CBCL LIMITED
Consulting Engineers

April 4th, 2017

Bruce Mans
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Dear Mr. Mans,

RE: Coastal Risk Assessment

The shores of Cumberland County are subject to the coastal conditions of very different regions: the Northumberland Strait and the Bay of Fundy, itself including Chignecto Bay and the Minas Basin. CBCL conducted a high level assessment of the vulnerability of these shores to storm surges, wave action and rising sea level. The assessment was completed as part of the new Municipal Planning Strategy which includes considerations for climate change mitigation and adaptation. CBCL assessment consisted of the following items:

- Review of relevant studies and reports, with emphasis on those published since 2011,
- Calculation of extreme water levels,
- Planning Recommendations to address coastal risk.

1 Existing Data Review

The reports that were reviewed vary widely and include one or several components ranging from field work, modelling, GIS analyses, policy reviews, best management practices, economic assessments and compilations of background historical or scientific information. Typically, these publications conclude with recommendations for both policy (e.g., Stantec 2011), as well as engineering design criteria and guidelines based on forecasted climate change stressors such as sea level rise (CBCL, Richards and Daigle 2011, 2014, ACASA 2015). A matrix has been constructed as a first order comparison of the publications (Appendix A). The matrix is not meant to be a comprehensive detailing of the contents of each study, but rather an orientation tool informing the reader where to obtain further information.

Dykes and dykelands are an important component of coastal risk along Fundy shores in the Municipality of Cumberland, as these are the first line of defense for inland flooding. The reviewed literature recognizes such coastal vulnerability and therefore places particular emphasis on dyke systems (van Proosdij and Page 2012, Webster et al. 2012a) in Cumberland County. Two studies focused exclusively on dykes: van Proosdij and Page (2012) and Webster et al. (2012a). The van Proosdij and Page (2012) publication provides an overview of coastal processes relevant to dykes and shoreline erosion, as well as a comprehensive review of international best practices for climate change adaptation in dykelands. Critical elevations of different dyke sections are obtained through both a physical assessment in the field and GIS mapping. Wester et al. (2012a) also use ground-truthed LIDAR information to identify critically low segments of dykes. Stillwater maps of flooding extent are provided for different elevations of flooding and used in combination with benchmark storms to illustrate flooding risk. Both studies identify vulnerable geographic areas, with van Proosdij and Page (2012) focusing on shore zones and marsh bodies, and Webster et al. (2012a) placing particular emphasis on transportation infrastructure corridors. Due to their broader regional importance, dykes are also addressed in several of the other studies reviewed (e.g., CBCL 2013, ACASA 2015, Withey et al. 2016).

Reports featuring computational modelling efforts are CBCL's report on the Amherst aboiteau (2013) and two Webster et al. publications (2012b, 2012c). The objectives of the CBCL study were to determine the optimum location and design criteria for a new aboiteau, as well as the configuration and design for channels delivering runoff to the aboiteau. In addition to the hydrologic and hydraulic models, a hydrodynamic model was built to study the impacts of the aboiteau on sediment transport. Webster et al. (2012b) was also interested in the impact a simulated aboiteau has on regional flooding. In the study, they used GIS tools, a rainfall-runoff model (not a 2D floodplain model), and a 2D hydrodynamic tide model to investigate flooding extents under a variety of scenarios. Webster et al. (2012c) shows these results in a presentation slide format, alongside results from other studies in Nova Scotia. Both studies contributed new data sets obtained in the study areas: the Webster et al. study included the processing of newly collected LIDAR data, and the CBCL study included field observations of suspended sediment concentrations.

In contrast to studies focused on the modelling of physical processes, other reports advice on economics and planning: Withey et al. (2016) provides the most significant economic analysis, and Stantec (2011) provides the most comprehensive review and recommendations for planning purposes. The Withey et al. (2016) publication is a cost-benefit analyses of climate change adaptation options for Atlantic Canada. This includes impacts and costs associated with increased flooding and erosion as well as costs of available adaptation options. Several of the other reviewed studies perform or cite economic assessments (CBCL 2009, van Proosdij and Page 2012, Wester 2012a, ACASA 2015, Savard). The purpose of the Stantec (2011) report is to provide recommendations for Municipal Planning Strategy amendments intended to preserve, restore, and enhance the environment (including the coastal environment). Existing policies are reviewed, and short- and long- term direction, policy recommendations, and engagement recommendations are provided. Several other studies address policies, best management practices, or planning approaches (Richards and Daigle 2011, van Proosdij and Page 2012, ACASA 2015, Savard et al. 2016).

CBCL (2009) provides an overview of the conditions of coastal areas and resources specific to Nova Scotia, including existing and projected concerns. Savard et al. 2016 gives the current state of planning or implementation for climate change adaptation in communities across the region. Scientific background (e.g., factors which cause sea-level rise, global climate models, estimation of extreme return periods) can also be found in CBCL (2009), Richards and Daigle (2011), van Proosdij and Page (2012), Webster et al. (2012a), CBCL (2013), Daigle (2014), and ACASA (2015).

2 Extreme Water Levels

Water levels are the main cause influencing coastal flooding hazards. Still water levels are determined by physical process that include tides, storm surge and the effect of sea level rise. Wave run-up, i.e. the vertical distance a wave travels up the shoreline above the still water level, occur on top of the still water level in areas exposed to wave action and can cause additional damage to coastal structures.

Extreme Water Levels (EWLs) occur when several physical drivers interact and develop simultaneously to create high water elevation at a specific location. In this study, EWLs will be described by:

$$EWLs = storm\ surge + high\ tide + sea\ level\ rise$$

2.1 Tides:

Error! Reference source not found. illustrates the variation in extreme tidal range along the Cumberland County shorelines. The site-specific variation in tide highlights the importance of spatially reporting and studying tidal ranges across the area of interest. When determining extreme water levels, the tidal range can play a significant role in the impact storm surge or wave run-up have on a local site.

Bay of Fundy Tide - Historic water levels are monitored by the Department of Fisheries and Oceans Canada (DFO) in the Bay of Fundy at Saint John (station #65). Considering both the location of the Saint John station in relation to the Area-of-Interest (AOI), and the complex tidal system in the Bay of Fundy, the raw data from station #65 cannot be easily applied to this study. Instead, three other data sources are considered and combined to construct a high-level interpretation of the extreme tidal levels in the AOI. These are:

1. DFO's WebTide numerical model;
2. Spring tidal range as defined by Cousineau J., Nistor I., Cornett A. (2012);
3. Higher High Water Large Tide (HHWLT) as summarized by Richards W., Daigle R., (2011) based on information from the Department of Fisheries and Oceans (DFO).

The output from the above sources are combined in **Error! Reference source not found.**. The spring tidal range is the most extreme tidal range and occurs around a full or new moon, when the gravitational forces of both the Sun and Moon are in phase. The spring tidal range gets progressively larger as one moves up the Bay of Fundy towards Joggins and Burncoat Head.

Northumberland Strait Tide - In contrast to the Bay of Fundy, the tidal ranges along the Northumberland Strait are significantly lower (e.g. Pictou - **Error! Reference source not found.**). Tidal ranges have been verified using the DFO's WebTide numerical model.

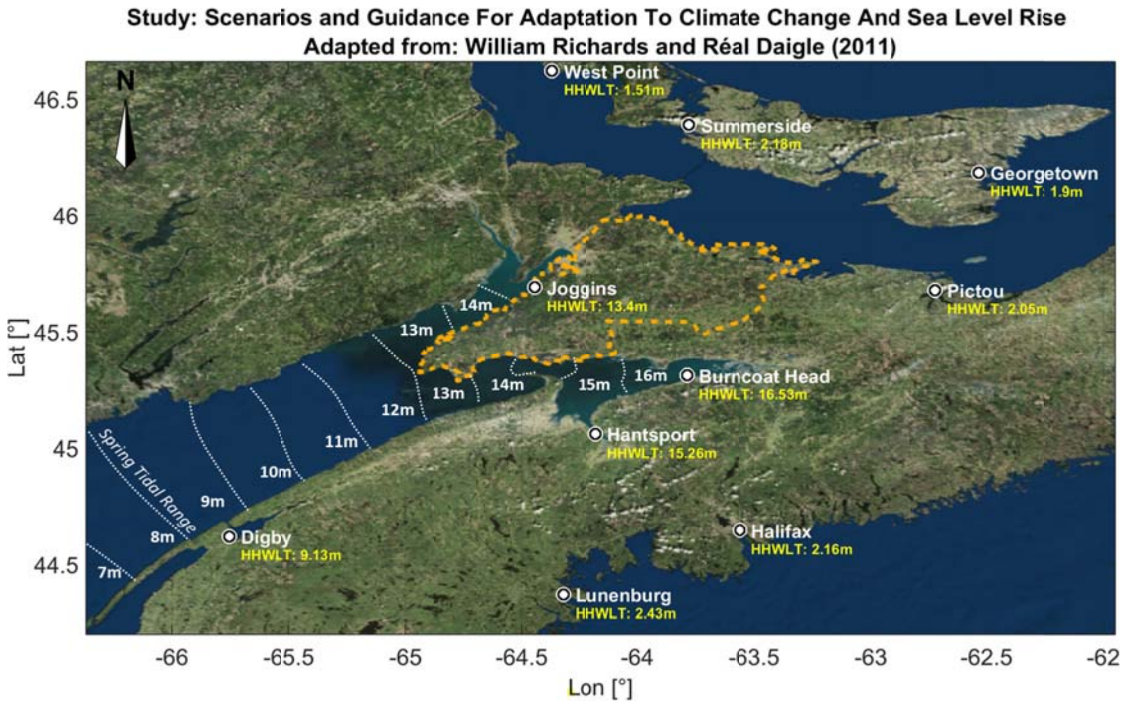

Figure 1: Water levels (Bay of Fundy)

- *HHWLT = Higher High Water Large Tide, i.e. the average of the 19 annual maxima over a 19-year full tidal cycle*
- *Vertical reference level is Chart Datum, where the zero is typically close to the lowest tide level. Therefore, the HHWLT elevation is a good indication of the total tidal range.*

2.2 Sea Level Rise

Projections of sea level rise in Nova Scotia and PEI are reported by Richards W. & Daigle R., (2011). This 2011 report was commissioned specifically for assisting municipalities in planning for sea level rise. Since 2011, scientists have updated sea level rise estimates. Notably, DFO (Zhai et al 2014) has issued sea level rise projections for all Canadian fishing harbours based on the 2013 Intergovernmental Panel on Climate Change 5th Assessment Report (IPCC AR5, 2013). The updated values are in the same order of magnitude as those reported in Richards & Daigle for the study area, i.e. approximately 1 m SLR by year 2100 for the high emission scenarios. Therefore, CBCL is still using the 2011 reference for consistency in terms of geographical sites and inclusion of tide and storm surge in a single reference. Estimates of SLR are considered for Hantsport, Joggins and Pictou as these are the three closest sites to the AOI. The findings from Richards W. & Daigle R., (2011) are summarized in Table 1 and consider several climate scenarios and models to derive the mean SLR and associated standard deviations. Factors considered to derive SLR include:

a) Thermal expansion of the oceans;
b) Melting of nonpolar glaciers and;
c) Changes in the volume of the ice sheets of West Antarctica and Greenland.

Sea levels along most coasts of Atlantic Canada are rising due to the fact that these coastlines are very slowly subsiding (up to a few tenths of meters per century). This factor relates to a post-glacial rebound of the earth’s crust (Richards W. & Daigle R., 2011).

Table 1: Estimated Total Sea Level Rise [m]

Location	2025		2055		2100	
Hantsport	0.16	+/- 0.03	0.86	+/- 0.36	1.10	+/- 0.48
Joggins	0.15	+/- 0.03	0.82	+/- 0.36	1.05	+/- 0.48
Pictou	0.15	+/- 0.03	0.82	+/- 0.15	1.05	+/- 0.48

Adapted from: Richards W. & Daigle R., (2011)

Most recently, a 2017 NOAA publication (Sweet W. et al, 2017) suggests that previous lobal Mean Sea Level (GMSL) predictions are too modest. The study incorporates the most up-to-date scientific literature on scientifically supported upper-end GMSL projections, including recent studies of the potential for rapid ice melt in Greenland and Antarctica. The results present a 2100 GMSL forecast range discretized into six GMSL rise scenarios: a Low (0.3m), Intermediate-Low (0.5m), Intermediate (1.0m), Intermediate-High (1.5m), High (2.0m) and Extreme (2.5m). A key finding was that along regions of the Northeast Atlantic (Virginia coast and northward), regional SLR is projected to be greater than the updated global average for almost all future scenarios (e.g. by 0.3 to 0.5 m under the Intermediate scenario by year 2100). Finally, studies indicate that the human carbon footprint to date has already committed Earth to a long-term GMSL rise of ~1.7 m (Clarke et al, 2015).

Given these findings, the values presented in this assessment (based on Richards and Daigle 2011) can be considered *Intermediate* projections, with *High* and *Extreme* SLR scenarios to range 1.0 to 1.5 m higher than previously anticipated. In conclusion, a SLR of at least 1.0 m is likely to occur within the coming century, even if the timeline remains uncertain. As a result, maintenance intervals for coastal infrastructure are expected to shorten, and flooding probabilities will significantly increase.

2.3 Storm Surge

Storm surge can be defined at the coast as the difference between the observed water level and the predicted astronomical tide. Large positive storm surges at times of high tide are events that lead to coastal flooding, whereas when they coincide with low tides, flooding problems are averted. For added safety in the context of planning purposes, it is assumed that the extreme storm surge coincides with the HHWLT. This is a reasonable assumption for areas with moderate tidal range such and relatively high storm surge, such as the Northumberland Strait. However, it is conservative along Fundy shorelines, because the 100-year storm surge residual coinciding with a HHWLT would represent an event of return period greater than 100 years.

Elevated sea levels enhance wave attack and coastal erosion. The magnitude of storm surges depends on the nature of the meteorological event responsible for the reduced atmospheric pressure and the strength of the winds associated with a particular event (Richards W. & Daigle R., 2011). As with the SLR predictions, storm surge residuals are considered for Hantsport, Joggins and Pictou (Table 2).

Table 2: Estimate Storm Surge (Residual) [m]

Return Period	Hantsport		Joggins		Pictou	
10-YR	0.85	+/- 0.20	0.85	+/- 0.20	1.12	+/- 0.10
25-YR	0.96	+/- 0.20	0.96	+/- 0.20	1.27	+/- 0.10
50-YR	1.04	+/- 0.20	1.04	+/- 0.20	1.38	+/- 0.10
100-YR	1.13	+/- 0.20	1.13	+/- 0.20	1.49	+/- 0.10

Ad*apted from: Richards W. & Daigle R., (2011)*

2.4 Total Extreme Water Levels:

Under current climate conditions, the sum of the high tides shown in Figure 2, and the storm surge estimates shown in table 2, provides estimates of the total extreme water levels for the regions of Northumberland, Chignecto Bay and Minas Basin (Table 3). Estimates of extreme water levels under climatic change conditions are presented in Table 4

Table 3: Estimated Extreme Water Level under Current Climatic Conditions

LOCATION	Return Period	Water Levels [m]			Total Water Levels (CD) [m]	Total Water Levels (GDVD28) [m]
		HHWLT [m]	Storm Surge [m]	+/-		
Northumberland Coast	1	2	0.9	0.1	2.9	1.6
	10		1.1	0.1	3.1	1.8
	25		1.3	0.1	3.3	2.0
	50		1.4	0.1	3.4	2.1
	100		1.5	0.1	3.5	2.2
Chignecto Bay & Bay of Fundy	1	13	0.5	0.2	13.5	7.7
	10		0.9	0.2	13.9	8.1
	25		0.9	0.2	13.9	8.1
	50		1.0	0.2	14.0	8.2
	100		1.1	0.2	14.1	8.3
Minas Basin & Bay of Fundy	1	13	0.5	0.2	13.5	6.0
	10		0.9	0.2	13.9	6.4
	25		0.9	0.2	13.9	6.4
	50		1.0	0.2	14.0	6.5
	100		1.1	0.2	14.1	6.6

*Table 4: Estimated Extreme Water Level under **Intermediate** Projections of Sea Level Rise*

LOCATION	Return Period	Total Water Level (GDVD28) [m]		
		2025	2055	2100
Northumberland Coast	1	1.71	2.4	2.6
	10	1.91	2.6	2.8
	25	2.11	2.8	3.0
	50	2.21	2.9	3.1
	100	2.31	3.0	3.2
Chignecto Bay (Bay of Fundy)	1	7.85	8.5	8.8
	10	8.25	8.9	9.2
	25	8.25	8.9	9.2
	50	8.35	9.0	9.3
	100	8.45	9.1	9.4
Minas Basin (Bay of Fundy)	1	6.16	6.9	7.1
	10	6.56	7.3	7.5
	25	6.56	7.3	7.5
	50	6.66	7.4	7.6
	100	6.76	7.5	7.7

2.5 Waves and Wave Runup

When ocean waves approach a coast, most of the wave energy is dissipated across the surf zone by wave breaking. However, a portion of that energy is converted to potential energy in the form of run-up on the foreshore of areas such as a beach. Wave run-up is important to coastal planners and coastal engineers because these motions deliver much of the energy responsible for dune and beach erosion (Sotckdon, et. al 2006), and can result in overtopping and additional localized flooding. During events with extreme water levels, less energy may be dissipated across the surf zone, and run-up values may be greater. This is especially the case for armoured shorelines or dikes where the toe of the structure may be submerged during a significant event. Such configuration results in considerable wave energy reaching the structure's slope, therefore creating significant run-up and heightening the chances of overtopping.

The typical metric for wave run-up height is $R_{u2\%}$. This is the wave run-up level, measured vertically from the still water line, which is exceeded by 2% of the number of incident waves. The number of waves exceeding this level is hereby related to the number of incoming waves and not to the number that runs up the slope (EurOtop, 2016). Run-up is relevant for beaches, smooth slopes and embankments and for rough slopes armoured with rock or concrete armour. When the crest elevation of coastal defense structures is below the run-up elevation, overtopping and flow discharge occurs. The larger the discharge from overtopping, the greater the potential for damage. Section 3 provides further insight on overtopping damage and how it is related to structure type and adjacent land use.

Calculating run-up is best performed on a case-by-case basis for a specific site as considerations such as slope, wave height, wave period and type of exposed structure change from site to site. Therefore, the wave runup values presented in the following tables are based on general assumptions about structure types, slopes and predominant wave climate along the Cumberland County shorelines. A detailed description of the methodology used to compute run-up values can be found in Appendix B

The presented run-up values aim to provide an estimate of suggested infrastructure crest elevations subject to nearshore wave action. The values are an attempt to guide planners whom are assessing areas exposed to waves during surge events. This values do not account for nearshore transformation and may have resulted in highly conservative values that would be representative only of areas directly exposed to wave action.

Site specific and detailed studies are recommended in order to determine cost-effective solutions and planning strategies. Depending on the specific characteristic of each site, these considerations can be translated in crest elevation for shore protection structures or additional horizontal setback in shore areas with mild slopes.

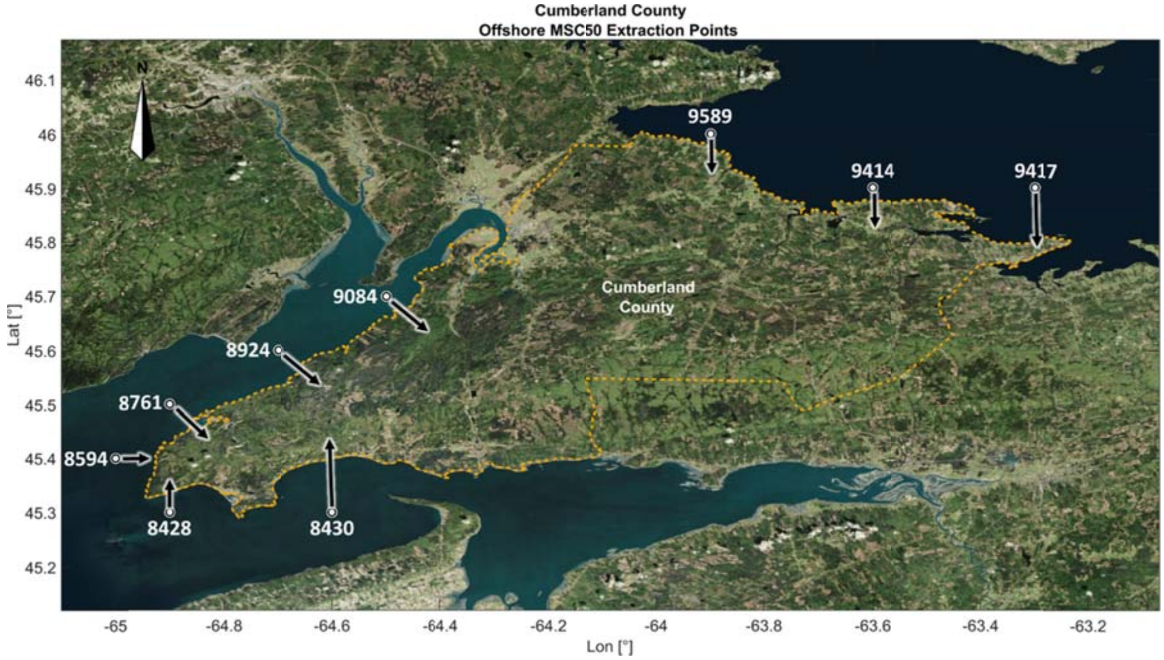

Figure 2:: Map of Locations for Offshore Wave Information

Table 5: 1 year return Run-up Value Estimates (not accounting for nearshore wave transformation, which results in highly conservative values that would be representative only for areas directly exposed to offshore waves)

LOCATION	Offshore Point	1-YR RUN-UP [m]					
		Beaches	+/-	Coastal Dikes & Embankments	+/-	Armoured Shorelines	+/-
Northumberland Coast	9589	0.3	0.1	1.5	0.8	1.5	0.3
	9414	0.5	0.2	2.9	1.6	2.9	0.7
	9417	0.6	0.3	3.0	1.6	2.9	0.6
Chignecto Bay & Bay of Fundy	9084	0.3	0.1	1.6	0.9	1.7	1.0
	8924	0.2	0.1	1.3	0.7	1.4	0.3
	8761	0.3	0.1	1.9	1.0	2.2	0.5
Minas Basin & Bay of Fundy	8594	0.7	0.3	3.9	2.1	4.0	0.9
	8428	0.4	0.2	2.3	1.2	2.4	0.6
	8430	0.3	0.1	1.6	0.9	1.7	0.4

Table 7: 1 in 10 year Run-up Value Estimates (not accounting for nearshore wave transformation, which results in highly conservative values that would be representative only for areas directly exposed to offshore waves)

LOCATION	Offshore Point	10-YR RUN-UP [m]					
		Beaches	+/-	Coastal Dikes & Embankments	+/-	Armoured Shorelines	+/-
Northumberland Coast	9589	0.3	0.1	1.7	0.9	1.8	0.4
	9414	0.7	0.3	3.2	1.7	3.0	0.7
	9417	0.7	0.3	3.3	1.7	3.1	0.7
Chignecto Bay & Bay of Fundy	9084	0.3	0.2	1.8	1.0	2.0	0.4
	8924	0.3	0.1	1.5	0.8	1.7	0.4
	8761	0.5	0.2	2.6	1.4	2.8	0.6
Minas Basin & Bay of Fundy	8594	1.0	0.4	5.6	3.0	5.5	1.3
	8428	0.6	0.3	3.4	1.8	3.5	0.8
	8430	0.3	0.2	1.9	1.0	2.0	0.5

Table 8: 1 in a 100 year return Run-up Value Estimates (not accounting for nearshore wave transformation, which results in highly conservative values that would be representative only for areas directly exposed to offshore waves)

LOCATION	Offshore Point	100-YR RUN-UP [m]					
		Beaches	+/-	Coastal Dikes & Embankments	+/-	Armoured Shorelines	+/-
Northumberland Coast	9589	0.5	0.2	2.7	1.5	2.4	0.6
	9414	0.8	0.3	3.7	2.0	3.5	0.8
	9417	0.9	0.4	3.9	2.1	3.6	0.7
Chignecto Bay & Bay of Fundy	9084	0.4	0.2	2.1	0.4	2.2	0.5
	8924	0.3	0.2	1.9	1.0	2.0	0.4
	8761	0.6	0.3	3.4	1.8	3.5	0.8
Minas Basin & Bay of Fundy	8594	1.3	0.6	7.2	3.8	7.1	1.7
	8428	0.8	0.4	4.7	2.5	4.9	1.1
	8430	0.4	0.2	2.3	1.2	2.4	0.6

Notes:

- *For consistency, all reported run-up values assume wave attack perpendicular to coastline from offshore MSC50 point. Run-up values may be slightly greater or lower in areas where wave attack is 45° clockwise or counterclockwise to the angle of perpendicular wave attack from offshore point. To observe these differences, consult Appendix B.*
- *Beach slope is assumed to be between 0.5° and 6°*
- *Dike & Embankment slope is assumed to be between 2.5° and 22°*
- *Armoured slopes are assumed to be between 15° and 45°*
- *It is assumed that the toe of each structure (dam, embankment, armoured shoreline) is at MSL.*
- *A foreshore of 1:40 has been assumed for shorelines with a dike, embankment or armoured shoreline. For shorelines with beaches a 1:10 to 1:100 is assumed.*
- *The effects of swell or low period waves are discussed in the appended material*

Accurate estimates of run-up values require the following information in detail:

a) Types of structures, shoreline and corresponding location
b) Dimensions of shoreline protection features
c) Site specific MSL and CD (determines submerged or dry toe)
d) Detailed bathymetry for each scenario to estimate wave transformation

e) Site-specific wave transformation modeling and run-up evaluation
f) Adjustments of storm surge for various climate change scenarios & return periods

3 Coastal Risk Assessment

Cumberland County hosts a wide variety of coastal features, such as natural beaches, dikes, embankments, armoured shorelines and seawalls. Coastal erosion and flooding risks along the Cumberland shores vary according to the combination of local coastal processes and site specific conditions. The large variety of shoreline types around the Cumberland County, in combination with some of the highest tides in the world, creates a complex and often vulnerable coastal environment for municipalities to manage. A County wide holistic management approach to mitigating coastal vulnerability and risk is therefore a complex task.

