickness should allow for this modification if required.

Adaptation pathways shall be considered in the design of the wall. The current design basis will protect against flooding from the current highest astronomical tides, the 100-year return period storm surge with SSP2-4.5 climate projections to 2103, or the 100-year return period storm surge with SSP5-8.5 climate projections to 2053. If sea-level rise and increased storm surge from more powerful winds is found to be tracking on the worst-case scenario, remedial work will be required to increase the level of protection from the wall in approximately thirty years. There is no way to predict what materials, technologies or funding will be available at this time, but the detail design should consider at least two possible solutions.

The first is extending the wall with additional concrete. The design shall demonstrate how an additional section of wall could be added to the top of the existing wall without compromising the function, global stability or bearing capacity of the existing wall and foundations.

The second option would be to retain the view through the handrail at the current design height and install a floating flood barrier that would brace against the handrail during high water levels and drop back below the top of wall once the surge recedes. The design shall demonstrate how such a mechanism could be developed and installed without compromising the function, global stability or bearing capacity of the existing wall and foundations. An illustrative sketch of such a-mechanism is shown in **Figure 4-1**.

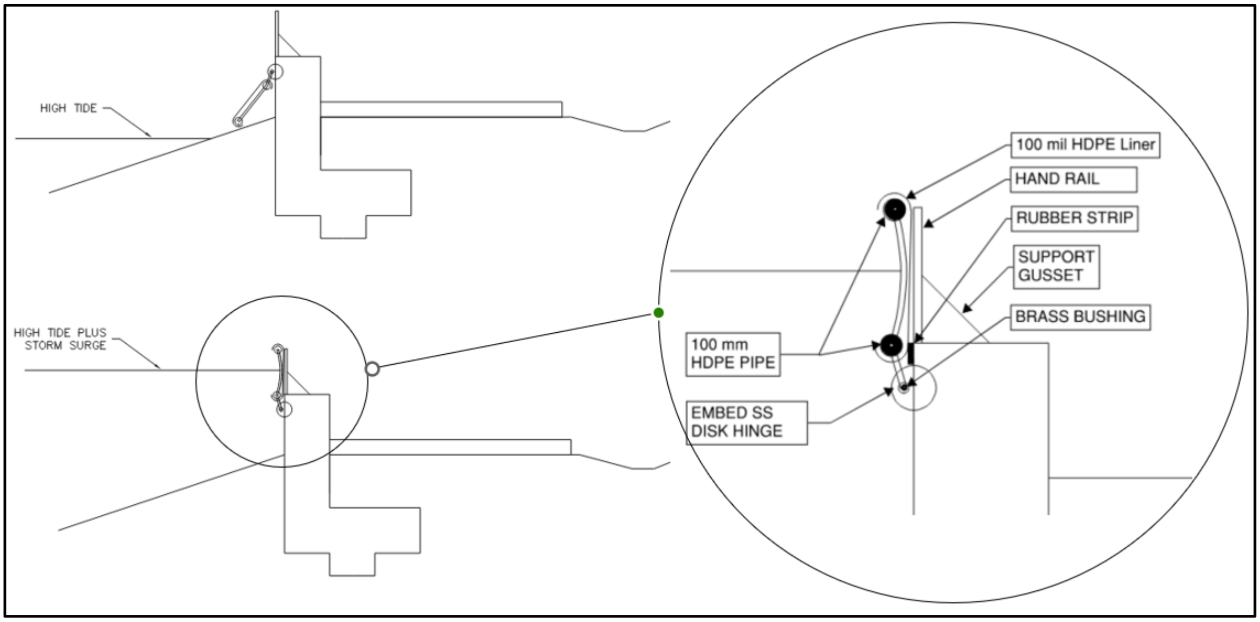

Figure 4-1: Schematic of Floating Flood Barrier

5 Culture and Heritage Considerations[5]

Annapolis Royal is known as the 'Cradle of our Nation.' Long before Europeans arrived here, the Mi'kmaq inhabited the area. The Annapolis River (previously known as the Dauphin River) was an important link in the overland route to the South Shore of what is now Nova Scotia. The site of present-day Annapolis Royal is situated on the shallow south facing banks of the Annapolis Basin – a good but shallow harbour and was firmly established as a Mi'kmaq habitation site.

The first Europeans visited the area in 1604 when the French explorers began a friendship with the Mi'kmaq under the leadership of Chief Membertou. Battles between the French and the English for control over these lands continued between 1613 and 1763 when France transferred

[5] Sources: https://annapolisroyal.com/visitors/history-timeline/
https://annapolisheritagesociety.com/community-history/history-annapolis-royal/
https://en.wikipedia.org/wiki/Annapolis_Royal
https://parks.canada.ca/lhn-nhs/ns/fortanne/culture/histoire-history

power over the land to Britain. The 17th and 18th Centuries saw the area become a center for European colonization.

The first fort was built in present-day Annapolis Royal by the Scottish in 1629. The French built the star shaped European fortification beginning in 1702 but by 1706 the British gained control and the area was named Annapolis Royal. The new Field Officers Quarters were built at the fort in the 1790's and the site became known as Fort Anne in 1800.

This area supported a thriving Acadian population until 1755 when they were deported during the Great Upheaval. They left behind a legacy of dykes which protected productive farmlands. Many of these are still in use today. The New England Planters began to settle in Annapolis County in 1760. The period between 1781-1783 saw an influx of United Empire Loyalists including Black families.

After the War of 1812, calm was restored to the area and attention turned to economic pursuits. Many lavish homes were built in Annapolis Royal using the wealth generated by the growth of the shipping industry and from ship building. The Annapolis Royal Port was connected to the productive Annapolis Valley farmlands by the Windsor – Annapolis Royal Railway. The sea link allowed this small town to achieve a high level of industry that belied its small size. The Town boasted a dozen working wharves at this time. This high level of economic growth allowed the culture of the area to thrive. There was a music hall, a rink, a theatre, numerous churches as well as numerous inns and many stylish homes.

When the British withdrew from the Town in 1854, the Town declined, but local citizens helped to establish the Town as Canadas first National Historic Site in 1917. It is the largest registered Historic District in Canada with 135 Registered Heritage Properties, Canada's oldest wood framed building and the oldest example of an Acadian style home. Since 1900, the Town's major economic activity has been tourism.

Annapolis Royal has long attracted a unique population of artists, writers, musicians and other creative people. The tranquil streets, historic sites, and scenic beauty make the small town a haven for those with an artistic spirit. The community celebrates and supports their local artisans – which has resulted in a thriving artistic community that adds a creative energy to the Town.

Community spirit shines in Annapolis Royal. There are many active volunteers who strengthen the unity and pride within the Town. This strong sense of community creates a warm and inviting atmosphere.

Multiple gardens (both public and private), tree lined streets, a public waterfront boardwalk, a unique shopping area, an enviable selection of restaurants, world class accommodations, important heritage sites, exciting art community and theatre combined with many wonderful recreation opportunities make this small town a must-see destination.

The proposed seawall project will protect this unique site with its rich diversity of culture and heritage. While the Town is small, it is not possible to relocate the resources of the worst flood prone area. The Town is only 2.04 square kilometers in size and there is no vacant land to move to even if the current buildings and infrastructure could be relocated. While the population of Annapolis Royal is only 530 inhabitants, the Town serves as a catchment for 9,000 local citizens. In addition, tourism numbers soar during the spring, summer and fall months.

