Final Draft

Flood Risk Assessment Town of Annapolis Royal

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Executive Summary

The Town has been well-informed of the threats posed by climate-change induced sea-level rise for many years.

There is overwhelming evidence that the Town faces a serious threat from sea-level-rise and storm surges. Spring high tides associated with a storm surge and storm driven wave action will 'create' what was referred to in 1998 as 'a fearful situation'.

Evidence suggests that the Town does not face a serious threat from overland flooding. A 100-year storm will have minimal impact and the probability of a maximum inundation caused by multiple Nova Scotia Power dam failures is small.

Evidence indicates that the Town will experience significant disruption regarding access to vital emergency and other public services unless adaptive measures to prevent flooding are adopted.

Evidence indicates that the sewer and drainage system of the Town will be negatively impacted unless adaptive measures to prevent flooding are taken.

The evidence is clear that the National Historic District and many of the heritage properties found therein face an existential threat unless adaptations are made to protect the district from the impact of sea-level-rise

Evidence is suggestive that tourism will undergo a very serious decline unless the National Historic District is protected from the impacts of sea-level-rise.

The Municipal Planning Strategy (MPS) recognizes the need to take account of both sea-level rise and an increase in the frequency and magnitude of storm events.

The MPS states 'the Town does not contain any designated flood risk areas' but goes on to say there is a need to consider 'impacts of potential sea level rise for those lands located adjacent to the Annapolis Basin'

The Land Use Bylaw (LUB) places controls on development in Environmentally Sensitive Area 1 (ESA 1) and Environmentally Sensitive Area 2 (ESA 2). ESA2 allows for residential, commercial, institutional, parks and open space uses and tourism and recreation uses through a permit process.

There are no specific environmentally-based controls on development in zones Heritage Waterfront Comprehensive Development District (HWCDD), Commercial General (CG), Commercial Heritage (CH) or Commercial Highway (CHW) all of which will be impacted by sea-level-rise induced flooding unless Adaptive measures are undertaken.

There is a tentative consensus that if the Town is to be protected from flooding consequent on sea-level-rise there needs to be an 8m -9m protective structure constructed from Fort Anne to the causeway. This would be approximately 1000m in length. Note that the land on which this would be constructed is approximately 5m above sea level requiring a structure of from 3 - 5m in height above the current situation.

The needed structure could conceptually be either a dike or a seawall.

Introduction

Background

In 2019 the Environment Advisory Committee identified sea-level-rise as the most immediate environmental threat facing the Town. To inform itself of the nature and extent of the threat the Committee sought input from experts specialising in flood control and coastal protection. Following discussions, a *Proposal for A Feasibility Study* was received from Vortex Management and Consulting Ltd. This study was to 'identify flood risks for the Town and develop mitigation strategies for such events.' It proposed a two-phase approach. Phase One proposed the development of a Flood Risk Assessment (FRA) with Phase Two being for Flood Hazard Mapping and, Flood Mitigation Planning. The Town did not have the resources to proceed with the proposed study.

This document is based on the Flood Risk Assessment proposed by Vortex Ltd. The intention is that it provide the necessary background information for companies submitting proposals for the work outlined in Phase Two of the original Vortex Proposal; if and when the Town is in a position to issue a call for expressions of interest for such work. When completed this work will provide the Town with the necessary engineering and environmental plans to be able to apply for project funding from higher levels of government.

Previous Studies

The Town has been well-informed of the threats posed by climate-change induced sea-level rise for many years. There has never been however an ordered summary of these reports and of their collective implications for the Town of sea-level-rise induced flooding. This Flood Risk Assessment is an attempt to provide such a summary.

The most important reports, those that deal with Annapolis Royal exclusively or use it as a case study, are listed below. They are ordered by the year of their publication. Other relevant studies are included in the BIbliography.

1. *Tidal Surge Project, The Coastal Flooding Component of the Annapolis Climate Change Outreach Program*, John Belbin and De Clyburn, Clean Annapolis River Project,**1998.**
2. *Climate Change Impacts and Adaptations for Land Use Planners.* Birch Hill GeoSolutions Inc. **2007**.
3. *Canadian communities' guidebook for adaptation to climate change. Including an approach to generate mitigation co-benefits in the context of sustainable*

development. Bizikova L., T. Neale and I. Burton First Edition. Environment Canada and University of British Columbia, Vancouver. **2008.**

4. *Back to the Future Town of Annapolis Royal Final Report to Council.* Town of Annapolis Royal, January 20, **2009**.
5. *Rising Sea Level and Storm Surge*, Letter and attachments, Hatch Mott MacDonald, March 24, **2009**
6. *Adapting to Climate Change :An introduction for Canadian Municipalities*. Richardson,G. Natural Resources Canada. **2010.**
7. *Preparing for Storm Surges in Annapolis Royal, Nova Scotia,* Natural Resources Canada, 2010.
8. *Annapolis Royal Flood Threat Very Real, Rising sea levels make storm surge disaster twice as likely,* Killen, H., p. F3, Annapolis County Spectator, 01 January **2009.**
9. *Flood Risk Mapping Using LiDAR for Annapolis Royal, Nova Scotia, Canada*. Webster, Tim L. , Remote Sensing.; 2(9): p.2060-p.2082. **2010**
10. Feifel, K. Annapolis Royal Tidal Surge Analysis. Case study on a project of the Clean Annapolis River Project, Climate Adaptation Knowledge Exchange, **2010**, updated **2020**
11. *Scenarios and Guidance for Adaptation to Climate Change and Sea-Level Rise - NS and PEI Municipalities*. Richards, William and Réal Daigle Prepared for: Nova Scotia Department of Environment, Atlantic Canada Adaptation Solutions Association: Oak Point, New Brunswick. August **2011**
12. *Municipal Climate Change Action Plan,* Municipality of the County of Annapolis, September **2013**, Revision 5
13. *Municipal Climate Change Action Plan* , Annapolis Royal ,CBCL Consulting Engineers, **2014**
14. *The FIrst Ten Metres. Coastal Flooding and Social Vulnerability of Populations in Nova Scotia*, Bryce, D,. Manuel,P., Rapaport, E. and Byung,J.K., Government of Nova Scotia, **2015**
15. *Sea Level Rise & You,* Summary of workshop held at the Annapolis Fire Hall July 24th **2018**

Little new information has been developed or studies conducted in the ten years since the MCCAP was commissioned.

The following section largely consists of relevant extracts, executive summaries, maps etc. from the above reports, Sources are identified. Some items have been summarized or written by the author.

The Threat from Sea-level-rise

Tidal Surge Project, The Coastal Flooding Component of the Annapolis Climate Change Outreach Program (1998)

- "Overtopping the dykes and extensive flooding of low-lying areas around the Bay of Fundy can occur when a northeast-tracking low-pressure system and associated storm surge moves up the Bay in phase with the tidal wave ... **It is clear ... that higher mean sea levels will increase the frequency of flooding at any given level**, assuming no shoreline adjustment..." (Introduction p. 5) *From Climate Change and Climate Variability in Atlantic Canada. Environment Canada, Proceedings of a Workshop*, Halifax, Nova Scotia, 1996.
- It is almost as if we are living in a lottery situation whenever a storm threatens - one day the numbers will come up! (Climate p. 13)
- In the Annapolis region a large surge occurring at the same the time of an unusually high tide would clearly overtop the dykes and flood the large area of low-lying lands behind them with huge volumes of salt water accompanying storm driven waves. ... a common misconception is that the damaging water would be short lived ... tidal surges normally arrive some hours BEFORE the storm that created them ... at the very time the water could begin to drain as the tide recedes the storm flood arrives ... by the time the storm is over you have another cycle of very high tides ... some people may be cut-off for extended periods of time ... the combined inundation would probably take several days to remove as the dykes themselves act as dams and restrict the flow. A slow-moving storm could create a fearful situation (Storm surge p. 2)

Climate Change Adaptations for Land Use Planners (2007)

- **Annapolis Royal is vulnerable to storm surges and sea level rise.** (Emphasis added). Although the Bay of Fundy has some of the largest tides in the world and the probabilities of a significant storm surge occurring on a high tide may be lower than some other regions of the Maritimes, past events such as the Groundhog Day storm of 1976 prove that this region is not immune to such events. Climate change will impact sea levels on a global scale and the local crustal conditions in this region will add to the problem as a result of subsidence, thus increasing the relative sea level rise. Currently the lower sections of the town particularly lower George St. near Kings Theatre and the government wharf, experience flooding at extreme high tide events in the absence of storms. When storm surges and high winds and waves occur with higher than usual tides, this area of the town is most vulnerable to flooding. The occurrence of these extreme high tides can be predicted based on astronomical conditions. The most significant high tides occur on Soras cycles, of which the most famous storm to cause coastal flooding in the Bay of Fundy region occurred; the “Saxby Gale” of 1869.

- **5.4 m flood: this includes the projected 100-year return period storm surge** (Emphasis added. See map below) combined with high tide (4.6 m) plus climate change effects (ocean rise, 0.5 m) plus crustal subsidence (southern Nova Scotia is gradually sinking, 0.2 m) plus tidal amplification in the Bay of Fundy (0.1 m). We will model the occurrence of these floods as a Poisson process. We will also assume that the storm surge duration is of the order of 12 hours, so that the storm surge is sure to coincide with a high tide. We note that the recurrence period of the 5.4 m flood really only becomes 100 years towards the end of this century, i.e. after ocean level rise, crustal subsidence, and tidal amplification has taken place. However, we take a conservative approach here and assume that the recurrence period is currently 100 years and will remain at that rate throughout the coming century. In other words, the mean rate at which the 5.4 m flood occurs is λ = 1/100 per year.
- Due to ocean level rise, crustal subsidence, and tidal amplification in the Bay of Fundy as it approaches resonance, the town of Annapolis Royal will be increasingly susceptible to flooding. We will consider here four alternative strategies that the town can adopt in light of the risk of flooding:
    - 1. do nothing: spend no additional money protecting the town against floods, but pay for flood damages as they occur;
    - 2. floodproof individual buildings threatened by the flood: floodproofing involves raising small buildings and the closure/sealing of basements and ground floors of larger buildings
    - 3. construct a levee around the town to protect against a 5.4 m flood (see below for a description), or
    - 4. construct a levee around the town to protect against a 6.5 m flood (see below for a description).(p.127)
- ... all strategies are aimed at a design life of 100 years (after which time a similar analysis can be repeated). We will also ignore the time value of money in the following analysis (partly because we don’t know when the flood damage will occur, although this could be handled probabilistically in a more detailed analysis).
- Regarding the construction of levees, we shall assume that the levee will have a 3 m wide crest (to accommodate heavy equipment) and 3.5H:1V side slopes. We shall also provide a 3 m freeboard above the required flood elevation to avoid overtopping (and subsequent erosion) by wave actions, which are sure to accompany a storm surge. The average elevation of the land around the town on which the levee would be placed is about 5.0 m and the levee would need to be approximately 900 m in length.(p.127-8)

- The details of the two levees being considered are as follows: for the 5.4 m flood, a 3 m freeboard brings the upper surface of the levee to an elevation of 8.4 m. The constructed height of the levee is thus $H = 8.4 - 5.0 = 3.4$ m having a cost of about $2,600/m. The total cost of this levee will therefore be 900 × 2, 600 = $2, 340, 000 for the 6.5 m flood, a 3 m freeboard results in a constructed levee height of $H = 9.5 - 5.0 = 4.5$ m having a cost of about $4,200/m. The total cost of this levee will therefore be 900 × 4200 = $3, 780, 000 (p.129)
- The lowest expected total cost is option 3. This suggests that the town should construct a levee to protect against the 5.4 m flood. (p.129)

Canadian communities' guidebook for adaptation to climate change. (2008)

- **Case Study 4**
  - **Focus, objectives and team in the adaptation initiative:** To use storm surge mapping to predict the impact of the design storm at current and projected sea levels. The project was initiated in 1998, by the Clean Annapolis River Project (CARP), a non-governmental organization in collaboration with the town of Annapolis Royal, focused on mapping storm surge.
  - **Current vulnerability and capacities:** With an average tidal range of 10 metres and an average frequency of two hurricane-type storms every three years, the Bay of Fundy and its surrounding coastal towns are susceptible to storm surges. Much of the inhabited land bordering the Bay is at or below sea level, having been reclaimed by Acadian settlers in the 17th century with an elaborate system of dykes. The dykes, which now protect a large population and economically significant agricultural lands, have been maintained and upgraded based on a historical design from 1869. However, **if projected impacts of climate change lead to unprecedented storm surges, they would surpass the dykes and overwhelm the coping capacity of the communities.** (Emphasis added)
  - **Estimated impacts of changing climate:** CARP encountered many obstacles in their efforts because the data critical to the completion of the exercise, like elevation maps with reasonably small contour intervals, were either non-existent or difficult to access. Nonetheless, they succeeded in generating maps, which indicated that much of the town would be flooded, and that critical infrastructure such as the fire department could be marooned from the rest of the community.
  - **Responses to climate change and their implementation:** Resulting adaptations in the risk management strategy included the re-distribution of some emergency response equipment and the purchase of a boat by the fire department. The maps also led to the organization of a mock disaster scenario to engage the public in disaster management planning. CARP has since

pursued some saltmarsh restoration in the Bay, a natural solution that can help reduce the impact of storm surges. **The maps indicated the need for changes in town planning and protection strategies.** Presently, adaptation strategies include reviewing the emergency preparedness plans, improving the early warning system and collaboration with a number of departments and institutions to ensure the effectiveness of the early warning systems. P.34 Emphasis added.

Back to the Future Town of Annapolis Royal Final Report to Council (2009)

Levee Construction

Advantages	**Disadvantages**
The Town realizes it is at risk of storm surge. The problem is compounded by subsidence of the Nova Scotia landmass.	High cost of building a levee
The evidence would appear to suggest that construction of a levee to protect against 5.4 meter flood is less than the cost of repairs as a result of flood damage.	
Protection of significant heritage resources	

- Recommendation 17 -**That the Town determine the order of Magnitude costs for building a levee along with all the required drainage systems'** (Emphasis added). It goes on to note 'As of the time of writing Hatch Mott MacDonald are working on order of magnitude costs for the Town' p.10
- From Council Minutes January 2009:

{b} Green Municipal Fund (Back to the Future)– Final Report	The report is complete and requires the approval of Council to be submitted. CAO Boyer said that there is $9,000.00 in funding linked to report submission. ***Motion #4*** ***It was moved by Deputy Mayor DeWolfe, seconded by Councillor Power to accept and approve the final Green Municipal Fund Report. Motion carried.***	CAO Boyer	

{c} Back to the Future Final Report	The Back to the Future Report is part of the Green Municipal Funds submission and is included for information purposes.	CAO Boyer	

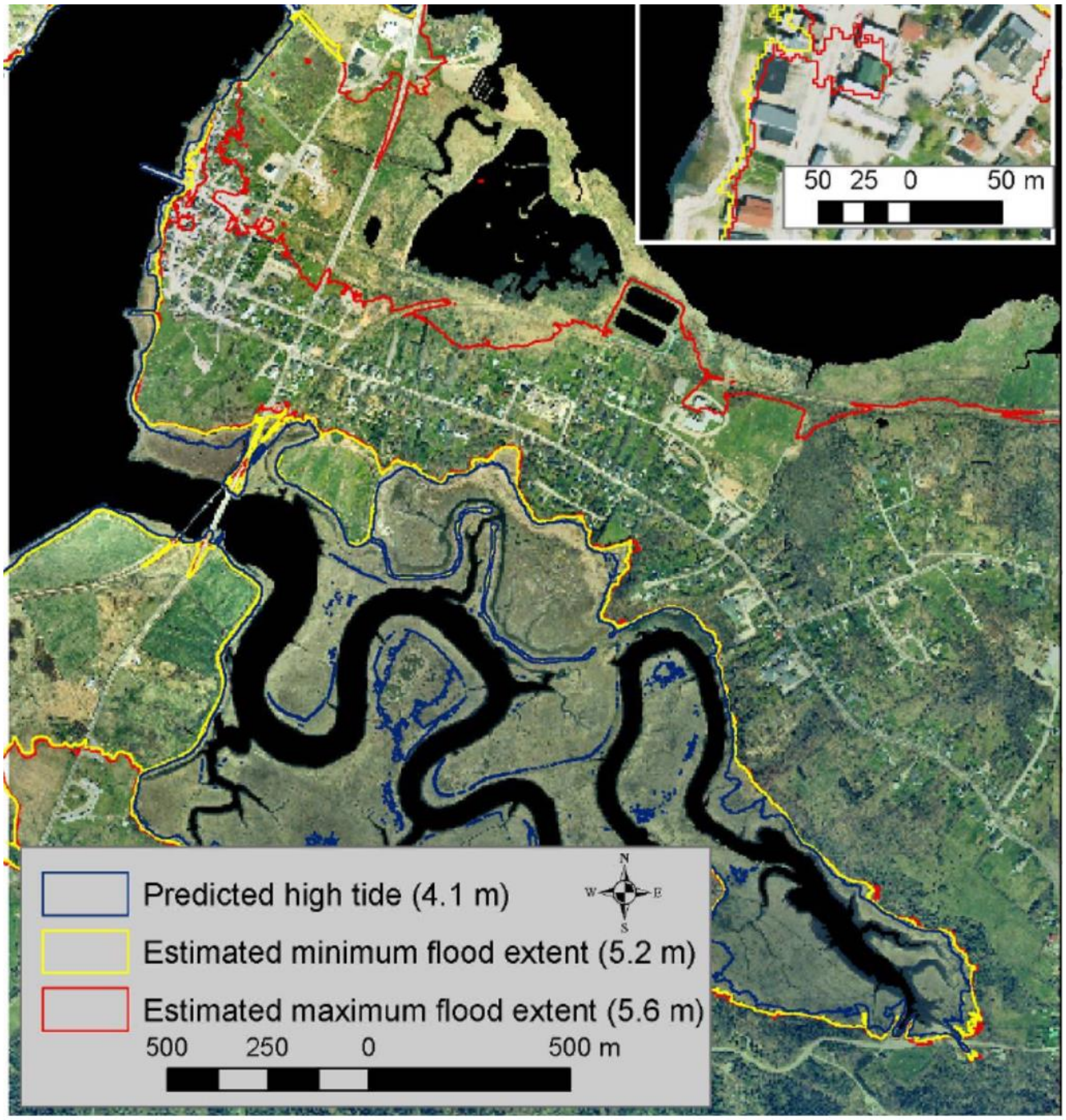
Rising Sea Level and Storm Surge (2009)

