Prince Edward Island Coastal Hazards –

Executive Summary

August 2021

Report prepared by:
Province of PEI, Department of Environment, Energy and Climate Action

Based on Davies, M.H. and N.J. MacDonald. (2021) Prince Edward Island Coastal Hazards Report, prepared for the Government of Prince Edward Island. Ottawa, Coldwater Consulting Ltd.

This document summarizes the report entitled Prince Edward Island Coastal Hazards (Davies and MacDonald, 2021) The purpose of the study was to develop province-wide coastal hazard maps for PEI's coast. The study was commissioned by the Government of Prince Edward Island, Department of Environment, Energy and Climate Action, and funded by Public Safety Canada's National Disaster Mitigation Program (NDMP).

Background

Coastal flooding is expected to become more frequent and severe in PEI due to a combination of ongoing post-glacial land subsidence, global sea level rise caused by climate change, and a changing coastal climate with less ice cover and more intense storms. Coastal water levels result from a combination of mean water level, relative sea level rise, tides, storm surge (atmospheric effects), setup and wave action, the latter of which are heavily influenced by shoreline geometry.

Coastal flood hazards vary both spatially and temporally. The tidal range around PEI (high tide to low tide) can vary by almost a factor of three, from as small as 1.0 m on the north shore near Tracadie, to almost 3 m near Charlottetown.

Storm surges can cause short-term increases in sea levels by up to 1.5 m. For PEI, storm surge patterns tend to increase from north to south with the largest surge amplitudes being observed along the south shore. The variation in surge magnitude is much smaller than the tidal variation. Surges on the north shore are typically 90-95% of that on the south shore.

The focus of the *Prince Edward Island Coastal Hazards* (Davies and MacDonald, 2021) study was coastal floodplain mapping to allow for the evaluation of infrastructure vulnerabilities. The study built upon a strong foundation of data that had been previously developed in PEI for coastal mapping and hazard identification. The new hazard maps support the identification of the spatial extent and severity of coastal flooding under both present-day conditions and future conditions based on projected climate change scenarios.

Historically, a fixed standards-based approach has been used for addressing natural hazards in Canada, where floodplain elevations are based on one specific design flood (typically for the 1% or 0.5% Annual Exceedance Probability, AEP). This approach however does not address the full range of potential flood events, where high frequency/low impact flooding may lead to cumulative impacts, or where rare but severe floods may lead to worse impacts than those experienced under the design flood. Rather than focusing on a single event, the new study moves away from the fixed standards-based approach towards a risk-based approach (Sayers, et al., 2013) by providing a range of coastal flood scenarios.

Methodology

Coastal flood hazard mapping required the evaluation of all the contributing factors to flood conditions for PEI, namely:

- mean sea level and relative sea level rise,
- tides,
- storm water levels, and
- waves.

Mean sea levels and relative sea level rise

Regression analysis shows that the rate of sea level rise in Charlottetown has been steady at 0.321 m/century (32.1 cm/decade). With climate change, sea levels are expected to increase significantly in the future, increasing the potential for coastal flood hazards. Natural Resources Canada (James, H. et al., 2014) presents detailed predictions for sea level rise at specific locations around Canada and adjacent US states. These projections are based on the Representative Concentration Pathway (RCP) scenarios of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5). They include contributions from the thermal expansion of the ocean, glacial melting and discharge, anthropogenic influences and local crustal movements (e.g., crustal subsidence and post-glacial isostatic rebound). The RCP8.5 scenario was adopted for future sea level scenarios in the Davies and MacDonald (2021) study.

Tides

Tides cause variations in water levels on timescales varying from hours to years. While the dominant tidal pattern around PEI is a semi-diurnal tide (6.2 hours from high tide to low tide), tidal patterns vary in response to the motions of the sun, the moon and other planets. Tidal ranges can vary by almost a factor of three around the Island due to the way the tides propagate in the Gulf of St. Lawrence and then wrap around the Island to meet (doubling up) in Hillsborough Bay.