The seawall is critical to protect this vibrant town with its iconic heritage and cultural landscape from destruction by rising flood waters and storm related events. The design allows the existing connection between the upland elements to remain. **Figure 5-1**, a section drawing at the Amphitheatre shows how the outdoor stage area will remain accessible to the boardwalk. This is a critical link for the Amphitheatre as this is the accessible connection to the stage area. The photograph in **Figure 5-2** shows the existing condition for reference. The low height of the wall (shown on the section drawing) continues to allow views to the Annapolis Basin. Additionally, the seawall construction will not disrupt the existing salt marsh habitat.

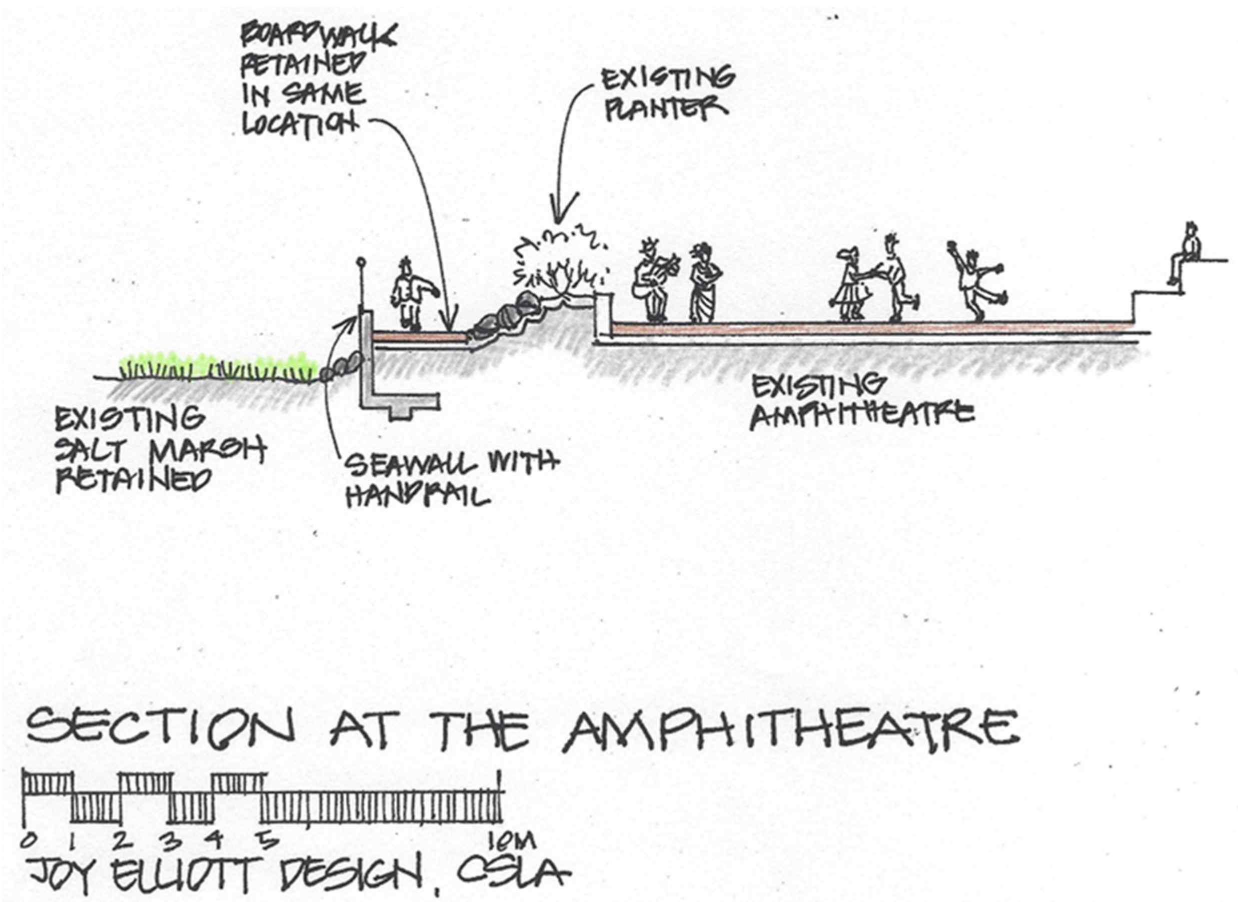

Figure 5-1: Section at the Amphitheatre

Further along the boardwalk, the seawall offers an opportunity to improve the crooked alignment of the existing boardwalk resulting in a safer condition. This important public connection between the boardwalk and the upland park is retained. There is also the opportunity to rearrange the existing boulders shore protection to create a biodiversity rich salt marsh habitat. **Figure 5-3** shows the new boardwalk location at the lighthouse and illustrates the existing crooked section of boardwalk that will be straightened with the new installation.

Figure 5-2: Existing Conditions at the Amphitheatre

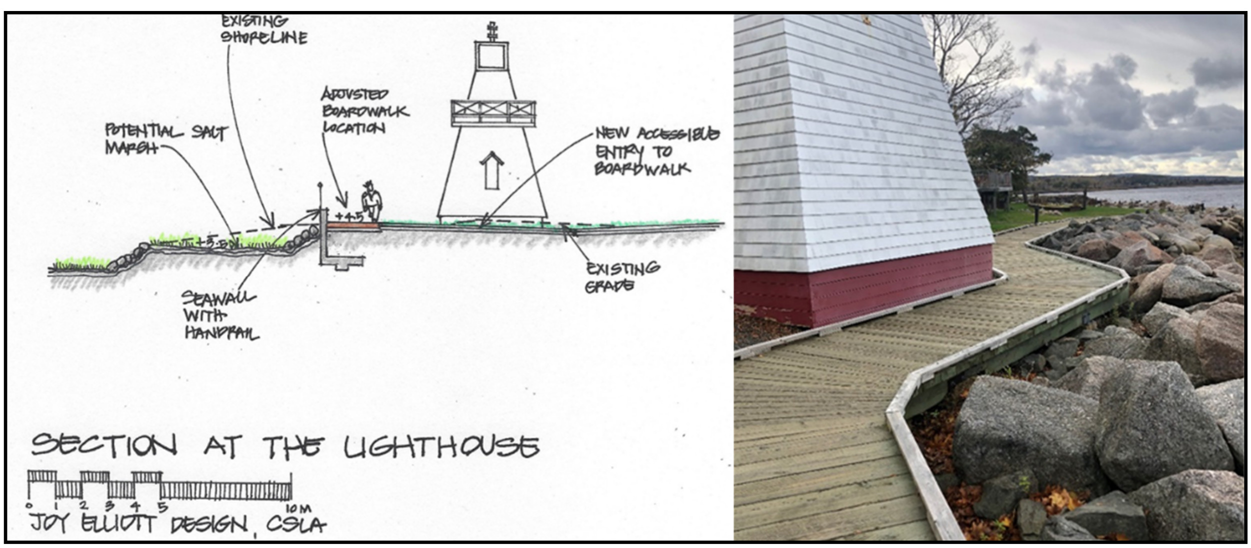

Figure 5-3: Boardwalk Improvement at the Lighthouse

The existing patio space on the boardwalk will be retained allowing this well-loved public gathering space to be retained. The important connection between the adjacent business patio remains unchanged and views of the Annapolis Basin will be left open, shown in **Figure 5-4**. This site also offers the potential to create a salt marsh habitat.