- ... we have come to the preliminary conclusion that if the Town of Annapolis Royal wishes to protect itself from rising sea level, it would have to construct a sea wall to a minimum of 8.0 metres and possibly as high as an elevation of 8.8 metres. p.1

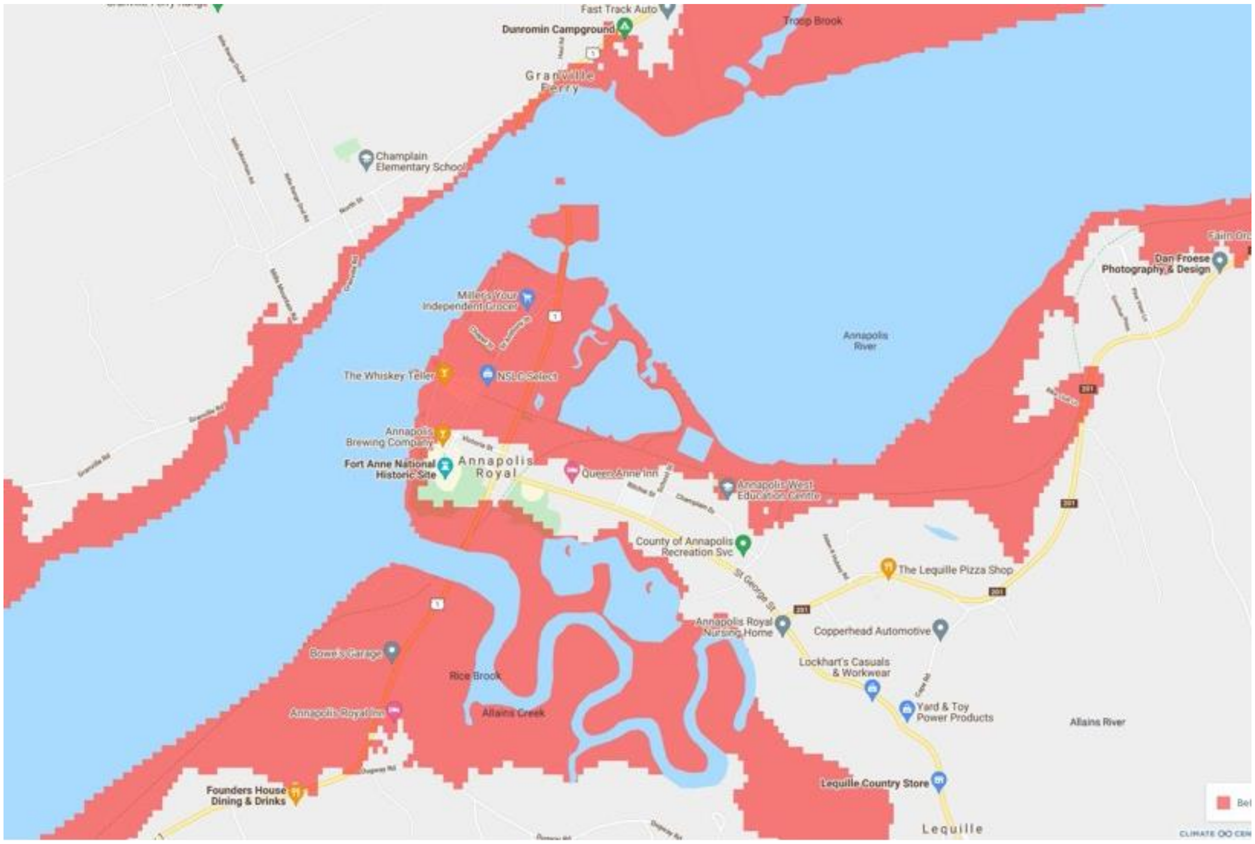
Flood Risk Mapping using LiDAR for Annapolis Royal, Nova scotia, Canada (2010)

- The community of Annapolis Royal, Nova Scotia, adjacent to the Bay of Fundy, has been surveyed with LiDAR and a 1 m DEM (Digital Elevation Model) was constructed for the flood inundation mapping. Validation of the LiDAR using survey grade GPS indicates a vertical accuracy better than 30 cm. **A benchmark storm, known as the Groundhog Day storm** (February 1–3, 1976), was used to assess the flood maps and to illustrate the effects of different sea-level rise projections based on climate change scenarios if it were to re-occur in 100 years time. Near shore bathymetry has been merged with the LiDAR and local wind observations used to model the impact of significant waves during this benchmark storm. Long-term (ca. greater than 30 years) time series of water level observations from across the Bay of Fundy in Saint John, New Brunswick, have been used to estimate return periods of water levels under present and future sea-level rise conditions. **Results indicate that under current sea-level rise conditions this storm has a 66 year return period. With a modest relative sea-level (RSL) rise of 80 cm/century this decreases to 44 years and, with a possible upper limit rise of 220 cm/century, this decreases further to 22 years years.** p.1 Emphasis added.

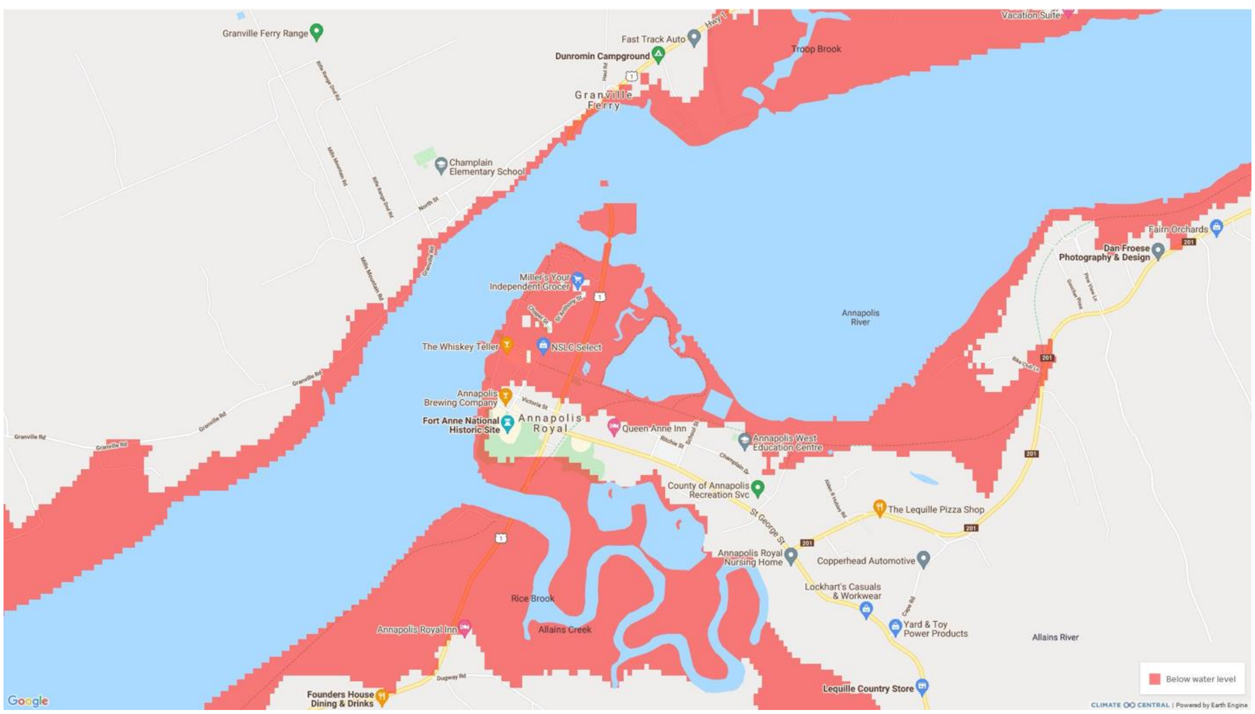
(Below are maps from Webster and others that complement and enhance Webster's analysis))



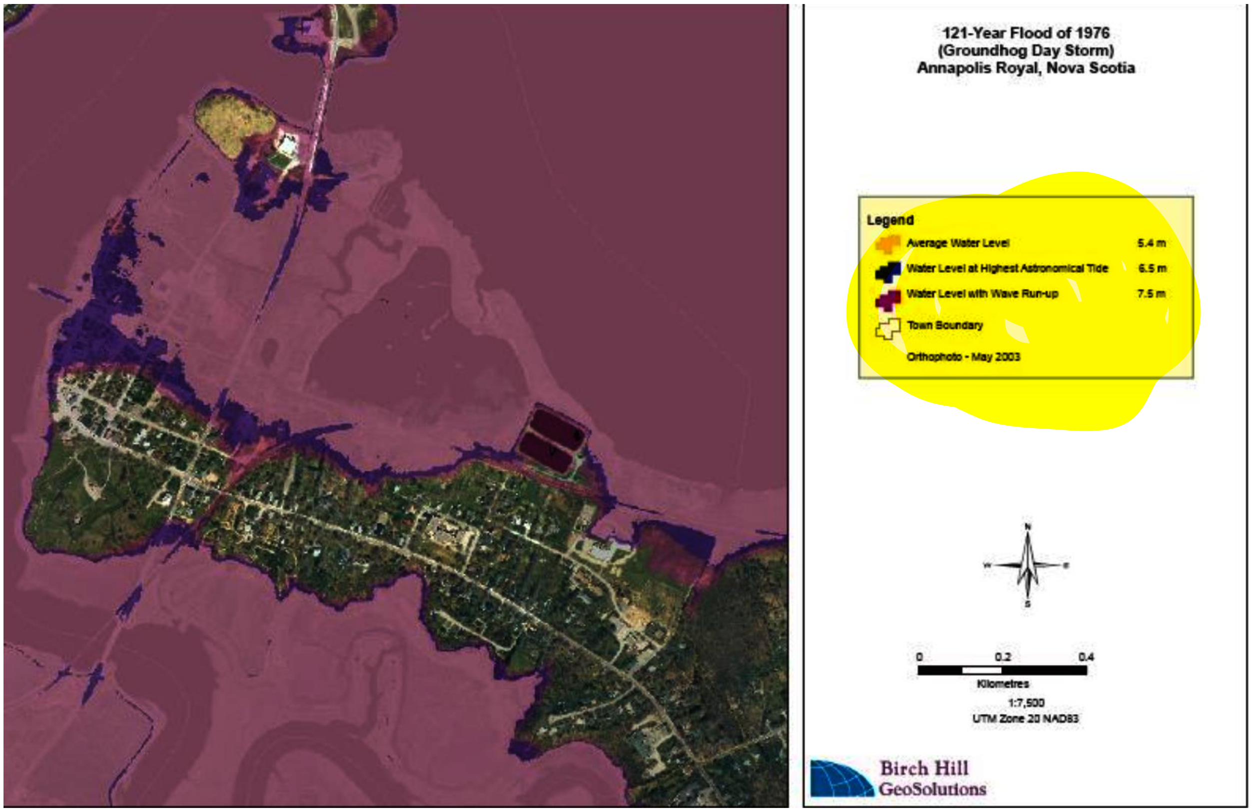
Webster 2010 p.2074



Above: Town of Annapolis Royal. Land Projected to be Below Annual Flood Level by 2030 and possibly permanently inundated by 2050 . Below: Land Projected to be Below 2.5M flood

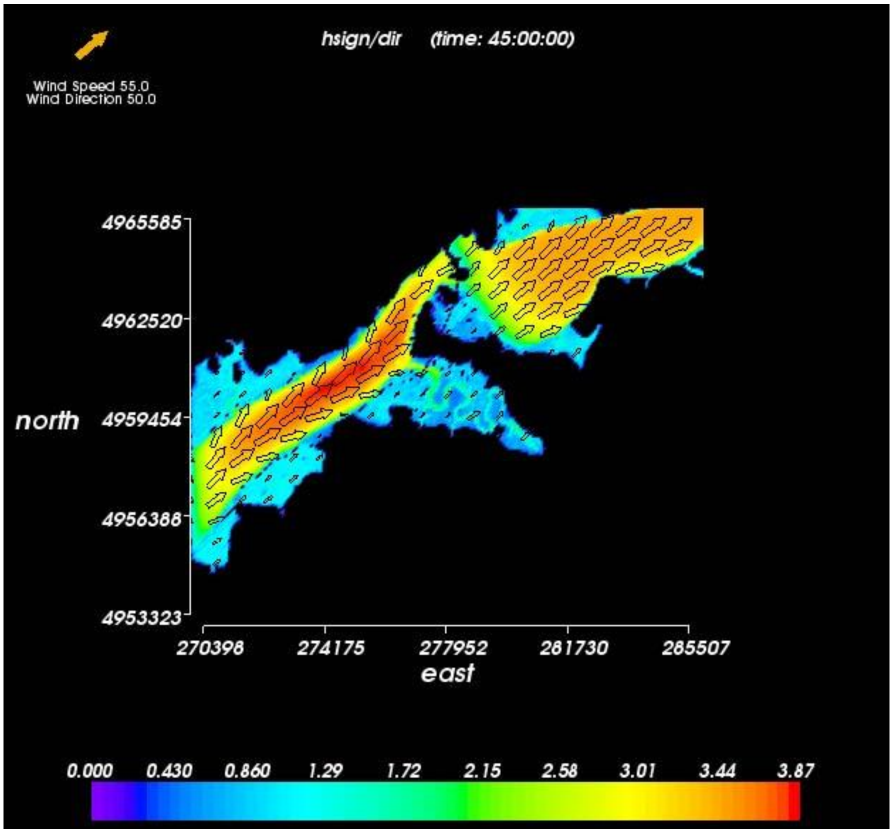


The Groundhog Day Storm of 1976



Extent of flooding in the 1976 **Groundhog Day Storm.**

- An upper-level low was stationary across the Desert Southwest of the United States, on January 28.[2] A system in the northern branch of the Westerlies known as a Saskatchewan Screamer, similar to an Alberta clipper but originating as a frontal wave in the next Canadian province to the east, moved east-southeast across Canada beginning on January 30, luring the system in the United States eastward. The cyclones merged by February 2, becoming a significant storm over New England before lifting northward through Quebec into the Davis Strait. At this time, maximum sustained winds reached 164 kilometers per hour (102 mph) in coastal areas (equal to a Category 2 hurricane on the Saffir-Simpson hurricane scale), with wind gusts of up to 188 kilometers per hour (116 mph). Wikipedia.