Storm water levels

Storm surge is the increase in water levels above tidal level caused by the combined effects of barometric pressure drops and winds. The most extreme storm surge on record for the Island is the Charlottetown storm of January 21st, 2000 when a 1.3 m storm surge caused peak sea levels to rise 2.45 m above mean sea level (MSL). Spatial variations in surge heights during storms are much more variable than these overall expected magnitudes. Depending on storm track and duration, storm surge can be localized to areas as small as a few tens of kilometres. In the Northumberland Strait, the incoming storm surge interacts with tidal currents leading to a blockage phenomenon resulting in storm surges in the Northumberland Strait that are almost twice as likely to occur at low tide than at high tide.

Waves

Along the north shore, storms can generate waves over 6 m high while waves of 1 to 3 m are more common in the waters of Northumberland Strait on the south shore. Wave setup is the increase in mean water level at the shore driven by wave breaking. Along PEI's north shore, significant wave heights of 5m can result in wave setup of 0.15 to 0.5m. Wave action during storms can contribute to coastal flooding through wave overwash in which low-lying plains are inundated by waves, wave setup and infra-gravity waves, and by wave runup on slopes. Wave runup varies greatly with slope – a broad sandy beach will dissipate wave energy resulting in wave runup that is typically 4-7% of the incident wave height. In contrast, in relatively deep-water wave runup increases with slope steepness and can vary between 1.5 and 3 times the incident wave height. The SWAN model was used to address nearshore wave conditions as well as the increases in coastal water levels due to wave breaking (wave set-up) and the inundation of low-lying coastal lands.

Hazard Mapping

The delineation of the vertical elevations and horizontal setbacks that constitute the coastal flood hazard required the following steps:

1. Establish local mean sea level over the planning timeframe (present-day to 2100).
2. Define statistics of extreme water levels at the site (addressing the joint probabilities of tides and storm surges).
3. Determine nearshore wave conditions (including wind- and wave-driven setup).
4. Wave modelling to include definition of the wave envelope and wave runup effects.
5. Define inundation and wave impact zones

In order to capture the spatial variations in flood levels and allow presentation of the data in coherent blocks with consistent results, the flood level results were mapped based on watersheds. The mapping was simplified on a watershed-by-watershed basis by mapping the results of the inundation maps onto each of the 286 watersheds delineated by the Province. Each of these watersheds terminates at the sea or major bay/estuary.

To allow hydraulic connection through embankments in the flood maps, the provincial hydrology network (containing all watercourses) and the provincial road network were analyzed, and culverts and bridges were assumed to exist at each intersection of the road and stream networks.

The flood plain mapping undertaken in this study uses the CGG2013 vertical datum except where noted otherwise.

Results

In keeping with conventional practice, hazard likelihood was expressed by the Annual Exceedance Probability (AEP). AEP refers to the probability of a coastal flood hazard being met or exceeded in any given year, represented as a percentage. The encounter probability (EP), or risk of exceedance of an event is a different, but related measure of extreme events. While an event might have a 1:100 (1%) chance of being exceeded in any given year, the total chance of exceeding the EP increases over time. For example, there is a 22.2% chance of water reaching the 1% AEP flood level within a 25-year planning horizon (*see* Figure 1). A 100-yr planning horizon raises the risk to 63%, i.e. the odds are higher than 50:50 that the 1% AEP event will occur within 100 years.