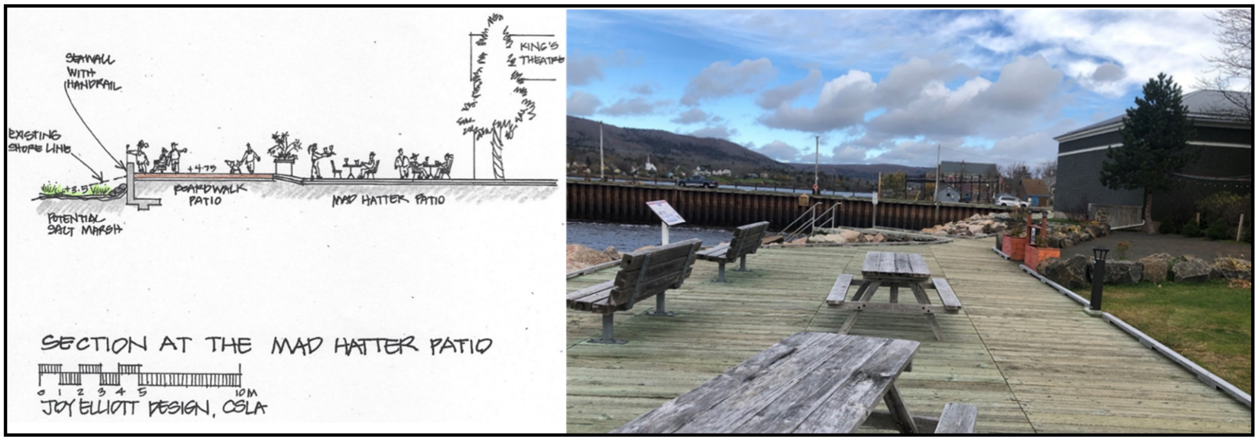

Figure 5-4: Proposed Wall at Boardwalk Patio

In addition, the wall offers a unique opportunity to add another layer of interest and attraction to the Town. Not only will the seawall hold back the flood waters, but the proposed 570 lineal meters of wall could become a canvas for the community to tell its story. The photos that follow show some images of concrete wall art to demonstrate the possibilities using cast or stamped concrete to tell a story of Annapolis Royal's history through art.





The proposed low seawall also offers the potential to add seating in select locations. Below are two image ideas, in **Figure 5-5**, showing what could be possible.

Figure 5-5: Integrated Wall Seating Areas

6 Indigenous Consultation

One of the guiding principles of Canada's National Adaptation Strategy is to respect jurisdictions and uphold Indigenous rights[6]. With respect to jurisdiction, all land in Nova Scotia is considered unceded Mi'kmaq territory[7]. 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. There is great potential for not only consultation, but collaboration on aspects of the project discussed in this report like shoreline restoration, native species habitat, historical markers, informative signage and storytelling through art.

7 Financial Analysis

The technical analysis in Appendix C demonstrates that it is more cost-effective to adapt to climate change than respond to a disaster through emergency response funding or insurance claims. The financial assessment in **Appendix C, Section C15** is summarized in **Table 7-1**. This table shows the risk weighted costs of flood damage. These costs are developed by weighting the total damage expected from a flood event, in current dollars by the percentage likelihood from **Table 7-2** that such an event will occur once, twice or more over the study period.

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

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

Table 7-1 Estimated Damage by Flood Depth

Scenario	Average Cost Impact per Event	Cumulative Percentage Weighted Cost
2053 RCP4.5	$5,982,799	$1,800,822
2103 RCP4.5	$7,563,329	$6,209,493
2053 RCP8.5	$9,102,445	$2,739,835
2103 RCP8.5	$20,626,968	$16,934,740

Table 7-2 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
Cumulative Sum	30.1%	82.1%

It is generally accepted that given current global climate policy, continuing reliance on fossil fuels, and still increasing annual greenhouse gas emissions, that the best-case scenario of RCP2.6 is not a realistic possibility to achieve by the end of the century, so it has not been considered here.

The estimated cost of the flood wall in current dollars is **$4.65 million**. **Table 7-1** demonstrates that, in current dollars, if climate change forecasts follow the moderate scenario of RCP4.5, which under current models has a high likelihood of being met or exceeded, that it would cost less to respond to a flood event than construct the wall before 2053. However, extending the projections to 2103, or considering the worst-case scenario, results in the wall being a lower cost of adaptation than the potential damage.

RCP8.5 is sometimes referred to as the “business as usual” scenario, where emissions continue along current trajectories. Under this scenario, the risk-weighted costs exceed the cost of the wall by 80% for the thirty-year period to 2053, and by 430% when considering the full study period of eighty years to 2103. Interpolating from these assessments, interim climate scenarios would be cost neutral over the medium term and still overwhelmingly cost positive over the longer term.

The financial assessment in **Appendix C** considers the cost of damage to structures. It does not consider other related costs such as interruption to the business community, access to services provided by those businesses if they are shut down for a long time, potential loss of heritage buildings if damage is severe enough and impacts to tourist traffic from functional loss of buildings like the King's Theatre. These are difficult to quantify but are important considerations in decision making.

8 Conclusions and Recommendations

Based on this analysis, there is increasing risk over the coming decades from coastal flood risk in Annapolis Royal from the impacts of climate change. The financial analysis demonstrates that under all but the most optimistic of climate projections that taking adaptation action will be more cost effective than waiting for and responding to disaster events which have increasing likelihood of occurring over time.

Near-term (five year) risk of a major flood event in the downtown area only slightly greater than historic baseline conditions. Sea level rise has been minimal over the last one-hundred years, but there is a weak statistical indication that wind energy, responsible for storm surges, has already increased somewhat. However, the period of record is too short for reliable statistical analysis of the magnitude of that increase.

The most urgent action needed is for the Town Wharf, which is at risk not only from climate driven events, but also from the aging sheet pile structure. This is recommended to be the first priority over the next five-years, with a decision made to rehabilitate or demolish the wharf.

There is substantial future risk of catastrophic flooding over the medium term (thirty-years). Managing this flood risk is recommended as a priority over the next twenty years, and sooner if funding is available to support long-term adaptation projects. The risk increases the longer adaptation activities are delayed. Out of the potential adaptation strategies, only two are feasible: emergency response planning to mitigate the consequences of flood events or construction of a structural barrier along the waterfront. Construction of a barrier should protect against flooding to CGVD2013 elevation 5.34. This will provide flood protection for intermediate forecasts to 2103, or for worst-case climate forecasts to 2053. The wall shall be designed to allow future expansion or alternative flood protection for the worst-case scenario to 2103 without having to remove or reconstruct the wall. Because climate forecasts are continually changing as new data and modeling is developed, the designers should consider whether to accommodate future expansion to RCP8.5 upper limits of 1.1 metres of sea level rise by 2100 or the modeling extreme worst-case scenario of 1.5 meters through a workshop to discuss the value of reduced risk versus cost in a workshop with the Town.