Modelled wave heights associated with the **Ground-hog Day Storm** of 1976. Note waves of between 2.5 - 3.5 m immediately off the boardwalk along Lower St. George Street. Birch HIll (p.114)\

- Southwest Nova Scotia and southern New Brunswick experienced coastal flooding of up to 1.6 meters (5 feet 3 inches) deep causing extensive damage to wharves, coastal buildings, boats and vessels. Power and communications lines were also knocked out. The tides along the coast were increased due to the convergence of anomalistic, synodical, and tropical monthly tidal cycles peaking simultaneously (known as Saros); a once in 18-year event.[12] Damage was estimated in the tens of millions of dollars.[13] Offshore New Brunswick, 12-m (39 ft) waves with swells of 10 metres (33 ft) were reported in the high seas. Wikipedia

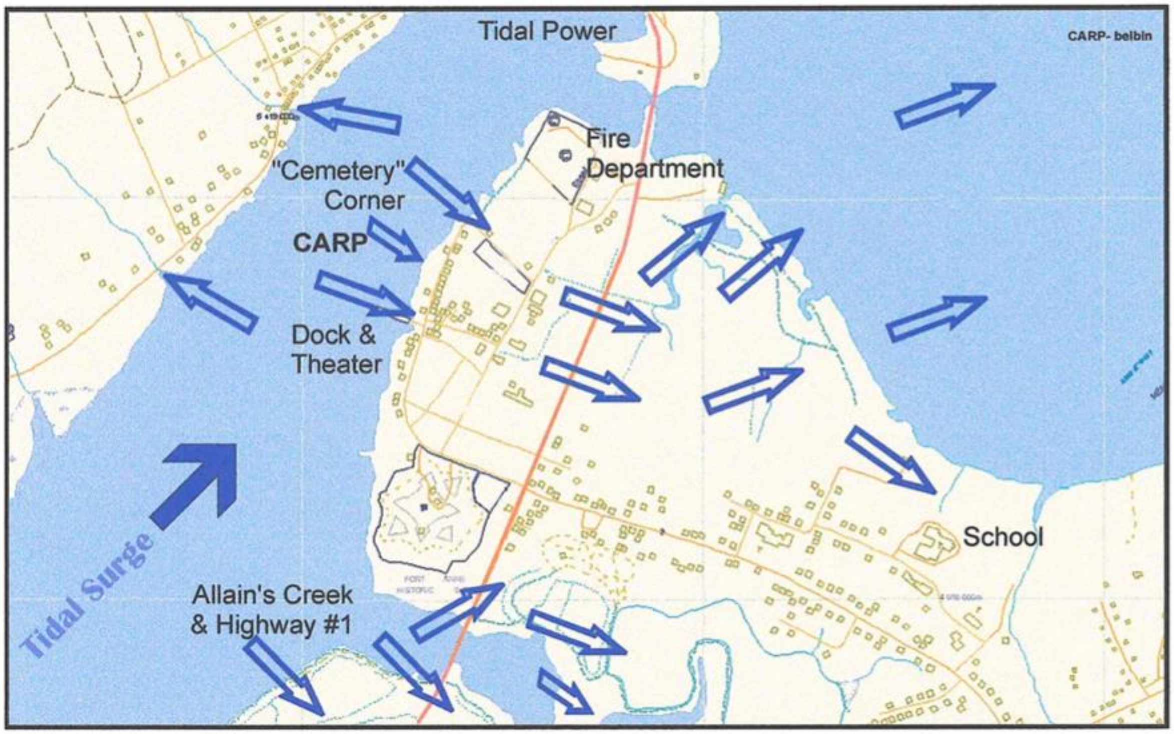
- **Return periods (years) of an occurrence of the Groundhog Day storm water level (4.95 m)** under current and projected sea-level rise conditions

Rate of relative sea-level-rise (RSL)	**36 Cms./100 years**	**80 Cms./100 years**	**220 Cms./100 years**
Return period in years with 65-75% Probability	30	23	14
Return period in years with 100% Probability	66	44	22

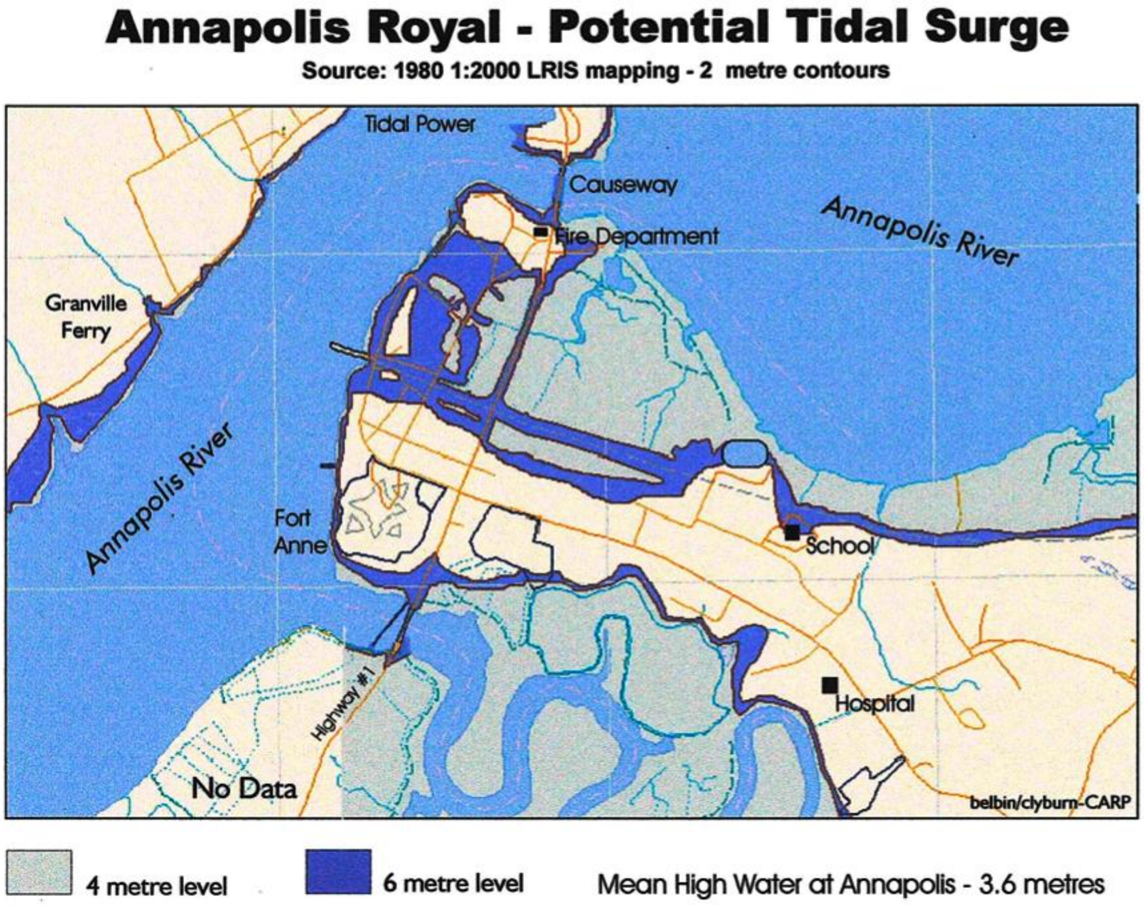
The above indicates that a flood as devastating as the Groundhog Day Storm can be expected on average every 23 years with an RSL of 80 cms .a century and every 30 years with a low estimate of 36 cms. a century.

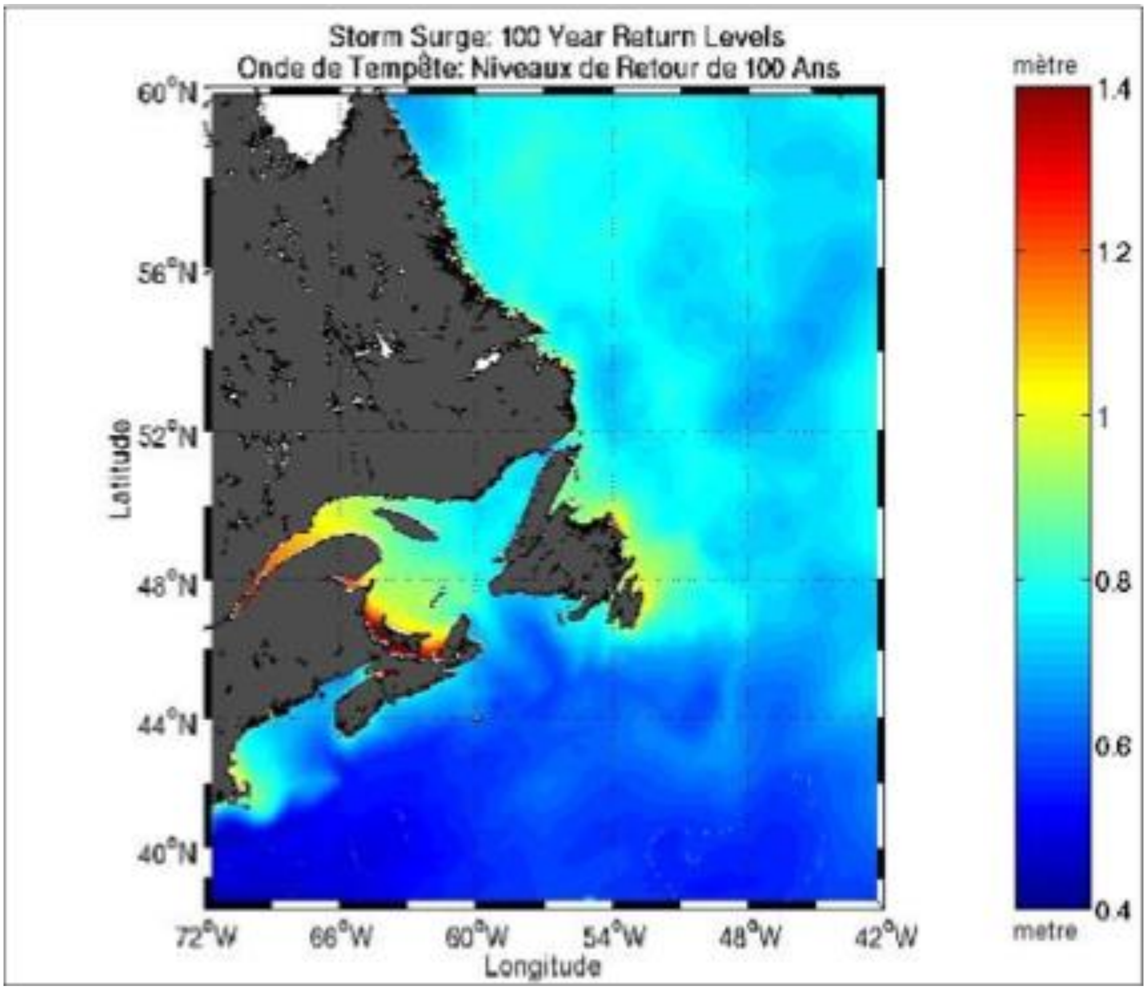
Storm / tidal surge threats

- A **storm surge** is a coastal flood phenomenon of rising water commonly associated with low-pressure weather systems, such as cyclones. It is measured as the rise in water level above the normal tidal level and does not include waves.
- The main meteorological factor contributing to a storm surge is the high-speed wind pushing water towards the coast over a long fetch. Other factors affecting storm surge severity include the shallowness and orientation of the water body in the storm path, the timing of tides, and the atmospheric pressure drop due to the storm. Wikipedia



Locations at risk for tidal surge flows


Annapolis Royal - Potential Tidal Surge
Source: 1980 1:2000 LRIS mapping - 2 metre contours
Tidal Power
Causeway
Fire Department
Annapolis River
Granville
Ferry
Annapolis River
Fort
Anne
School
Hospital
Highway #1
No Data
belbin/clyburn-CARP
4 metre level
6 metre level
Mean High Water at Annapolis - 3.6 metres



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

- Storm surges are not as serious a threat in the Annapolis Basin as they are in the St. Lawrence and along the Northumberland shore. As demonstrated by the Saxby gale and the **Groundhog Day Storm** they can however increase the likelihood of waters reaching flood levels.

Annapolis Royal Tidal Surge Analysis (2010)

- Annapolis Royal, Nova Scotia, has historically flooded when storm surges coincided with high tides. It is prone to flooding because the town was built upon reclaimed land using dykes constructed in the 17th century and the surrounding land is naturally subsiding. Sea level rise, coupled with more frequent and intense storm surges, increase the vulnerability of the town to flooding. To assess the future impacts of climate change, flood risk assessments were completed using LIDAR data, water modeler software, and historical tidal and flood records. Results indicate that climate change will make the town more prone to flooding.

A risk and cost-benefit analysis was conducted to assess four adaptation strategies. It was concluded that the town should construct a 5.4 meter levee around the town because the insurance cost to replace the buildings damaged by future floods would exceed the cost of constructing the levee. The final report was given to the Annapolis Royal Town Council (p.1)

- The Clean Annapolis River Project (CARP) initiated the Tidal Surge Project in 1998 to assess the town's vulnerability to storm surges. It analyzed available historical records to identify the cause of past major floods and found that most major floods were due to storm surges that occurred concurrently with high tides in the Bay of Fundy. To assess the impact sea level rise will have on the town's vulnerability, a team at the Geomatics Center at Nova Scotia Community College (NSCC) generated a flood risk assessment using LIDAR data, water modeler software, and historical tidal and flood records. They concluded that if sea level were to increase by 80 cm and a storm equivalent to the Groundhog Day Storm occurred, the town's 5 meter high dykes are likely to be breeched. The likelihood that extreme flooding would occur in Annapolis Royal increases from an average ranging from once every 43-121 years to once every 23-55 years. In 2007, an outside consultant, Birch Hill Geosolutions, was hired to assess climate change impacts and adaptations to these impacts in Nova Scotia; Annapolis Royal was selected as a case study. Using LIDAR data and the water modeler software from NSCC, they were able to accurately recreate the flooding extent of the 1976 Groundhog Day Storm using GIS tools. (p.1)
- ... A risk and cost-benefit analysis was conducted for the construction of levees in Annapolis Royal to protect against flooding. Four alternative strategies were tested: 1. Do nothing; 2. Flood-proof individual buildings; 3. Construct a levee around the town to protect against a 5.4 meter flood; and 4. Construct a levee around the town to protect against a 6.5 meter flood. (p.1)
- Results indicated that option 3 was the best because the insurance cost of replacing or restoring the buildings damaged during a flood would actually exceed the cost of constructing the levee. Option 4 would offer more protection but the chance of a 6.5 meter flood occurring is negligible since a storm surge would have to coincide with the highest astronomical tide. (p.1)

Annapolis Royal Municipal Climate Adaptation Plan (2013)

- The Town has a number of studies that indicate risks of flooding and inundation due to climate change (Birch Hill Geosolutions 2007a, 2007b, 2007c; Webster 2010). These risks have been incorporated into the planning documents for the Town such as the Development Potential Map and Generalized Future Land Use Map. However, **the risks associated with flooding and inundation due to climate change are going to become more acute over time and the Town should take some**

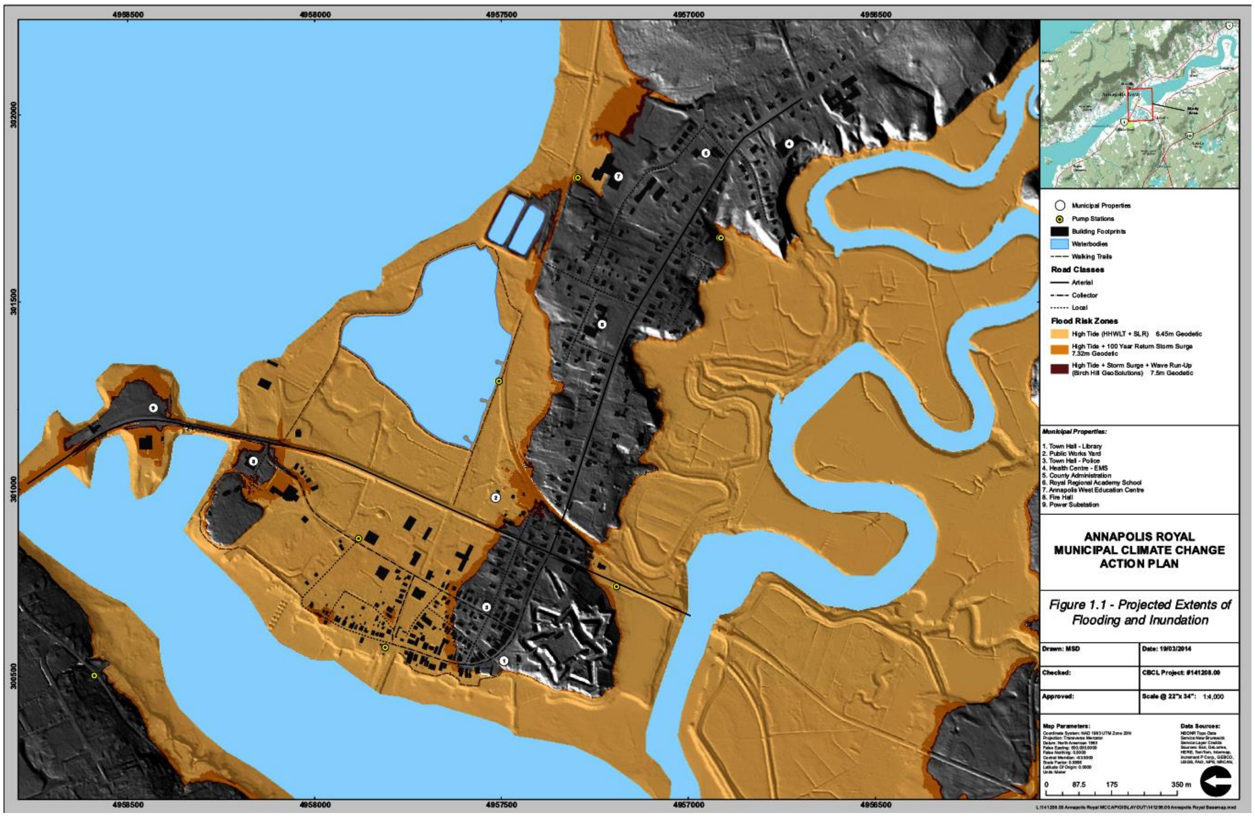
actions to be better prepared. (Annapolis Royal Municipal Climate Chane Adaptation Plan (p. E1) Emphasis added.

