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.

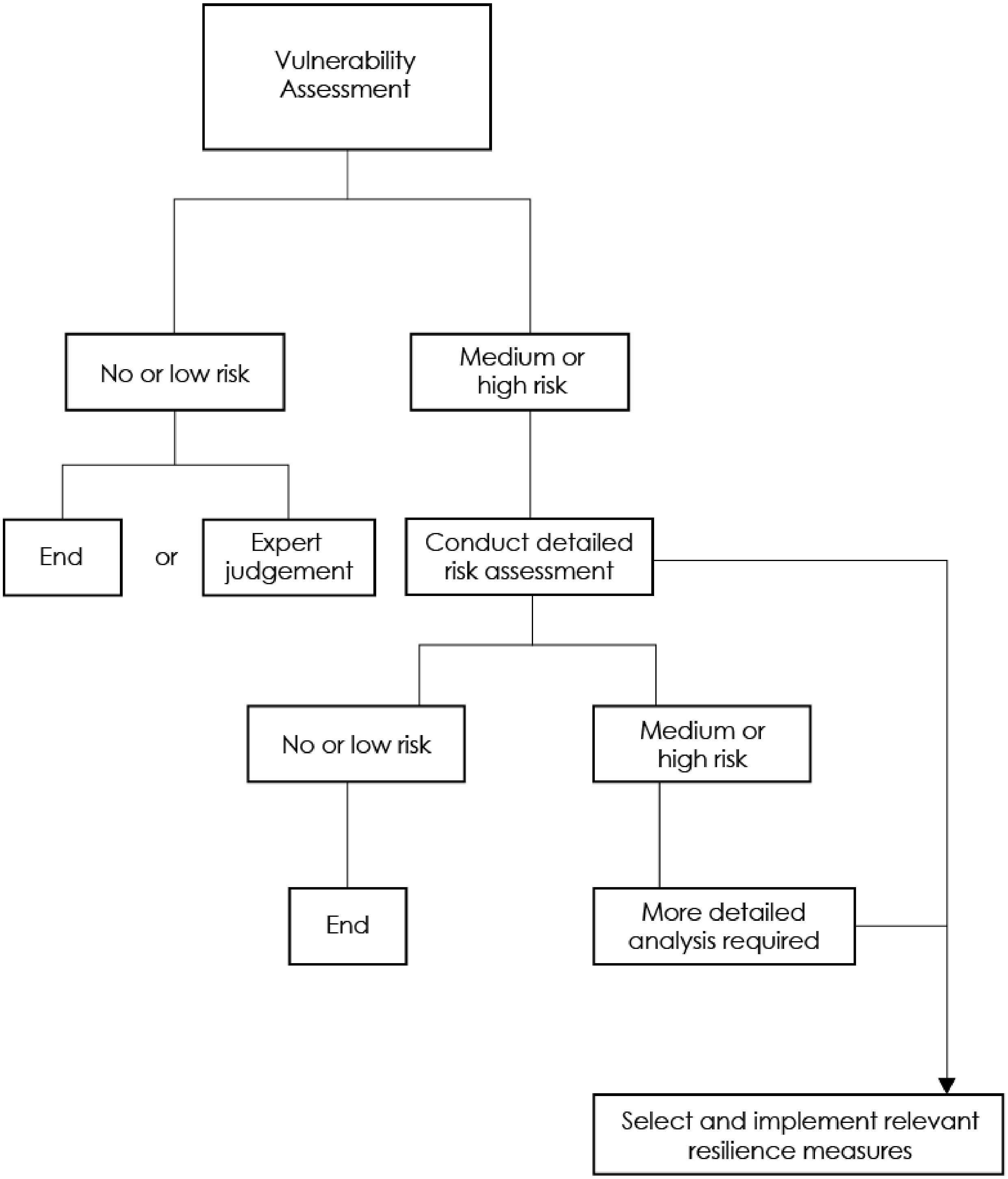


Figure C-1 Flowchart of Resilience Assessment

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%

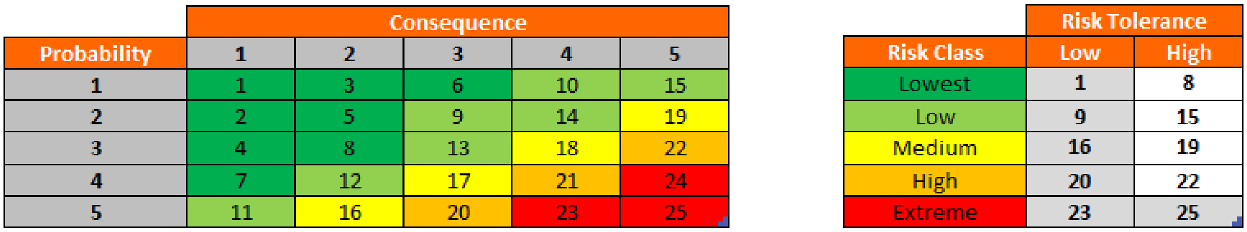
Typically, these probabilities are considered in asset management risk assessments over the five-year, near-term planning period. With longer range climate impacts as those considered in this assessment, it is necessary to consider both short and long-term probabilities to make decisions.

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 time frame of the risk exposure. As the time frame approaches zero, the likelihood of experiencing a failure also approaches zero. As the time frame gets longer, the likelihood increases, becoming almost certain over extended 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 time frame:

- 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 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**.