For example storm surges are highest in the Northumberland Strait where tidal range is the shortest. Therefore, the potential impact of a storm surge in this area varies little with the stage of the tide. Sediment transport along the shore of the Northumberland Strait are the result of the oblique action of waves. In contrast, in the Bay of Fundy, tidal ranges are large and the potential level of impact of a storm surge in this area varies greatly with the stage of the tide. During high tide the level of damage of a storm surge or an extreme precipitation event will be stronger than during low tide. Additionally, tidal currents in the Bay of Fundy cause the movement of large amount of sediment. This results in risks of either scour or sedimentation around critical infrastructure such as bridges or stormwater outlets.

3.1 Identification of Vulnerable Areas

Coastal flood impacts vary markedly from one location to another. The assessment of the degree of vulnerability of a community to coastal hazards requires a thorough evaluation of the predominant natural processes in the area and their interaction with the shoreline type, the land uses and the geographical characteristics of the area.

For example, communities such as Parrsboro are subject to different coastal hazards than those observed in Pugwash, even though both communities are located in estuarine zones. Some examples of the mechanisms which differentiate coastal hazards in each community include; the tidal range, land use and exposure, natural features such as rivers, and effectiveness of flood protection methods. In Pugwash, flooding risks associated with the joint action of extreme river flows from the Pugwash River and the coastal water levels from the Northumberland Strait require an evaluation that consider the hydrodynamic interaction of both processes and the potential flow constrictions caused by the Highway 6 Bridge. In Parrsboro, the assessment would require evaluating the effect of the Two Island Rd Aboiteau during extreme precipitation taking into consideration coastal water levels at different stages of the tide.

Another example includes the assessment of coastal risks along the shores of Heather Beach (situated 40 km southeast of Amherst on the Northumberland Shore) which would require an evaluation of wave action from the Northumberland Strait. In this area, coastal communities are exposed not only to flooding caused by the combination of tidal levels and storm surges, but also to the effect of run-up. The impact of run-up in these areas depends on the slope of the foreshore and the type of shore (e.g. sandy shores, stone revetment, embankments, cliffs, etc). Additionally, sandy shores in these areas are vulnerable to erosion caused by longshore transport, i.e. the movement of sand caused by the oblique action of waves. Risk of coastal damage in these areas are also a function of the elevation of the land in comparison to the amount of overtopping discharge. Damage due to overtopping is a function not only of the discharge rate but the land use at the vulnerable area. Guidelines of tolerable overtopping limits, as presented in the Coastal Engineering Manual (CEM) are shown in the following figure.

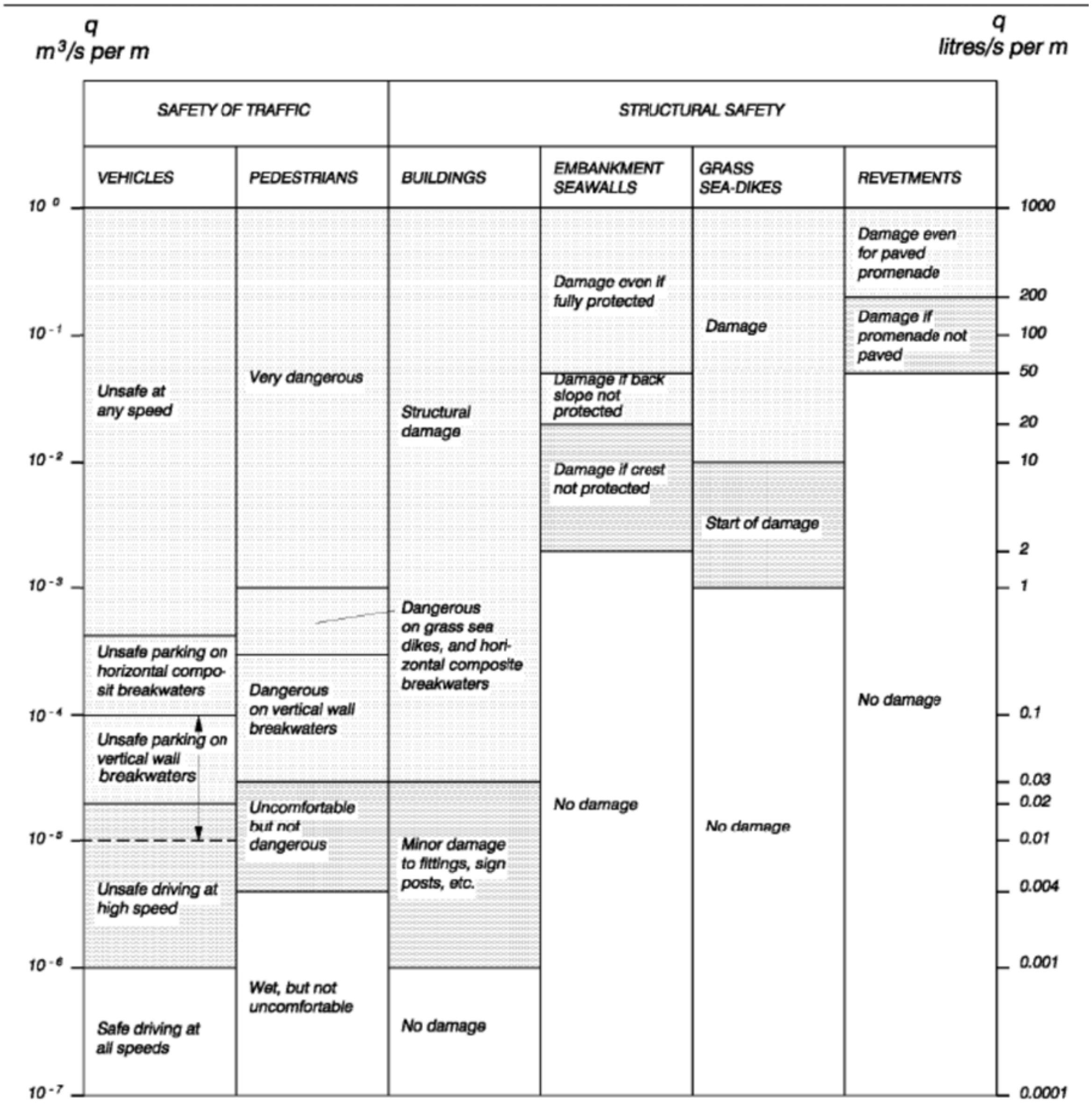

Figure 4:Critical Values of Average Overtopping Discharges. From the Coastal Engineering Manual (USACE, 2012)

High level assessments of potential flooding and coastal risks based solely on still extreme water levels and its intersection with a particular terrain elevation can only provide a preliminary evaluation of the degree of vulnerability of a particular site. The risk of applying such an approach is that it typically does not account for site specific hydrodynamic processes, land uses, and existing coastal infrastructure. This type of assessment therefore provides a limited capacity for seeking cost effective solutions that strengthen the natural ecosystem, enhance resilience and facilitate adaptability.

3.2 Coastal Risks Management Approaches

The selection of measures to address the impact of coastal processes in a vulnerable nearshore region is typically a function of land use, the environmental impacts of implementing hard protection measures, the effect that both hazards and mitigation measures exert over stakeholders and their properties and the cost-benefit relation between consequence of damage and the benefits of protection. Strategies for protection against coastal damage include:

- **Protection against hazards**: This approach involves implementing defenses against high water levels and effect of erosion. Existing land uses are maintained and coastal areas can be reclaimed for development. The design of protection measures is generally associated with the probability of encountering an event magnitude that causes the protection measure to fail. Usually protection measures have a limited life span and require periodic maintenance and upgrade. In areas where space is limited, protection measures consist mainly of hard structures. In areas where enough space is available, softer or nature-based approaches may be implemented. The implementation of flood protection strategies requires understanding and evaluation of the residual risk; i.e. vulnerabilities and risks introduced by the design of new flood protection infrastructure

  The following table provides a general overview of the design span of traditional flood defense infrastructure and its relationship with the level of protection they are able to provide.

Design Life	Risk of Human Life or Environmental Damage in Case of Failure	Hazard Type and Reason	Typical Level of Protection (Return Period, Years)	Encounter Probability of the Design Event Over the Lifetime (0 to 1)
25	Small	Temporary or short term measures, e.g. pavements	25	0.64
			50	0.40
50	Moderate	Majority of shoreline protection works, general use infrastructure, e.g. sea dikes in rural areas	50	0.64
			100	0.40
100	High	Flood defences protecting large areas at risk, e.g. dykes in urban areas	100 to 10,000	0.64 down to 0.01
200	Very high	Special structures with very high cost (e.g. some European storm surge barriers)	Up to 10,000	Down to 0.02

  Soft measures or nature based solutions include approaches such as the construction of sills and living shorelines. These approaches aim to restore saltmarshes and coastal wetlands to not only reduce the impacts of flooding and erosion but also to strengthen the natural eco-system. Engineered living shorelines combine plant stabilization, wetlands or marsh restoration with strategically located hard structures. This approach has the added benefit of providing environmental, recreational and aesthetic enhancements that will most likely be valued by users and the greater community at large. Other environmental benefits typically include improved water quality, increased quality and size of habitat, improving access for aquatic species, using vegetation to filter surface water runoff and improving shoreline stability.

- **Accommodate:** This approach allows use of the area exposed to risks with changes to the use of the land or the existing infrastructure to tolerating uses. Examples of this approach include raising or flood proofing vulnerable infrastructure and using floating structures.
- **Retreat:** This is a long term approach that consists in relocating people and infrastructure away from hazardous coastal areas. Managed retreat involves selecting what to relocate and mitigating the environmental impacts of leaving infrastructure exposed to the natural processes. Abandonment is another type of retreat that does not involve planning for relocation or for the impacts that abandonment may cause over the environment. Abandonment is not a beneficial adaptation strategy but may be necessary in cases of emergency.
- **Avoid:** This approach prevents development in hazardous coastal areas and locates critical infrastructure such as hospitals and emergency services in areas where risks of flooding is negligible.
- **Procedural:** This approach raises awareness and enhances preparedness by generating climate information, producing flood risk maps and disseminating this information to stakeholder and the public. Other measures include detailed hydrodynamic flood forecasting and civil contingency planning

Implementations of these strategies are not mutually exclusive. Protection against flooding events primarily involves engineering methods and approaches. However, the uncertainties inherent to flood frequency estimation and the possibility of encountering events that exceed the design of flood defenses require the combination of several types of strategies. This improves the adaptability and resilience of developments built in flood prone areas.

Regards,

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Attachments:

- Literature Review Matrix
- Detailed Wave Runup Calculations
- References

Project No: 161055.00

Document Name & Purpose	Coastal Processes and Related Risks	Analysis					Outcomes	
		Field	Modelling, or GIS Analysis	Policy or BMP Review	Economic Assessment	Background (e.g., Historical, Scientific)	Vulnerable Locations Identified	Recommendations (e.g., Policy, Engineering Criteria)
CBCL (2009) "State of Nova Scotia's Coast Technical Report"	– Flooding – Coastal Erosion – Degredation of sensitive coastal ecosystems and habitat	N/A	N/A	N/A	– Table 7-2 : qualitative socio-economic impactgs of sea-level rise and storm events – Costs provided for Hurricane Juan – Cost discussion for Acadian dykelands	– Key points on Coastal Management Framework – Factors that cause sea-level rise in NS – In addition to Economic, the social and ecological implications of SLR and storms	– Draws attention to different magnitures of SLR across the province – General characteristics of areas greatest at risk	N/A
Richards and Daigle (2011) "Scenarios and Guidance for Adaptation to Climate Change and Sea-level Rise"	– Flooding (extreme water levels)	N/A	N/A	– A few examples of adaptation strategies in various municipalities but policies not reviewed explicitly	N/A	– Main contribution is review of scientific approach to use of scenarios (e.g., indices used, ensembles, model validation,etc.) and explanation of processes involved in climate change(e.g., crustal subsidence, changes in storm surge return periods, etc.)	– Some areas addressed as case studies. Values provided for future climate and coastal water levels for 22 target municipalities in NS and PEI, but locations are not specifically compared in terms of vulnerability.	– Reviews research and recommendations from certain groups (IPCC, Adaptation and Impacts Research Section of Environment Canada) – Main contribution is recommended future climate and coastal water level values to used for climate change action plans
Stantec (2011) "Environmental Planning Framework"	– Flooding – Coastal Erosion	N/A	N/A	– Review of policies in different jurisdictions and evaluation of currently policies in Cumberland County, with sections on: development setback and vegetative buffers, coastal elevation requirements, shoreline stabilization, flooding, and coastal vulnerability.	N/A	N/A	N/A	– Short-term, Long Term Direction, Policy Recommendations or Engagement Recommendations for each area of policy review. – Recommendations for Inter-jurisdictional Cooperation based on similarities in challenges.

Longhurst and Milton (2012)	– Coastal flooding – Sea level rise	N/A	N/A	N/A	N/A	– Background on the geography, development and history, economy, and social context of Amherst. – Identification of climate change issues of concern in Amherst	N/A	proposed climate adapatation activities (e.g., review policy recommendations from other sources)
van Proosdij and Page (2012) “Best Management Practices for Climate Change Adaptation in Dykelands”	– Overtopping and breaching of dykes – Shoreline erosion – Coastal squeezing	– A physical assessment was done for all of the dykes within the Fundy ACAS study areas, including field visits, wave exposure analysis and historical erosion rates, foreshore width and observed erodibility as well as type and extent of shore protection applied. – Shore zone characterization project focussing on composition, type and material, as well as evidence of erosion, sedimentation, storm damage and manmade shoreline protection.	– GIS comparison of surveyed elevations with critical dyke elevations for the Fundy ACAS communities	– An analysis of engineering best practices (e.g., slope, crest elevation, material, maintenance of foreshore, creek modifications) using information from NS, NB and BC, as well as other regions in the world. – A comprehensive review of international best practices for climate change adaptation in dykeland areas, including three main climate change adaptation approaches: hold the line (defend), re-align (retreat) or abandon. – Adaptation can take the form of either engineering solutions or management approaches. Engineering solutions can include both hard (e.g. rock armouring) or soft (e.g. salt marsh restoration or terracing).	– Economic cost of temporary flooding delays are cited. – Dykeland values are assessed	– Overview of coastal processes relevant to dykes and shoreline erosion	– critical elevations of different dyke sections are obtained – shorezones of concern are characterized – vulnerable marsh bodies are flagged	– A number of recommendations are made for salt marsh/foreshore protection and dyke maintenance/adjustments – Cooperation is required at federal, provincial and local levels to find funding for dyke heightening, with a combination of both an engineering and management approach.

Webster *et al.* (2012a) “An Evaluation of Flood Risk to Infrastructure Across the Chignecto Isthmus”	– Flooding, in particular due to dyke overtopping – Salt water damage	– field surveys to ground-truth the digital elevation model and flood modeling predictions	– GIS used to prepare set of flood risk maps of the Isthmus area, water level assumed to be a flat plane – Hydrodynamic modelling (Mike21) during perigean spring tides in November 2012.	N/A	– Public and private assets of dykeland quoted to > $70 million in NS – Dyke overtopping and flooding of portions of the railway and highway would results in delays in trade of $50 million per day. – Public and private assets have more than ten times the value of agricultural assets in the dykelands	– Background review of the state of historically high water levels, estimating high water level return periods, estimates for sea-level rise and physical processes involved in sea-level rise	– Thirteen locations were identified where sections of the dyke elevation is low enough to allow overtopping at critical water level elevations – critically-low segments within agricultural dykes in NS and NB that would flood during storm surges that coincide with high tides were identified – areas and transportation infrastructure at risk on the Isthmus were identified	– identify potential alternative routes for sustainable transportation; – recommend considerable upgrades to the dyke system or other adaptation options be implemented – A hypothetical connector route along the highest terrain is identified

Webster *et al.* (2012b) "River Flood Risk Study of the Nappan River Incorporating Climate Change"	– flooding – changes in sedimentation	– Lidar was obtained for the region in Oct 2009 – installed a pressure sensor to measure river stage for one field season – visited the site on several occasions through the field season of 2011, measuring flow and stage, recording water levels with survey grade GPS, and executing a bathymetric survey of the river bed	– a series of models were assembled to study the impact of a simulated aboiteau on flooding – constructed a seamless elevation model (lidar + bathymetry) to facilitate the extraction of river cross-sections used in the 1D hydraulic river model – Modelling also included a watershed rain-fall runoff model and a 2D hydrodynamic tide model for the Upper Bay of Fundy (to better control the function of the aboiteau in the model) – Past flooding events were simulated as well as two and three times the rainfall to simulate possible increases in precipitation with climate change	N/A	N/A	– a review of flooding issues in Nappan is presented – considerations for a potential aboiteau (siltation, restricted drainage, etc.) are explained	– flood mapping reveals areas vulnerable to flooding under different scenarios	– To improve the modelling, a 2D floodplain model should be used, precipitation estimates should be improved using radar the Environment Canada Radar Precipitation map or additional weather stations, and additional field work could be conducted in order to survey the floor of the aboiteau at low water.
Webster *et al.* (2012c)	– Flooding	– Lidar surveys of the coastal communities	– stillwater flood levels every 10 cm (like other Webster report)	N/A	N/A	– expected return periods of benchmark storms under present and future conditions	N/A	N/A

CBCL (2013) "Design & Construction of the LaPlanche River Aboiteau"	– Flooding	– Site visit, Topographic surveys, geotechnical investigations – Field observations of suspended sediment concentrations used to calibrated sediment transport model	– Hydrologic and Hydraulic model, tide levels – Hydrodynamic and sediment transport modeling	– Costs of flood damage (agricultural lang use, other infrastructure and land uses) – Costs of flood protection (raising dykes, improving marsh drainage) – Estimated probable costs of constructing an Aboiteau at each of the three sites	N/A	– Current background of the site (existing dykes and aboiteaux, existing configuration of marsh drainage, current land use) – Review of impacts of climate change – Proposed aboiteaux locations were evaluated	N/A	– Aboiteau design recommendations,operation and maintenance – Recommendations outlined within the recent ACAS dykeland vulnerability and best practices report (van Proosdij and Page, 2012) should be applied as a minimum. – Measures for flood protection (including Implementation plan for Aboiteau), Flood proofing existing development, Recommendations for potential future development of the marshes
Daigle (2014) "Sea-Level Rise and Coastal Flooding Estimates for Chignecto Isthmus and Halifax Harbour"	– Flooding from sea-level rise and storm surge	N/A	– regional sea-level rise value for Chignecto Isthmus was extrapolated from the Shediac, Charlottetown, Saint John and Halifax values	N/A	N/A	– addresses the main components of regional sea level rise (global sea-level rise, distribution of glacial meltwater, vertical land motion, regional oceanographic effects, bay of fundy tidal range, – review two main reports for updated sea-level rise: IPCC AR5 and James et al. Report – use these in conjunction with previously prepared storm surge return period statistics to produce new extreme water level estimates for the Chignecto Isthmus	N/A	N/A
ACASA (2015) "Engineering Tools for CC Adaptation in Coastal Areas of Atl. Can."	– Flooding – Unstable shorelines (from wave scour, sediment transport,	N/A	N/A	– Tools (land use planning, engineering structures) depending on different coastal type and wave exposutre – soft and hard engineering – Shoreline stabilization	– Order-of magnitude installation cost range	– Adaptation approaches (protect, retreat, etc.) – Summary of coastal processes and engineering implications (water levels, waves, currents, sediment transport and erosion)	– Key variations of coastal concerns across atlantics provinces (regional scale only)	N/A

Withey *et al.* (2016) “Chignecto Isthmus Cost Benefit Analysis Results”.	– Disruption of transportation across the isthmus due to flooding	N/A	N/A	– Disruption to Trans-Canada Highway, the CN railway and electricity transmission lines.trade and traffic flows – Damage to infrastructure, cost due to trade and traffic delays – indirect impactssuch as clean-up, emergency services and commercial delays are ignored. – impact on agricultural land and marshland is considered, however only in the adaptation options – analysis does not consider impacts to residential or commercial infrastructure, as this is beyond the scope of the project. Wilson et al. (2012) – cost of adapatation options (including raising dykes, building new dykes, rerouting highway, replacing aboiteaux	N/A	N/A	– Trans- Canada Highway, the CN railway and electricity transmission lines. – Region itself is identified as vulnerable	– No, just tools given to be taken into consideration
Savard *et al.* (2016) “Perspectives on Canada’s East Coast region”	– Relative sea level – Storm surge and extreme water level – Wave climate and sea ice – Geomorphology, sediment supply and coastal dynamics – Saltwater intrusion – failure of coastal infrastructure – shoreline erosion – coastal and inland flooding – ice pile-ups – saltwater intrusion	N/A	N/A	– Current state of planning or implementation for of climate change adaptation in communities across the region – Discussion of exposure, sensitivity, vulnerability, and adaptability in general terms.	– Economic impacts on fisheries, aquaculture, transportation, and tourism.	– Observations and projections in relevant climate changed (sea-surface temperatures, ocean acidity, sea ice cover, wind and storms) – Changes in coastal processes (sea-level rise, storm surge and extreme water levels, wave climate and sea ice, geomorphology)	N/A	– Factors affecting adaptation and adaptation options including no active intervention, avoidance and retreat, accommodation, and protection.