- For residents and businesses of the municipality located in the northern portion of the downtown core, the significant hazard associated with climate change is the anticipated level of future sea level rise. It can also be linked to (potentially greater) risks of overland coastal flooding of both private homes and critical public infrastructure (i.e. roads, buildings, subsurface pipes, etc.) during extreme weather events. Of particular concern is the waterfront area that is the centre of economic activity in Annapolis Royal. (ditto)
- (The table below) provides projected elevations for sea level rise and storm surge in the Annapolis Royal area. The largest projected mean sea level rise of 1.53 m provides an average level between the high and low tide marks. However, the Higher High Water Large Tide (HHWLT), which on average occurs every month on a spring tide, means lands below 6.45 m will be regularly inundated .... There are also the longer cycles of 41⁄2 and 18 years, which will increase the tides beyond this level. (p. 4)

Parameter	**2000**	**2025**	**2055**	**2085**	**2100**
Total sea-level rise in metres					
Average projection		.15	.42	.82	1.05
Upper-bound projection		.18	.57	1.18	1.53
Extreme upper bound projection-HHWLT + SLR		5.1	5.49	6.1	6.45

High tide elevation represented by Higher High Water Large Tide (HHWLT) plus Sea Level Rise (SLR). The above estimates were converted from Daigle and Richards (Reformatted from MCCAP p.4)

- **Sea-level rise appears to be the most serious issue** with the projected high tide (HHWLT + SLR) covering major portions of the central area of Annapolis Royal and causing access between the northern and southern portions of Town to be cut. Increased water depths as a result of storm surge ... will only add slightly to the problem. (p.5. Emphasis added)



MCCAP 2013) p. 4-5.

Summary of findings concerning the flood risk posed by sea-level-rise

- **There is overwhelming evidence that the Town faces a serious threat from sea-level-rise and storm surges. Spring high tides associated with a storm surge and storm driven wave action will 'create' what Belbin and Clyburn referred to in 1998 as 'a fearful situation'.**
- **The solution appears to require the construction of a dike running from the Boardwalk below Fort Anne to the causeway of sufficient height to deal with a 5.4 - 5.6 m flood tide. (See Impacts section for a discussion of the impacts of flooding)**

A brief discussion of on Mean Sea Level, Storm Surge, Flood Heights etc.

Appendix One details how tide heights etc are calculated.

- A key datum is **Mean Sea Level (MSL)** which is calculated by averaging tide heights throughout each daily cycle over a period of many years. It is expressed as a height above Mean Low Tide (MLT). It is important as it is the datum from which the elevation of locations on land are calculated. Thus a point of land on the 5m contour is 5m above MSL. (but not necessarily above some high tides.

- Another key datum is **Mean High Tide (MHT)** which is calculated by averaging daily high tide levels over many years. Levels are expressed as the height above Mean Low Tide (MLT).
- **Mean Large Tide (MLaT)** is as above but for particularly high tides (Colloquially known as spring tides).
- **The tidal range** in Annapolis royal is from approximately 0.5m to 8.8m above MLT. MSL is thus approximately 4.65m.
- **A high tide of 8.5m** in Annapolis Royal **is thus approximately 3.85m above MSL and thus above any land surface below that height.**
- **A flood tide of 10.25m, approximately 1.4 m above current spring high tides, would flood areas below 5.6m.** See the Webster map above for the area flooded.

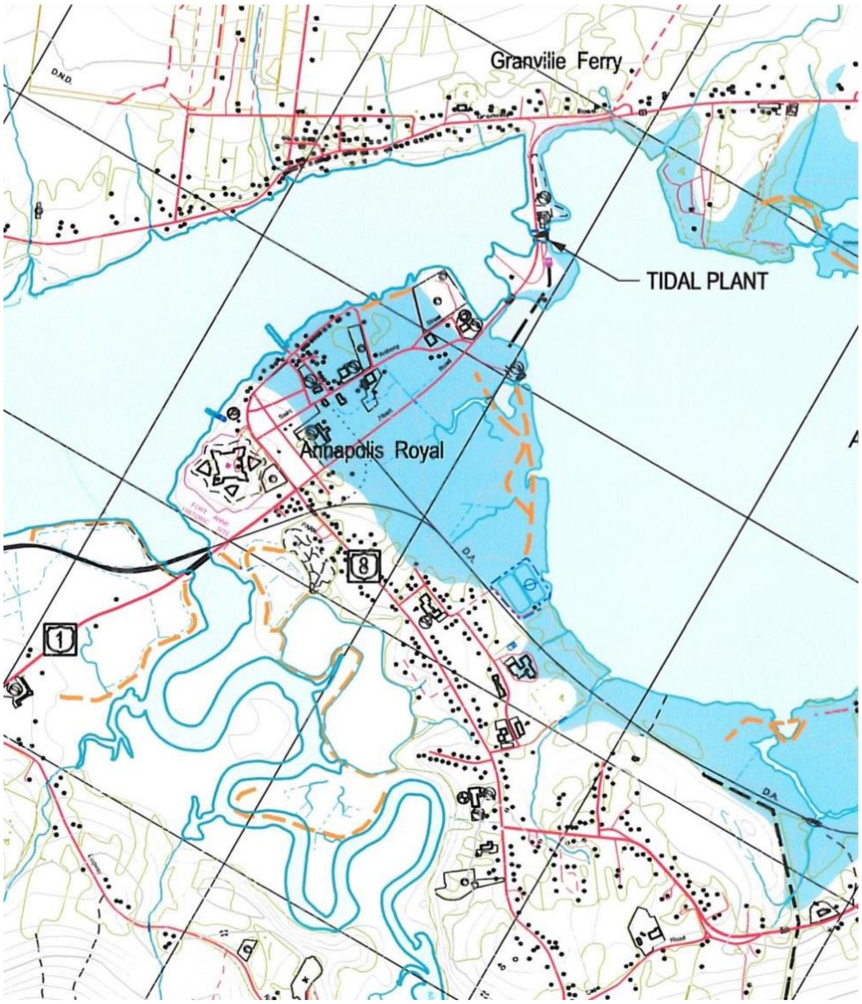
The Threat from Overland flooding

Annapolis Royal Municipal Climate Adaptation Plan (2013)

- Annapolis Royal is located downstream of the Nova Scotia Power Nictaux and Paradise Hydro Systems, a complex of power generation dams operated by Nova Scotia Power (NSP). Emergency Preparedness Plans ... include ... mapping showing the potential flooding in the area including Annapolis Royal under a 100-year storm and under an unlikely catastrophic event called a probable maximum flood.
- **Provided that the tidal sluice gates at the Causeway are operational and the marshland dykes remain intact, a 1:100 year flood would have little impact on Annapolis Royal.** A slight increase in the tidal plant headpond water elevation would occur.
- The probable maximum flood represents the worst-case scenario of multiple events acting in a domino effect. Simulations of the dam system determined that a mid-August (summer/fall all- season maximum) probable maximum precipitation falling on the catchment area of the dams saturated by 1/100-year pre-storm combined with multiple breaches of the dams in the system could result in a probable maximum flood event. **While this is regarded as a rare possibility, the impacts would be severe and large ...** The tidal plant headpond would rise approximately 4.8 m above normal full supply level. Flooding would extend up the south side of the river up to Victoria Street, including the causeway and roadway to the south of the tidal plant. The extents of this flooding correspond to the projected flooding due to sea level rise and a 1:100 year storm surge. (my emphasis)
- This maximum probable flood scenario for the dam system does not take into consideration high astronomical tides and the effect of high winds and wave run-up in the Annapolis Basin and only looks at effects up-stream of the tidal plant. A combined storm-flood event ... would have wider ranging consequences. (All p.11-14) Emphases added)

1 in 100 Year Overland Flood Inundation Limits (Source: Nova Scotia Power, Emergency Preparedness Plan Paradise Hydro System, Plate 12.3)

- As noted in the previous section 'Provided ... the tidal sluice gates at the Causeway are operational and the marshland dykes remain intact, a 1:100 year flood would have little impact on Annapolis Royal. A slight increase in the tidal plant headpond water elevation would occur.'



Probable Maximum Flood Inundation Limits (Source: Nova Scotia Power, Emergency Preparedness Plan Paradise Hydro System, MCCAP p.1

- As noted in the previous section 'While this is regarded as a rare possibility, the impacts would be severe and large'.

Summary of findings concerning the overland flood risk

- **Evidence suggests that the Town does not face a serious threat from overland flooding. A 100-year storm will have minimal impact.**
- **The probability of a maximum inundation caused by multiple NSP dam failures is small.**

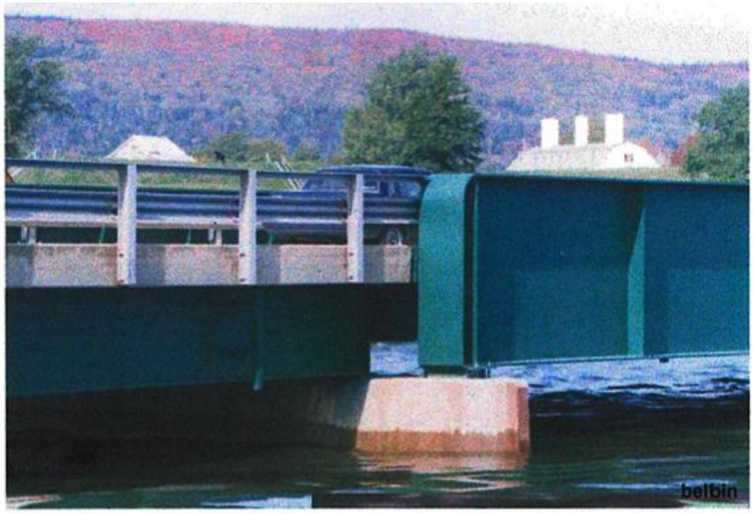
Illustrating the threats - Historical Photographs

Minor flooding of the Wharf/Lower St. George Street area occurs from time to time at high tide. The photograph below document such an events.

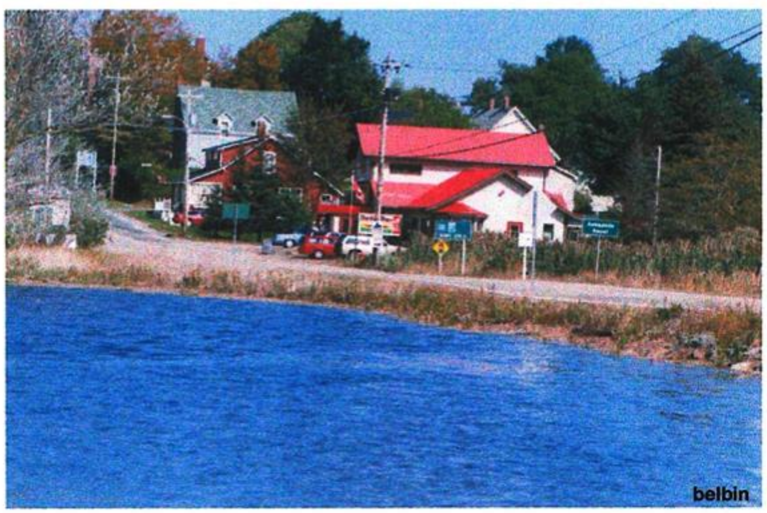
Inundated Boardwalk in 1997.

Boardwalk 2008

George St. at end of wharf looking South-west Source O'Dell House) 2008



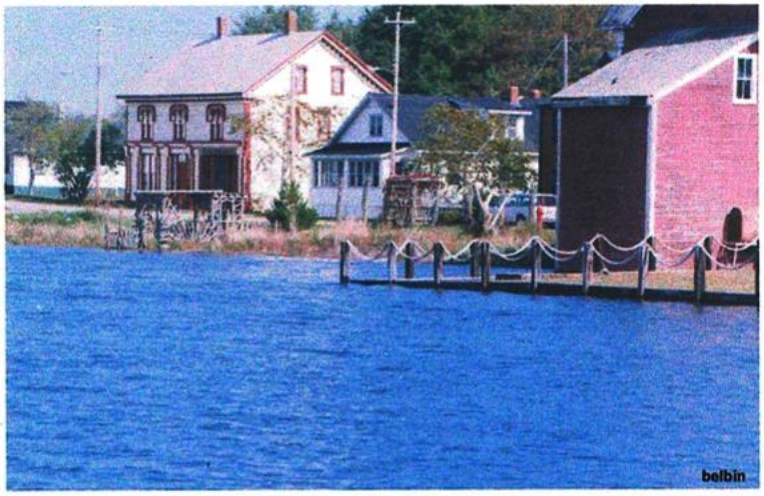
Ideal conditions - What happens if you add 1.5 metres of water and a storm?



Perigean Tide at Highway #1 - Allain's Creek

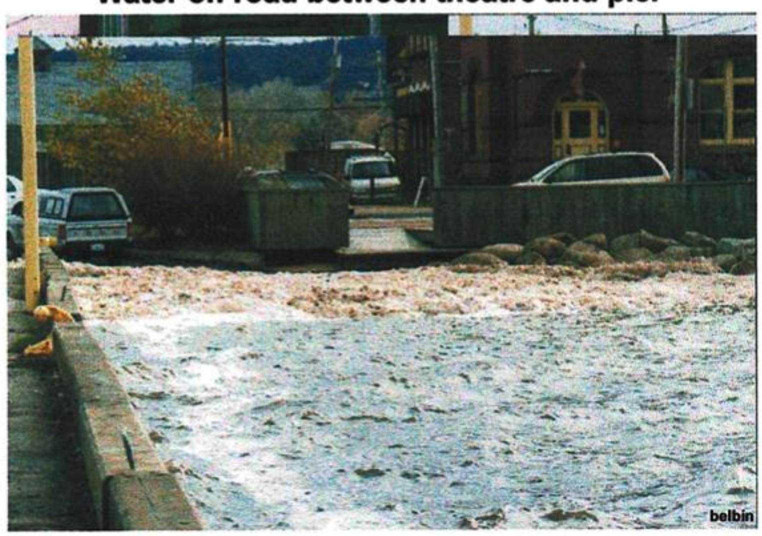
1998

- A perigean spring tide occurs **when the moon is either new or full and closest to Earth**. Often between 6-8 times a year, the new or full moon coincides closely in time with the perigee of the moon — the point when the moon is closest to the Earth. These occurrences are often called 'perigean spring tides. Wikipedia.



Heritage buildings and small park

Water on road between theatre and pier



"Getting Close" - 2 different perigean tides
Annapolis Royal

Illustrating the threats - Recent Photographs

This photograph is of the Boardwalk and the rear of KIng's Theatre. The area immediately to the left of the line of foam was underwater at High Tide. The level of the tide is discernable from the darker, still wet, area on the rocks. The photograph was taken at Noon (twenty minutes after High Tide) on 03 January 2022 (One day after the New-Moon High Tide). Conditions were clear and windless with no waves. The tide was marginally higher on 02 January - New Moon. (Source. J. Bottomley)

This photograph is of the Town Wharf. The area immediately closer than the line of foam was underwater at High Tide. The level of the tide is discernable from the darker, still wet, area on the Wharf's stanchions. At High Tide water was within 25 cms. of the surface of the wharf. The photograph was taken at Noon (twenty minutes after High Tide) on 03 January 2022 (One day after the New-Moon High Tide). Conditions were clear and windless with no waves. The tide was marginally higher on 02 January - New Moon. (Source. J. Bottomley)

Above is a photo of the shoreline of Annapolis Royal at high tide in October 2021. Note the height of the water is close to topping the wharf despite this being a calm day with no storm surge or significant wind. (source. S. Cardwell)

The old Allains Creek Railway Bridge. This is of approximately the same height as the bridge carrying Highway 1 over Allains Creek. The photo was taken when the high tide was approximately 8.5m. With an 8.8m hightide water would be lapping at the base of the girders. Add a storm surge and waves and the bridges would be inundated without any effects of sea-level-rise. Taken February 26th 2022.

Impacts of sea-level-rise

This section consists of the relevant sections, executive summaries etc. from existing reports, Community Plans, Heritage designations, Community Bylaws etc. as well as original analyses of data obtained from the Town and elsewhere. Each source is identified. Details of where each can be accessed are given. At the end of this section is a summary of findings.