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

a) **Emergency response planning**: This is a low-cost, high value exercise that can be started immediately. The Town should develop an emergency response plan 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. procedures 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) **Wharf Rehabilitation**: The wharf can be abandoned (removed), rehabilitated or replaced. The cost to rehabilitate or replace the wharf is on the order of **$2.5 million** dollars to **$5 million** dollars, depending on rehabilitation versus replacement, the size of a replacement and aesthetics of the wharf finish. The Town should consider the costs versus benefits of retaining this structure. Benefits may include considerations other than financial (such as tourism, community support and heritage value) but these need to translate into a community willingness to support the financial requirements of the work. Costs may also be experienced in less obvious ways, such as lost opportunities to upgrade existing roads and underground utilities, resulting in a lower service level from these core municipal services.

c) **Climate Adaptation**: If the Town decides to invest in adaptation through constructing a flood barrier along the existing boardwalk and trail system, there are several other actions recommended to accompany pursuit of funding from conventional sources.

   i. Consider the "do-nothing" option. The greatest risk to municipal service infrastructure is the wastewater treatment plant, which can be protected through operational flood control through the causeway. There is potential for hydraulic connections from flooding on the west side of town, but this could be addressed with temporary flood barriers like the ones described earlier in this report. Most of the infrastructure protected by a proposed seawall is privately owned. Even with outside financing, there will be a substantial municipal contribution required which will increase municipal debt loads and delay upgrades to roads, facilities and underground utilities. Continuing public consultation is recommended to ensure that the community understands these trade-offs and compromises and the purpose for which they are intended.

   ii. Commence consultation with Bear River First Nation to understand the cultural implications of this work and explore opportunities for collaboration.

   iii. Engage with sponsors / potential contributors through businesses or large industry. Annapolis Royal is a premier destination in Nova Scotia. Corporate contributions to this project would be highly visible to thousands of people per year. With its proximity to the amphitheatre, Fort Anne and the downtown core, there is ample opportunity to publicize contributions of engaged corporate citizens.

   iv. Consult with local businesses to determine their current protection from overland flooding through insurance and costs of that insurance. Some commercial insurance policies do not cover overland flooding, and deductibles vary greatly. Hurricane Fiona demonstrated that disaster relief funding can be slow to arrive. There may be a business case for local corporate contribution to the project through lump sum or installments when costs of deductibles, loss of revenue following a flood event and increasing rates as the insurance industry absorbs more frequent costs from climate change.

   v. Seek funding from tourism related sources and incorporate this as an opportunity to build an attraction, not just flood protection infrastructure. Allow for input from the community and local experts on the function and design of the installation.

   vi. Consider the big picture. Annapolis Royal's response to climate change is just one other key event in a long and storied history. With such a vibrant and creative community, actions taken now can reflect the place of Annapolis Royal within Canada's history, and the place of these decisions within Annapolis Royal's history.

   vii. 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.

viii. Engage provincial and federal elected officials to determine proposed courses of action to fund needed adaptation projects for small coastal communities in Nova Scotia.

9 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

Seawall Technical Assessment

C1 Project Definition

The intended outcomes of this report are 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.

C2 Scope

This report uses Engineers Canada's PIEVC Protocol model for risk assessment and draws on the recommended risk evaluation and treatment analysis methodologies outlined in Infrastructure Canada's Climate Lens Guideline and strives 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, temperature or others not explicitly mentioned.

Figure C-1 is an excerpt from Infrastructure Canada's Climate Lens – General Guidance. Based on historical reports of catastrophic coastal flooding (the Saxby Gale of 1869 and Groundhog Day Storm of 1976) within the last 150 years and 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.

C3 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 supports the recommendations in the main body of the report.

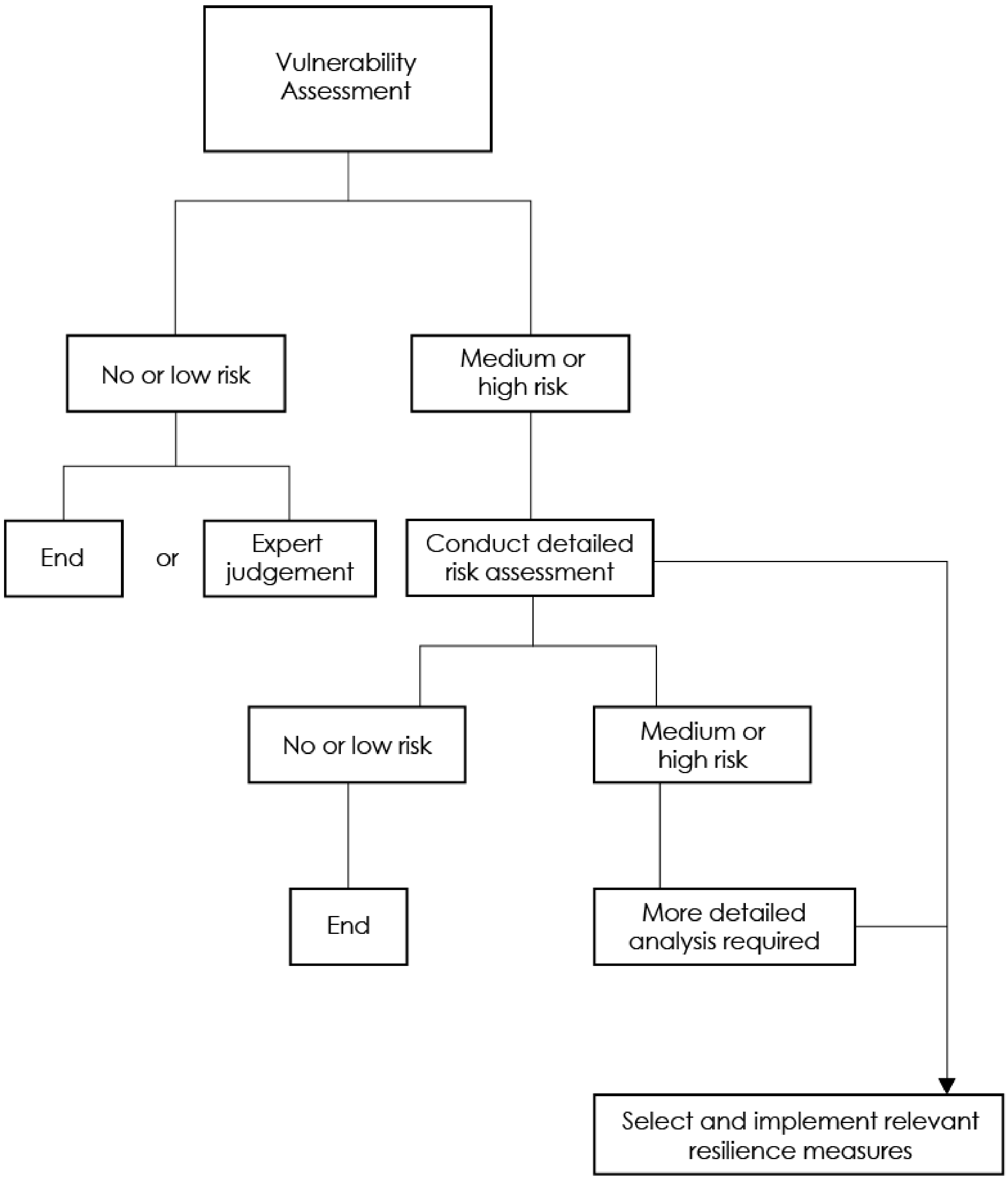

Figure C-1 Flowchart of Resilience Assessment

The report expands on these recommendations to provide a roadmap for adaptation with actions that can be taken immediately. These actions recognize that adaptation based on worst-case scenarios is not possible using only the Town's financial resources and existing funding structures from other levels of government. The adaptation plan provides options not based on what "should" be done, as risks have been clear from numerous past reports over the last decade, but instead to support what *can* be done, including activities to remove the barriers to proper adaptation that currently exist.