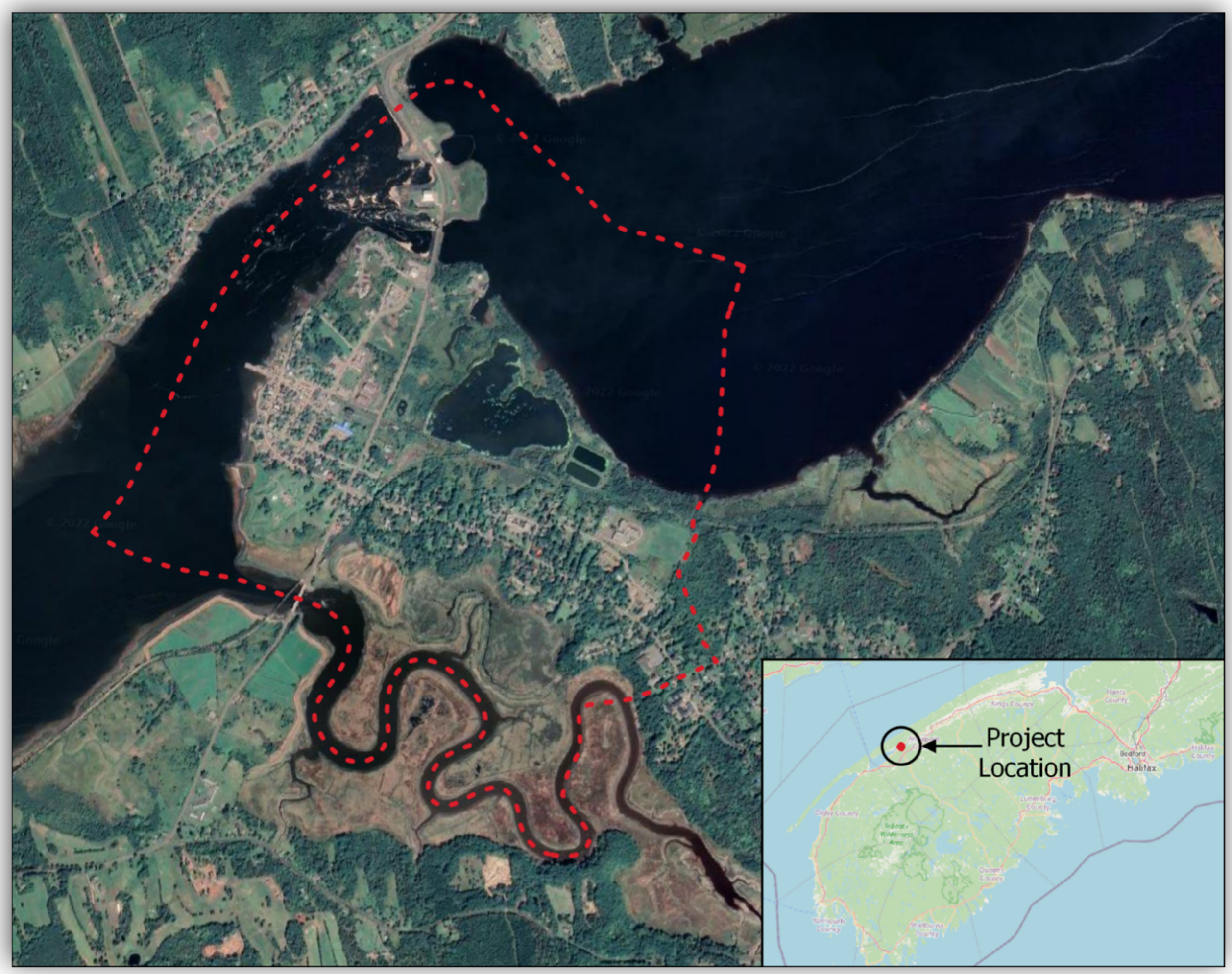


Figure C-3 Geographic Setting

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.