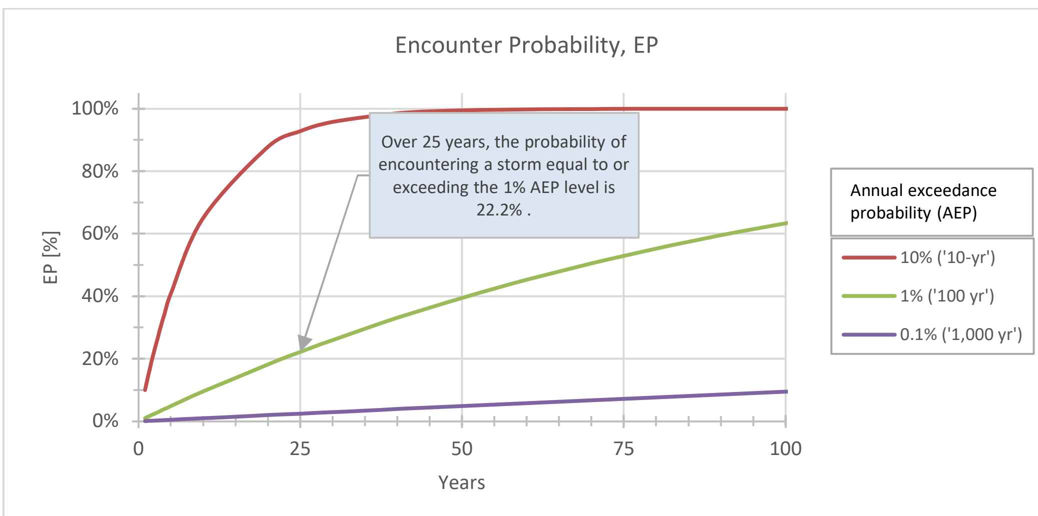

Figure 1. Encounter probability (EP), the risk of exceedance of a storm event over time (Davies and MacDonald, 2021)

As a step toward developing a more flexible, risk-based approach to coastal flood hazards, the work presented Designated Flood Elevations (DFEs), water levels that reflect relative sea level rise, variability, tides and wave setup, for a range of AEPs for present-day conditions (2020), 2050 and 2100.

Figure 2 provides an example of a "Site Output" data sheet which summarizes the flood conditions at various risk levels and times periods for a selected watershed, in this case the Charlottetown Watershed (SiteID: WS_52). Similar data sheets were made available for each of the 286 watersheds identified by the province.

Coastal Flooding Summary
Flood elevations in metres relative to geodetic datum (CGVD2013)

Climate scenario RCP8.5 using sea levels of James et al (2014)
Note that surveying and mapping pre-2014 tends to use either CGVD28 or Chart Datum for elevations.

SiteID	WS_52	
Watershed	Charlottetown	
CGVD28	*0.335*	*Add this number to elevations to convert from CGVD2013 to CGVD28*
CD	*2.008*	*Add this number to elevations to convert from CGVD2013 to CD*

Sea levels: Mean Sea Level (MSL) and astronomic tides (Mean Higher High Water, MHHW)

Year	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
MSL	-0.23	-0.19	-0.13	-0.07	0.02	0.11	0.17	0.28	0.40	0.46
LAT	-2.04	-2.00	-1.94	-1.88	-1.79	-1.70	-1.64	-1.53	-1.41	-1.35
MLLW	-1.32	-1.28	-1.22	-1.16	-1.07	-0.98	-0.92	-0.81	-0.69	-0.63
MHHW	0.59	0.63	0.69	0.75	0.84	0.93	0.99	1.10	1.22	1.28
HAT	1.03	1.07	1.13	1.19	1.28	1.37	1.43	1.54	1.66	1.72

Designated Flood Elevations (DFE) - These 'storm tide' water levels reflect relative sea level rise, variability, storm surge, tides and wave setup.

Annual exceedance probability, AEP	Return Period, T_r (years)	Year 2020	2050	2100
100%	1.0	1.30	1.53	2.11
10.0%	10	1.76	1.99	2.57
1.0%	100	2.24	2.47	3.05
0.1%	1,000	2.71	2.94	3.52
Extreme (0.1% AEP + 0.65m RSLR due to West Antarctic Ice)				4.17

Encounter Probability, EP_{years}. This is the probablity of encountering a storm of at least this severity within a give time span

AEP	EP_1	EP_{10}	EP_{25}	EP_{100}
100%	100%	100%	100%	100%
10.0%	10%	65.1%	92.8%	100%
1.0%	1%	9.6%	22.2%	63.4%
0.1%	0.1%	1.0%	2.5%	9.5%

e.g. Over a 25 yr time span, there is a 22% chance of encountering the 1% AEP

Figure 2. Coastal Flooding Summary for the Charlottetown Watershed (Davies and MacDonald, 2021)

In addition to the Site Output data sheets, GIS map flood inundation layers were produced for the DFE for 2020 and 2100 with a 1% AEP for all watersheds. The flood layers allow for visual evaluation of sites and infrastructure based on both the range of hazards possible and the potential consequences of a flood event.

Works Cited

Davies, M.H. and N.J. MacDonald. (2021) Prince Edward Island Coastal Hazards. Report prepared for the Government of Prince Edward Island. Ottawa, Coldwater Consulting Ltd.

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