C4 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 C-1**.

Table C-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%

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.

Probability of failure (PoF) percentages are the likelihood 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.

The second component of risk is the consequence of failure. This is the impact to the community if the service failure occurs. Consequences of failure are defined in **Table C-2**. To interpret these risk assessments, it is important to consider the timeframe of the risk exposure. As the timeframe approaches zero, the likelihood of experiencing a failure also approaches zero. As the timeframe gets longer, the likelihood increases, ultimately becoming almost certain over long periods without intervention. To determine the most critical risk infrastructure, the risk screening considers increasing likelihood of events with the same consequences, seen in the risk assessment tables in **Appendix B**.

Annapolis Royal's risk tolerance is represented in the risk tolerance matrix developed in the risk workshop during asset management plan development. This defines how critical action is for climate change event exposure. **Figure C-2** shows the risk tolerance used in the assessments in **Appendix B**. Action is prioritized over the relevant timeframe:

- Extreme Risks: Take immediate action.
- High Risk: Plan action within assessment time frame.
- Medium Risk: Review risk sensitivity and determine if further action needed.
- Low: Monitor risk profile.
- Very Low: No action required.

	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 C-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 C-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.

The results of the five-year horizon risk assessment indicate that action needs to be taken within the next five years to manage risk exposure to the Town Wharf, while flood risk is within the Town’s acceptable risk tolerance for coastal flooding from the Annapolis River. Because the Town is already pursuing options to replace, repair or rehabilitate the wharf, it is not assessed further in this report. However, any design for the wharf shall consider the climate change conclusions presented here in the design specifications.

The results of the twenty-year horizon risk assessment indicate that action needs to be taken to address risks related to coastal flooding of the downtown core in the next six to twenty-years, and that potential the wastewater treatment plant should be considered in this assessment. The remainder of this section provides the detailed technical assessment of these impacts.

The long-term horizon risk assessment does not indicate any other critical risk factors other than those already identified, and provided appropriate action is taken to address the medium-term risks, there are no residual risks to be considered.

C5 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 C12** of this appendix.

C6 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 approaching the end of proposed design life in eighty-years to 2103.

C7 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 C15** of this appendix is potential damage and disaster repair costs from these events. However, the consequence of failure matrix 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.

C8 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 C-3**.

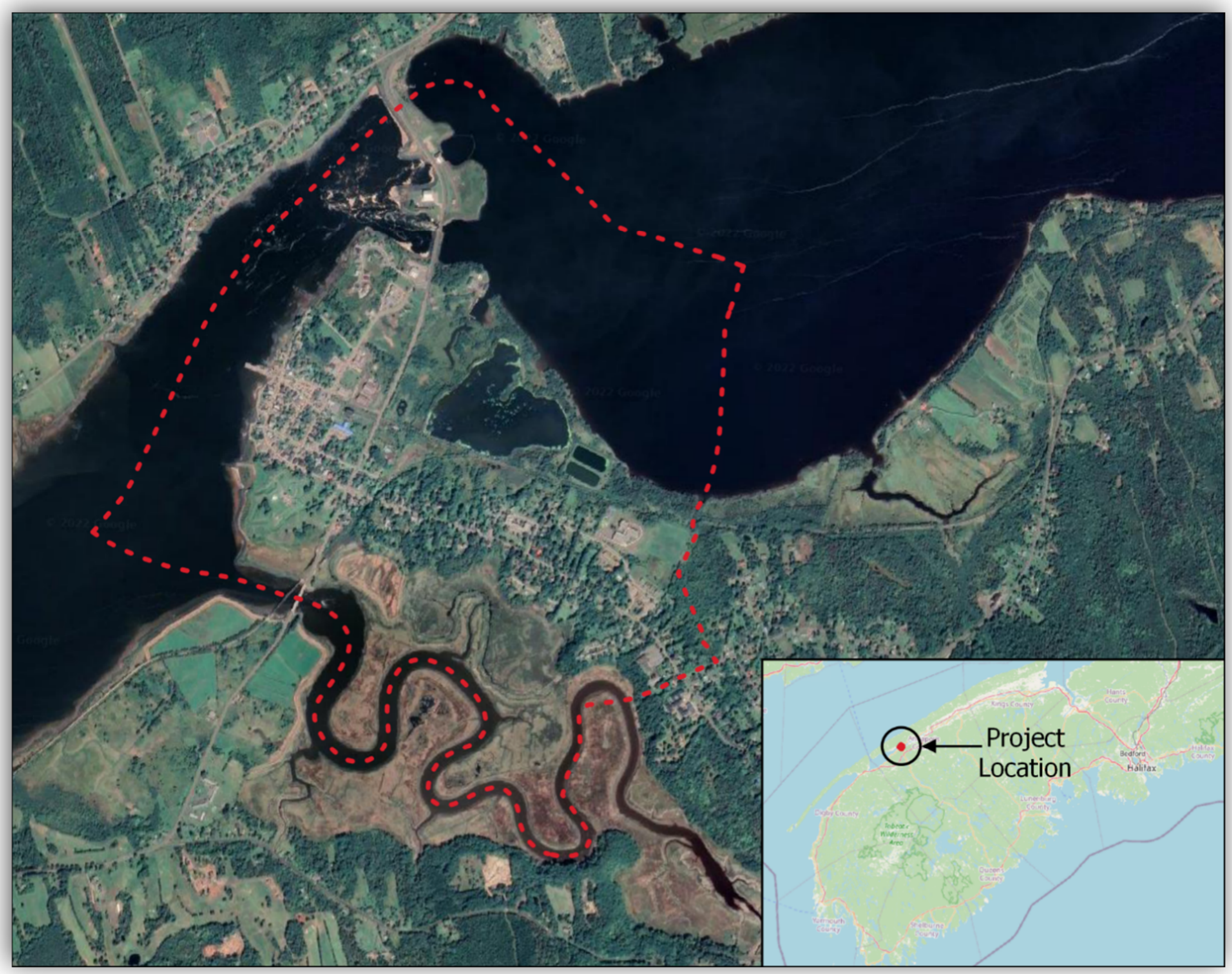

Figure C-3 Geographic Setting

C9 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 is considered as well. In addition to the Town jurisdiction, the land lies within the Mi'kmaq district of Kespukwitk, and consultation with Bear River First Nation is 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.

C10 Participating Stakeholders

This report has been developed using input from reports produced by 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, Wharf Committee, Town Council and Public Works staff.

C11 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.

C12 Baseline Data and Climate Change

Benchmark tide elevations for the tide station at Digby are shown in **Table C-3**. Tide elevations, adjusted to CGVD2013 geodetic elevation has been derived from tide charts at the Town of Digby provided by Fisheries and Oceans Canada. The tide station elevations are provided using Chart Datum, with a conversion factor of -4.429 to convert to the Canadian Geodetic Vertical Datum of 1928 (CGVD28)[8]. The current standard for vertical survey datum in Nova Scotia is CGVD2013, which has replaced CGVD28 and requires a further adjustment of -0.637, using the benchmark at Annapolis Royal Town Hall[9].