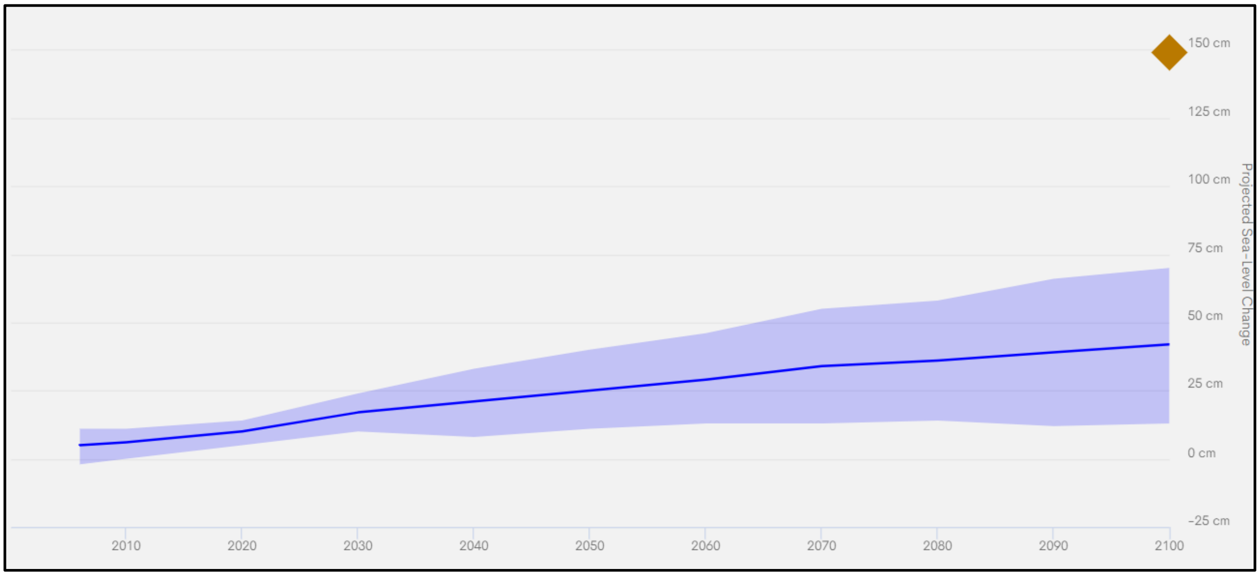


Figure C-4 Sea Level Rise Projection for RCP2.6[10]

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.