Appendix B – Compilation of Extreme Water Levels and Coastal Vulnerability

Cumberland County hosts a wide variety of coastal features, such as natural beaches, dikes, embankments, armoured shorelines and seawalls (Figure 1). Such a variety of shoreline types in combination with some of the highest tides in the world, creates a complex and often vulnerable coastal environment for municipalities to manage. A County wide holistic management approach to mitigating coastal vulnerability and risk is therefore a complex task. The following high-level study aims to illustrate the challenges and potential regions of concern for extreme water levels along the Cumberland County shoreline. The study will focus on beaches, dikes and armoured shorelines. Seawalls will not be considered, for such structures are best studied on a case-by-case basis.

Figure 1: Shoreline Types Influencing Wave Action

TL: Bayswater Beach, NS (source: NS Parks, 2017), TR: Embankment or Dike (source: EurOtop, 2016),
BL: Cow Bay Revetment, NS (source: National Post, 2012), BR: Seawall (source: EurOtop, 2016).

Extreme Water Levels (EWLs) occur when several physical drivers interact and develop simultaneously to create higher than usual water elevation at a specific location. Such drivers are typically, storm surge, extreme waves (run-up), Highest Astronomical Tide (HAT), and effects such as Sea-Level-Rise (SLR). In this study, EWLs will be described by:

$$EWLs = storm\ surge + high\ tide + sea\ level\ rise + wave\ run\ up$$

1.1 Tides, Sea Level Rise & Storm Surge

Tides – Historic water levels are monitored by the Department of Fisheries and Oceans Canada (DFO) in the Bay of Fundy at Saint John (station #65). Considering both the location of the Saint John station in relation to the Area-of-Interest (AOI), and the complex tidal system in the Bay of Fundy, the raw data from station #65 cannot be easily applied to this study. Instead, three other data sources are considered and combined to construct a high-level interpretation of the extreme tidal levels in the AOI. These are:

1. DFO's WebTide numerical model;
2. Spring tidal range as defined by Cousineau J., Nistor I., Cornett A. (2012);
3. Higher High Water Large Tide (HHWLT) as summarized by Richards W., Daigle R., (2011) based on information from the Department of Fisheries and Oceans (DFO).

The output from the above sources are combined in Figure 2. The spring tidal range is the most extreme tidal range and occurs around a full or new moon, when the gravitational forces of both the Sun and Moon are in phase. The spring tidal range gets progressively larger as one moves up the Bay of Fundy towards Joggins and Burncoat Head. In contrast to the Bay of Fundy, the tidal ranges along the Cumberland Strait are significantly lower (e.g. Pictou - Figure 2). Tidal ranges have been verified using the DFO's WebTide numerical model.

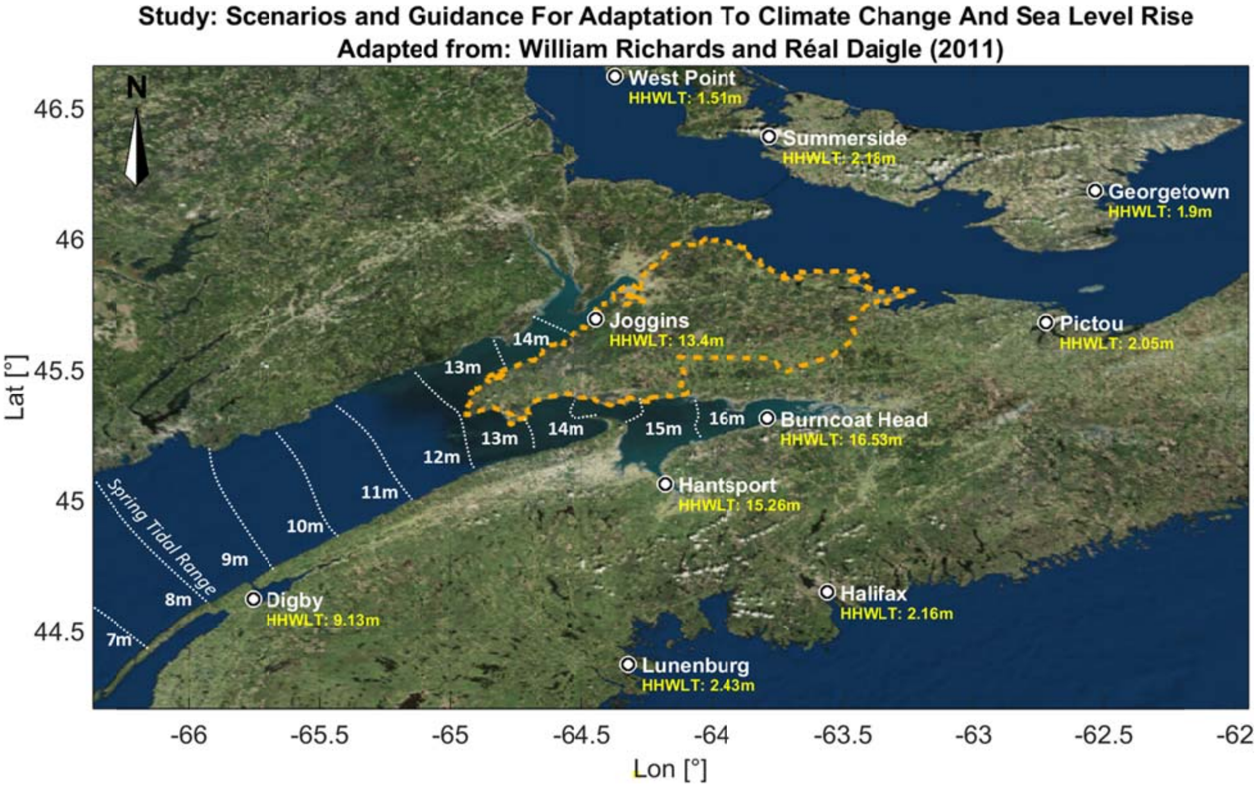


Figure 2: Water levels (Bay of Fundy)

- *HHWLT = Higher High Water Large Tide, i.e. the average of the 19 annual maxima over a 19-year full tidal cycle*
- *Vertical reference level is Chart Datum, where the zero is typically close to the lowest tide level. Therefore, the HHWLT elevation is a good indication of the total tidal range.*

Figure 2 illustrates the variation in extreme tidal range along the Nova Scotia and Cumberland County shorelines. The site-specific variation in tide highlights the importance of spatially reporting and studying tidal ranges across the area of interest. When determining extreme water levels, the tidal range can play a significant role in the impact storm surge or wave run-up have on a local site.

Sea Level Rise projections in Nova Scotia and PEI are reported by Richards W. & Daigle R., (2011). This 2011 report was commissioned specifically for assisting municipalities in planning for sea level rise. Since 2011, scientists have updated sea level rise estimates. Notably, DFO (Zhai et al 2014) has issued sea level rise projections for all Canadian fishing harbours based on the 2013 Intergovernmental Panel on Climate Change 5th Assessment Report (IPCC AR5, 2013). The updated values are in the same order of magnitude as those reported in Richards & Daigle for the study area, i.e. approximately 1 m SLR by year 2100 for the high emission scenarios. Therefore, CBCL is still using the 2011 reference for consistency in terms of geographical sites and inclusion of tide and storm surge in a single reference. Estimates of SLR are considered for Hantsport, Joggins and Pictou as these are the three closest sites to the AOI. The findings from Richards W. & Daigle R., (2011) are summarized in Table 1 and consider several climate scenarios and models to derive the mean SLR and associated standard deviations. Factors considered to derive SLR include:

a) Thermal expansion of the oceans;
b) Melting of nonpolar glaciers and;
c) Changes in the volume of the ice sheets of West Antarctica and Greenland.

Sea levels along most coasts of Atlantic Canada are rising due to the fact that these coastlines are very slowly subsiding (up to a few tenths of meters per century). This factor relates to a post-glacial rebound of the earth's crust (Richards W. & Daigle R., 2011).

Table 1: Estimated Total Sea Level Rise [m]

Location	**2025**	**2055**	**2100**
Hantsport	0.16 *+/- 0.03*	0.86 *+/- 0.36*	1.10 *+/- 0.48*
Joggins	0.15 *+/- 0.03*	0.82 *+/- 0.36*	1.05 *+/- 0.48*
Pictou	0.15 *+/- 0.03*	0.82 *+/- 0.15*	1.05 *+/- 0.48*

Adapted from: Richards W. & Daigle R., (2011)

Storm Surge can be defined at the coast as the difference between the observed water level and the predicted astronomical tide. Large positive storm surges at times of high tide are events that lead to coastal flooding, whereas when they coincide with low tides, flooding problems are averted. For added safety in the context of planning purposes, it is assumed that the extreme storm surge coincides with the HHWLT. This is a reasonable assumption for areas with moderate tidal range and relatively high storm surge, such as the Northumberland Strait. However, it is conservative along Fundy shorelines, because the 100-year storm surge residual coinciding with a HHWLT would represent an event of return period greater than 100 years.

Elevated sea levels enhance wave attack and coastal erosion. The magnitude of storm surges depends on the nature of the meteorological event responsible for the reduced atmospheric pressure and the strength of the winds associated with a particular event (Richards W. & Daigle R., 2011). As with the SLR predictions, storm surge residuals are considered for Hantsport, Joggins and Pictou (Table 2).

Table 2: Estimate Storm Surge (Residual) [m]

Return Period	Hantsport	Joggins	Pictou
10-YR	0.85 *+/- 0.20*	0.85 *+/- 0.20*	1.12 *+/- 0.10*
25-YR	0.96 *+/- 0.20*	0.96 *+/- 0.20*	1.27 *+/- 0.10*
50-YR	1.04 *+/- 0.20*	1.04 *+/- 0.20*	1.38 *+/- 0.10*
100-YR	1.13 *+/- 0.20*	1.13 *+/- 0.20*	1.49 *+/- 0.10*

Adapted from: Richards W. & Daigle R., (2011)

These results in Table 2 are based from a combination of historical tide gauge observations and modeling such as the work by Bernier et Thompson (2006) presented in Figure 3. This Figure illustrates that the Northumberland shore is more prone to high storm surge residuals than the Fundy shore.

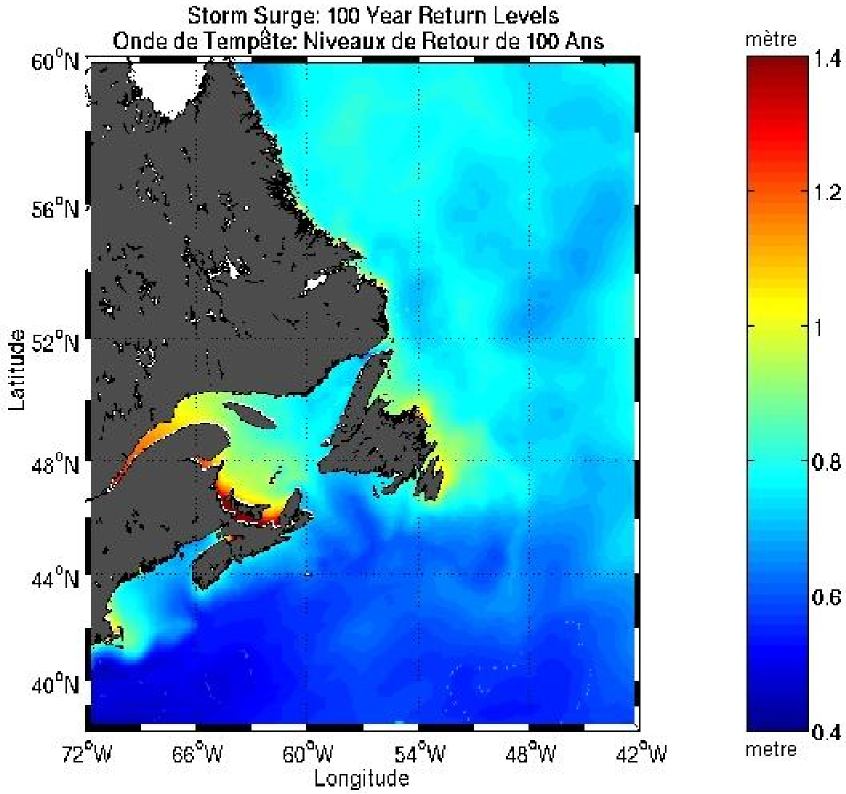


Figure 3: Modeled Extreme Storm Surge Residual (source: Environment Canada, based on Bernier et Thompson 2006)

Water levels can fluctuate significantly above the toe of a coastal structure. Understanding the submergence of the structure toe during extreme events, in relation to a local datum, is necessary to forecast whether the hinterland may be vulnerable to flooding from surge, run-up and overtopping. Each coastal structure is uniquely different and often referenced to a highly-localized Chart Datum (CD); a datum level used on navigation charts, defined to be close to lower low-water at large tides. The data presented in this study is referenced as closely as possible to CD sourced from Canadian Hydrographic Service (CHS) navigation charts. Mean Sea Level (MSL) values are recorded from various CHS charts and summarized in Figure 4. The MSL is representative of the average of HHWLT and CD-zero. For land planning purposes, GIS applications make use of a geodetic reference level (i.e. CGVD28), requiring a conversion between CD and CGVD28 that is specific to each location. CGVD28-zero value represents approximately the MSL value, but there are varying differences depending on the location (normally within 10-25 cm) (Richards W. & Daigle R., 2011). The MSL is an important parameter in this study as it will be used to determine the magnitude of wave run-up on generic profiles of embankments, dikes and armoured shorelines.

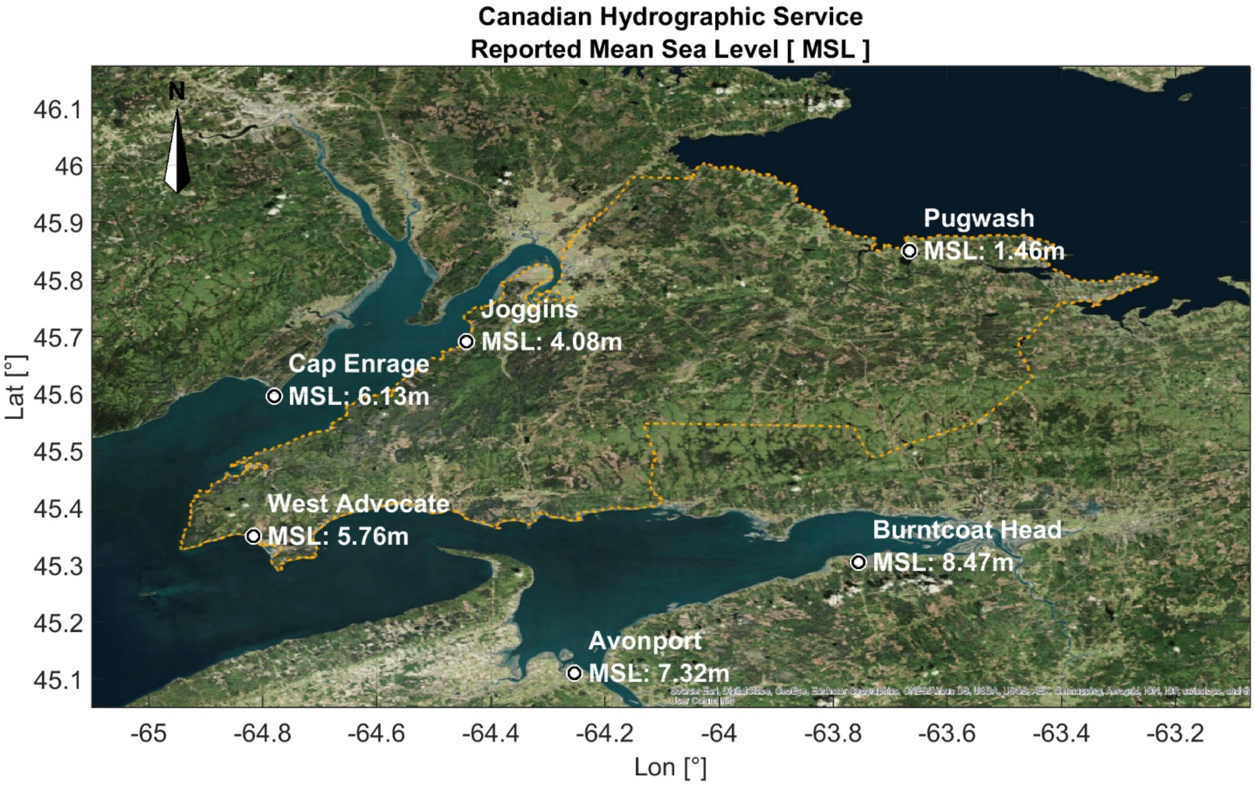


Figure 4: Reported Mean Sea Level (MSL) relative to Chart Datum

1.2 Wave Climate

Richards W. & Daigle R., (2011) note that the residual values they report for storm surge exclude the incremental value of any wave run-up that could potentially accompany a storm surge event. Wave run-up varies significantly from site to site depending on local wave conditions and physical shoreline features. Wave run-up increases local extreme water levels, resulting in localized overtopping, which could introduce additional hinterland hazards, risks and potential for damage. To accurately compute run-up a site specific coastal engineering assessment is typically required, using hydrodynamic modeling with high resolution bathymetry (which is outside the present scope). As this is a high-level study, a series of generalized run-up investigations will be performed using regional inputs, general design guidelines, tolerances and thresholds.

An offshore wave climate is defined to generate the required nearshore wave inputs for run-up computations. The MSC50 hindcast (covering the period from 1954-2013) is used in this study to determine the characteristic wave climate along the Cumberland County shore. The MSC50 project was funded by the Climate Research Division of Environment Canada and the Federal Program of Energy Research and Development and is provided for this study by Environment Canada. Nine MSC50 points are extracted from the model for this analysis (Figure 5).

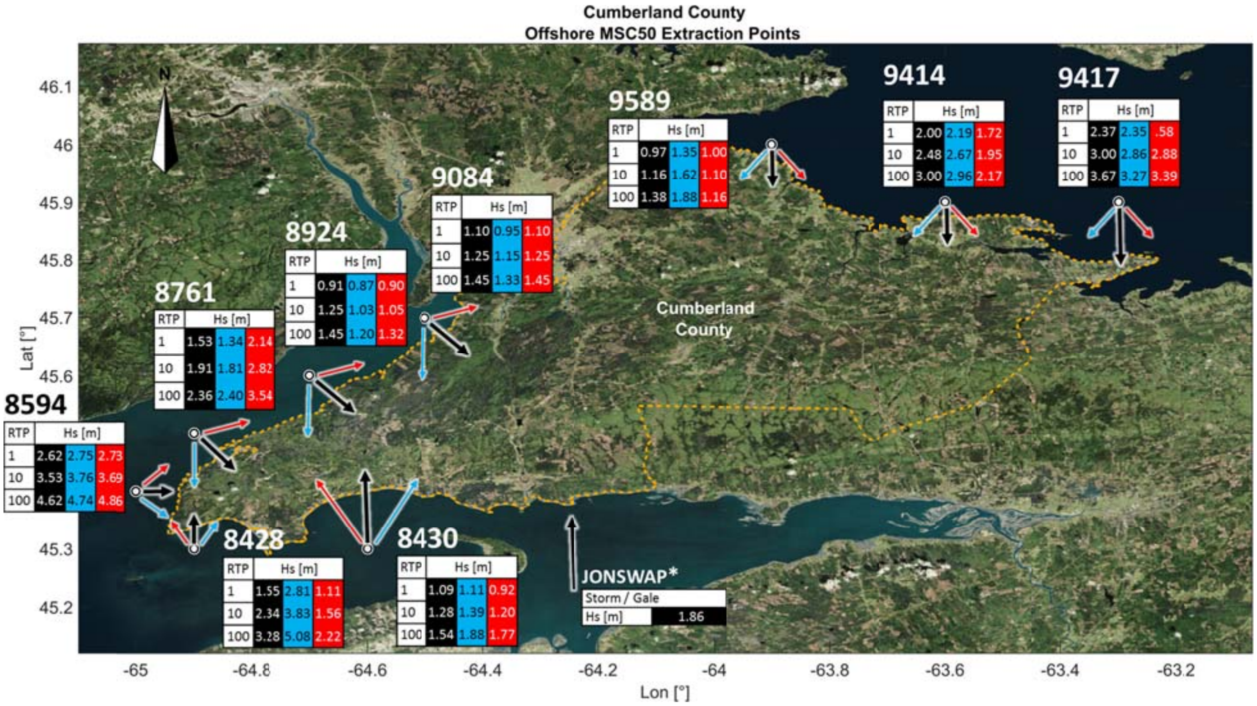


Figure 5: Extreme Offshore Wave Climate: Cumberland County (1-, 10-, 100-yr return periods)

The offshore MSC50 wave height and period data is split into directional bins ("going towards" where north is 0°), perpendicular (black arrows) to the nearest shoreline, and in bins 45° clockwise (CW – blue arrows) and counter-clockwise (CCW – red arrows) to the perpendicular incident offshore waves. The angles of wave attack will be used in the run-up analysis and are anticipated to produce the most dramatic result given their offshore origin and orientation in relation to the shoreline. For each directional bin of each MSC50 point, a peak-over-threshold (POT) analysis is performed to isolate the largest storm events. The output from the POT is then used to derive wave height return periods (1-, 10-, 100-yr) using an extreme-value-analysis (EVA). The POT data is fitted to either a Weibull distribution, generalized extreme value distribution or a generalized Pareto distribution. The results of this analysis are plotted in Figure 5 per directional bin.