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

[8] Government of Canada Tides, Currents and Water Levels, https://www.tides.gc.ca/en/stations/325

[9] https://webapp.csrs-scrs.nrcan-rncan.gc.ca/geod/data-donnees/station/report-rapport.php?id=69N012

Table C-3 Digby Tide Elevation - Relative to CGVD2013

Name		Description	Elevation (m)
Highest Astronomical Tide	HAT	The highest predicted tide expected over the period of 40 years.	**4.314**
Higher High Water Large Tide	HHWLT	The average of the highest high waters, 1 from each of 19 years of predictions.	**4.104**
Higher High Water Mean Tide	HHWMT	The average from all the higher high waters from 19 years of predictions.	**2.874**
High Water Level	HWL	The highest level reached at a place by the water surface in 1 tide cycle.	**2.734**
Mean Water Level	MWL	The average of all hourly water levels over the available period of record.	**-0.526**
Low Water Level	LWL	The lowest level reached at a place by the water surface in 1 tide cycle.	**-3.816**
Lower Low Water Mean Tide	LLWMT	The average of the lowest low waters, 1 from each of 19 years of predictions.	**-3.936**
Lower Low Water Large Tide	LLWLT	The average of all the lower low waters from 19 years of predictions.	**-5.226**
Lowest Astronomical Tide	LAT	The lowest predicted tide expected over the period of 40 years.	**-5.416**

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). This is not appropriate to use for a risk assessment. The tide and storm surge are independent events. The likelihood of a 100-year (or one-percent chance of occurring each year) storm surge occurring during a king tide, which only happens one or two days out of the year, would be a lower probability than the 100-year event.

More consistently, high tides occur around an average of the **higher high water mean tide** (HHWMT), or the average elevation of the higher high tide range. This means that on any given day, it is as likely as not that the higher tide will reach this level.

Storm surges can last several hours to near a day, so when the 100-year storm surge occurs, it is probable that it will be coincident with a level approaching the HHMT. For greater tides, such as a king tides, the frequency of occurrence is less than that of the HHMT. For this reason, the HHMT is used as the base tide condition for analysis.

C12.1 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 above or below that mean as we project further into the future. **Figure C-4** demonstrates this for one climate case.

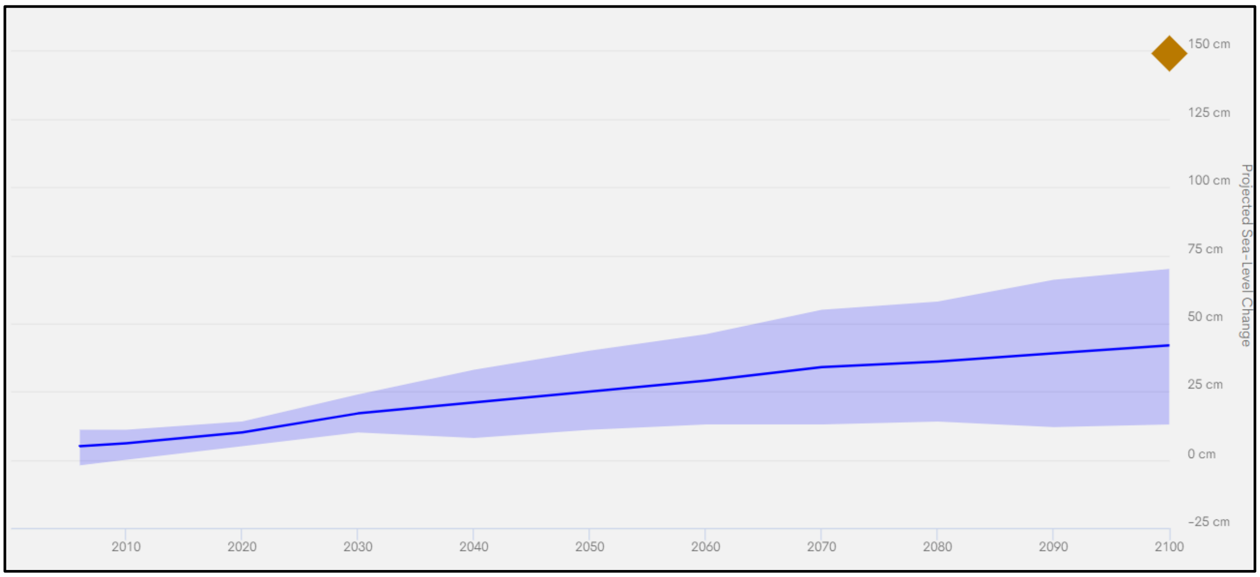

Figure C-4 Sea Level Rise Projection for RCP2.6[10]

Figure C-4 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.

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.

[10] 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. **Figure C-5** shows the relative greenhouse gas emissions and mean worldwide temperature increase for different RCPs.

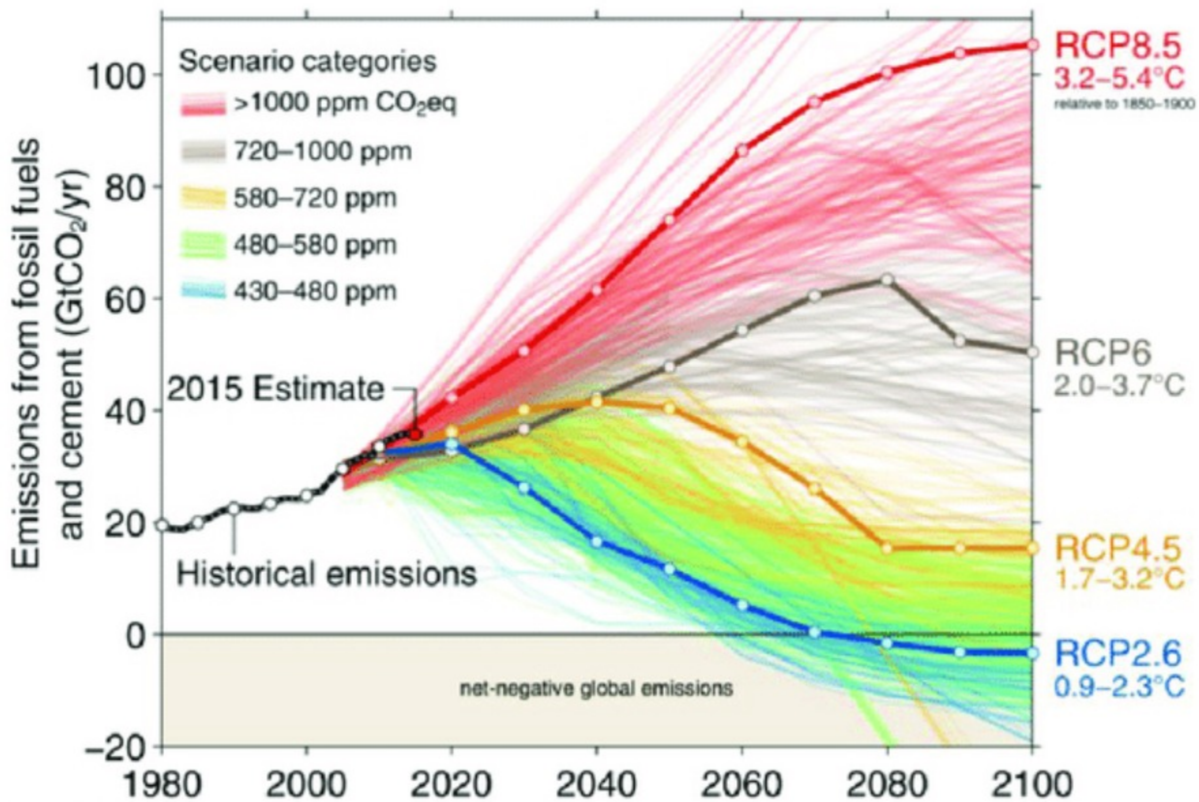

Figure C-5 RCP Pathways and Mean Global Temperature Increase[11]

Consider the contrast between RCP2.6, the best-case scenario of aggressive emissions reduction with RCP8.5, a projection that assumes there are no aggressive climate policies adopted worldwide. RCP8.5 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.