Elevation of flood	4.7	4.9	5.4	6.5
No. of buildings affected	0	1	42	116
Sq. Ms. of buildings affected	0	212	12,672	23,182
No. of high priority buildings	none	none	See below	See below
Meters of flooded roads	0	0	1,300	2,460

Birch Hill 2007 p.128

For the 5.4 m flood ... the expected total cost of the “do-nothing” option is $4,044,902 in (2007 dollars - $5,237,744 in 2022 dollars). (p.129)

Implications for Town Property Tax Revenues

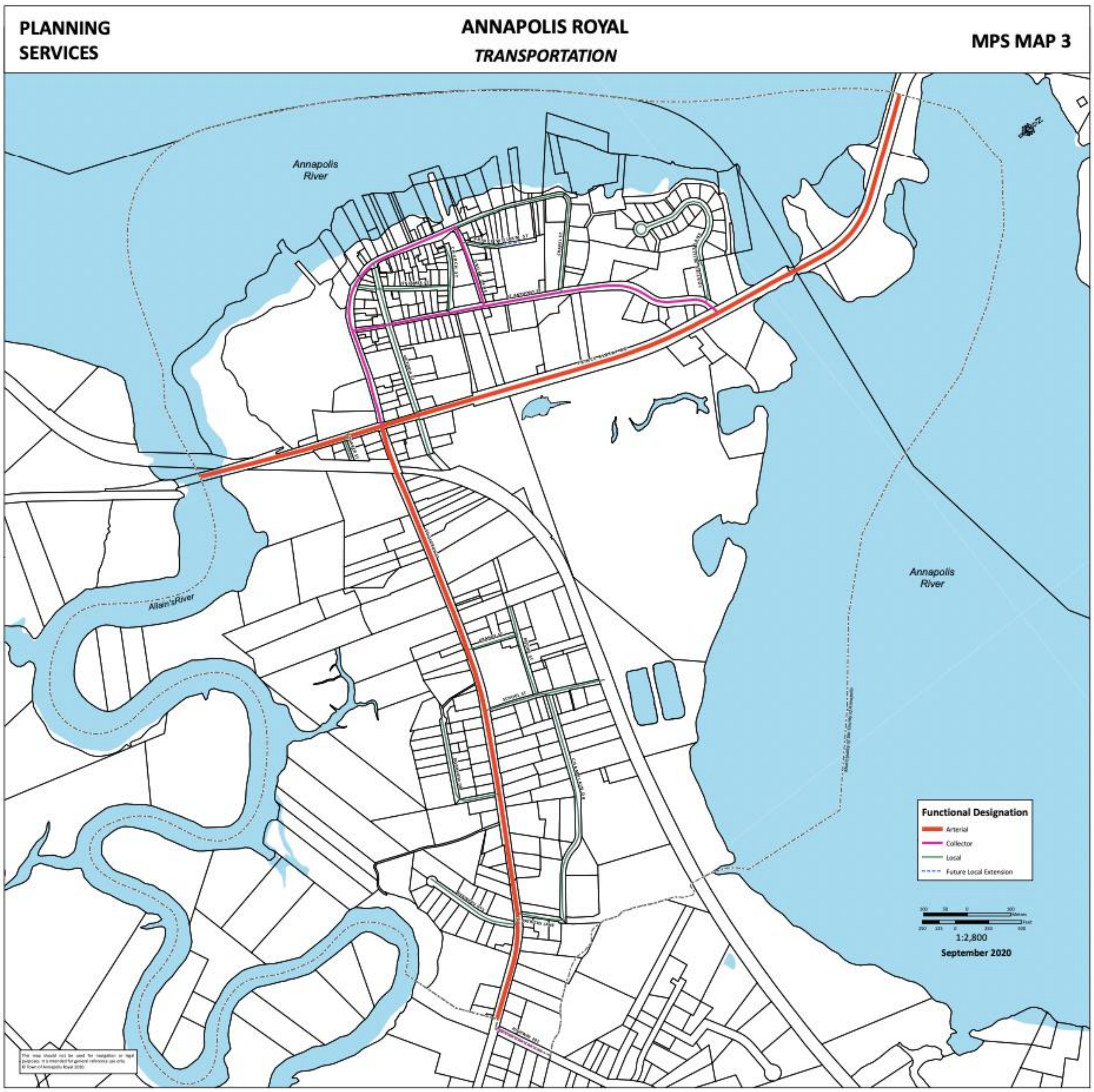
The following is a list of businesses and services impacted by a 5.4m flood.

AIRO offices, Annapolis Brewing Company, Annapolis Eye Centre, Arch&Po, Armstrong Law, Bailey House Bed-and Breakfast, Bainton's Tannery and Books, Bank of Nova Scotia, Cafe-Restaurant Compose, Charlie’s Place Restaurant, Coastal Reflections Gallery, The Comfort Station, The Courtyard, Engel and Volkers Real Estate, Fairview Insurance Brokers, Far-fetched Antiques, Farmers Market, Foodland, Fort Anne, Free-Mason's Hall, St. Anthony Street Gallery, Historic Gardens, Homebody, Home Hardware Building Centre, Independent Supermarket, JoAnn's Chocolate Shop, Jost Architects, Kaulback Undertakers, King's

Theatre, Loose Ends, Little Gallery, Lucky Rabbit Gallery, Mad Hatter Wine Bar, NSLC Select, O'Dell Museum, Public Works yard, Reardon Law, Sinclair Inn, St.. Anthony Street Gallery, The Haul-up, The Old Dairy. The Whiskey Teller. These represent a very significant proportion of the Town's commercial establishments and hence of the Town's commercial tax base. (NOTE: a percentage figure is forthcoming)

Approximately thirty residential properties will be impacted by a 5.4 m flood. These represent a significant but not major proportion of the Town's residential tax base.

Infrastructure and Services impacted by a 5.4m flood



The following are from MCCAP 2014

Impacts on the road network

- Flooding of sections of arterial Highway 1 between the causeway and Victoria Street and of the Allains Creek bridge. With the projected sea level rise, a 1:100 year storm occurring during a high high water large tide would flood most of the waterfront properties and a central portion of the Town. Flooding would cover a large section of Prince Albert Road as well as St. Anthony Street from Fortier Mills Lane to beyond Church Street cutting the Town in two. The new development at Fortier Mills Lane would be isolated from the Town and could lose escape routes if the Causeway failed or tides reached maximum extent. The Fire Hall would also be cut-off from the rest of the town. The only safe route out of town would be St. George Street
- Flooding of sections of collector streets St. George Street, Drury Lane and St. Anthony Street.
- Flooding of several residential streets.
- Isolation of Annapolis Royal Volunteer Fire Department.
- Isolation of Emergency Medical Services.
- Isolation of Legal Aid Nova Scotia.

Impacts on water utility

- The Town is adequately serviced with multi-routing and valve redundancy that would allow service to be maintained for most areas if there was a localized system failure. The weak link in the chain is the main service line across the causeway, which if severed would disrupt service to the entire Town

- The main climate change risks to the Municipality's water system infrastructure include the following:

    - Erosion of the bank along the Annapolis River undermining the Granville Ferry watermain supplying the Town of Annapolis Royal;
    - Erosion or damage to the Causeway undermining the watermain supplying the Town of Annapolis Royal;
    - An increase in storm intensity and runoff that could wash out local roads containing watermains.

Impacts on Wastewater Treatment

- A key concern for wastewater infrastructure is increased flooding and run-off due to increased frequency and intensity of rain events. Wastewater collection infrastructure including gravity sewers, lift stations, force mains and treatment plants are located near low elevations. Lift stations specifically tend to be located close to rivers or streams. Should the watercourse flood its banks, it could inundate the lift station with runoff as the covers to lift stations tend not to be watertight.

- Localized flooding can produce increased inflow and infiltration in sanitary sewers. Inflow and infiltration increase costs for pumping and treating runoff. With increased inflow and infiltration, there is also the risk of sewers backing up into homes and businesses, increase in lift station overflow frequency and volume, and "washouts" of wastewater treatment plants impacting overall discharge objectives. The primary concern with the lift stations in the event of a flood or power outage is the fact they do not have back-up power and will not be able to continue functioning.
- There are six sewage lift stations throughout the Town of Annapolis Royal:

  1) Near wharf (St. Georges/Drury);

  2) St. Anthony/Chapel;

  3) On access road next to secondary lagoon;

  4) Near tennis courts at the Education Centre;

  5) Half way between Riverview Drive and Babineau Heights; and

  6) Off Prince Albert Road past Bohaker Street near Allain's Creek.

  NOTE: All but number five are in the potential flood zone.

Impacts on Stormwater Infrastructure

- Stormwater infrastructure owned by the Municipality includes primarily ditches, catch basins, storm sewers and culverts. Outfalls for the stormwater system in the downtown are all located near the wharf off St. Georges Street and the rest of the outfalls for the town drain into Allain's Creek. There are significant portions of Annapolis Royal that do not have any stormwater infrastructure and rely on natural drainage.
- Though the drainage system for the Town is excellent, the main concern is if extreme high tides and storm events occur concurrently, outfalls and drain pipes with check valves may be blocked causing back-up in the system. This will lead to additional water pooling on the surface and increased erosion as the pooled water attempts to find a new drainage path. Building basements are also likely to be flooded.

Impacts on Power Utilities

- The electrical substation supplying the Town is located adjacent to the tidal power plant on the Causeway and the mapping indicates that it is slightly above the projected 1:100 year storm levels. However, impacts to service would be widespread if the connection between the substation and the Town were severed, which is a potential threat.

Summary of findings concerning impacts on Infrastructure and Services

- **Evidence indicates that the Town will experience significant disruption regarding access to vital emergency and other public services unless adaptive measures to prevent flooding are adopted.**
- **Evidence indicates that the sewer and drainage system of the Town will be negatively impacted unless adaptive measures to prevent flooding**

Social impacts of Flooding

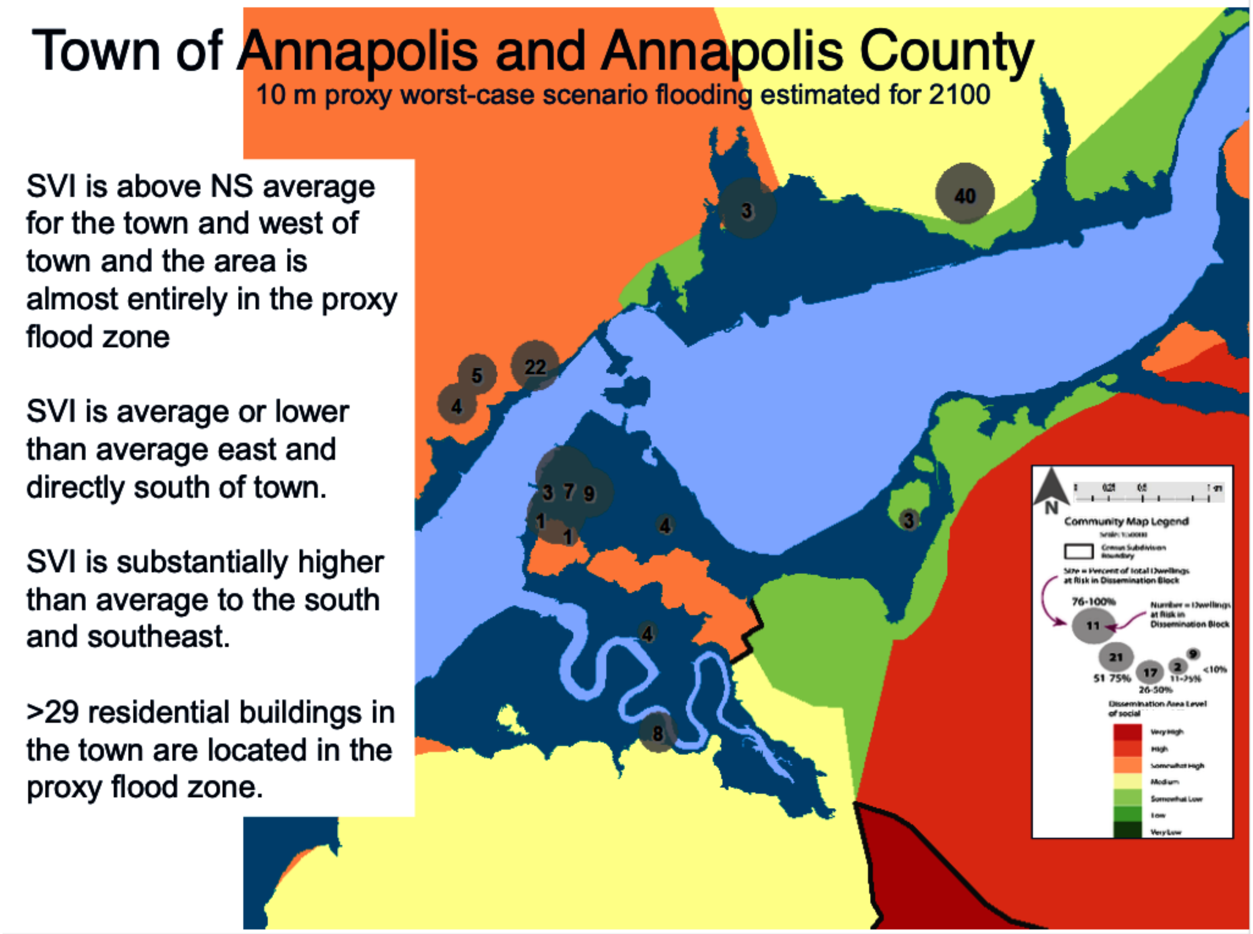
There are many ways to quantify the relative social vulnerabilities of populations. One method is outlined below. An indication of social vulnerability for Annapolis Royal and surrounding area is indicated on the map that follows.

Social Vulnerability Index - SVI

SVI is calculated using statistics that represent measures of Social Determinants of Health

- Children
- Seniors
- Seniors living alone
- Lone parent families
- No knowledge of English or French
- Recent immigrants
- Low income
- Unemployed
- Visible minority
- No secondary education
- Aboriginal identity

- Calculate an index for each SV variable
- Each variable index is the Standard Deviation (SD) from the NS mean for the variable.
- SVI is the average of the sum of SDs of all variables
- SVI scaled from high to low in steps of +/-0.5 SD
- Average is -0.5 to +0.5 SD