For more detailed information, such as the wave period associated with each wave height, Table 3 can be referenced in Section 1.5. Swell events for points 8430, 8428, 8594, and 8761 are also considered (Table 3), due to the considerable impact that these types of waves can have on run-up. There is no MSC50 data available for the southeastern coastal section of Cumberland County. To account for this area, an offshore wave height is generated using a JONSWAP distribution with the characteristics of a 23km fetch, 12hr storm duration, and gale magnitude winds from the south (worst case scenario).

1.3 Run-up Analysis

When ocean waves approach a coast, most of the wave energy is dissipated across the surf zone by wave breaking. However, a portion of that energy is converted to potential energy in the form of run-up on the foreshore of areas such as a beach. Wave run-up is important to coastal planners and coastal engineers because these motions deliver much of the energy responsible for dune and beach erosion

(Sotckdon, et. al 2006), and can result in overtopping and additional localized flooding. During events with extreme water levels, less energy may be dissipated across the surf zone, and run-up values may be greater. This is especially the case for armoured shorelines or dikes where the toe of the structure may be submerged during a significant event. Such configuration results in considerable wave energy reaching the structure's slope, therefore creating significant run-up and heightening the chances of overtopping.

The wave run-up height is given by $R_{u2\%}$. This is the wave run-up level, measured vertically from the still water line, which is exceeded by 2% of the number of incident waves. The number of waves exceeding this level is hereby related to the number of incoming waves and not to the number that runs up the slope (EurOtop, 2016). Run-up is relevant for beaches, smooth slopes and embankments and for rough slopes armoured with rock or concrete armour. Wave run-up does not have an equivalent parameter for vertical structures.

Many factors influence the magnitude of run-up height ($R_{u2\%}$), these include but are not limited to:

a) **Wave height -** In many cases, a foreshore is present on which waves can shoal and break, by which the significant wave height is reduced. In this investigation, offshore wave heights are transformed to nearshore conditions using the Goda (2000) formulations. This approach was selected to obtain order-of-magnitude estimates over a large area for planning purposes. However it is not substitute for site-specific wave transformation modeling that would be required for engineering design at a given site.

b) **Wave period** significantly influences wave run-up as it determines the breaker parameter (surf similarity or Iribarren number). The breaker parameter determines what type of empirical relationship is used to compute run-up for dikes, embankments and armoured shorelines as per EurOtop, (2016) guidelines.

c) **Water level** is one of the most important parameters for predicting run-up levels or overtopping. In shallow areas, the extreme water level often determines the water depth and thereby the upper limit for wave heights. Given the significant tidal range along the Cumberland County shoreline, and the large variety of shoreline features, general toe water levels are difficult to estimate, let alone for specific locations. **It is assumed that the toe of each structure (dam, embankment, armoured shoreline) is at MSL.** Given this assumption, the compounded effects of surge, high tide and sea level rise introduce a significant depth at the toe of each structure in addition to the MSL. The adopted approach provides more conservative results (higher run-up). If for example, the toe of a dike is at HHWLT, much of the wave energy may dissipate on the foreshore and run-up would be significantly reduced. It is recognized that this study is a very high-level approximation for deriving water levels and associated run-up. Significant variation in structure or shoreline features exist from site-to-site. **The most accurate way to determine run-up is to complete a survey of each individual coastal feature of interest.**

d) **Breaker parameter -** The combination of structure slope and wave steepness gives a certain type of wave breaking. The breaker parameter determines what type of empirical relationship is used to compute run-up for dikes, embankments and armoured shorelines as per EurOtop, (2016) guidelines.

e) **Toe of structure -** where the foreshore meets the front slope of the structure or the toe structure in front of it. The wave height that is always used in wave overtopping calculations for structures is the incident wave height at the toe. Determining the location of the toe relative to CD and MSL is critical in understanding the characteristic of the incident wave and subsequent run-up. This high-level study assumes that the toe of each structure (dam, embankment, armoured shoreline) is at MSL.

f) **Foreshore -** The foreshore is the section in front of a beach, breakwater, coastal structure or sea wall, and can be horizontal or up to a maximum slope of 1:10 (as per EurOtop, (2016) relationships). The foreshore can be deep, shallow or very shallow. If the water is shallow or very shallow then shoaling and depth limiting effects will need to be considered so that the wave height at the toe, or end of the foreshore, can be considered as well as the wave period. A foreshore is defined as having a minimum length of one wavelength. Without proper soundings, it is difficult to estimate the slope of the foreshore. In this study, it has been assumed that the water level at the toe of the structures is quite high (due to storm surge, etc.), therefore the foreshore plays a relatively minor role in wave transformation. A foreshore of 1:40 has been assumed for shorelines with a dike, embankment or armoured shoreline. For shorelines with beaches a 1:10 to 1:100 is assumed.

g) **Structure slope -** Part of a structure profile is defined as a slope if the slope of that part lies between 1:1 and 1:8. For this investigation, slopes ranging from 1:1 to 1:8 are tested, depending on the structure type (steeper slopes for armoured shorelines and slightly gentler slope for dikes/embankments). The slope has a significant impact on the wave run-up and can only be accurately incorporated if a survey of the structure in question is obtained.

h) **Permeability, porosity and roughness -** A smooth structure like a dike or embankment is mostly impermeable to water or waves and the slope has no, or almost no roughness. Roughness on the slope will dissipate wave energy during wave run-up and will therefore reduce wave overtopping. Roughness factors are adjusted in this investigation based on structure type.

i) **Effect of oblique waves -** Wave run-up and wave overtopping can be assumed to be equally distributed along the longitudinal axis of a dike. If this axis is curved, wave run-up or wave overtopping will increase for concave curves; with respect to the seaward face; due to the accumulation of wave run-up energy. Similarly, wave run-up and overtopping will decrease for convex curves, due to the distribution of wave run-up energy. In this investigation, it is assumed that there are no oblique waves and that all waves are incident perpendicular to the structure.

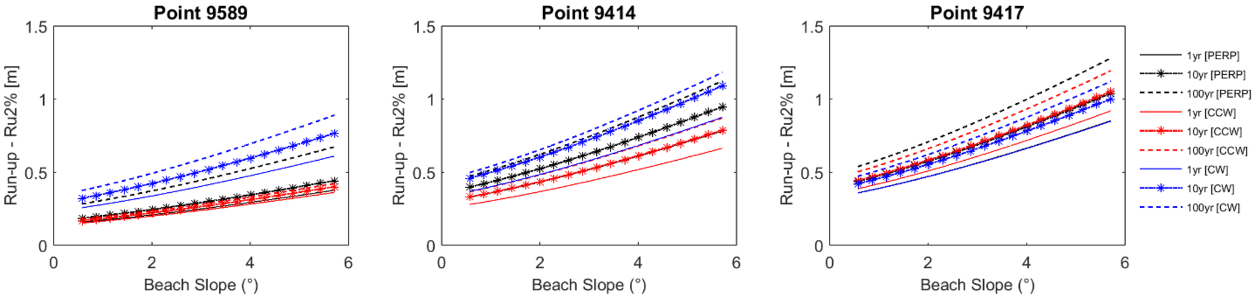
Given the extensive list of variables presented above, it is evident that **calculating run-up is best performed on a case-by-case basis for a specific site, where extensive information is made available regarding the natural and built environment.** The upcoming section attempts to consolidate the above-mentioned assumptions and limitations to illustrate the variety in wave run-up which may be experienced along the shorelines of Cumberland County.

To appreciate the magnitude of the total extreme water level, the run-up value should be added to the HHLWT, SLR, and storm surge (residual). Note that the wind wave conditions for the Minas Basin shoreline have not been included in the run-up graphs presented below. The wind wave conditions are relatively similar to the 100-yr CW event described by point 8430. Therefore, refer to this (8430) event when analyzing the southeastern portion of the County.

1.3.1 Beach environments

For the evaluation of wave run-up on beaches, the Stockdon et al. (2006) best-fit linear model is used. The plots are color coordinated according to the wave heights presented in Figure 5 and may be identified by offshore return period. The plots illustrate that wave variability along the Cumberland shoreline significantly influences wave run-up. It was found that run-up is typically lower in the sheltered eastern portion of the Bay of Fundy, and along the northeastern coastal regions of the Northumberland Strait. The western portion of Cumberland is exposed to mature waves propagating through the Bay of Fundy. Results indicate it is possible to observe run-up values close to 2m for a 100-yr storm event along potential beaches populating the western coastal zone of Cumberland. Rocky shorelines are not considered for this study.

Northumberland Strait



Bay of Fundy

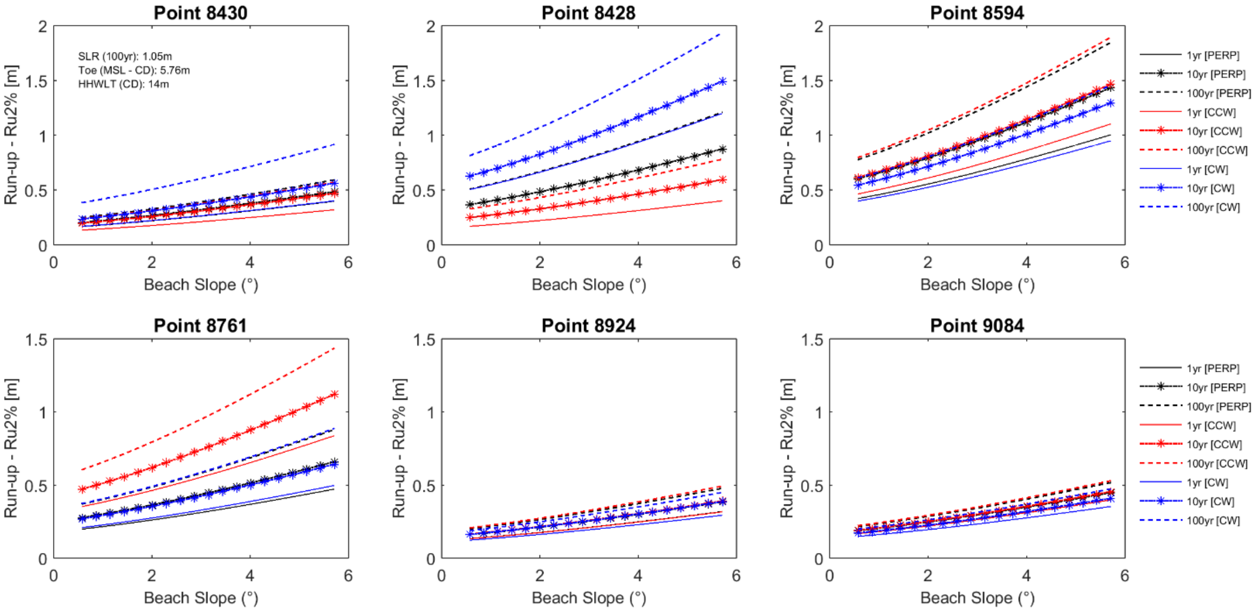


Figure 6: Run-up on Beach Environments (assumes 100-YR SLR, HHWLT & storm surge associated with return period)

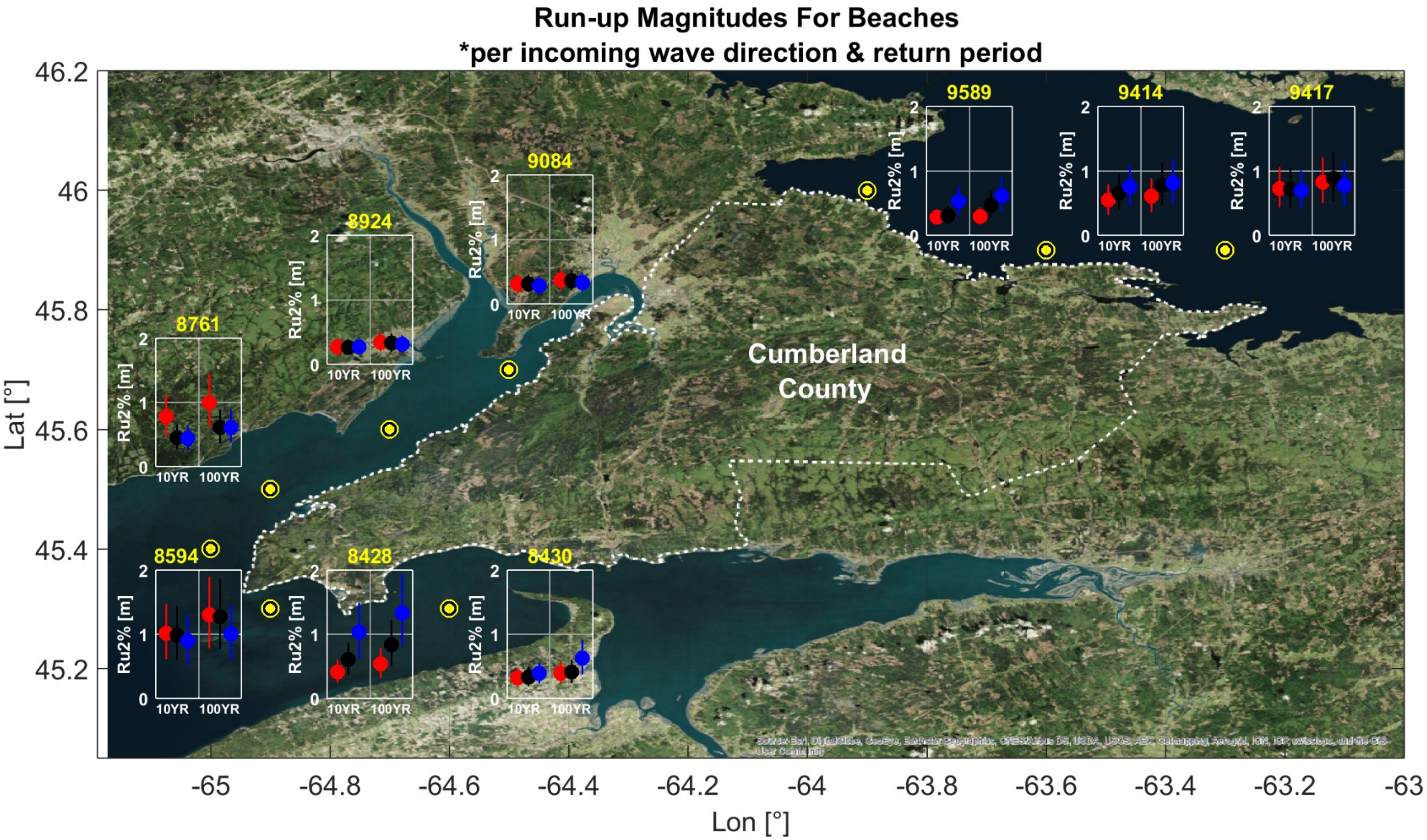


Figure 7: Average forecasted Run-up on Beaches (incl. max & min), assumes 100-YR SLR, HHWLT & storm surge associated with return period

Black dots *are color coordinated with the data presented in Figure 6 and represent wave attack perpendicular to shore from offshore MSC50 point*

Red dots *are color coordinated with the data presented in Figure 6 and represent wave attack CCW (45° bin CCW, perpendicular to shore) from offshore MSC50 point*

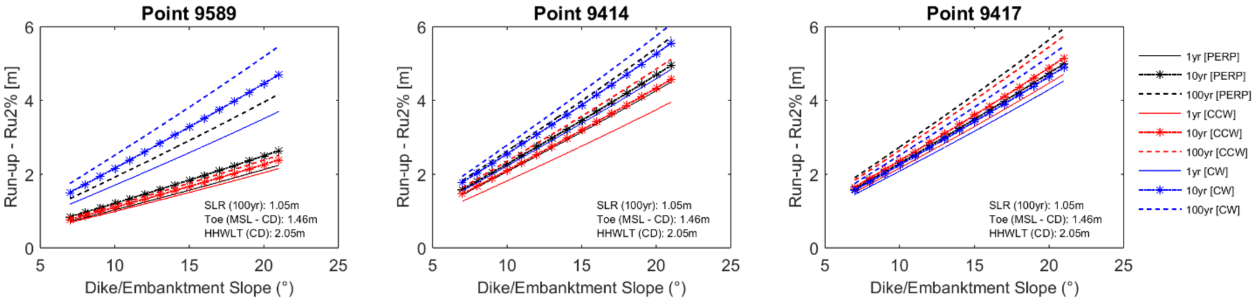
Blue dots *are color coordinated with the data presented in Figure 6 and represent wave attack CW (45° bin CW, perpendicular to shore) from offshore MSC50 point*

$Selected\ required\ inputs\ to\ estimate\ EWLs = storm\ surge + local\ high\ tide + 100YR\ SLR + \boldsymbol{wave\ run\ up}\ (from\ above\ plot)$

1.3.2 Coastal dikes and embankments

For the evaluation of wave run-up on coastal dikes and embankments the EurOtop, (2016) relationships are used in combination with Goda's (2000) wave transformation theory. An exact mathematical description of the wave run-up and wave overtopping process for coastal dikes or embankment seawalls is not possible due to the stochastic nature of wave breaking and wave run-up and the various factors influencing the wave run-up and wave overtopping process. Therefore, wave run-up and wave overtopping for coastal dikes and embankment seawalls are mainly determined by empirical formulae derived from experimental investigations. The influence of roughness elements, wave walls, berms, etc. is taken into account by introducing influence factors. The plots are color coordinated according to the wave heights presented in Figure 5 and may be identified by offshore return period. It can be observed that significant run-up can occur for very steep, impermeable slopes.

Northumberland Strait



Bay of Fundy

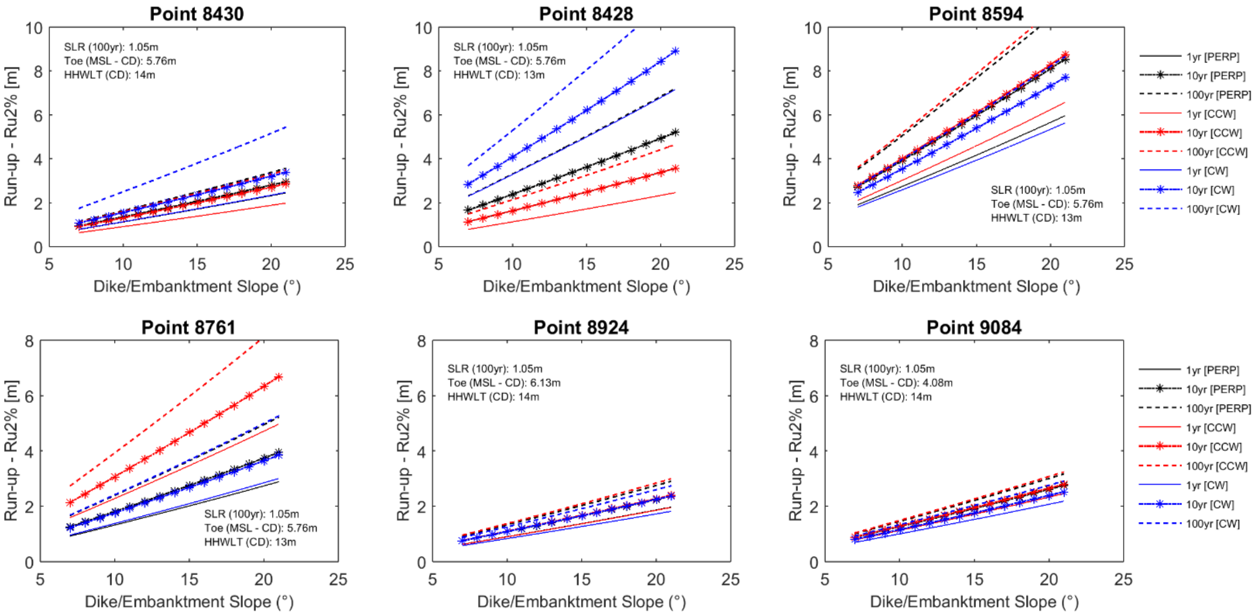


Figure 8: Run-up on Embankments & Dikes (assumes 100-YR SLR, HHWLT & storm surge associated with return period)

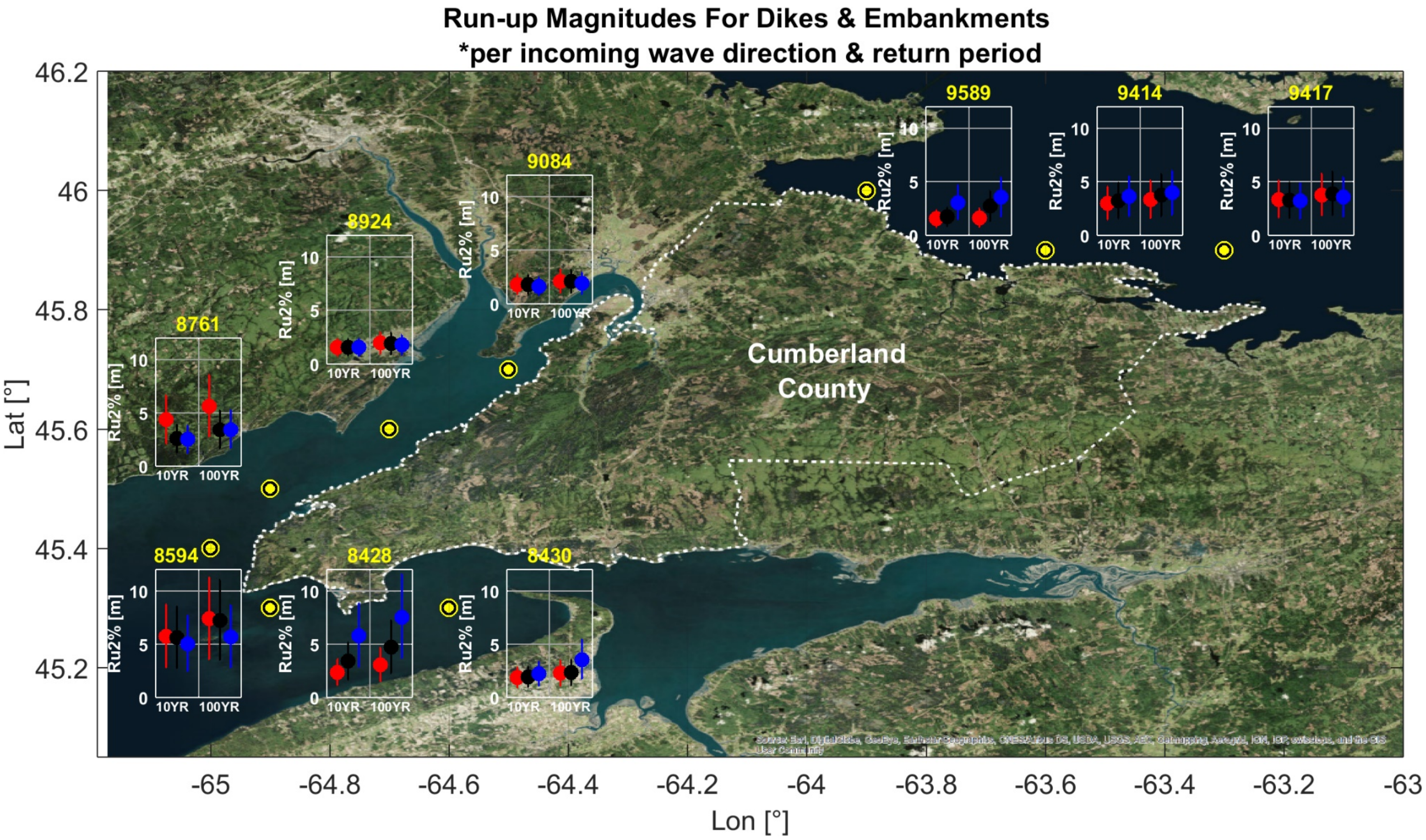


Figure 9: Average forecasted Run-up on Dikes & Embankments (incl. max & min), assumes 100-YR SLR, HHWLT & storm surge associated with return period

Black dots *are color coordinated with the data presented in Figure 8 and represent wave attack perpendicular to shore from offshore MSC50 point*

Red dots *are color coordinated with the data presented in Figure 8 and represent wave attack CCW (45° bin CCW, perpendicular to shore) from offshore MSC50 point*

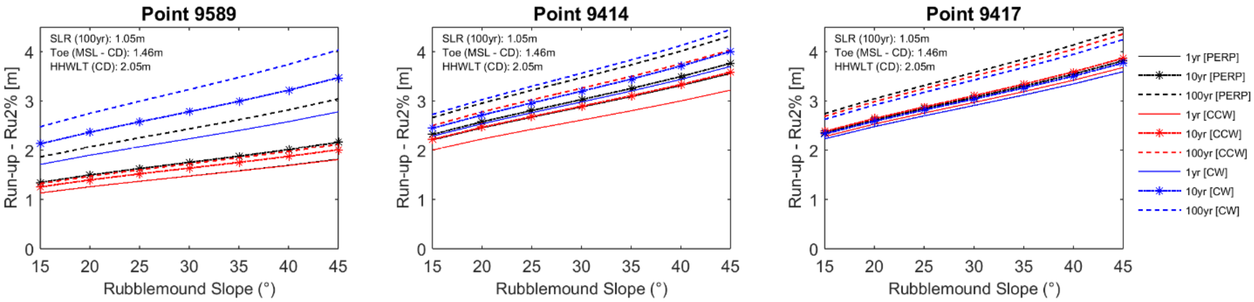
Blue dots *are color coordinated with the data presented in Figure 8 and represent wave attack CW (45° bin CW, perpendicular to shore) from offshore MSC50 point*

$Selected\ required\ inputs\ to\ estimate\ EWLs = storm\ surge + local\ high\ tide + 100YR\ SLR + \boldsymbol{wave\ run\ up}\ (from\ above\ plot)$

1.3.3 Armoured shorelines

For the evaluation of wave run-up on armoured shorelines the EurOtop, (2016) relationships were used in combination with Goda's (2000) wave transformation theory. Wave run-up has typically been less important for rock slopes and rubble mound structures as the crest height of these type of structures is typically been based on allowable overtopping, or even on allowable transmission (low-crested structures). The plots are color coordinated according to the wave heights presented in Figure 5 and may be identified by offshore return period.