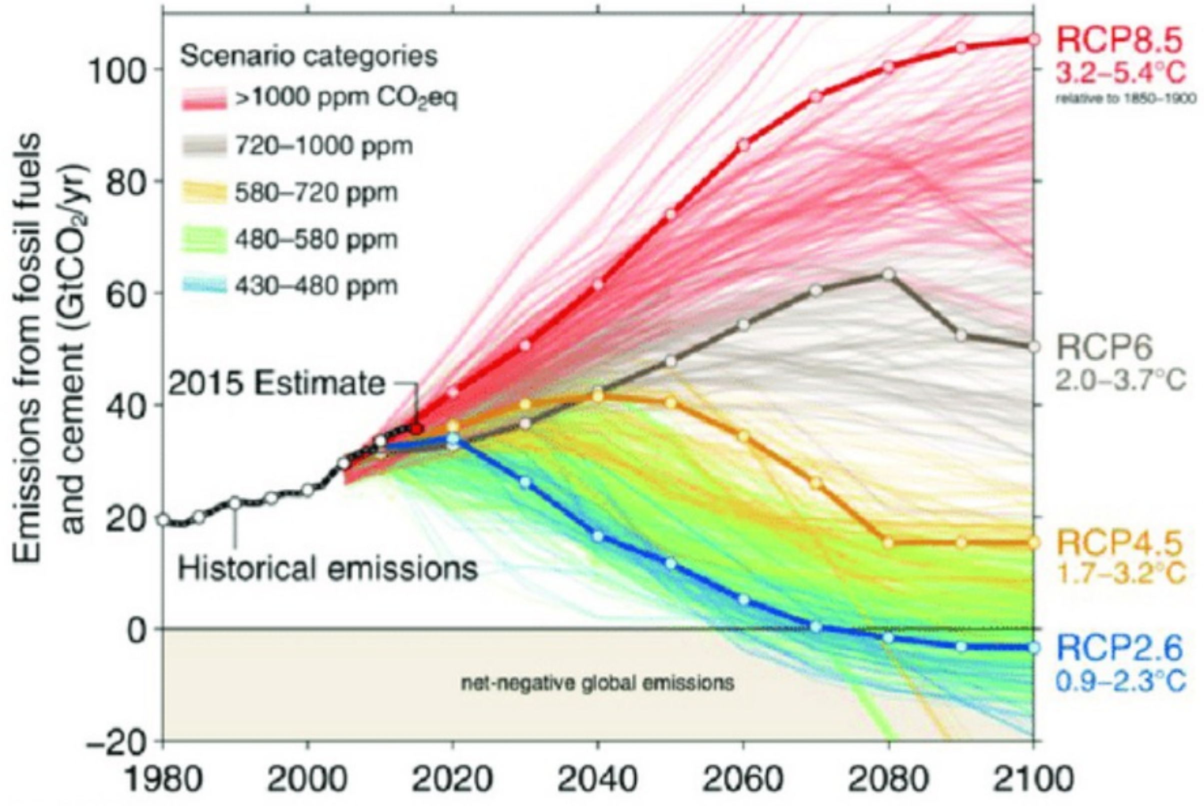


Figure C-5 RCP Pathways and Mean Global Temperature Increase[11]

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.

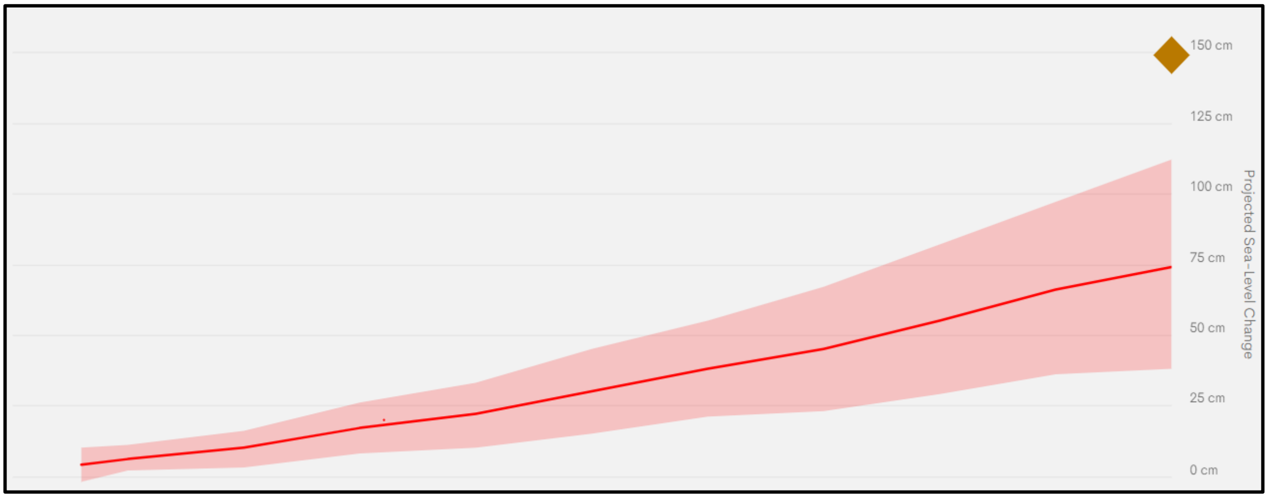


Figure C-6 Sea Level Rise Projection for RCP8.5[12]

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.