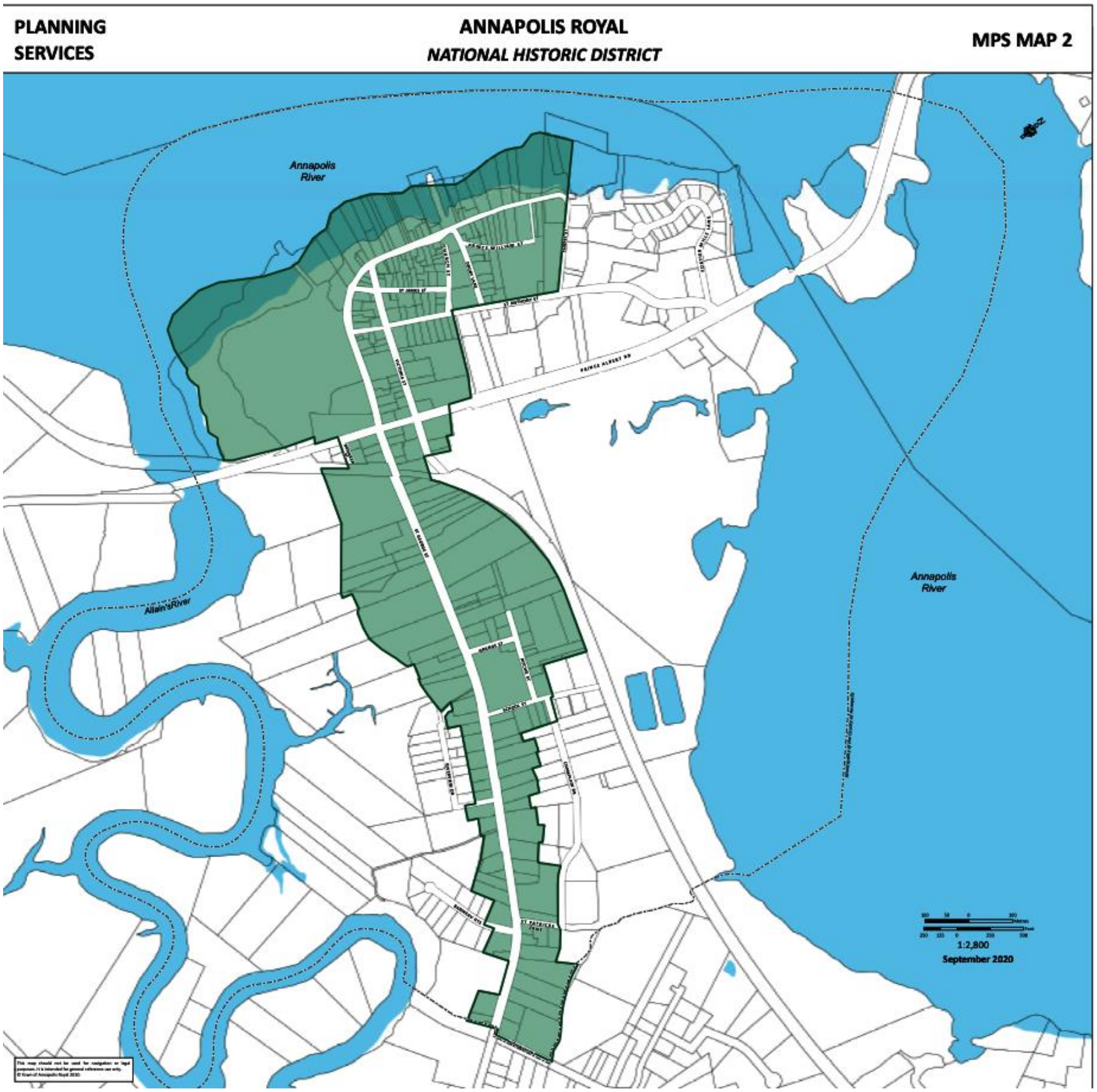
Both from Bryce et al 2015

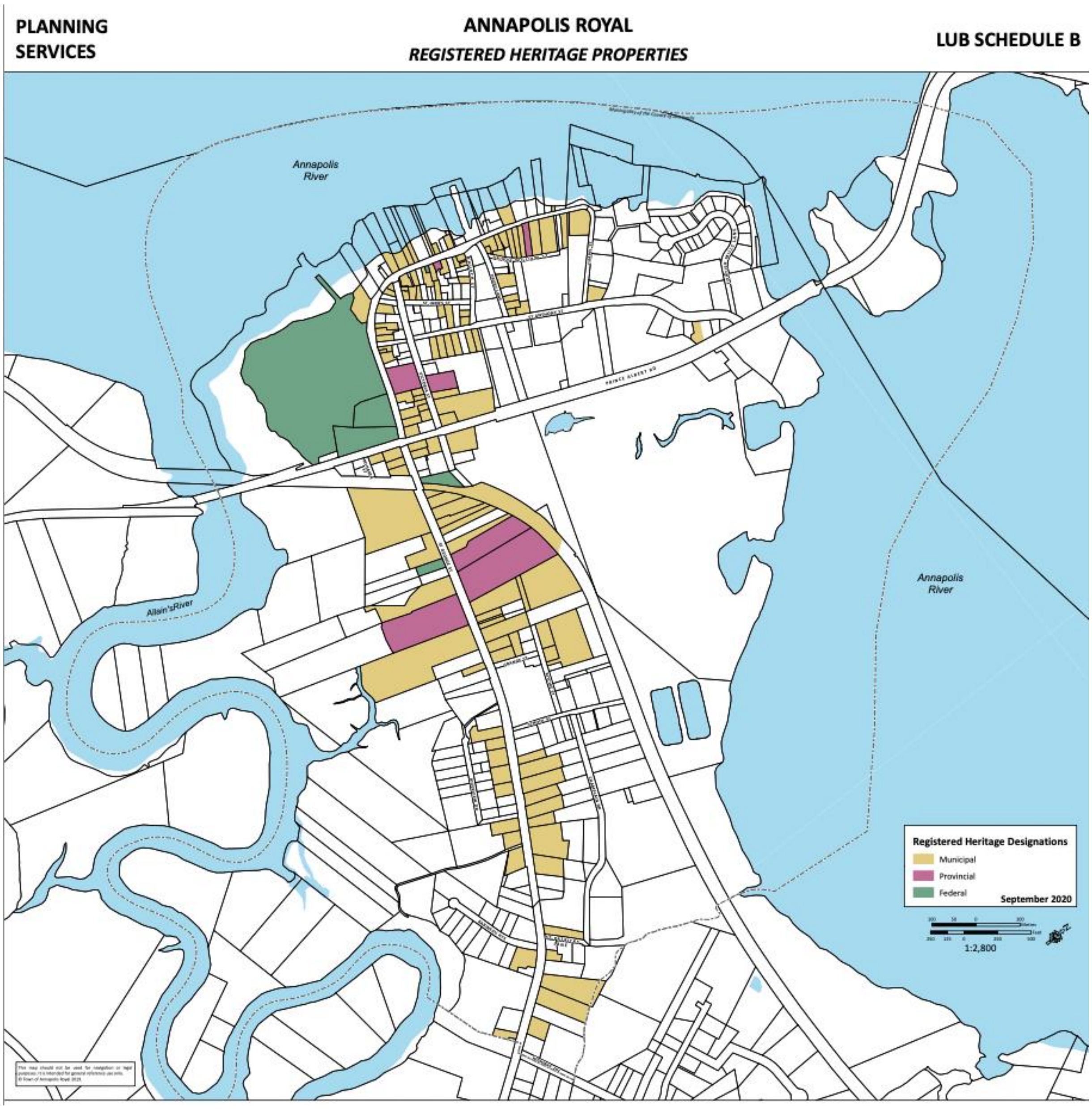
Impacts on heritage resources and tourism

- Annapolis Royal is a major tourist destination in Nova Scotia. Figures from Tourism Nova Scotia indicate that since 2010 the Annapolis – Fundy Bay region has attracted approximately 350,000 tourist bed-nights per year. July, August and September are the high season months with June and October being shoulder season months with still considerable numbers of visitors. Approximately 85% of these bed-nights are spent in hotels, motels or B&Bs. A larger number, between 450,000 and 500,000 site-nights are sold at campsites across the region. Total visitation to the region approaches 1,000,000 individuals per annum. (National Cost Sharing Program for Heritage Places Funding Application. Part F Question 1 2021)
- Many tourists are attracted to the Town because of the rich historic and architectural heritage, the unique attractions and the natural beauty and atmosphere of the

Town. Among the Major attractions are Fort Anne and the Historic Gardens. Both are important heritage sites. Fort Anne is a National Historic Site and the Historic Gardens are responsible for the maintenance of significant Acadian dykes in the Allain's Creek estuary. Both will be impacted by sea level rise. (NCSPHP Part F Question 1)

- The Historic District and the buildings therein are in excellent condition ... and expertly managed by the Town and its Planning and Heritage Advisory Committee. **The site faces an existential threat over the next three decades because of climate change induced sea-level-rise.** (NCSPHP Part F Question 1) Emphasis added.
- The Annapolis Royal Municipal Climate Change Action Plan (2014) identified sea-level-rise as a major issue facing the Town. It noted that the northern portion of the downtown core and Lower St. George Street faced a 'significant hazard' from sea-level-rise. ... These scenarios indicate that Higher High Water Large Tide (HHWLT) plus Sea Level Rise (SLR) levels associated with a storm surge such as experienced in 1976 would inundate almost the entire Downtown and Lower St. George area of the Town. **Subdistricts three and four of the historic site would be flooded in their entirety. (NCSPHP Part F Question 1)** Emphasis added.


PLANNING
SERVICES
ANNAPOLIS ROYAL
NATIONAL HISTORIC DISTRICT
MPS MAP 2
Annapolis River
Annapolis River
Allain's River
PRINCE ALBERT RD
1:2,800
September 2020



Summary of findings concerning the impact on heritage resources and tourism

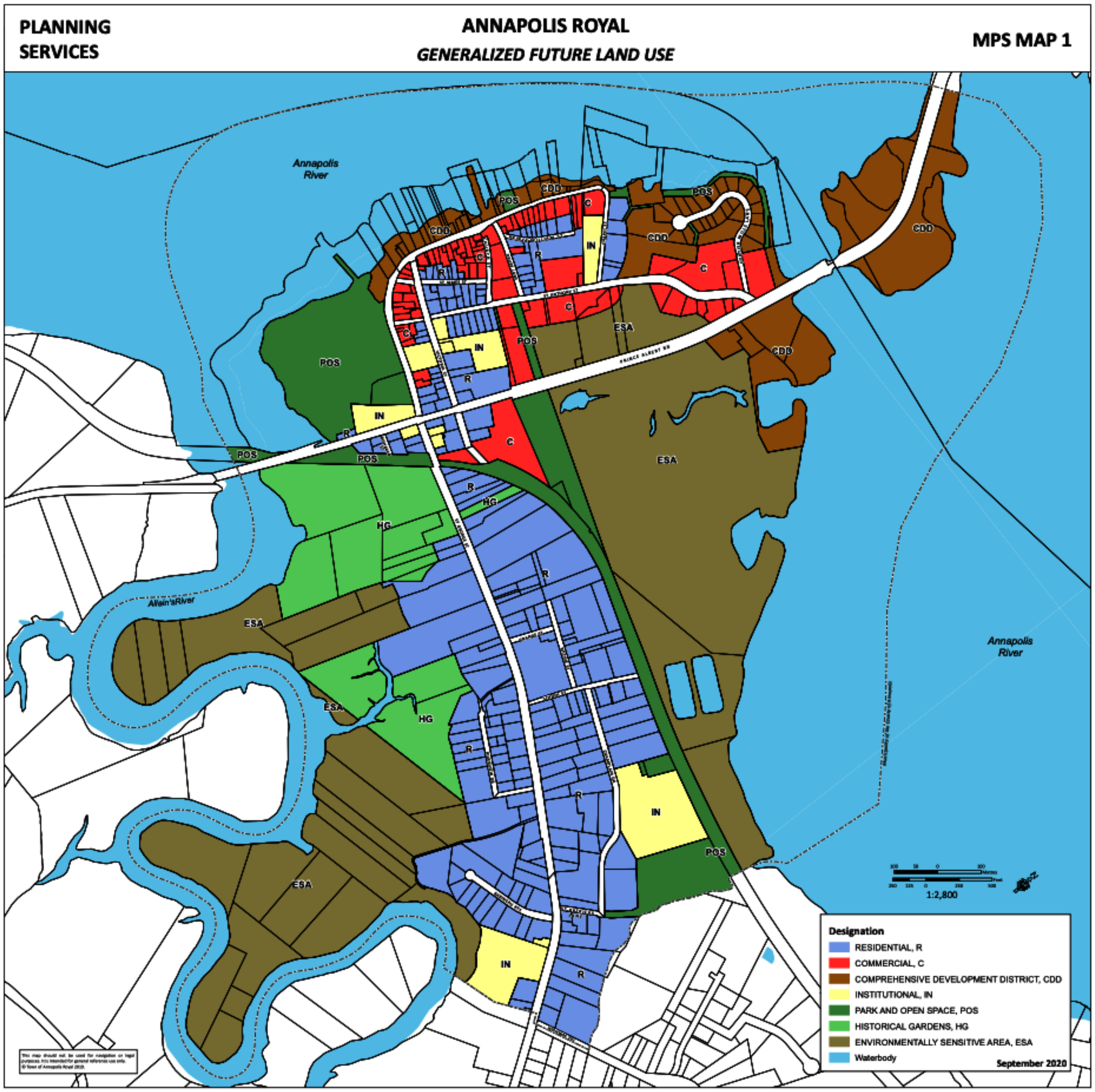
Summary of findings concerning impacts on heritage resources and tourism

- The evidence is clear that the National Historic District and many of the heritage properties found therein face an existential threat unless adaptations are made to protect the district from the impact of sea-level-rise
- Evidence is very suggestive that tourism will undergo a very serious decline unless the National Historic District is protected from the impacts of sea-level-rise

Response of land use planning.

Town of Annapolis Royal Municipal Planning Strategy (2010)

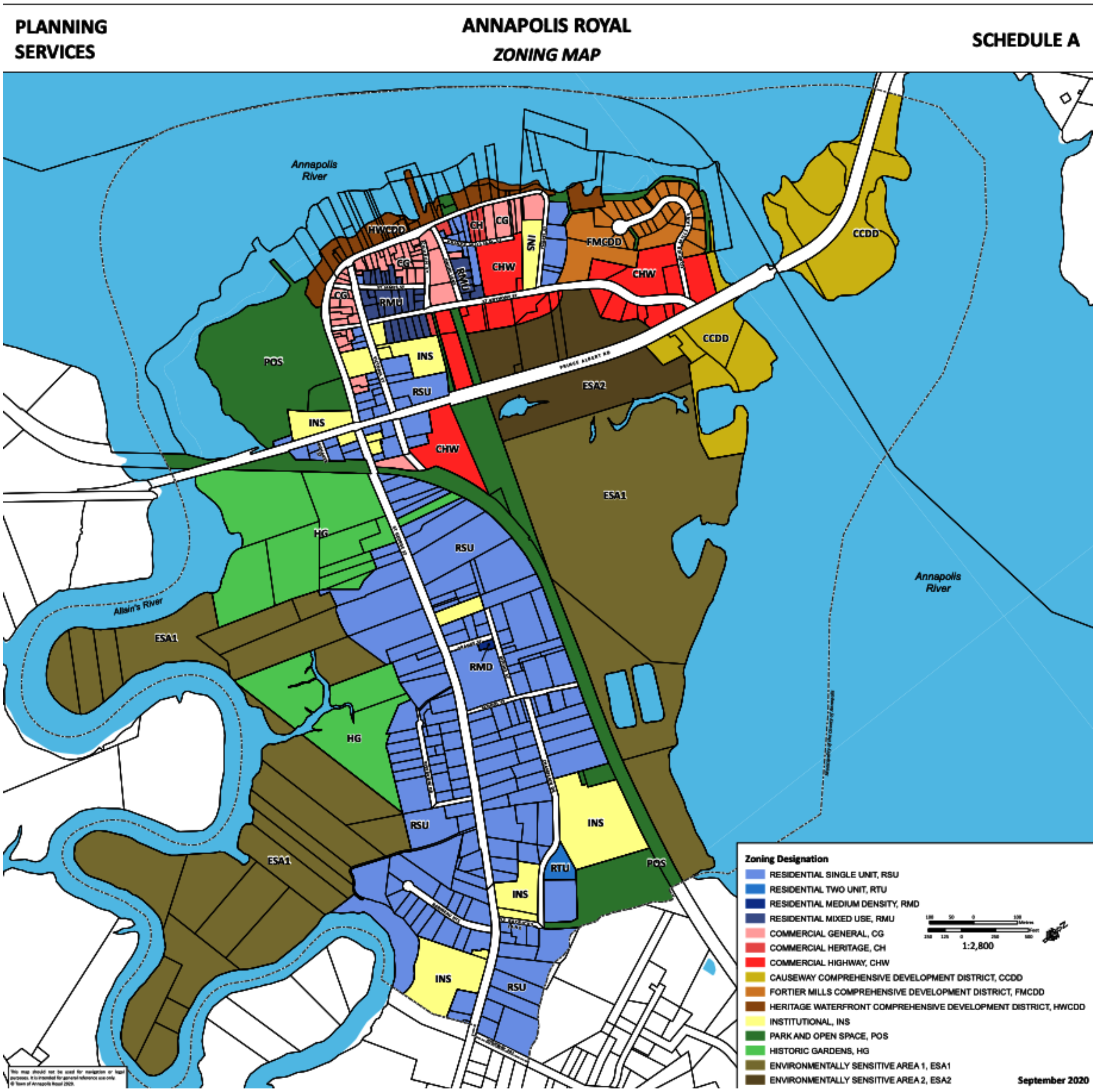
- **The Province of Nova Scotia has adopted Statements of Provincial Interest relating to specific land use issues:** the protection of drinking water supplies; the efficient and responsible use and extension of municipal infrastructure; the preservation of high-quality agricultural lands; **development within identified flood risk areas; and** the provision of adequate housing. (p. 6) Emphasis added.
- **The Town does not contain any designated flood risk areas**. The Town is located adjacent to the Annapolis River and **the Strategy and Land Use By-law provide for development control provisions for development adjacent to the Annapolis River and in particular consideration of the impacts of potential sea level rise for those lands located adjacent to the Annapolis Basin**. (p. 6) Emphasis added.
- Annapolis Royal (has) jurisdiction over land use and through the management of development, the Town seeks to balance growth with environmental protection and preservation. **Planning for the impacts of climate change, including sea-level rise and an increase in the frequency and magnitude of storm events, is also critical to managing appropriate future growth** and development in the Town. (p. 30) Emphasis added.
- ...lands on the east side of Prince Albert Road (see ESA2 on Map below) generally between the causeway and St. George Street, may be appropriate for development subject to technical evaluation and study and the required engineering and site preparation. (p. 30)
- The Town recognizes that development in environmentally sensitive areas presents a number of problems. Potential foundation instability, corrosive effects of salt-water on concrete, a high- water table, unstable soils, and other environmental conditions have, in the past, made these lands traditionally unsuitable for substantial development. Proposals for use in environmentally sensitive areas shall be considered only when site-specific development studies are completed. (p. 30)
- The Town ... recognizes that data and studies relating to such matters as flood mapping, topography, soil conditions and habitat conditions are important public decision-making tools. (p. 30)



Town of Annapolis Royal Land Use By-law (2010)

- No development permit shall be issued in an Environmentally Sensitive Area 1 (ESA1) Zone except
    - for one or more of the following uses:
    - Interpretation
    - Tourism and recreation
    - Non-polluting agricultural uses that do not require permanent buildings

    - Service or utility uses
    - Institutional uses
    - Conservation projects and accessory uses and structures
    - Garden and landscape projects
    - Sewage treatment facilities
    - Crop farming, grazing and pasturage (p. 53)
- No development permit shall be issued in an Environmentally Sensitive Area 2 (ESA2) Zone except for one or more of the following uses:
    - Residential Uses
    - Commercial Uses
    - Institutional Uses
    - Parks and Open Space Uses
    - Tourism and recreation Uses (p. 54)



Summary of findings concerning impacts on the Municipal Planning Strategy (MPS) and the Land Use By-law (LUB)

- The MPS recognizes the need to take account of both sea-level rise and an increase in the frequency and magnitude of storm events.
- The MPS states 'the Town does not contain any designated flood risk areas' but goes on to say there is a need to consider 'impacts of potential sea level rise for those lands located adjacent to the Annapolis Basin'
- The LUB places controls on development in Environmentally Sensitive Area 1 (ESA 1) and Environmentally Sensitive Area 2 (ESA 2) .ESA2 allows for residential,

commercial, institutional, parks and open space uses and tourism and recreation uses through a permit process.