Northumberland Strait



Bay of Fundy

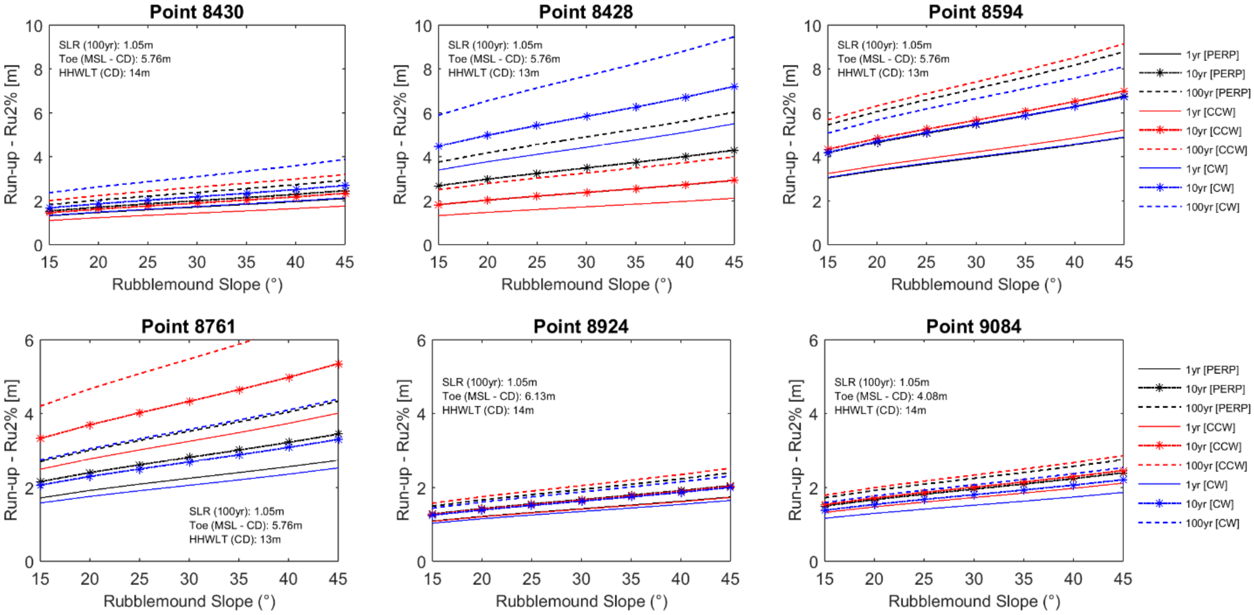


Figure 10: Run-up on Armoured Shorelines (assumes 100-YR SLR, HHWLT & storm surge associated with return period)

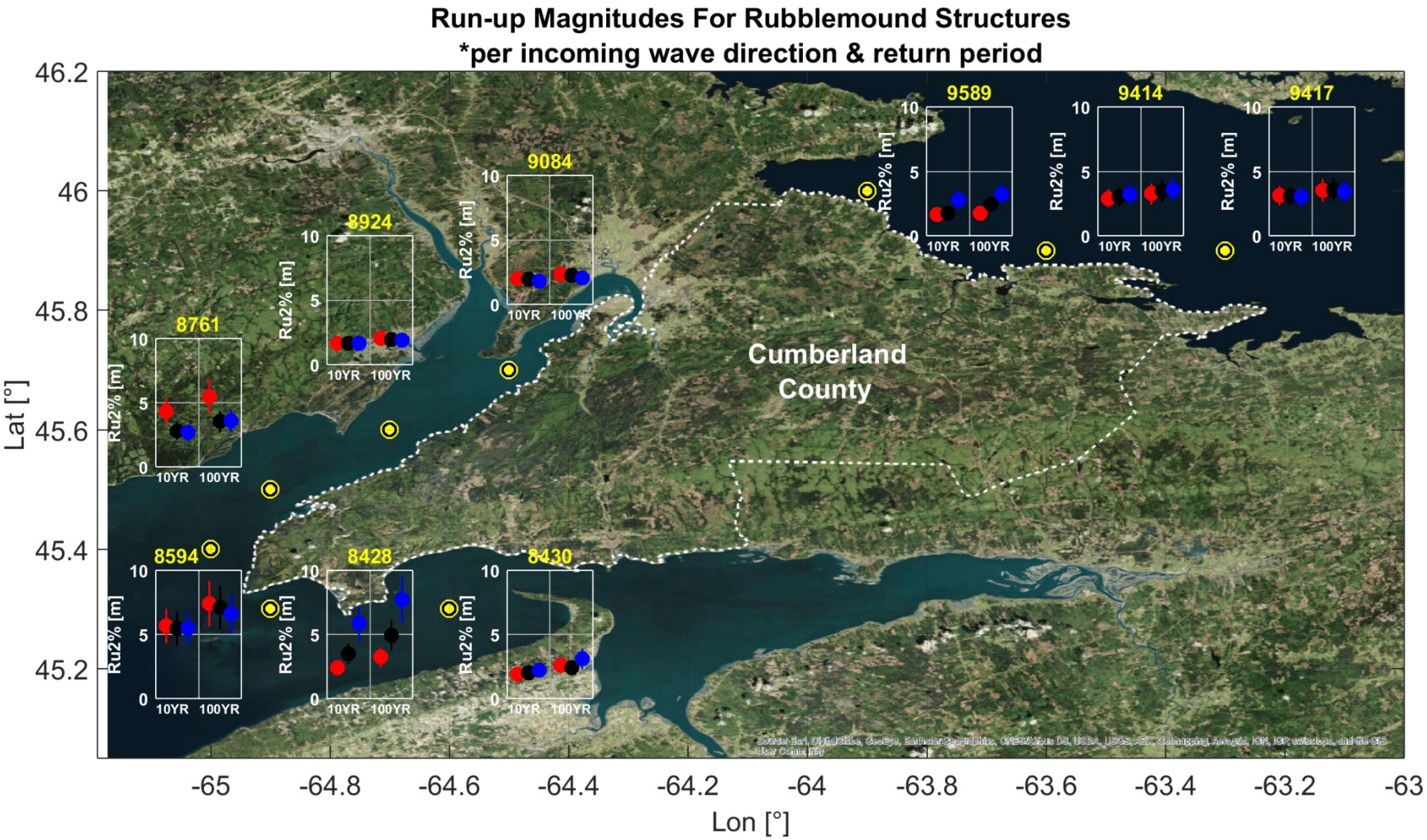


Figure 11: Average forecasted Run-up on Armoured Shorelines (incl. max & min), assumes 100-YR SLR, HHWLT & storm surge associated with return period

Black dots *are color coordinated with the data presented in Figure 10 and represent wave attack perpendicular to shore from offshore MSC50 point*

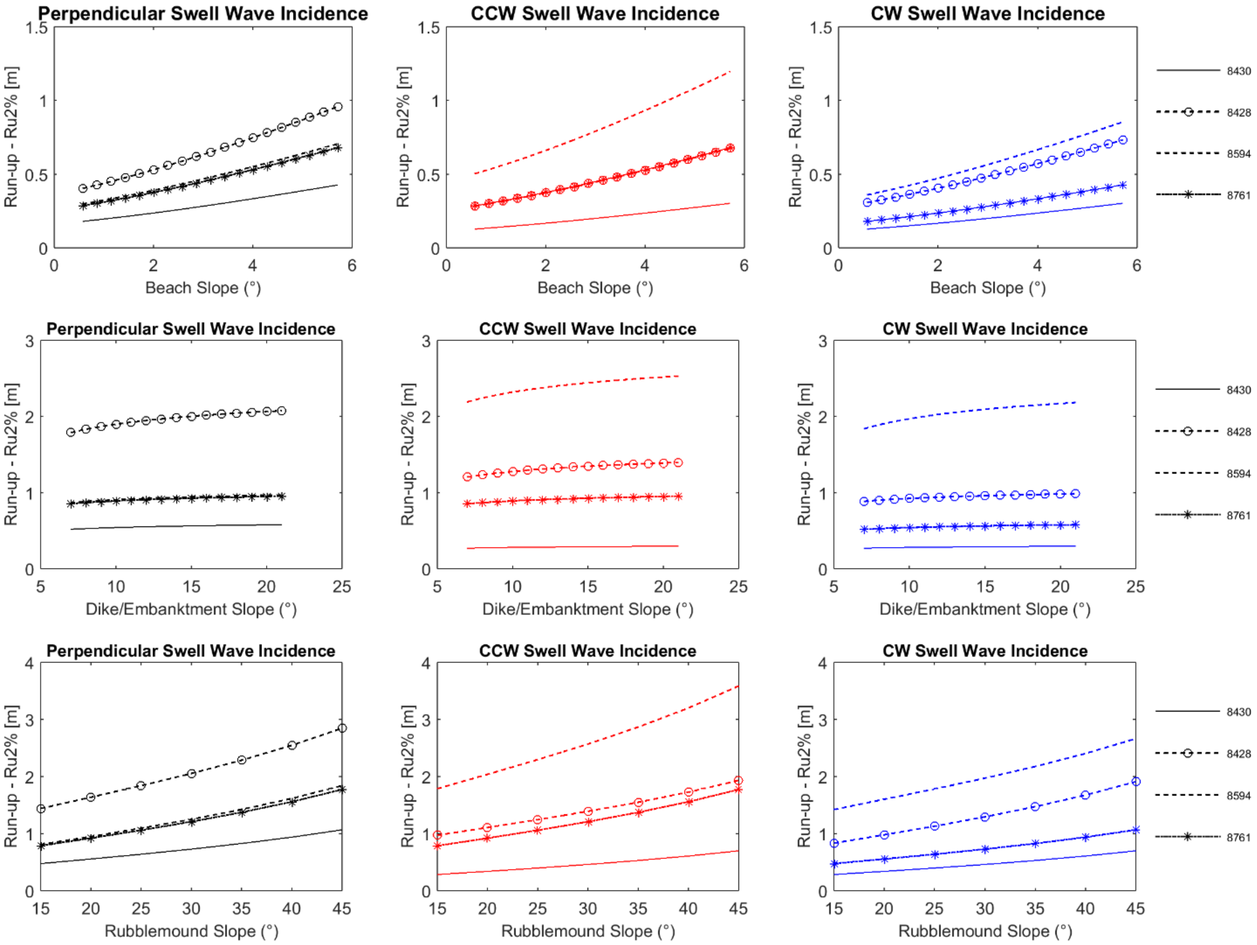
Red dots *are color coordinated with the data presented in Figure 10 and represent wave attack CCW (45° bin CCW, perpendicular to shore) from offshore MSC50 point*

Blue dots *are color coordinated with the data presented in Figure 10 and represent wave attack CW (45° bin CW, perpendicular to shore) from offshore MSC50 point*

Selected required inputs to estimate EWLs = storm surge + local high tide + 100YR SLR + ***wave run up*** *(from above plot)*

1.3.4 *Swell generated run-up*

The plots are color coordinated according to the direction of wave propagation (as per Figure 5) and identified by their MSC50 ID. The wave height and period is associated with each scenario is presented in Table 3. Where applicable, the most commonly occurring swell conditions are selected from the hindcast data for each MSC50 point and used to compute run-up.



1.4 Data Gaps

Most of the data gaps have already been identified in Section 0. These include, but are not limited to:

a) Types of structures, shoreline and corresponding location
b) Dimensions of shoreline protection features
c) Site specific MSL and CD (determines submerged or dry toe)
d) Detailed bathymetry for each scenario to estimate wave transformation
e) Site-specific wave transformation modeling and run-up evaluation
f) Adjustments of storm surge for various climate change scenarios & return periods

1.5 Additional Outputs

Table 3: Offshore Wave Climate Analysis

Offshore msc50 Location		**EVA Distribution**	**Angle of attack [from N, going to]**		**Return Period [yrs]**						**Typical Historic Swell Conditions**	
					1		**10**		**100**			
			From [°]	**To [°]**	**Hs [m]**	**Tp [sec]**	**Hs [m]**	**Tp [sec]**	**Hs [m]**	**Tp [sec]**	**Hs [m]**	**Tp [sec]**
NORTHUMBERLAND STRAIT - Cumberland County												
9589	**Perp. To shore**	WBL	150	120	0.97	4.00	1.16	4.30	1.38	6.00	-	-
		WBL	90	150	0.99	3.80	1.10	4.00	1.16	4.10	-	-
		GPD	210	270	1.35	5.50	1.62	6.30	1.88	6.80	-	-
9414	**Perp. To shore**	WBL	150	210	1.99	5.80	2.48	6.30	3.00	6.80	-	-
		WBL	90	150	1.72	5.30	1.95	5.90	2.17	6.20	-	-
		GPD	210	270	2.19	6.20	2.67	7.00	2.96	7.20	-	-
9417	**Perp. To shore**	WBL	150	210	2.37	5.80	2.99	6.30	3.67	7.00	-	-
		GEV	90	150	2.58	6.00	2.88	6.50	3.39	6.80	-	-
		GPD	210	270	2.35	5.80	2.86	6.20	3.27	6.50	-	-
BAY OF FUNDY - Cumberland County												
8430	**Perp. To shore**	WBL	330	30	1.09	4.00	1.28	4.50	1.54	5.00	0.20	10.00
		GEV	270	330	0.92	3.50	1.20	4.50	1.77	4.50	0.10	10.00
		GEV	30	90	1.11	4.00	1.39	5.00	1.88	7.00	0.10	10.00
8428	**Perp. To shore**	WBL	330	30	1.55	5.00	2.34	6.00	3.28	7.00	0.70	12.00
		GEV	270	330	1.11	4.00	1.56	5.00	2.22	5.50	0.50	10.00
		WBL	30	90	2.81	7.50	3.83	8.00	5.08	9.00	0.30	14.00
8594	**Perp. To shore**	WBL	60	120	2.62	6.50	3.53	8.00	4.62	9.00	0.30	13.50
		WBL	0	60	2.73	7.00	3.69	8.00	4.86	9.00	0.80	14.00
		GPD	120	180	2.75	6.00	3.76	7.00	4.74	7.00	0.80	10.00
8761	**Perp. To shore**	WBL	100	160	1.53	4.00	1.91	5.00	2.36	6.00	0.30	13.00
		WBL	40	100	2.14	6.00	2.82	7.00	3.54	8.00	0.30	13.00
		GPD	160	220	1.34	4.50	1.81	5.00	2.40	6.00	0.20	10.00
8924	**Perp. To shore**	WBL	100	160	0.91	3.50	1.07	3.90	1.24	4.5	-	-
		WBL	40	100	0.90	3.50	1.05	4.00	1.32	4.5	-	-
		WBL	160	220	0.87	3.30	1.03	4.00	1.20	4.3	-	-
9084	**Perp. To shore**	WBL	100	160	1.09	4.00	1.25	4.20	1.45	4.5	-	-
		WBL	40	100	1.09	4.00	1.29	4.20	1.52	4.5	-	-
		GPD	160	220	0.95	3.80	1.15	4.00	1.33	4.3	-	-
JONSWAP	**Perp. To shore**	-	330	30	-	-	-	-	1.86	5.11	-	-

Appendix C

References

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Document Name & Purpose	Coastal Processes and Related Risks	Analysis					Outcomes	
		Field	Modelling, or GIS Analysis	Policy or BMP Review	Economic Assessment	Background (e.g., Historical, Scientific)	Vulnerable Locations Identified	Recommendations (e.g., Policy, Engineering Criteria)
CBCL (2009) "State of Nova Scotia's Coast Technical Report"	– Flooding – Coastal Erosion – Degredation of sensitive coastal ecosystems and habitat	N/A	N/A	N/A	– Table 7-2 : qualitative socio-economic impactgs of sea-level rise and storm events – Costs provided for Hurricane Juan – Cost discussion for Acadian dykelands	– Key points on Coastal Management Framework – Factors that cause sea-level rise in NS – In addition to Economic, the social and ecological implications of SLR and storms	– Draws attention to different magnitures of SLR across the province – General characteristics of areas greatest at risk	N/A
Richards and Daigle (2011) "Scenarios and Guidance for Adaptation to Climate Change and Sea-level Rise"	– Flooding (extreme water levels)	N/A	N/A	– A few examples of adaptation strategies in various municipalities but policies not reviewed explicitly	N/A	– Main contribution is review of scientific approach to use of scenarios (e.g., indices used, ensembles, model validation,etc.) and explanation of processes involved in climate change(e.g., crustal subsidence, changes in storm surge return periods, etc.)	– Some areas addressed as case studies. Values provided for future climate and coastal water levels for 22 target municipalities in NS and PEI, but locations are not specifically compared in terms of vulnerability.	– Reviews research and recommendations from certain groups (IPCC, Adaptation and Impacts Research Section of Environment Canada) – Main contribution is recommended future climate and coastal water level values to used for climate change action plans
Stantec (2011) "Environmental Planning Framework"	– Flooding – Coastal Erosion	N/A	N/A	– Review of policies in different jurisdictions and evaluation of currently policies in Cumberland County, with sections on: development setback and vegetative buffers, coastal elevation requirements, shoreline stabilization, flooding, and coastal vulnerability.	N/A	N/A	N/A	– Short-term, Long Term Direction, Policy Recommendations or Engagement Recommendations for each area of policy review. – Recommendations for Inter-jurisdictional Cooperation based on similarities in challenges.

Longhurst and Milton (2012)	– Coastal flooding – Sea level rise	N/A	N/A	N/A	N/A	– Background on the geography, development and history, economy, and social context of Amherst. – Identification of climate change issues of concern in Amherst	N/A	proposed climate adapatation activities (e.g., review policy recommendations from other sources)
van Proosdij and Page (2012) “Best Management Practices for Climate Change Adaptation in Dykelands”	– Overtopping and breaching of dykes – Shoreline erosion – Coastal squeezing	– A physical assessment was done for all of the dykes within the Fundy ACAS study areas, including field visits, wave exposure analysis and historical erosion rates, foreshore width and observed erodibility as well as type and extent of shore protection applied. – Shore zone characterization project focussing on composition, type and material, as well as evidence of erosion, sedimentation, storm damage and manmade shoreline protection.	– GIS comparison of surveyed elevations with critical dyke elevations for the Fundy ACAS communities	– An analysis of engineering best practices (e.g., slope, crest elevation, material, maintenance of foreshore, creek modifications) using information from NS, NB and BC, as well as other regions in the world. – A comprehensive review of international best practices for climate change adaptation in dykeland areas, including three main climate change adaptation approaches: hold the line (defend), re-align (retreat) or abandon. – Adaptation can take the form of either engineering solutions or management approaches. Engineering solutions can include both hard (e.g. rock armouring) or soft (e.g. salt marsh restoration or terracing).	– Economic cost of temporary flooding delays are cited. – Dykeland values are assessed	– Overview of coastal processes relevant to dykes and shoreline erosion	– critical elevations of different dyke sections are obtained – shorezones of concern are characterized – vulnerable marsh bodies are flagged	– A number of recommendations are made for salt marsh/foreshore protection and dyke maintenance/adjustments – Cooperation is required at federal, provincial and local levels to find funding for dyke heightening, with a combination of both an engineering and management approach.