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

Figure C-4, for RCP2.6 has a median sea level rise of 380 millimetres, with a margin of error predicting at least 130 millimetres of rise but no more than 700 millimetres. This can be contrasted with RCP8.5, shown in **Figure C-6**, which has a median sea level rise prediction of 750 millimetres, almost double that of the RCP2.6 scenario. The maximum projection is 1120 millimetres, a 60% increase over the RCP2.6 scenario. Also note the diamond at the top right of the projection. This is the current theoretical maximum given current modeling, 1500 millimetres of sea level rise by the year 2100.

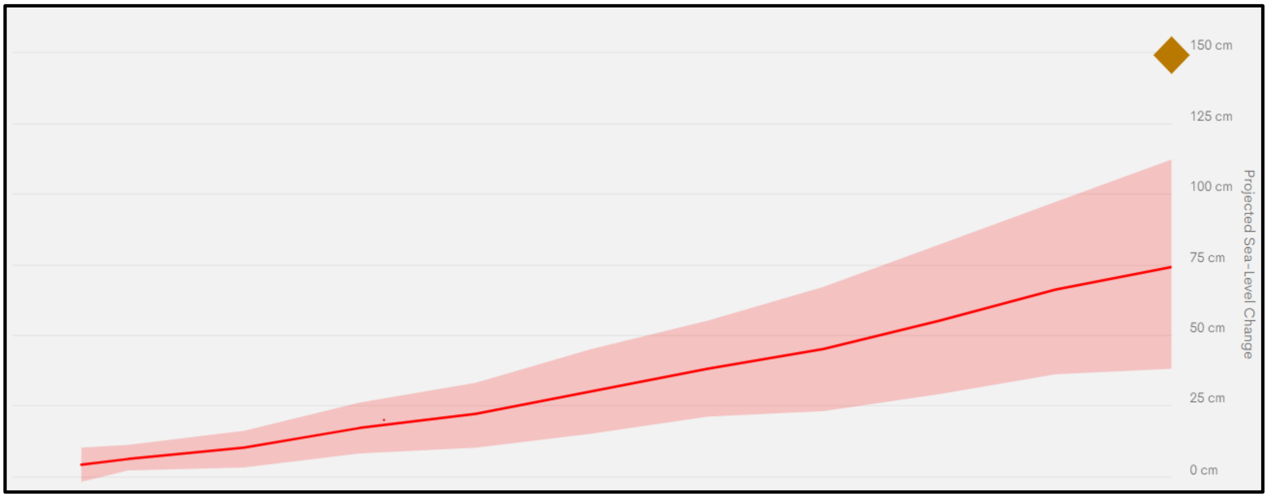

Figure C-6 Sea Level Rise Projection for RCP8.5[12]

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.

In addition to sea level rise from climate change, flood elevation projections need to 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 on top of climate impacts.

As an addendum to this section, this report uses both RCP and Shared Socioeconomic Pathway (SSP) terminology, depending on which IPCC report is being referenced. Since the original version of this report, the IPCC AR6 was released which replaced RCP designations with SSP designations.

[12] https://climatedata.ca/

Figure C-7 shows the relation from the 5th assessment report (AR5) RCP designation and the AR6 SSP designation.

Category in WGIII	Category description	GHG emissions scenarios (SSPx-y*) in WGI & WGII	RCPy** in WGI & WGII
C1	limit warming to 1.5°C (>50%) with no or limited overshoot***	Very low (SSP1-1.9)	
C2	return warming to 1.5°C (>50%) after a high overshoot***		
C3	limit warming to 2°C (>67%)	Low (SSP1-2.6)	RCP2.6
C4	limit warming to 2°C (>50%)		
C5	limit warming to 2.5°C (>50%)		
C6	limit warming to 3°C (>50%)	Intermediate (SSP2-4.5)	RCP 4.5
C7	limit warming to 4°C (>50%)	High (SSP3-7.0)	
C8	exceed warming of 4°C (>50%)	Very high (SSP5-8.5)	RCP 8.5

Figure C-7: Representative Concentration Pathways and Shared Socioeconomic Pathways[13]

C12.2 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 short duration 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 C-5**, warming could be up to four to five degrees above the global mean under the RCP8.5 scenario, which would increase the energy in the atmosphere and 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.

[13] IPCC, 2023: Summary for Policymakers. In: Climate Change 2023: Synthesis Report.

The project team used a plot of storm surge versus wind speed for the Bay of Fundy developed using methods from the *Guide to Storm Surge Forecasting*, World Meteorological Association. 2011. The projected curve is shown in **Figure C-8**.

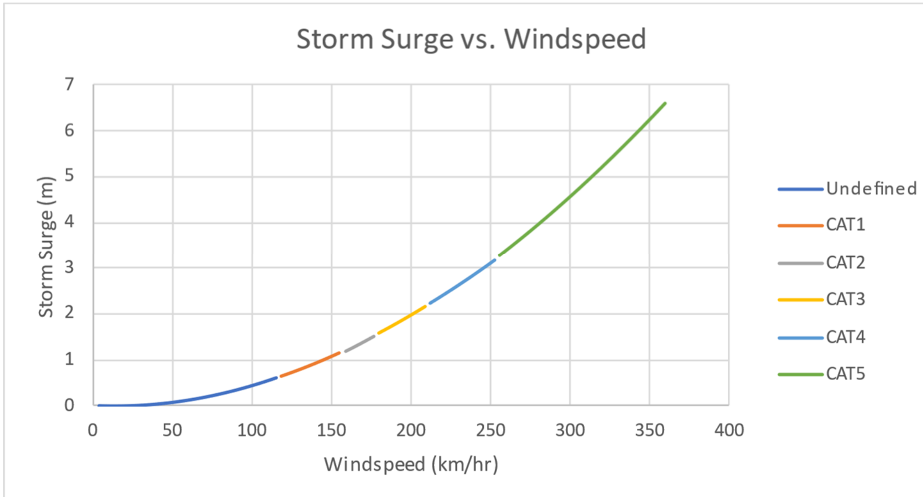

Figure C-8: Storm Surge vs Wind Speed

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[14]. 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, 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 storm 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) 1.8 metres as the high likelihood, best-case 1:100-year return period event in 2100, and
c) 2.0 metres as the low likelihood, worst-case, 1:100-year return period event in the year 2100

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

C12.3 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 or gauge data suggesting elevated waters or 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 is consistent with the Annapolis River flow regime based on the cross section of the river at Annapolis Royal. The width of the river is 420 metres as it opens into the Annapolis Basin, 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.