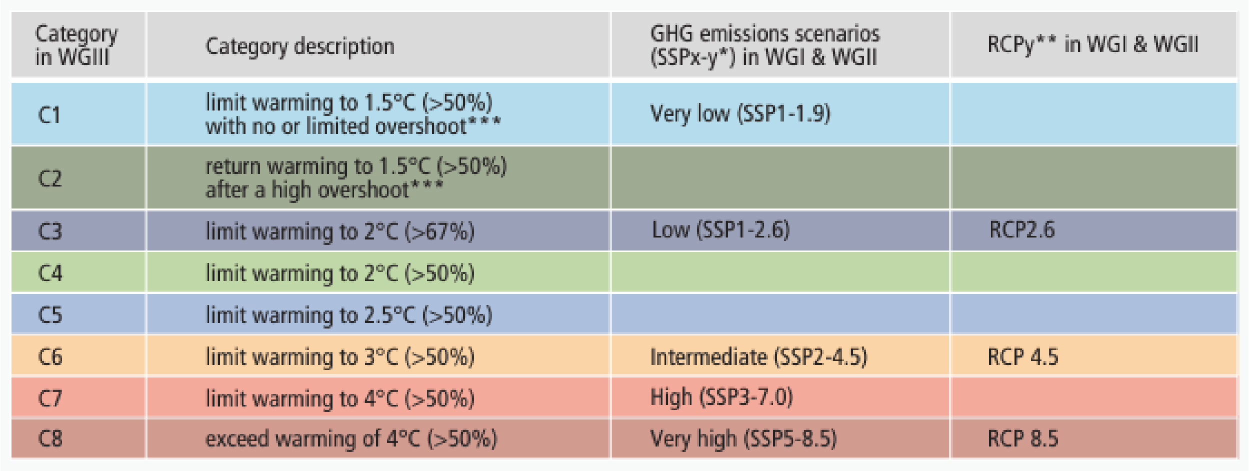
In addition to sea level rise from climate change, flood elevation projections need to include a factor for land subsidence. Nova Scotia is sinking in elevation at a rate of approximately one millimetre per year, which causes an apparent rise in sea level of the same amount on top of climate impacts.

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 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**.

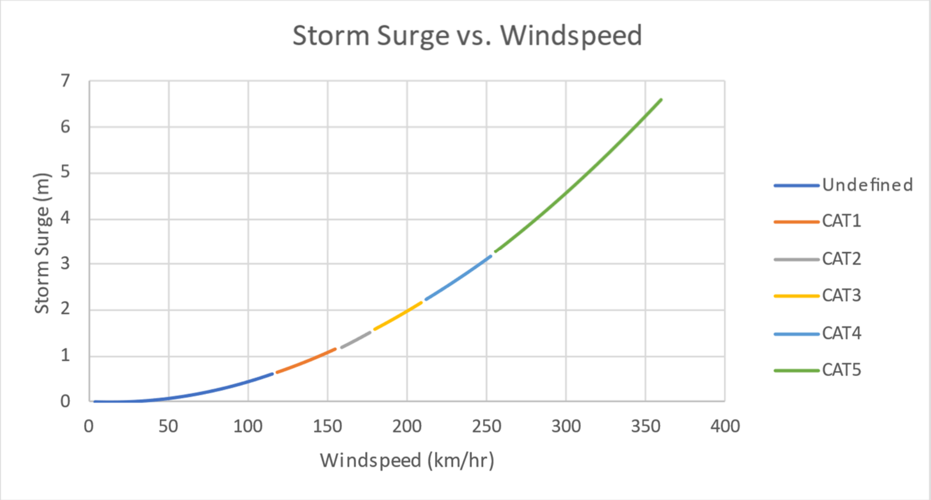


Figure C-8: Storm Surge vs Wind Speed

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 two 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 thirty 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 different from 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.

---

[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 m^2)	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