Webster *et al.* (2012a) “An Evaluation of Flood Risk to Infrastructure Across the Chignecto Isthmus”	– Flooding, in particular due to dyke overtopping – Salt water damage	– field surveys to ground-truth the digital elevation model and flood modeling predictions	– GIS used to prepare set of flood risk maps of the Isthmus area, water level assumed to be a flat plane – Hydrodynamic modelling (Mike21) during perigean spring tides in November 2012.	N/A	– Public and private assets of dykeland quoted to > $70 million in NS – Dyke overtopping and flooding of portions of the railway and highway would results in delays in trade of $50 million per day. – Public and private assets have more than ten times the value of agricultural assets in the dykelands	– Background review of the state of historically high water levels, estimating high water level return periods, estimates for sea-level rise and physical processes involved in sea-level rise	– Thirteen locations were identified where sections of the dyke elevation is low enough to allow overtopping at critical water level elevations – critically-low segments within agricultural dykes in NS and NB that would flood during storm surges that coincide with high tides were identified – areas and transportation infrastructure at risk on the Isthmus were identified	– identify potential alternative routes for sustainable transportation; – recommend considerable upgrades to the dyke system or other adaptation options be implemented – A hypothetical connector route along the highest terrain is identified

Webster *et al*. (2012b) “River Flood Risk Study of the Nappan River Incorporating Climate Change”	– flooding – changes in sedimentation	– Lidar was obtained for the region in Oct 2009 – installed a pressure sensor to measure river stage for one field season – visited the site on several occasions through the field season of 2011, measuring flow and stage, recording water levels with survey grade GPS, and executing a bathymetric survey of the river bed	– a series of models were assembled to study the impact of a simulated aboiteau on flooding – constructed a seamless elevation model (lidar + bathymetry) to facilitate the extraction of river cross-sections used in the 1D hydraulic river model – Modelling also included a watershed rain-fall runoff model and a 2D hydrodynamic tide model for the Upper Bay of Fundy (to better control the function of the aboiteau in the model) – Past flooding events were simulated as well as two and three times the rainfall to simulate possible increases in precipitation with climate change	N/A	N/A	– a review of flooding issues in Nappan is presented – considerations for a potential aboiteau (siltation, restricted drainage, etc.) are explained	– flood mapping reveals areas vulnerable to flooding under different scenarios	– To improve the modelling, a 2D floodplain model should be used, precipitation estimates should be improved using radar the Environment Canada Radar Precipitation map or additional weather stations, and additional field work could be conducted in order to survey the floor of the aboiteau at low water.
Webster *et al.* (2012c)	– Flooding	– Lidar surveys of the coastal communities	– stillwater flood levels every 10 cm (like other Webster report)	N/A	N/A	– expected return periods of benchmark storms under present and future conditions	N/A	N/A

CBCL (2013) “Design & Construction of the LaPlanche River Aboiteau”	– Flooding	– Site visit, Topographic surveys, geotechnical investigations – Field observations of suspended sediment concentrations used to calibrated sediment transport model	– Hydrologic and Hydraulic model, tide levels – Hydrodynamic and sediment transport modeling	– Costs of flood damage (agricultural lang use, other infrastructure and land uses) – Costs of flood protection (raising dykes, improving marsh drainage) – Estimated probable costs of constructing an Aboiteau at each of the three sites	N/A	– Current background of the site (existing dykes and aboiteaux, existing configuration of marsh drainage, current land use) – Review of impacts of climate change – Proposed aboiteaux locations were evaluated	N/A	– Aboiteau design recommendations,operation and maintenance – Recommendations outlined within the recent ACAS dykeland vulnerability and best practices report (van Proosdij and Page, 2012) should be applied as a minimum. – Measures for flood protection (including Implementation plan for Aboiteau), Flood proofing existing development, Recommendations for potential future development of the marshes
Daigle (2014) “Sea-Level Rise and Coastal Flooding Estimates for Chignecto Isthmus and Halifax Harbour”	– Flooding from sea-level rise and storm surge	N/A	– regional sea-level rise value for Chignecto Isthmus was extrapolated from the Shediac, Charlottetown, Saint John and Halifax values	N/A	N/A	– addresses the main components of regional sea level rise (global sea-level rise, distribution of glacial meltwater, vertical land motion, regional oceanographic effects, bay of fundy tidal range, – review two main reports for updated sea-level rise: IPCC AR5 and James et al. Report – use these in conjunction with previously prepared storm surge return period statistics to produce new extreme water level estimates for the Chignecto Isthmus	N/A	N/A
ACASA (2015) “Engineering Tools for CC Adaptation in Coastal Areas of Atl. Can.”	– Flooding – Unstable shorelines (from wave scour, sediment transport,	N/A	N/A	– Tools (land use planning, engineering structures) depending on different coastal type and wave exposutre – soft and hard engineering – Shoreline stabilization	– Order-of magnitude installation cost range	– Adaptation approaches (protect, retreat, etc.) – Summary of coastal processes and engineering implications (water levels, waves, currents, sediment transport and erosion)	– Key variations of coastal concerns across atlantics provinces (regional scale only)	N/A

Withey *et al.* (2016) "Chignecto Isthmus Cost Benefit Analysis Results".	– Disruption of transportation across the isthmus due to flooding	N/A	N/A	– Disruption to Trans-Canada Highway, the CN railway and electricity transmission lines.trade and traffic flows – Damage to infrastructure, cost due to trade and traffic delays – indirect impactssuch as clean-up, emergency services and commercial delays are ignored. – impact on agricultural land and marshland is considered, however only in the adaptation options – analysis does not consider impacts to residential or commercial infrastructure, as this is beyond the scope of the project. Wilson et al. (2012) – cost of adapatation options (including raising dykes, building new dykes, rerouting highway, replacing aboiteaux	N/A	N/A	– Trans- Canada Highway, the CN railway and electricity transmission lines. – Region itself is identified as vulnerable	– No, just tools given to be taken into consideration
Savard *et al.* (2016) "Perspectives on Canada's East Coast region"	– Relative sea level – Storm surge and extreme water level – Wave climate and sea ice – Geomorphology, sediment supply and coastal dynamics – Saltwater intrusion – failure of coastal infrastructure – shoreline erosion – coastal and inland flooding – ice pile-ups – saltwater intrusion	N/A	N/A	– Current state of planning or implementation for of climate change adaptation in communities across the region – Discussion of exposure, sensitivity, vulnerability, and adaptability in general terms.	– Economic impacts on fisheries, aquaculture, transportation, and tourism.	– Observations and projections in relevant climate changed (sea-surface temperatures, ocean acidity, sea ice cover, wind and storms) – Changes in coastal processes (sea-level rise, storm surge and extreme water levels, wave climate and sea ice, geomorphology)	N/A	– Factors affecting adaptation and adaptation options including no active intervention, avoidance and retreat, accommodation, and protection.

Appendix B – Compilation of Extreme Water Levels and Coastal Vulnerability

Cumberland County hosts a wide variety of coastal features, such as natural beaches, dikes, embankments, armoured shorelines and seawalls (Figure 1). Such a variety of shoreline types in combination with some of the highest tides in the world, creates a complex and often vulnerable coastal environment for municipalities to manage. A County wide holistic management approach to mitigating coastal vulnerability and risk is therefore a complex task. The following high-level study aims to illustrate the challenges and potential regions of concern for extreme water levels along the Cumberland County shoreline. The study will focus on beaches, dikes and armoured shorelines. Seawalls will not be considered, for such structures are best studied on a case-by-case basis.

Figure 1: Shoreline Types Influencing Wave Action

TL: Bayswater Beach, NS (source: NS Parks, 2017), TR: Embankment or Dike (source: EurOtop, 2016),
BL: Cow Bay Revetment, NS (source: National Post, 2012), BR: Seawall (source: EurOtop, 2016).

Extreme Water Levels (EWLs) occur when several physical drivers interact and develop simultaneously to create higher than usual water elevation at a specific location. Such drivers are typically, storm surge, extreme waves (run-up), Highest Astronomical Tide (HAT), and effects such as Sea-Level-Rise (SLR). In this study, EWLs will be described by:

$$EWLs = storm\ surge + high\ tide + sea\ level\ rise + wave\ run\ up$$

1.1 Tides, Sea Level Rise & Storm Surge

Tides – Historic water levels are monitored by the Department of Fisheries and Oceans Canada (DFO) in the Bay of Fundy at Saint John (station #65). Considering both the location of the Saint John station in relation to the Area-of-Interest (AOI), and the complex tidal system in the Bay of Fundy, the raw data from station #65 cannot be easily applied to this study. Instead, three other data sources are considered and combined to construct a high-level interpretation of the extreme tidal levels in the AOI. These are:

1. DFO's WebTide numerical model;
2. Spring tidal range as defined by Cousineau J., Nistor I., Cornett A. (2012);
3. Higher High Water Large Tide (HHWLT) as summarized by Richards W., Daigle R., (2011) based on information from the Department of Fisheries and Oceans (DFO).

The output from the above sources are combined in Figure 2. The spring tidal range is the most extreme tidal range and occurs around a full or new moon, when the gravitational forces of both the Sun and Moon are in phase. The spring tidal range gets progressively larger as one moves up the Bay of Fundy towards Joggins and Burncoat Head. In contrast to the Bay of Fundy, the tidal ranges along the Cumberland Strait are significantly lower (e.g. Pictou - Figure 2). Tidal ranges have been verified using the DFO's WebTide numerical model.

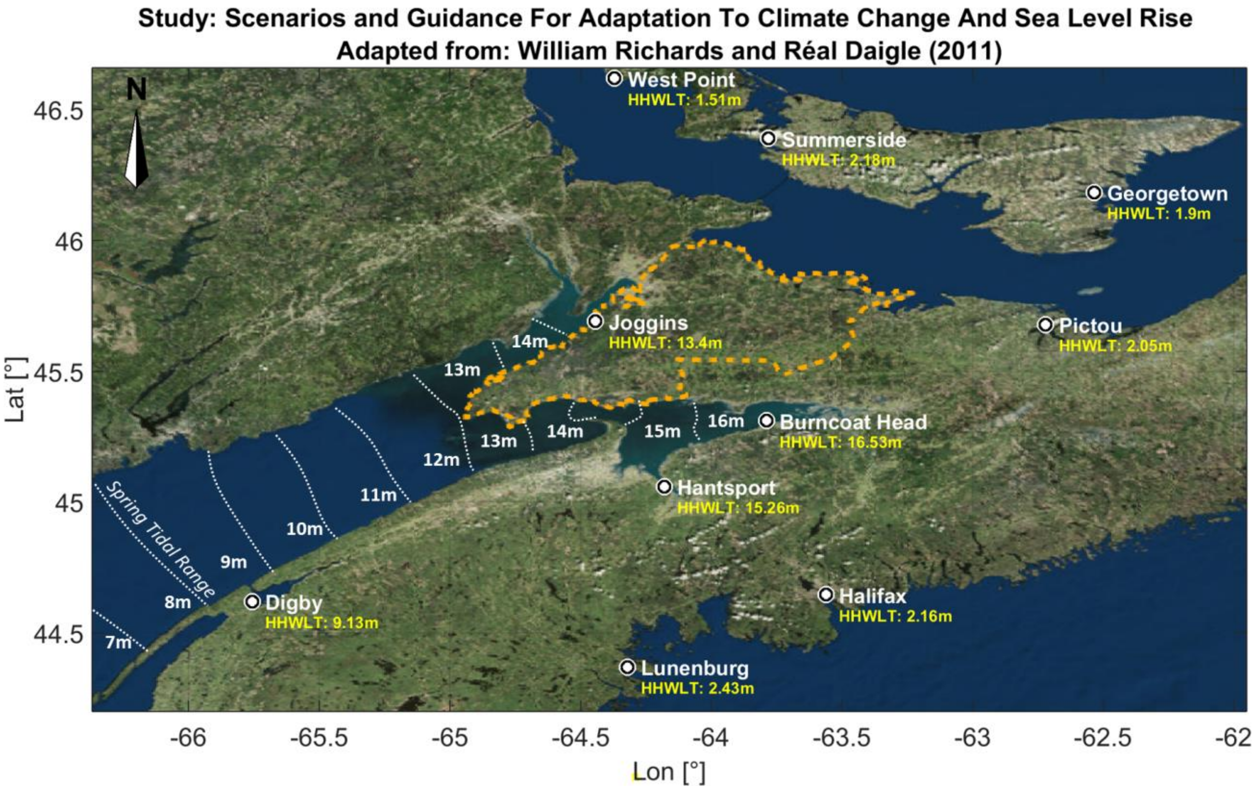


Figure 2: Water levels (Bay of Fundy)

- *HHWLT = Higher High Water Large Tide, i.e. the average of the 19 annual maxima over a 19-year full tidal cycle*
- *Vertical reference level is Chart Datum, where the zero is typically close to the lowest tide level. Therefore, the HHWLT elevation is a good indication of the total tidal range.*

Figure 2 illustrates the variation in extreme tidal range along the Nova Scotia and Cumberland County shorelines. The site-specific variation in tide highlights the importance of spatially reporting and studying tidal ranges across the area of interest. When determining extreme water levels, the tidal range can play a significant role in the impact storm surge or wave run-up have on a local site.

Sea Level Rise projections in Nova Scotia and PEI are reported by Richards W. & Daigle R., (2011). This 2011 report was commissioned specifically for assisting municipalities in planning for sea level rise. Since 2011, scientists have updated sea level rise estimates. Notably, DFO (Zhai et al 2014) has issued sea level rise projections for all Canadian fishing harbours based on the 2013 Intergovernmental Panel on Climate Change 5th Assessment Report (IPCC AR5, 2013). The updated values are in the same order of magnitude as those reported in Richards & Daigle for the study area, i.e. approximately 1 m SLR by year 2100 for the high emission scenarios. Therefore, CBCL is still using the 2011 reference for consistency in terms of geographical sites and inclusion of tide and storm surge in a single reference. Estimates of SLR are considered for Hantsport, Joggins and Pictou as these are the three closest sites to the AOI. The findings from Richards W. & Daigle R., (2011) are summarized in Table 1 and consider several climate scenarios and models to derive the mean SLR and associated standard deviations. Factors considered to derive SLR include:

a) Thermal expansion of the oceans;
b) Melting of nonpolar glaciers and;
c) Changes in the volume of the ice sheets of West Antarctica and Greenland.

Sea levels along most coasts of Atlantic Canada are rising due to the fact that these coastlines are very slowly subsiding (up to a few tenths of meters per century). This factor relates to a post-glacial rebound of the earth's crust (Richards W. & Daigle R., 2011).

Table 1: Estimated Total Sea Level Rise [m]

Location	2025	2055	2100
Hantsport	0.16 *+/- 0.03*	0.86 *+/- 0.36*	1.10 *+/- 0.48*
Joggins	0.15 *+/- 0.03*	0.82 *+/- 0.36*	1.05 *+/- 0.48*
Pictou	0.15 *+/- 0.03*	0.82 *+/- 0.15*	1.05 *+/- 0.48*

Adapted from: Richards W. & Daigle R., (2011)

Storm Surge can be defined at the coast as the difference between the observed water level and the predicted astronomical tide. Large positive storm surges at times of high tide are events that lead to coastal flooding, whereas when they coincide with low tides, flooding problems are averted. For added safety in the context of planning purposes, it is assumed that the extreme storm surge coincides with the HHWLT. This is a reasonable assumption for areas with moderate tidal range and relatively high storm surge, such as the Northumberland Strait. However, it is conservative along Fundy shorelines, because the 100-year storm surge residual coinciding with a HHWLT would represent an event of return period greater than 100 years.

Elevated sea levels enhance wave attack and coastal erosion. The magnitude of storm surges depends on the nature of the meteorological event responsible for the reduced atmospheric pressure and the strength of the winds associated with a particular event (Richards W. & Daigle R., 2011). As with the SLR predictions, storm surge residuals are considered for Hantsport, Joggins and Pictou (Table 2).

Table 2: Estimate Storm Surge (Residual) [m]

Return Period	Hantsport	Joggins	Pictou
10-YR	0.85 *+/- 0.20*	0.85 *+/- 0.20*	1.12 *+/- 0.10*
25-YR	0.96 *+/- 0.20*	0.96 *+/- 0.20*	1.27 *+/- 0.10*
50-YR	1.04 *+/- 0.20*	1.04 *+/- 0.20*	1.38 *+/- 0.10*
100-YR	1.13 *+/- 0.20*	1.13 *+/- 0.20*	1.49 *+/- 0.10*

Adapted from: Richards W. & Daigle R., (2011)

These results in Table 2 are based from a combination of historical tide gauge observations and modeling such as the work by Bernier et Thompson (2006) presented in Figure 3. This Figure illustrates that the Northumberland shore is more prone to high storm surge residuals than the Fundy shore.

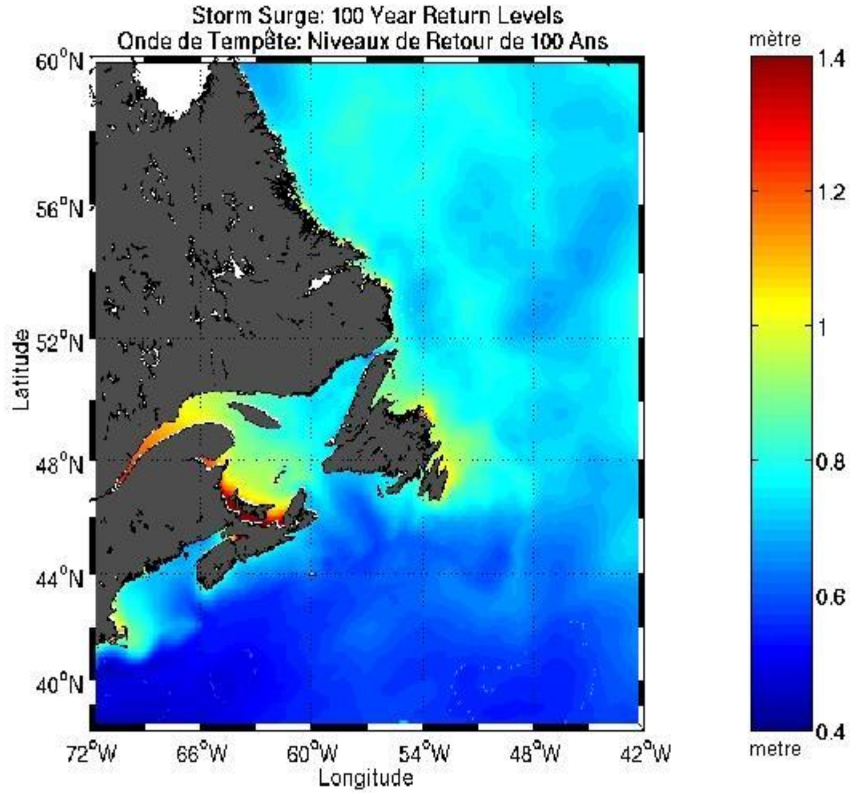


Figure 3: Modeled Extreme Storm Surge Residual (source: Environment Canada, based on Bernier et Thompson 2006)

Water levels can fluctuate significantly above the toe of a coastal structure. Understanding the submergence of the structure toe during extreme events, in relation to a local datum, is necessary to forecast whether the hinterland may be vulnerable to flooding from surge, run-up and overtopping. Each coastal structure is uniquely different and often referenced to a highly-localized Chart Datum (CD); a datum level used on navigation charts, defined to be close to lower low-water at large tides. The data presented in this study is referenced as closely as possible to CD sourced from Canadian Hydrographic Service (CHS) navigation charts. Mean Sea Level (MSL) values are recorded from various CHS charts and summarized in Figure 4. The MSL is representative of the average of HHWLT and CD-zero. For land planning purposes, GIS applications make use of a geodetic reference level (i.e. CGVD28), requiring a conversion between CD and CGVD28 that is specific to each location. CGVD28-zero value represents approximately the MSL value, but there are varying differences depending on the location (normally within 10-25 cm) (Richards W. & Daigle R., 2011). The MSL is an important parameter in this study as it will be used to determine the magnitude of wave run-up on generic profiles of embankments, dikes and armoured shorelines.

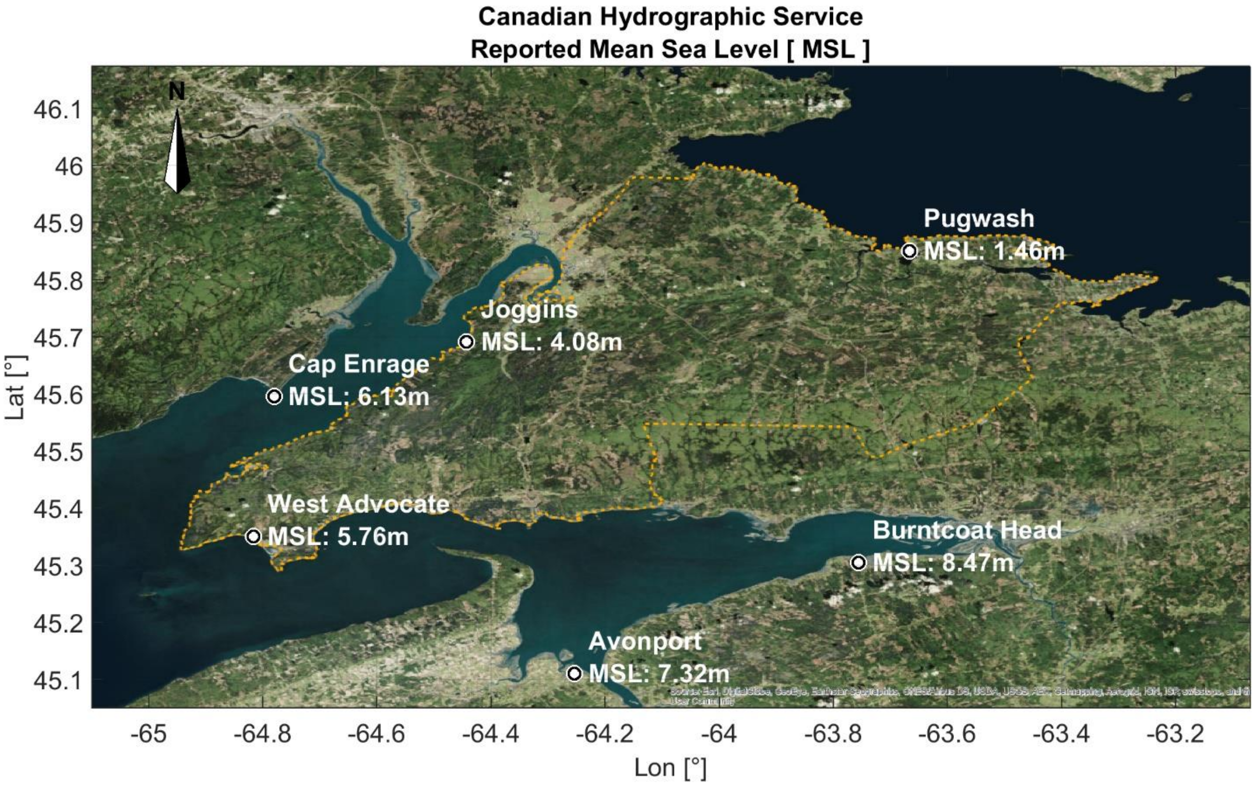


Figure 4: Reported Mean Sea Level (MSL) relative to Chart Datum

1.2 Wave Climate

Richards W. & Daigle R., (2011) note that the residual values they report for storm surge exclude the incremental value of any wave run-up that could potentially accompany a storm surge event. Wave run-up varies significantly from site to site depending on local wave conditions and physical shoreline features. Wave run-up increases local extreme water levels, resulting in localized overtopping, which could introduce additional hinterland hazards, risks and potential for damage. To accurately compute run-up a site specific coastal engineering assessment is typically required, using hydrodynamic modeling with high resolution bathymetry (which is outside the present scope). As this is a high-level study, a series of generalized run-up investigations will be performed using regional inputs, general design guidelines, tolerances and thresholds.