- There are no specific environmentally-based controls on development in zones Heritage Waterfront Comprehensive Development District (HWCDD), Commercial General (CG), Commercial Heritage (CH) or Commercial Highway (CHW) all of which will be impacted by sea-level-rise induced flooding unless Adaptive measures are undertaken.

Conceptual mitigative options and order of magnitude cost estimates

We have come to the preliminary conclusion that if the Town of Annapolis Royal wishes to protect itself from rising sea level, it would have to construct a sea wall to a minimum of 8.0 metres and possibly as high as an elevation of 8.8 metres. **Hatch, Mott, McDonald 2009 p.1**

Regarding the construction of levees, we shall assume that the levee will have a 3 m wide crest (to accommodate heavy equipment) and 3.5H:1V side slopes. We shall also provide a 3 m freeboard above the required flood elevation to avoid overtopping (and subsequent erosion) by wave actions, which are sure to accompany a storm surge. **The average elevation of the land around the town on which the levee would be placed is about 5.0 m and the levee would need to be approximately 900 m in length**. The details of the two levees being considered are as follows:

For the 5.4 m flood, a 3 m freeboard brings the upper surface of the levee to an elevation of 8.4 m. The constructed height of the levee is thus $H = 8.4 - 5.0 = 3.4$ m having a cost of about $2,600/m. The total cost of this levee will therefore be 900 × 2, 600 = $2, 340, 000. for the 6.5 m flood, a 3 m freeboard results in a constructed levee height of $H = 9.5 - 5.0 = 4.5$ m having a cost of about $4,200/m. The total cost of this levee will therefore be 900 × 4200 = $3, 780, 000 **Birch HIll Geo-solutiions p.127 -128**

In the "Back to the Future" Report (Town of Annapolis Royal, 2009), the Town recognizes it is at risk of storm surge and that it appears that construction of a levee to protect against 5.4 m flood is less than the cost of repairs as a result of flood damage. The Town should ... begin budgeting for the design and construction of this levee. To enable the levee to protect the Town better in the future given sea level rise predictions, the town should consider raising the levee to a higher elevation initially or to design the structure in a way that this can be done efficiently in the future. **MCCAP p.27 2014**

There is a tentative consensus that if the Town is to be protected from flooding consequent on sea-level-rise there needs to be an 8m -9m protective structure constructed from Fort Anne to the causeway. This would be approximately 1000m in length. Note that the land on which this would be constructed is approximately 5m above sea level requiring a structure of from 3 - 5m in height above the current situation.

The needed structure could conceptually be either a dike or a seawall. See Appendix 2 for a detailed description of the advantages and disadvantages of these two technologies. The table below summarises this information.

Technology	Advantages	Disadvantages
Seawalls	• High level of protection against elevated sea levels • High level of protection against erosion • Possible to further elevate in response to SLR • If maintained are long-lived structures	• Subject to high loadings from wave impacts • May be subject to sea-bed scour at foot of wall • May affect sediment availability along adjacent shores • May cause coastal squeeze.
Sea dikes	• High level of protection against elevated sea levels • Low-cost option when land costs are low. • Low impact on adjacent shorelines • Low risk of sea-bed scour.	• Require high volumes of material to resist pressures. • Have a large footprint requiring large areas of land • Subsequent raisings increase the land footprint.

A key aspect of any future engineering and environment study will be to determine which of these two technologies is best suited to achieve desired outcomes.

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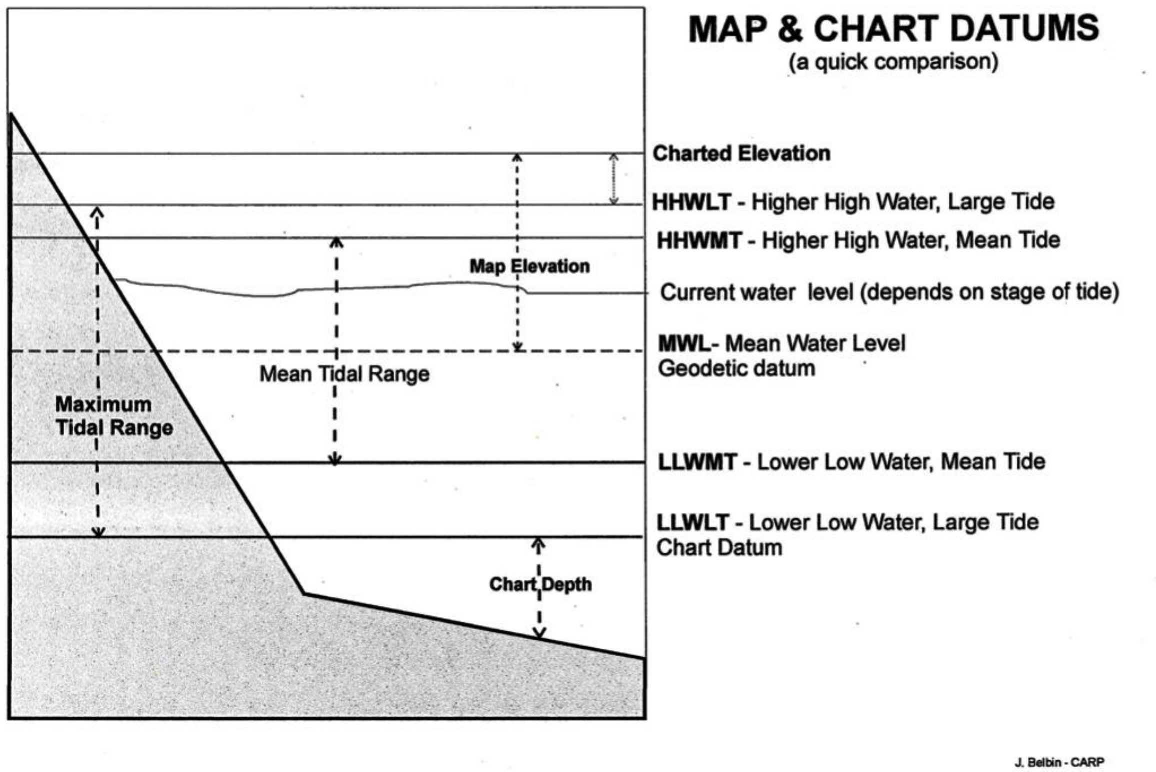
Appendix One -Notes on Mean Sea Level, Storm Surge, Flood Heights etc.



TIDAL NOTES:

DATUM

Tidal datum in the tide tables is normally the same as chart datum for that locality. By international agreement, chart datum is a plane below which the tide will seldom fall. The Canadian Hydrographic Service has adopted the plane of **Lowest Normal Tides (LNT)** as the datum level. To find the depth of water in chart tables, the height of the tide must be added to the depth shown on the chart. Occasionally a figure will be preceded by a (-) and these tidal heights must be subtracted from the charted depth.

A word of caution is appropriate here, tidal predictions and that normally includes computer software, that have been generated in the United States differ from those of Canada. **The United States tidal datum is Mean Lower Low Water and can differ from the Canadian datum by as much 1.50 metres.** In border waters such as the Gulf of Maine and the Bay of Fundy, that can be highly confusing.

METEOROLOGICAL EFFECTS

Meteorological conditions can cause significant variations between the predicted tidal levels and their actual occurrence. Mostly these factors are caused by barometric pressure changes and strong, prolonged winds.

A change of 30 millibars in atmospheric pressure can cause a rise or fall in the sea level of roughly 0.3 metres. HIGH pressure depresses sea level and LOW pressure raises it. This effect is not seen immediately a pressure change occurs but it is the result of the average change over a wide area.

Wind will also considerably effect sea level, depending on the topography of the region, the strength, duration and fetch of the wind itself. A strong wind blowing on shore will raise the level of the water. This is especially noticeable at the head of long, narrow, shallow bays and when it is coupled with low barometric pressure can create exceptionally high tides. **The dramatic increase in sea level is called a STORM SURGE and is the single factor, which does the most damage to coastal communities in a hurricane.** Winds blowing off shore tend to have the opposite effect and reduce the sea levels.

TIDE TIMES

Tide Tables are normally prepared in **Standard Times** for that region and are based on the 24-hour clock. In this region we use **Atlantic Standard Time (AST)** to which 4 hours must be added to obtain the universal reference of **Greenwich Mean Time (GMT).** Greenwich Mean Time is the mean solar time at the Greenwich Meridian (the prime meridian used for mapping) and is the same as Universal Time (UT). It is also sometimes called Co-ordinated Universal Time. If Daylight Saving Time is in use, one hour must be added to the expected tidal times.

MAP AND CHART REFERENCE LEVELS

CHARTS

In direct contrast to topographic maps, marine charts must show heights and depths above and below water surface which itself fluctuates within hours. Thus charts use two different datum's and several other reference points in order to accomplish this safely.

The most important information on a chart is the minimum depth of water at a given point so that vessels may navigate safely. The primary reference datum used for marine charting is **LNT or Lowest Normal TIDES**, giving the minimum depth of water at a given point. Depths below this level are known as SOUNDINGS. (In the USA the similar Mean Low Water found on many small boat charts is an average, and as in many areas one of the two daily tides is considerably lower than the other, individual low waters can often be lower than this point - a major safety consideration)

In the INTERTIDAL ZONES, heights are measured upwards from the same level and are normally UNDERLINED on the face of the chart. Some charts use the word "DRIES" next to these figures and refer to them as DRYING HEIGHTS.

A different datum is used to identify the land areas of the chart. The phenomenon of **SPRING TIDES**, the twice-monthly peak of tidal range, is generally used to determine this datum. It may be labeled as Higher Water Ordinary Spring Tides (HWOST), Mean High Water Springs, Highest Astronomic Tide, Mean Higher High Water etc.

The **SHORELINE** shown on charts is the Mean High Water line except in areas of marsh, - it is the outer edge of the vegetation (berm line) which is used.

TOPOGRAPHIC MAPS

MEAN SEA LEVEL (MSL)
This is a recording of tidal values over a 19-year period. These are taken to eliminate the variations in sea level, which are due to tidal fluctuations and which are such a concern to mariners. These readings are then averaged. The MSL North American Datum was adjusted in 1929 and again in 1983. MSL is in fact a datum which fluctuates according to atmospheric pressure changes, winds, tidal forces etc., variations of up to a metre have been noted. Despite this potential inaccuracy, MSL has been adopted by most countries as their topographic reference datum.

Coastlines shown on many topographic maps can be quite different from those shown on charts of essentially the same area. They are often photogrammetrically defined and a common line is obtained from the edge of the winter storm berm, which can be identified on aerial photography. In other areas or maps the vegetation edge is used. In recent years there has been an effort to coordinate the coastline on both types of mapping. This is still a major concern for all those involved in shoreline mapping projects.

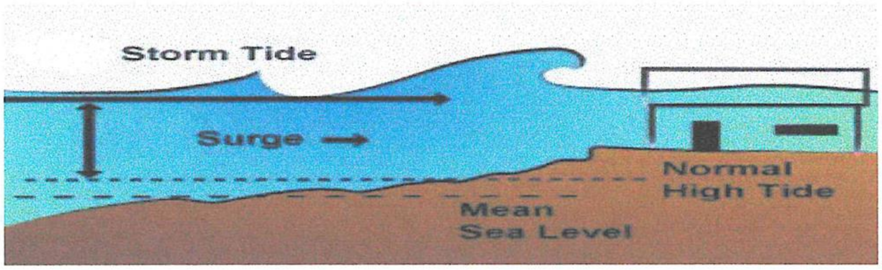
TIDAL HEIGHTS
Predicted tidal heights are those expected under average weather conditions. Users of such information must realize that tides can vary considerably from those predicted, during weather conditions which are not average for that region. General, prolonged on-shore winds or a low barometric pressure can produce higher levels than expected, while the opposite conditions can result in lower levels than predicted.

During times of storm surges or when extreme weather conditions are imminent, people living near or using coastal regions should place close attention to local weather forecasts as they relate to tide levels expected.

A few commonly met terms are:-

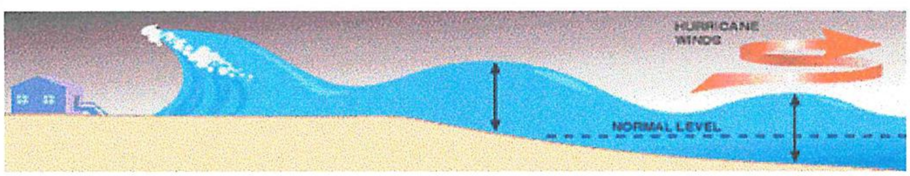
Mean tide range - is the difference between the heights of higher high water and lower low water at mean tides.
Large tide range - is the difference between the heights of higher high water and lower low water.
Mean water level - is the height above Chart Datum of the mean of all hourly observations used for tidal analysis at that location.
Semi-diurnal tide (SD)- There are two complete tidal oscillations daily - both of the high waters having similar heights as well as both low waters of the same day.
Diurnal Tide (D) - one complete tidal oscillation daily.
Mixed, mainly semi-diurnal tide (MSD) - two daily tidal oscillations with unequal levels and times.

Storm Surge



Introduction

Storm surge is by far a hurricane's biggest killer and the most destructive force of many storms of marine origin! A powerful storm is usually described in terms of its wind speeds, but flooding of coastal regions (caused by the high water a storm brings) kills many more people than wind. Coastal flooding is also responsible for a great deal of destruction. Boats ripped from their moorings, utility poles, smashed docks and other debris travelling on the storm surge often destroy buildings not badly damaged by the winds. Even without the weight of debris, water is a powerful destructive force. A cubic foot of seawater weighs 64 pounds. Water does more than batter; it scours away the sand of beaches and dunes and undermines the foundations of structures of all kinds. The surge, aided by the effect of breaking waves, has the potential to destroy everything in its path. Records show that surges caused by storms in Nova Scotia have destroyed roads, bridges, railway lines, dykes, docks, homes, farmland and businesses on many occasions in the past. They are a continuing threat to all who live or work near to our coastlines. As they can occur up to 5 hours before the storm that generated them actually arrives, escape routes can be cut off, trapping people in the danger areas.



Storm Surge Formation

Storm surge is a rise in the level of the sea due to effects of wind and low atmospheric pressure on the ocean surface. When a hurricane moves ashore, this mound of water creates a storm surge that can drown places near the coast under 6 metres or more of water. Storm surges result from high winds (100 kph or higher) and low pressure conditions associated with typhoons and hurricanes. Any landmass in the path of a storm surge will be affected to a greater or lesser extent, depending upon a number of factors. The stronger the storm and the shallower the offshore waters, the higher the storm surge.

Storm surges can be either positive or negative, that is, a positive surge is one where the height of sea level increases, and a negative surge is one where the level decreases from normal. Strong onshore winds or winds parallel to the shore, where the shore is to the right of the wind flow, cause positive storm surges. Offshore winds or winds parallel to the shore, where the shore is to the left of the flow, cause negative storm surges. Obviously these are of far less importance to local residents than the damaging positive variants.

Storm Tide

A storm tide is the combination of a storm surge and the normal astronomical tide. If a storm surge arrives at the same time as a high tide, the water height will be even greater. For example, if a normal astronomical tide is 5 metres and a storm surge is 2 metres, then the resulting storm tide will be 7 metres, and driven ashore by the winds. This mound of water, topped by battering waves, moves ashore along an area of the coastline as much as 150 km wide. This combination of storm surge, battering waves and high winds is deadly.