C12.4 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 two-dimensional, unsteady flow.

Rainfall intensity-duration-frequencies were derived from the IDF_CC tool from the University of Western Ontario[15]. Current peak rainfall is based on a 1:50 (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[16].

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.

C12.5 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.

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 and begins to inundate a greater number of buildings.

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

C13 Design Values

Based on the analysis above, **Table C-4** shows the range of peak water elevations in the Annapolis River for high-confidence RCP4.5 (very likely) and low confidence RCP8.5 (less likely) projections. RCP4.5 has been selected as the lower range because there is general consensus in the climate change community that the aggressive political and policy action required for emission reduction in the RCP2.6 scenario is no longer possible.

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[15] 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.

16 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

Table C-4 Peak Water Elevations (Elevations in CGVD2013)

RCP	Year	100 yr. Flood Elevation (m)	Higher High Mean Tide (HHMT) Elevation, 2023 (m)	Sea Level Rise (m)[17]	100 yr. Storm Surge (m)	Subsidence (m)
RCP4.5 High confidence	2023	4.37	2.85	0.00	1.5	0.00
	2053	4.64	2.85	0.14	1.6	0.03
	2103	4.96	2.85	0.21	1.8	0.08
RCP8.5 Low confidence	2023	4.37	2.85	0.00	1.5	0.00
	2053	5.04	2.85	0.44	1.7	0.03
	2103	6.06	2.85	1.11	2.0	0.08
RCP8.5 Worst Cast	2023	4.37	2.85	0.00	1.5	0.00
	2103	6.43	2.85	1.48	2.0	0.08

Table C-4 shows that under various climate scenarios, a 1:100-year return event, the 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 is based on the first interpretation, and the risk assessment to determine when action should be taken is based on the second interpretation. The reason for these approaches is that adaptation action should be driven by the increasing likelihood of given events that infrastructure was originally designed to accommodate, while risk-based cost estimates are better represented by the increasing damage potential from a similarly recurring event.

[17] https://climatedata.ca/

C14 Infrastructure Elements

The impact of increased stormwater intensity, rising sea level and increased wave runup from storm surge impacts both public and private infrastructure. The risk assessment in Appendix B presents a chart view of this analysis and the infrastructure elements considered in that analysis.

C15 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.

C15.1 Probability Analysis

Section C4 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. A statistical method called a Monte Carlo simulation established the percentage likelihood of a 1:100-year return period design event occurring once, more than once or not at all in a given time frame. 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 that time period. This is repeated thousands of times to determine the average percentage chance of occurrence for each frequency of occurrence. **Table C-5** shows the results of this simulation.

Table C-5 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
Cumulative Sum	30.1%	82.1%

C15.2 Cost Analysis

The Federal Flood Damage Estimation Guidelines for Buildings and Infrastructure, Version 1.0[18] has been used to develop a stage / damage curve for different levels of flooding in Annapolis Royal, shown in **Table C-6 to C-9**. 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). Note that cost data is not available to reflect inflation to 2024, but in general the costs below could be considered to underestimate damage by ten to twenty percent.

Table C-6 Estimated Damage by Flood Depth: RCP4.5, Projection to 2053[1]

Flood Depth in Structure (m)	Affected Structures	Footprint (Cumulative m²)	Estimated Damage (Cumulative)
0 - 0.1	4	1,224	$616,771
0.1 - 0.3	4	1,168	$846,662
0.3 - 0.6	3	1,059	$940,709
0.6 - 0.9	1	139	$130,266
0.9 - 1.3	3	1,098	$1,093,900
1.3 - 1.5	1	1,105	$1,103,111
1.5 - 1.8	2	802	$800,125
1.8 - 2.1	1	64	$64,010
2.1 - 2.4	-	-	$-
> 2.4	1	388	$387,246
TOTAL:	20	7,047	$5,982,799

1. Replacement of the wharf is not included in damage estimates.

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

Table C-7 Estimated Damage by Flood Depth: RCP4.5, Projection to 2103[1]

Flood Depth in Structure (m)	Affected Structures	Footprint (Cumulative m^2)	Estimated Damage (Cumulative)
0 - 0.1	7	1,247	$628,488
0.1 - 0.3	2	319	$231,615
0.3 - 0.6	13	2,392	$2,123,705
0.6 - 0.9	5	1,059	$989,439
0.9 - 1.3	2	251	$249,500
1.3 - 1.5	2	948	$945,784
1.5 - 1.8	2	1,145	$1,142,615
1.8 - 2.1	3	802	$800,926
2.1 - 2.4	1	64	$64,010
> 2.4	1	388	$387,246
TOTAL:	38	8,614	$7,563,329

1. Replacement of the wharf is not included in damage estimates.

Table C-8 Estimated Damage by Flood Depth: RCP8.5, Projection to 2053[1]

Flood Depth in Structure (m)	Affected Structures	Footprint (Cumulative m^2)	Estimated Damage (Cumulative)
0 - 0.1	6	1,234	$621,730
0.1 - 0.3	13	1,970	$1,428,505
0.3 - 0.6	6	1,492	$1,325,063
0.6 - 0.9	6	1,331	$1,243,116
0.9 - 1.3	2	1,036	$1,031,535
1.3 - 1.5	1	111	$110,809
1.5 - 1.8	2	987	$985,287
1.8 - 2.1	3	1,907	$1,905,143
2.1 - 2.4	1	64	$64,010
> 2.4	1	388	$387,246
TOTAL:	41	10,520	$9,102,445

1. Replacement of the wharf is not included in damage estimates.

Table C-9 Estimated Damage by Flood Depth: RCP8.5, Projection to 2103[1]

Flood Depth in Structure (m)	Affected Structures	Footprint (Cumulative m^2)	Estimated Damage (Cumulative)
0 - 0.1	3	492	$247,838
0.1 - 0.3	8	3,004	$2,177,545
0.3 - 0.6	16	3,229	$2,867,659
0.6 - 0.9	28	5,179	$4,837,374
0.9 - 1.3	20	3,361	$3,347,547
1.3 - 1.5	5	1,335	$1,332,471
1.5 - 1.8	6	1,331	$1,328,297
1.8 - 2.1	1	896	$895,311
2.1 - 2.4	2	251	$250,251
> 2.4	7	3,346	$3,342,674
TOTAL:	96	22,424	$20,626,968

1. Replacement of the wharf is not included in damage estimates.

C15.3 Economic Consequence of Failure

Combining **Table C-5** and **Tables C-6 to C-9** yields a percentage weighted cost impact of storm surge flooding, shown in **Table C-10**. Because all years are equally likely to experience a given magnitude 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 P_n is the probability of occurrence for n storms in the period.

Table C-10 Estimated Damage by Flood Depth

Scenario	Average Cost Impact per Event	Cumulative Percentage Weighted Cost
2053 RCP4.5	$5,982,799	$1,800,822
2103 RCP4.5	$7,563,329	$6,209,493
2053 RCP8.5	$9,102,445	$2,739,835
2103 RCP8.5	$20,626,968	$16,934,740

Appendix D

Flood Extent Mapping

Appendix E

General Arrangement Drawing

Appendix F

Cost Estimates

Appendix G

Drilling Report