An offshore wave climate is defined to generate the required nearshore wave inputs for run-up computations. The MSC50 hindcast (covering the period from 1954-2013) is used in this study to determine the characteristic wave climate along the Cumberland County shore. The MSC50 project was funded by the Climate Research Division of Environment Canada and the Federal Program of Energy Research and Development and is provided for this study by Environment Canada. Nine MSC50 points are extracted from the model for this analysis (Figure 5).

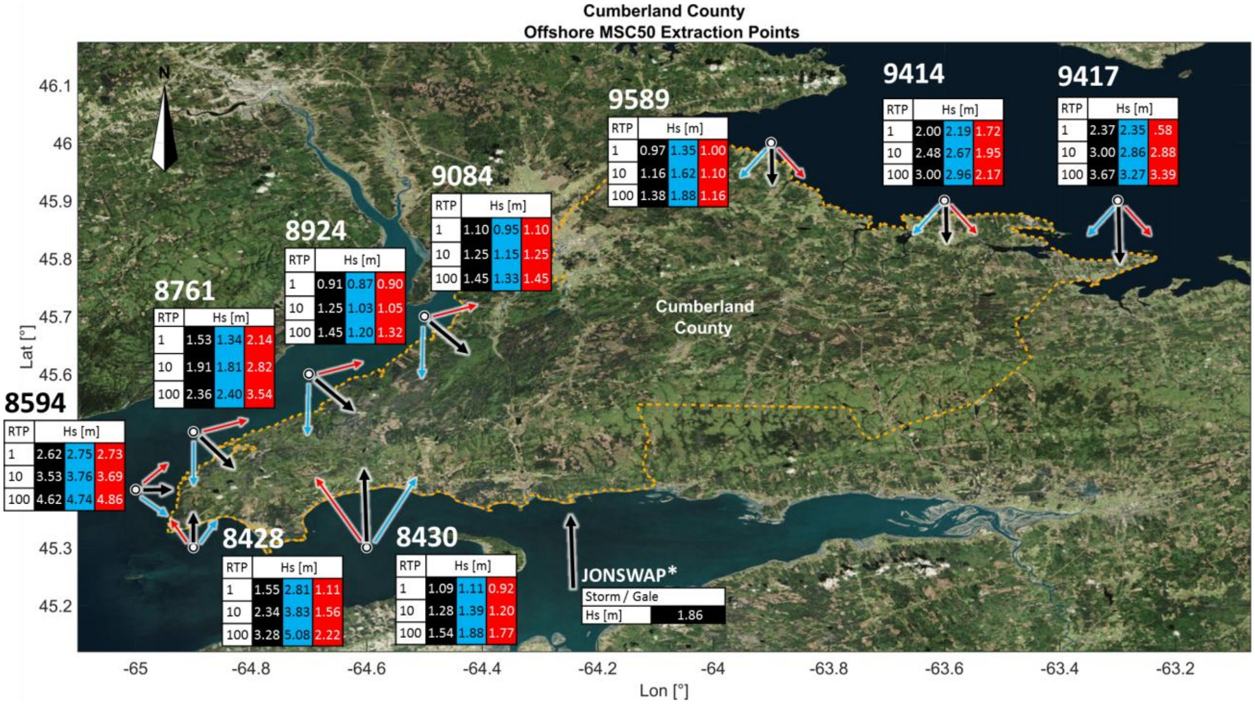


Figure 5: Extreme Offshore Wave Climate: Cumberland County (1-, 10-, 100-yr return periods)

The offshore MSC50 wave height and period data is split into directional bins ("going towards" where north is 0°), perpendicular (black arrows) to the nearest shoreline, and in bins 45° clockwise (CW – blue arrows) and counter-clockwise (CCW – red arrows) to the perpendicular incident offshore waves. The angles of wave attack will be used in the run-up analysis and are anticipated to produce the most dramatic result given their offshore origin and orientation in relation to the shoreline. For each directional bin of each MSC50 point, a peak-over-threshold (POT) analysis is performed to isolate the largest storm events. The output from the POT is then used to derive wave height return periods (1-, 10-, 100-yr) using an extreme-value-analysis (EVA). The POT data is fitted to either a Weibull distribution, generalized extreme value distribution or a generalized Pareto distribution. The results of this analysis are plotted in Figure 5 per directional bin.

For more detailed information, such as the wave period associated with each wave height, Table 3 can be referenced in Section 1.5. Swell events for points 8430, 8428, 8594, and 8761 are also considered (Table 3), due to the considerable impact that these types of waves can have on run-up. There is no MSC50 data available for the southeastern coastal section of Cumberland County. To account for this area, an offshore wave height is generated using a JONSWAP distribution with the characteristics of a 23km fetch, 12hr storm duration, and gale magnitude winds from the south (worst case scenario).

1.3 Run-up Analysis

When ocean waves approach a coast, most of the wave energy is dissipated across the surf zone by wave breaking. However, a portion of that energy is converted to potential energy in the form of run-up on the foreshore of areas such as a beach. Wave run-up is important to coastal planners and coastal engineers because these motions deliver much of the energy responsible for dune and beach erosion

(Sotckdon, et. al 2006), and can result in overtopping and additional localized flooding. During events with extreme water levels, less energy may be dissipated across the surf zone, and run-up values may be greater. This is especially the case for armoured shorelines or dikes where the toe of the structure may be submerged during a significant event. Such configuration results in considerable wave energy reaching the structure's slope, therefore creating significant run-up and heightening the chances of overtopping.

The wave run-up height is given by $R_{u2\%}$. This is the wave run-up level, measured vertically from the still water line, which is exceeded by 2% of the number of incident waves. The number of waves exceeding this level is hereby related to the number of incoming waves and not to the number that runs up the slope (EurOtop, 2016). Run-up is relevant for beaches, smooth slopes and embankments and for rough slopes armoured with rock or concrete armour. Wave run-up does not have an equivalent parameter for vertical structures.

Many factors influence the magnitude of run-up height ($R_{u2\%}$), these include but are not limited to:

a) **Wave height -** In many cases, a foreshore is present on which waves can shoal and break, by which the significant wave height is reduced. In this investigation, offshore wave heights are transformed to nearshore conditions using the Goda (2000) formulations. This approach was selected to obtain order-of-magnitude estimates over a large area for planning purposes. However it is not substitute for site-specific wave transformation modeling that would be required for engineering design at a given site.

b) **Wave period** significantly influences wave run-up as it determines the breaker parameter (surf similarity or Iribarren number). The breaker parameter determines what type of empirical relationship is used to compute run-up for dikes, embankments and armoured shorelines as per EurOtop, (2016) guidelines.

c) **Water level** is one of the most important parameters for predicting run-up levels or overtopping. In shallow areas, the extreme water level often determines the water depth and thereby the upper limit for wave heights. Given the significant tidal range along the Cumberland County shoreline, and the large variety of shoreline features, general toe water levels are difficult to estimate, let alone for specific locations. **It is assumed that the toe of each structure (dam, embankment, armoured shoreline) is at MSL.** Given this assumption, the compounded effects of surge, high tide and sea level rise introduce a significant depth at the toe of each structure in addition to the MSL. The adopted approach provides more conservative results (higher run-up). If for example, the toe of a dike is at HHWLT, much of the wave energy may dissipate on the foreshore and run-up would be significantly reduced. It is recognized that this study is a very high-level approximation for deriving water levels and associated run-up. Significant variation in structure or shoreline features exist from site-to-site. **The most accurate way to determine run-up is to complete a survey of each individual coastal feature of interest.**

d) **Breaker parameter -** The combination of structure slope and wave steepness gives a certain type of wave breaking. The breaker parameter determines what type of empirical relationship is used to compute run-up for dikes, embankments and armoured shorelines as per EurOtop, (2016) guidelines.

e) **Toe of structure -** where the foreshore meets the front slope of the structure or the toe structure in front of it. The wave height that is always used in wave overtopping calculations for structures is the incident wave height at the toe. Determining the location of the toe relative to CD and MSL is critical in understanding the characteristic of the incident wave and subsequent run-up. This high-level study assumes that the toe of each structure (dam, embankment, armoured shoreline) is at MSL.

f) **Foreshore -** The foreshore is the section in front of a beach, breakwater, coastal structure or sea wall, and can be horizontal or up to a maximum slope of 1:10 (as per EurOtop, (2016) relationships). The foreshore can be deep, shallow or very shallow. If the water is shallow or very shallow then shoaling and depth limiting effects will need to be considered so that the wave height at the toe, or end of the foreshore, can be considered as well as the wave period. A foreshore is defined as having a minimum length of one wavelength. Without proper soundings, it is difficult to estimate the slope of the foreshore. In this study, it has been assumed that the water level at the toe of the structures is quite high (due to storm surge, etc.), therefore the foreshore plays a relatively minor role in wave transformation. A foreshore of 1:40 has been assumed for shorelines with a dike, embankment or armoured shoreline. For shorelines with beaches a 1:10 to 1:100 is assumed.

g) **Structure slope -** Part of a structure profile is defined as a slope if the slope of that part lies between 1:1 and 1:8. For this investigation, slopes ranging from 1:1 to 1:8 are tested, depending on the structure type (steeper slopes for armoured shorelines and slightly gentler slope for dikes/embankments). The slope has a significant impact on the wave run-up and can only be accurately incorporated if a survey of the structure in question is obtained.

h) **Permeability, porosity and roughness -** A smooth structure like a dike or embankment is mostly impermeable to water or waves and the slope has no, or almost no roughness. Roughness on the slope will dissipate wave energy during wave run-up and will therefore reduce wave overtopping. Roughness factors are adjusted in this investigation based on structure type.

i) **Effect of oblique waves -** Wave run-up and wave overtopping can be assumed to be equally distributed along the longitudinal axis of a dike. If this axis is curved, wave run-up or wave overtopping will increase for concave curves; with respect to the seaward face; due to the accumulation of wave run-up energy. Similarly, wave run-up and overtopping will decrease for convex curves, due to the distribution of wave run-up energy. In this investigation, it is assumed that there are no oblique waves and that all waves are incident perpendicular to the structure.

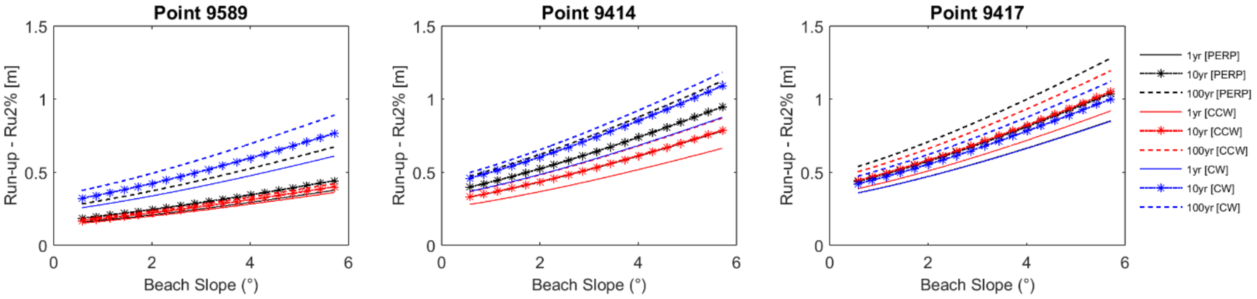
Given the extensive list of variables presented above, it is evident that **calculating run-up is best performed on a case-by-case basis for a specific site, where extensive information is made available regarding the natural and built environment.** The upcoming section attempts to consolidate the above-mentioned assumptions and limitations to illustrate the variety in wave run-up which may be experienced along the shorelines of Cumberland County.

To appreciate the magnitude of the total extreme water level, the run-up value should be added to the HHLWT, SLR, and storm surge (residual). Note that the wind wave conditions for the Minas Basin shoreline have not been included in the run-up graphs presented below. The wind wave conditions are relatively similar to the 100-yr CW event described by point 8430. Therefore, refer to this (8430) event when analyzing the southeastern portion of the County.

1.3.1 Beach environments

For the evaluation of wave run-up on beaches, the Stockdon et al. (2006) best-fit linear model is used. The plots are color coordinated according to the wave heights presented in Figure 5 and may be identified by offshore return period. The plots illustrate that wave variability along the Cumberland shoreline significantly influences wave run-up. It was found that run-up is typically lower in the sheltered eastern portion of the Bay of Fundy, and along the northeastern coastal regions of the Northumberland Strait. The western portion of Cumberland is exposed to mature waves propagating through the Bay of Fundy. Results indicate it is possible to observe run-up values close to 2m for a 100-yr storm event along potential beaches populating the western coastal zone of Cumberland. Rocky shorelines are not considered for this study.

Northumberland Strait



Bay of Fundy

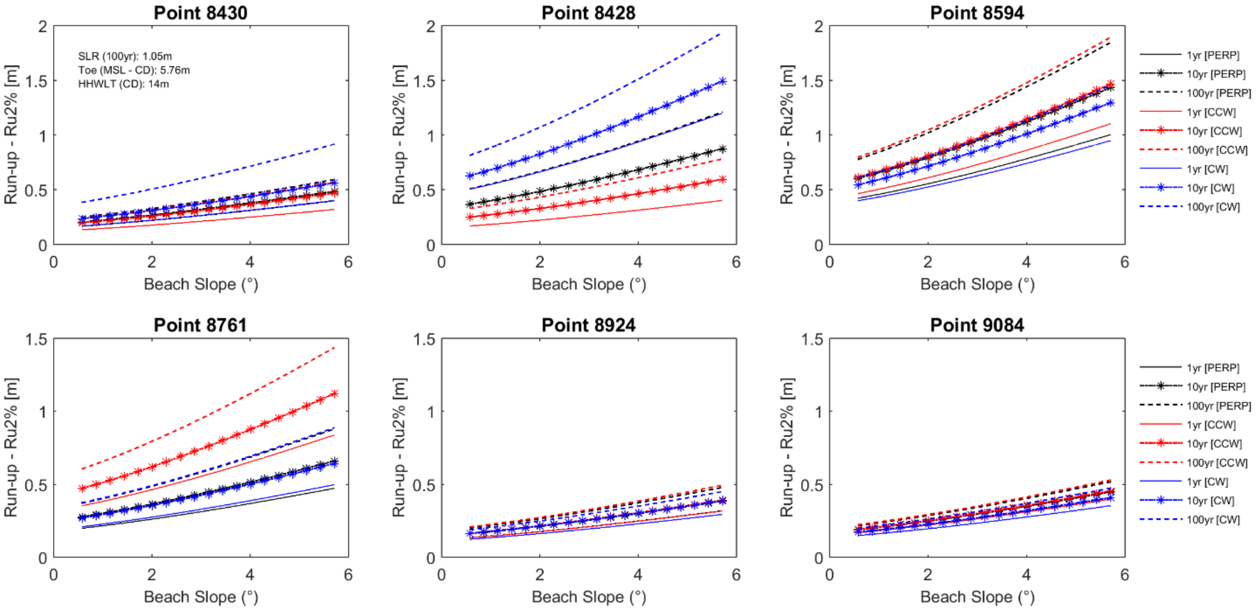


Figure 6: Run-up on Beach Environments (assumes 100-YR SLR, HHWLT & storm surge associated with return period)

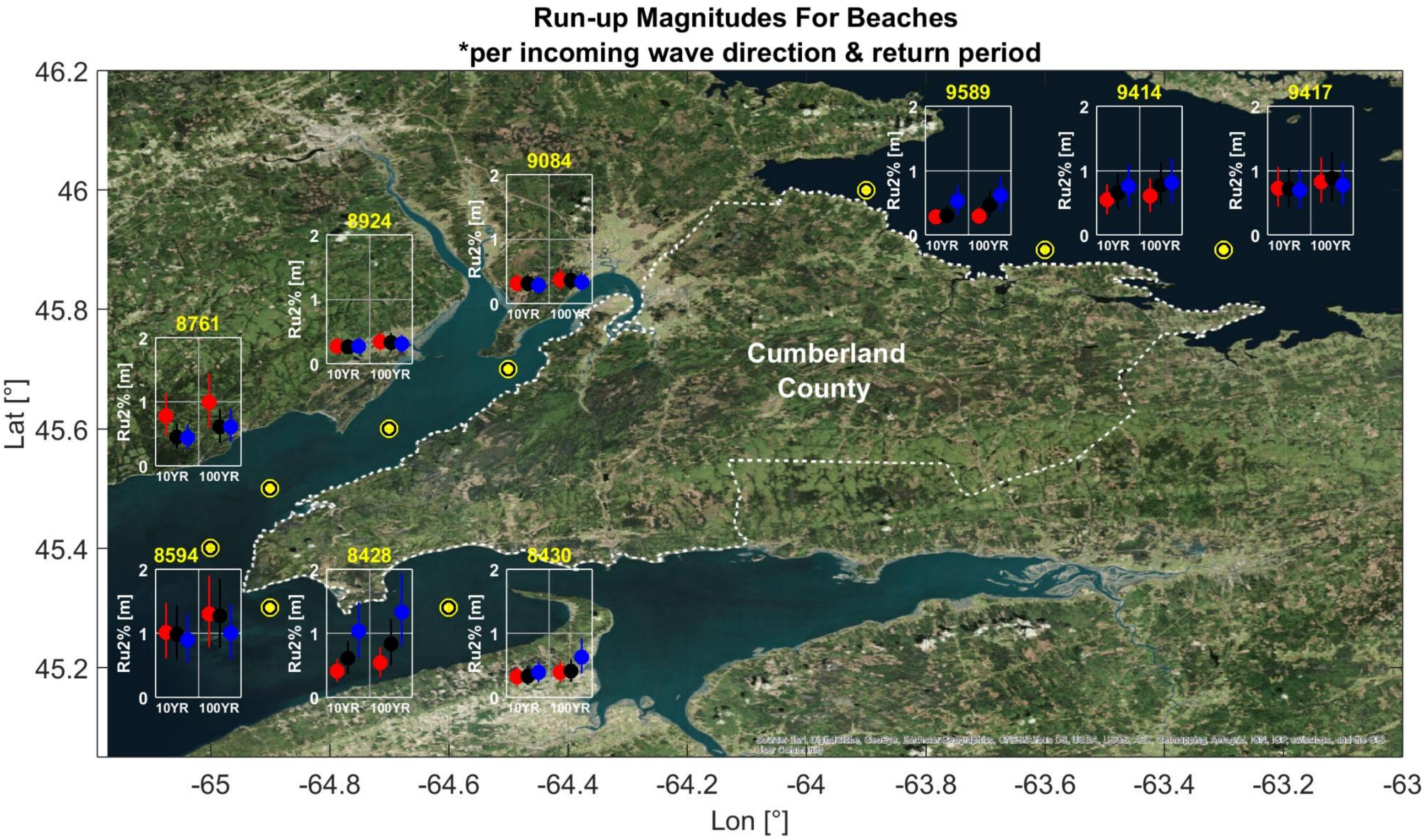


Figure 7: Average forecasted Run-up on Beaches (incl. max & min), assumes 100-YR SLR, HHWLT & storm surge associated with return period

***Black dots** are color coordinated with the data presented in Figure 6 and represent wave attack perpendicular to shore from offshore MSC50 point*

***Red dots** are color coordinated with the data presented in Figure 6 and represent wave attack CCW (45° bin CCW, perpendicular to shore) from offshore MSC50 point*

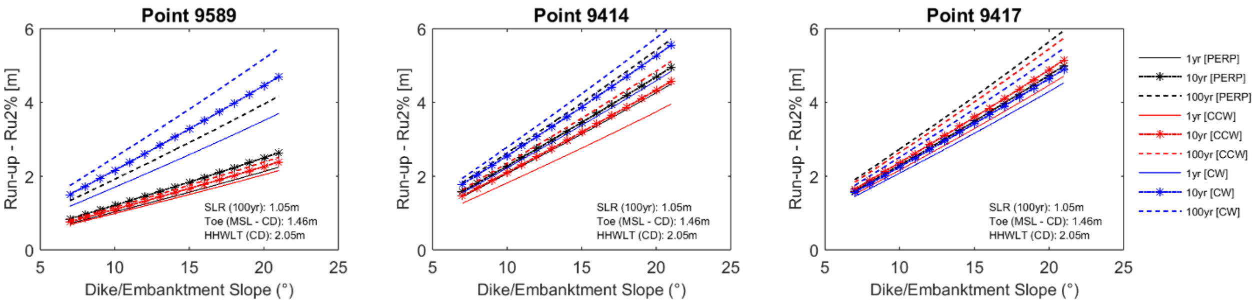
***Blue dots** are color coordinated with the data presented in Figure 6 and represent wave attack CW (45° bin CW, perpendicular to shore) from offshore MSC50 point*

$Selected\ required\ inputs\ to\ estimate\ EWLs = storm\ surge + local\ high\ tide + 100YR\ SLR + \boldsymbol{wave\ run\ up}\ (from\ above\ plot)$

1.3.2 *Coastal dikes and embankments*

For the evaluation of wave run-up on coastal dikes and embankments the EurOtop, (2016) relationships are used in combination with Goda's (2000) wave transformation theory. An exact mathematical description of the wave run-up and wave overtopping process for coastal dikes or embankment seawalls is not possible due to the stochastic nature of wave breaking and wave run-up and the various factors influencing the wave run-up and wave overtopping process. Therefore, wave run-up and wave overtopping for coastal dikes and embankment seawalls are mainly determined by empirical formulae derived from experimental investigations. The influence of roughness elements, wave walls, berms, etc. is taken into account by introducing influence factors. The plots are color coordinated according to the wave heights presented in Figure 5 and may be identified by offshore return period. It can be observed that significant run-up can occur for very steep, impermeable slopes.