As much of the population of eastern North America lives close to the coastline the risk is severe. It is estimated that a large percentage of the total population lives or works at a base level of less than 3 metres above sea level. In our region, a large proportion of the town of Annapolis Royal would be includes in such a zone. In fact, a considerable area of Annapolis Royal is located at less than 2 metres above sea level, as can be clearly seen from the maps that accompany this report.

In this region about four significant surge events are recorded each year. Fortunately, most occur at times other than the infrequent tidal peaks and so go unnoticed by most of the population. Because of the extreme range of our tides, we are therefore protected from most of these events in a way that regions with more normal tidal regimes would not be. The surge in water simply occurs in what for us is our normal tidal range, and therefore has little or no destructive impact. However, it is precisely this built-in protection which leads us to overlook the potential for damaging surges when extreme tides occur at the same time as a storm surge. Then we have no protection whatever.

Wave and current action associated with the surge also causes extensive damage. Waves batter anything in their path and have incredible power, some buildings in our region have been totally demolished after being hit by only three storm waves in rapid succession. Currents set up along the coast by the gradient in storm surge heights and wind combine with waves to severely erode beaches and coastal highways. Many buildings withstand hurricane winds until their foundations, undermined by erosion, are weakened and fail. Storm tides, waves, and currents in confined harbors severely damage ships, marinas, and pleasure boats. In estuarine areas, intrusions of salt water endanger the public health; this would be a concern in the Annapolis region.

In the Annapolis region a large surge occurring at the time of an unusually high tide would clearly overtop the dykes and flood the large area of low-lying lands behind them with huge volumes of salt water accompanying storm driven waves. This would obviously produce a great deal of damage to the land, the buildings and the safety of local residents. However, a common misconception is that the damaging water would be short lived and promptly drains from the land. Tidal surges normally arrive some hours BEFORE the storm that created them and the land will already be deeply flooded when the peak of the storms rainfall and winds arrives. Thus at the very time that the water could begin to drain as the tide recedes the storm flood arrives. By the time the storm is over you have another cycle of very high tides, which will cause another salt-water flood if any of the dykes have been damaged. With roads and bridges being normally damaged by such events some people may be cut-off for extended periods of time. The combined inundation would probably take several days to remove as the dykes themselves act as dams and restrict the outflow. A slow moving storm could create a fearful situation.

Appendix Two - Notes on Seawalls and Sea Dikes

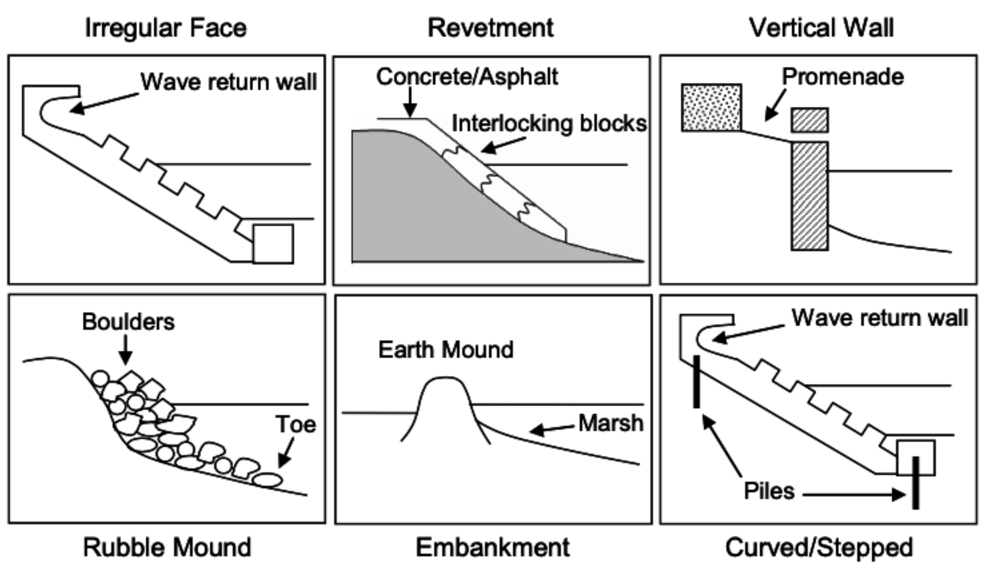
All Extracts are from *Technologies for Climate Change Adaptation -Coastal Erosion and Flooding*. UNEP RISO Centre, Zhu, (ed), Linham and Nicholls 2010

Seawalls

Seawalls are hard engineered structures with a primary function to prevent further erosion of the shoreline. They are built parallel to the shore and aim to hold or prevent sliding of the soil, while providing protection from wave action (UNFCCC, 1999). Although their primary function is erosion reduction, they have a secondary function as coastal flood defences. p.37

The physical form of these structures is highly variable; seawalls can be vertical or sloping and constructed from a wide variety of materials. They may also be referred to as revetments. p.37

Seawalls range in type and may include steel sheetpile walls, monolithic concrete barriers, rubble mound structures, brick or block walls or gabions[5] (Kamphuis, 2000). Some typical seawall designs are shown in (the) Figure (below). Seawalls are typically, heavily engineered, inflexible structures and are generally expensive to construct. p.38



Hard, concrete structures are typically replaced by revetments and embankment-type structures in more sheltered environments

The shape of the seaward face is important in the deflection of incoming wave energy; smooth surfaces reflect wave energy while irregular surfaces scatter the direction of wave reflection .... Waves are likely to impact the structure with high forces and are also likely to move sand off- and along-shore, away from the structure ... Since seawalls are often built as a last resort, most are continually under severe wave stress. p.38

Seawalls usually have a deep foundation for stability. Also, to overcome the earth pressure on the landward side of the structure, ‘deadmen’ or earth anchors can be buried upland and connected to the wall by rods. p.38

The main advantage of a seawall is that it provides a high degree of protection against coastal flooding and erosion. A well maintained and appropriately designed seawall will also fix the boundary between the sea and land to ensure no further erosion will occur – this is beneficial if the shoreline is home to important infrastructure or other buildings of importance. p.39

As well as fixing the boundary between land and sea, seawalls also provide coastal flood protection against extreme water levels. Provided they are appropriately designed to withstand the additional forces, seawalls will provide protection against water levels up to the seawall design height. p.39

Seawalls also have a much lower space requirement than other coastal defences such as dikes (Section 4.1.4), especially if vertical seawall designs are selected. ... The increased security provided by seawall construction also maintains hinterland values and may promote investment and development of the area. ... When considering adaptation to climate change, another advantage of seawalls is that it is possible to progressively upgrade these structures by increasing the structure height in response to SLR. p.39

Seawalls are subjected to significant loadings, as a result of wave impact. These loadings increase with water depth in front of the structure because this enables larger waves close to the shoreline. Seawalls are designed to dissipate or reflect incoming wave energy and as such, must be designed to remain stable under extreme wave loadings. The effects of SLR, increased wave heights and increased storminess caused by climate change must all be taken into account. p.39

The problems of wave reflection and scour can be reduced to some degree by incorporating slopes and irregular surfaces into the structure design. Slopes encourage wave breaking and therefore energy dissipation while irregular surfaces scatter the direction of wave reflection p.40

Because seawalls are immovable defences, they can also interfere with natural processes such as habitat migration which is naturally induced by sea level change. Seawalls obstruct the natural inland migration of coastal systems in response to SLR, therefore causing coastal squeeze. ... This process causes a reduction in the area of intertidal habitats such as sandy beaches and saltmarshes because these environments are trapped between a rising sea level and unmoving, hard defences. p.41

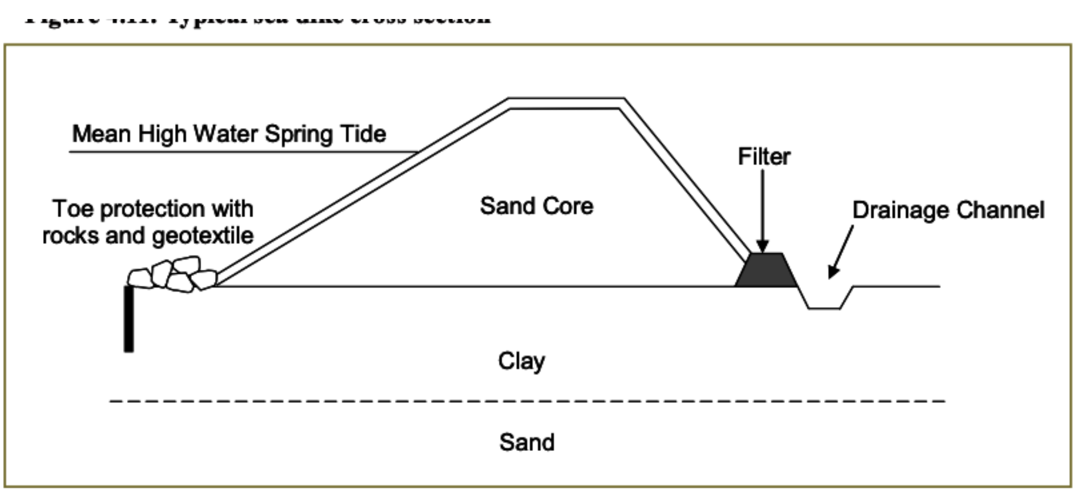
Some of the best unit cost information is given by the English Environment Agency (2007), for unit costs relevant to the UK. This source gives an average construction cost for seawalls of US$2.65 million (at 2009 price levels for 1km of dike). This cost includes direct construction costs, direct overheads, costs of associated construction works, minor associated work, temporary works, compensation events and delay costs.

Sea Dikes

The primary function of sea dikes is to protect low-lying, coastal areas from inundation by the sea under extreme conditions (Pilarczyk, 1998a). Dikes are not intended to preserve beaches which may occur in front of the structure or any adjoining, unprotected beaches.

These structures have a high volume which helps to resist water pressure, sloping sides to reduce wave loadings and crest heights sufficient to prevent overtopping by flood waters. They may also be referred to as dykes, embankments, levees, floodbanks and stopbanks. p.47

Dikes are widely used to protect low-lying areas against inundation. As such, they have been widely applied in countries such as Vietnam, Bangladesh, Thailand, the Netherlands and the USA. The Figure shows a typical dike cross-section. It is a predominantly earth structure consisting of a sand core, a watertight outer protection layer, toe protection and a drainage channel. These structures are designed to resist wave action and prevent or minimise overtopping. p.47



Dikes have been extensively utilised as flood defences in the Netherlands over the past several hundred years. As such, the Dutch have extensive experience in their design. As a result, many countries apply Dutch design practice in dike construction. p.47

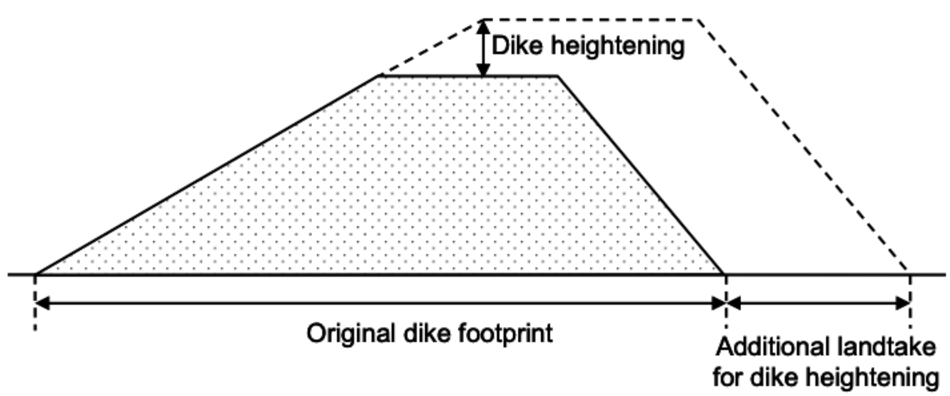
Dikes provide a high degree of protection against flooding in low-lying coastal areas. They often form the cheapest hard defence when the value of coastal land is low p.47

The sloped seaward edge of a dike leads to greater wave energy dissipation and reduced wave loadings on the structure compared to vertical structures. This is achieved because the seaward slope forces waves to break as the water becomes shallower. Wave breaking causes energy dissipation and is beneficial because the process causes waves to lose a significant portion of their energy. Because the waves have lost energy, they are less capable of causing negative effects such as erosion of the shoreline. By reducing wave loadings, the probability of catastrophic failure or damage during extreme events is also reduced. p.47

Dikes require high volumes in order to resist high water pressures on their seaward faces (Barends, 2003). As a result, their construction uses large volumes of building materials, including sand, clay and asphalt, which can be costly. p.49

Another disadvantage of applying dikes is that the shallow slopes applied to facilitate wave energy dissipation cause dikes to have large footprints; i.e. their construction requires significant areas of land. This can increase dike construction costs where coastal land is valuable. p. 49

Raising dikes in response to SLR can cause the area of land required for dike construction to grow if slope gradients are maintained (see Figure below). The area of land take can be problematic as coastal areas often have high associated land values. Further, construction of dikes prevents use of the coastal area for other development, hence, leading to competition for land. Extending dikes seaward may overcome this problem, but it raises costs significantly. p. 49



Schematic illustration of the large land areas required for dike construction and the additional land take required upon dike heightening

Maintenance costs are an ongoing requirement for sea dikes, to ensure the structure continues to provide design levels of protection. p. 50

Appendix Three - Notes on Insurance Issues

The following is taken from the website of OTC Insurance Brokers (https://www.otcinsurance.ca/olf)

- **What is Overland Flooding?**
  - Overland flooding is defined as floodwaters that flow from an outside source or body of water onto dry land, causing water damage. The two most likely causes of overland flooding include snowmelt and rainstorms. Overland flood insurance covers flooding from surface water accumulation as well as from bodies of water, such as lakes, rivers or streams.
  - **Understanding what is and what is not considered flooding from an insurance perspective is critical** to ensuring you secure the appropriate policies to protect against water damage.
- **Overland Flood Endorsements**
  - Standard home, condo (strata) and tenant policies often exclude overland flood damage coverage. However, because extreme weather events are becoming more frequent, many insurers are now providing policyholders with the option to purchase add-ons (endorsements).
  - In general, overland flood endorsements provide a level of flood insurance that was previously unavailable. Specifically, the overland flood endorsement can protect against damage resulting from melting snow, excess rain and overflowing riverbeds.
  - **With overland flood insurance, it is important to understand what is and what is not covered.** Overland flood insurance covers damage from freshwater sources. This means that **any claims related to coastal flooding, tsunamis and other saltwater sources are excluded**. Dam breaks are also specifically designated as uncovered occurrences.
  - Overland water endorsements are available to most property owners across Canada. However, a small number of dwellings may not qualify if the risk of flooding is too high in their area. The best way to determine your coverage eligibility is to contact OTC Insurance today and learn all about your options

- ***The Co-operators becomes first Canadian insurer to offer storm surge flood coverage in British Columbia and Nova Scotia***
  - GUELPH, ON, May 7, 2018 /CNW/ - Today, The Co-operators announced the addition of **storm surge coverage to its Comprehensive Water product**,

becoming the **first and only** insurer in Canada to offer it. Waves caused by storms and hurricanes, known as storm surges, present a significant flood risk, especially in coastal regions where extreme weather patterns have noticeably intensified with the changing climate. Until now, storm surges have been uninsurable.

  - "Overland flooding has been identified as the most pervasive and costliest cause of damage to Canadian homes, yet most are inadequately protected against this growing risk. As a co-operative, it's our priority to protect the financial security of Canadians. This is why we first introduced overland flood insurance in Canada," said Rob Wesseling, president and CEO of The Co-operators. "Now**, with the inclusion of storm surge coverage, we're adding another layer of protection** and providing peace of mind for those who need it most."
  - Comprehensive Water is the only overland flood insurance in Canada available to those at the highest risk of flooding. Homeowners in British Columbia and Nova Scotia can now add this coverage to protect against the most common causes of water damage: overflowing lakes, rivers and creeks, sewer or septic backup, heavy rain and storm surge.
  - "The insurance industry has a critical role to play in building resilience in Canadian communities and addressing major risks like flooding," said Paul Kovacs, executive director, Institute for Catastrophic Loss Reduction. "It's encouraging to see companies like The Co-operators providing risk-appropriate options for coverage, while taking an active role in educating Canadians on their flood risk."

- **Liberal leader Justin Trudeau** announc(ed) on Wednesday that a re-elected Liberal government would create a national flood insurance program, and design an EI benefit specifically for those who miss work due to natural disasters. (I Politics Published on Sep 25, 2019 2:30pm)
- Today, the Minister of Public Safety and Emergency Preparedness, the Honourable Bill Blair, and the Minister of Families, Children and Social Development, the Honourable Ahmed Hussen, announced the **creation of an interdisciplinary Task Force on Flood Insurance and Relocation.** As a first step in creating a National High Risk **Residential** Flood Insurance Program, the Task Force will look at options to protect homeowners who are at high risk of flooding and don’t have adequate insurance protection, and examine the viability of a low-cost national flood insurance program. November 23, 2020