Northumberland Strait



Bay of Fundy

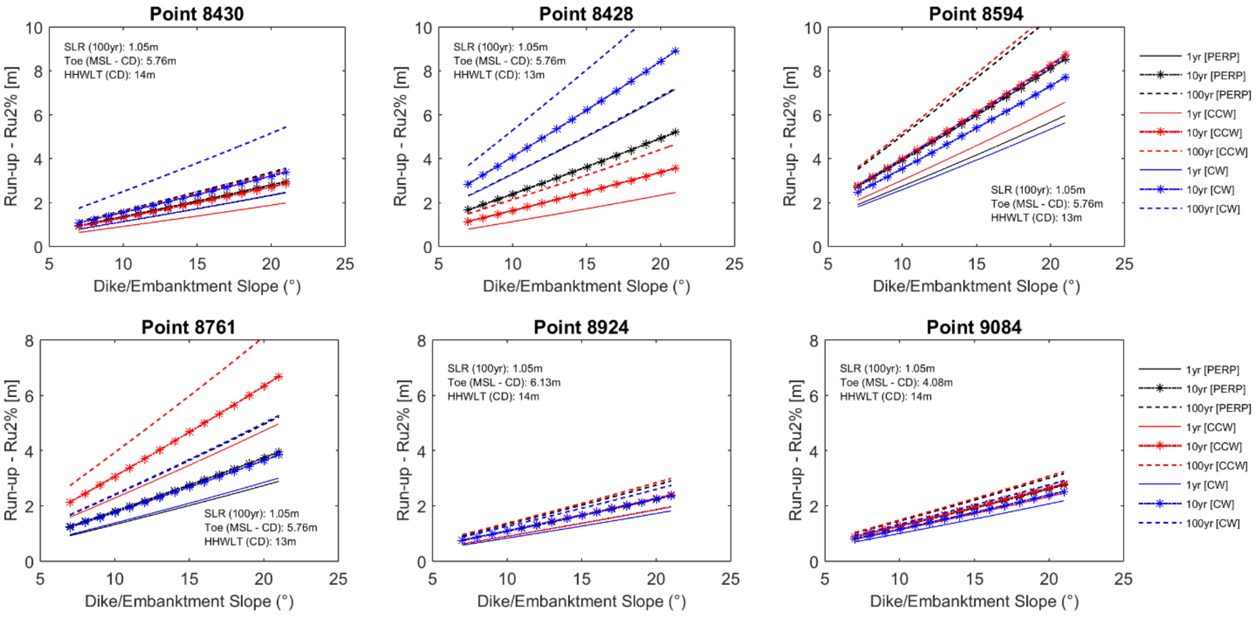
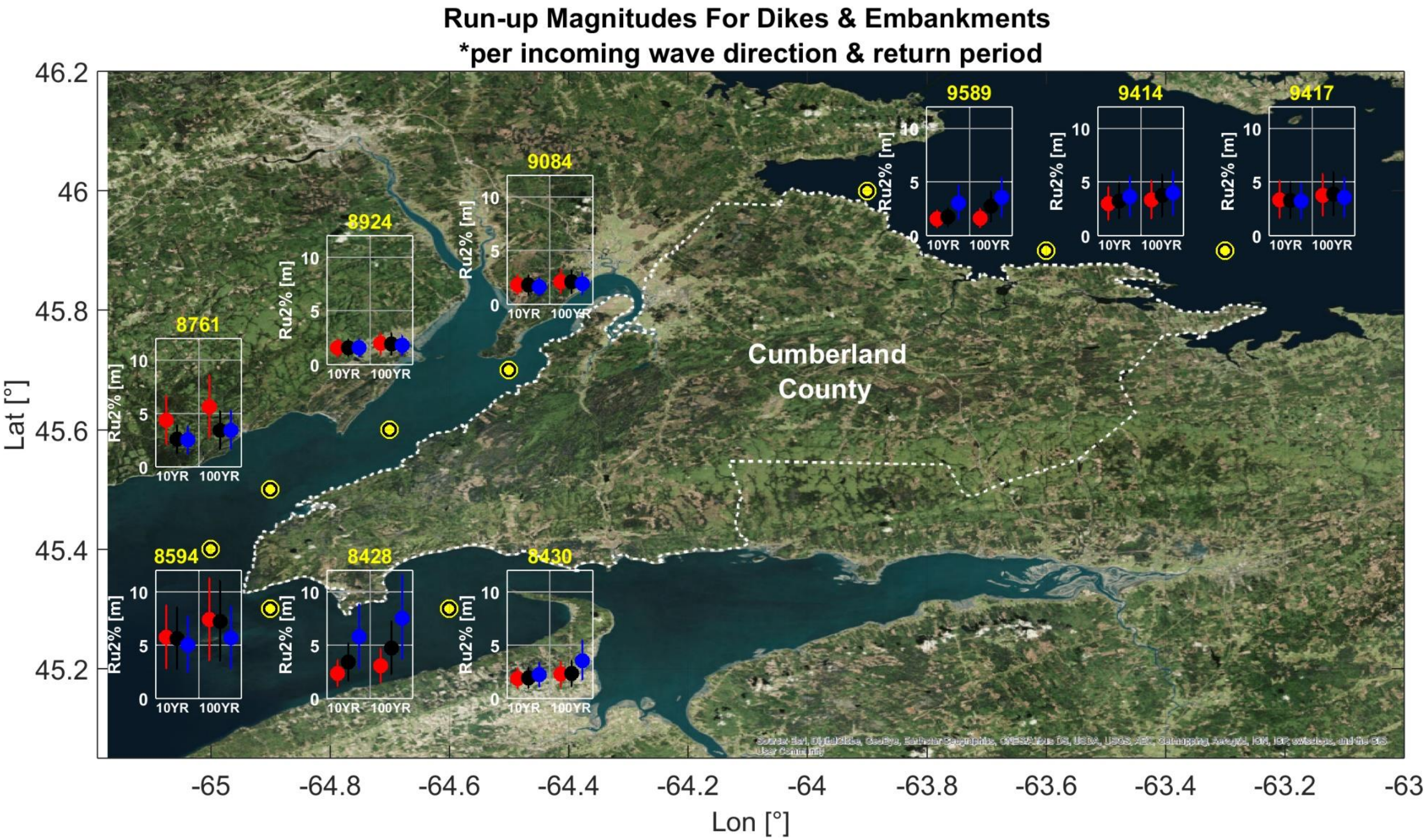


Figure 8: Run-up on Embankments & Dikes (assumes 100-YR SLR, HHWLT & storm surge associated with return period)



Run-up Magnitudes For Dikes & Embankments
*per incoming wave direction & return period

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 9: Average forecasted Run-up on Dikes & Embankments (incl. max & min), assumes 100-YR SLR, HHWLT & storm surge associated with return period

Black dots *are color coordinated with the data presented in Figure 8 and represent wave attack perpendicular to shore from offshore MSC50 point*

Red dots *are color coordinated with the data presented in Figure 8 and represent wave attack CCW (45° bin CCW, perpendicular to shore) from offshore MSC50 point*

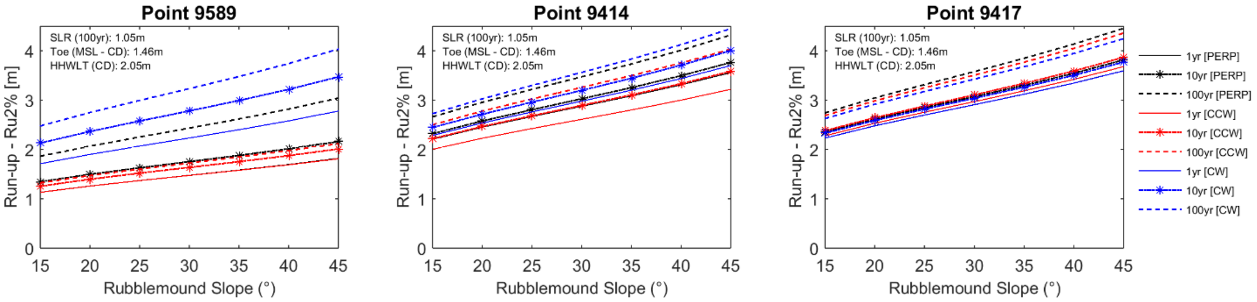
Blue dots *are color coordinated with the data presented in Figure 8 and represent wave attack CW (45° bin CW, perpendicular to shore) from offshore MSC50 point*

$\text{Selected required inputs to estimate } EWLs = \text{storm surge} + \text{local high tide} + 100YR\ SLR + \mathbf{wave\ run\ up}\ (\text{from above plot})$

1.3.3 *Armoured shorelines*

For the evaluation of wave run-up on armoured shorelines the EurOtop, (2016) relationships were used in combination with Goda's (2000) wave transformation theory. Wave run-up has typically been less important for rock slopes and rubble mound structures as the crest height of these type of structures is typically been based on allowable overtopping, or even on allowable transmission (low-crested structures). The plots are color coordinated according to the wave heights presented in Figure 5 and may be identified by offshore return period.

<u>Northumberland Strait</u>



<u>Bay of Fundy</u>

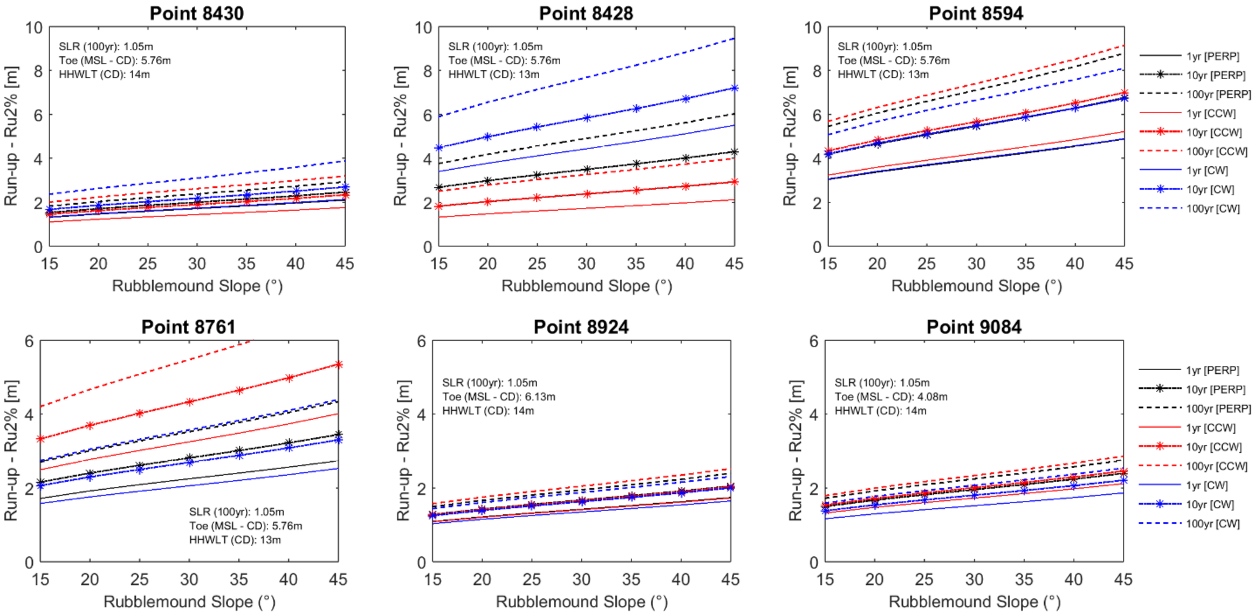


Figure 10: Run-up on Armoured Shorelines (assumes 100-YR SLR, HHWLT & storm surge associated with return period)

Run-up Magnitudes For Rubblemound Structures
*per incoming wave direction & return period

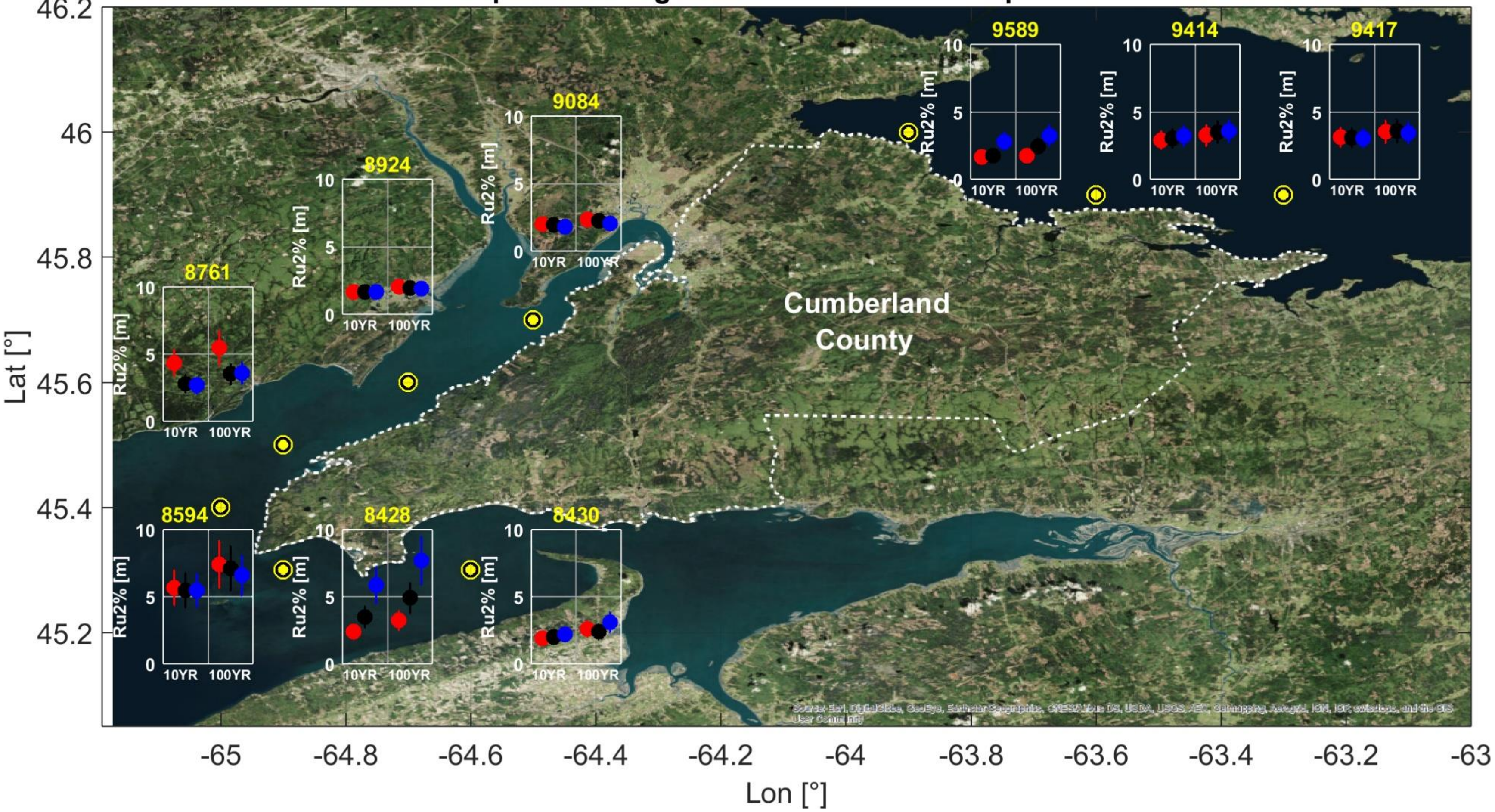


Figure 11: Average forecasted Run-up on Armoured Shorelines (incl. max & min), assumes 100-YR SLR, HHWLT & storm surge associated with return period

Black dots *are color coordinated with the data presented in Figure 10 and represent wave attack perpendicular to shore from offshore MSC50 point*

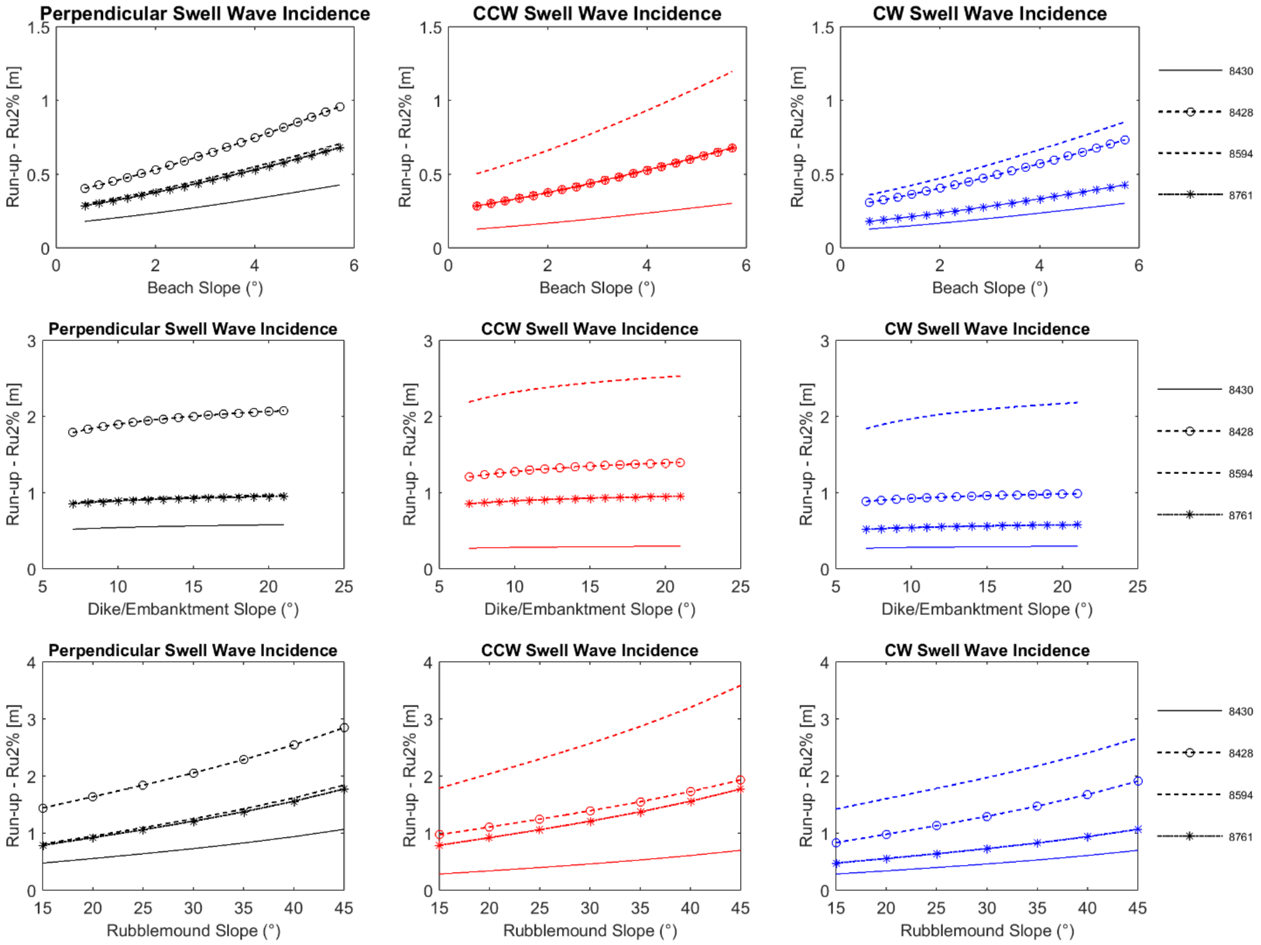
Red dots *are color coordinated with the data presented in Figure 10 and represent wave attack CCW (45° bin CCW, perpendicular to shore) from offshore MSC50 point*

Blue dots *are color coordinated with the data presented in Figure 10 and represent wave attack CW (45° bin CW, perpendicular to shore) from offshore MSC50 point*

$$Selected\ required\ inputs\ to\ estimate\ EWLs = storm\ surge + local\ high\ tide + 100YR\ SLR + \boldsymbol{wave\ run\ up}\ (from\ above\ plot)$$

1.3.4 Swell generated run-up

The plots are color coordinated according to the direction of wave propagation (as per Figure 5) and identified by their MSC50 ID. The wave height and period is associated with each scenario is presented in Table 3. Where applicable, the most commonly occurring swell conditions are selected from the hindcast data for each MSC50 point and used to compute run-up.



1.4 Data Gaps

Most of the data gaps have already been identified in Section 0. These include, but are not limited to:

a) Types of structures, shoreline and corresponding location
b) Dimensions of shoreline protection features
c) Site specific MSL and CD (determines submerged or dry toe)
d) Detailed bathymetry for each scenario to estimate wave transformation
e) Site-specific wave transformation modeling and run-up evaluation
f) Adjustments of storm surge for various climate change scenarios & return periods

1.5 Additional Outputs

Table 3: Offshore Wave Climate Analysis

Offshore msc50 Location		**EVA Distribution**	**Angle of attack [from N, going to]**		**Return Period [yrs]**						**Typical Historic Swell Conditions**	
					1		**10**		**100**			
			From [°]	**To [°]**	**Hs [m]**	**Tp [sec]**	**Hs [m]**	**Tp [sec]**	**Hs [m]**	**Tp [sec]**	**Hs [m]**	**Tp [sec]**
NORTHUMBERLAND STRAIT - Cumberland County												
9589	**Perp. To shore**	WBL	150	120	0.97	4.00	1.16	4.30	1.38	6.00	-	-
		WBL	90	150	0.99	3.80	1.10	4.00	1.16	4.10	-	-
		GPD	210	270	1.35	5.50	1.62	6.30	1.88	6.80	-	-
9414	**Perp. To shore**	WBL	150	210	1.99	5.80	2.48	6.30	3.00	6.80	-	-
		WBL	90	150	1.72	5.30	1.95	5.90	2.17	6.20	-	-
		GPD	210	270	2.19	6.20	2.67	7.00	2.96	7.20	-	-
9417	**Perp. To shore**	WBL	150	210	2.37	5.80	2.99	6.30	3.67	7.00	-	-
		GEV	90	150	2.58	6.00	2.88	6.50	3.39	6.80	-	-
		GPD	210	270	2.35	5.80	2.86	6.20	3.27	6.50	-	-
BAY OF FUNDY - Cumberland County												
8430	**Perp. To shore**	WBL	330	30	1.09	4.00	1.28	4.50	1.54	5.00	0.20	10.00
		GEV	270	330	0.92	3.50	1.20	4.50	1.77	4.50	0.10	10.00
		GEV	30	90	1.11	4.00	1.39	5.00	1.88	7.00	0.10	10.00
8428	**Perp. To shore**	WBL	330	30	1.55	5.00	2.34	6.00	3.28	7.00	0.70	12.00
		GEV	270	330	1.11	4.00	1.56	5.00	2.22	5.50	0.50	10.00
		WBL	30	90	2.81	7.50	3.83	8.00	5.08	9.00	0.30	14.00
8594	**Perp. To shore**	WBL	60	120	2.62	6.50	3.53	8.00	4.62	9.00	0.30	13.50
		WBL	0	60	2.73	7.00	3.69	8.00	4.86	9.00	0.80	14.00
		GPD	120	180	2.75	6.00	3.76	7.00	4.74	7.00	0.80	10.00
8761	**Perp. To shore**	WBL	100	160	1.53	4.00	1.91	5.00	2.36	6.00	0.30	13.00
		WBL	40	100	2.14	6.00	2.82	7.00	3.54	8.00	0.30	13.00
		GPD	160	220	1.34	4.50	1.81	5.00	2.40	6.00	0.20	10.00
8924	**Perp. To shore**	WBL	100	160	0.91	3.50	1.07	3.90	1.24	4.5	-	-
		WBL	40	100	0.90	3.50	1.05	4.00	1.32	4.5	-	-
		WBL	160	220	0.87	3.30	1.03	4.00	1.20	4.3	-	-
9084	**Perp. To shore**	WBL	100	160	1.09	4.00	1.25	4.20	1.45	4.5	-	-
		WBL	40	100	1.09	4.00	1.29	4.20	1.52	4.5	-	-
		GPD	160	220	0.95	3.80	1.15	4.00	1.33	4.3	-	-
JONSWAP	**Perp. To shore**	-	330	30	-	-	-	-	1.86	5.11	-	-

Appendix C

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