CITY OF CAMPBELL RIVER SEA LEVEL RISE STUDY
PHASE 3 – ADDITIONAL FCL ASSESSMENT

FINAL REPORT

Prepared for:

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City of Campbell River, BC

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EXECUTIVE SUMMARY

The City of Campbell River (the City) is located on the east coast of Vancouver Island on Discovery Passage at the northern end of the Strait of Georgia, and along the estuary of the Campbell River. Much of the development in the city is concentrated in lands that are only 4 m above mean water level. The community has faced flood and erosion hazards both along its riverfront from high river flows and oceanfront from king tides and storm surge.

The objective of this study is to determine the 2050 and 2100 flood construction levels (FCL) for the Campbell River shoreline extending from Ocean Grove to Duncan Bay by considering the impacts of sea level rise in combination with extreme weather and tide events. The results are not expected to be considered as official floodplain mapping but are to serve as a high-level planning tools for the City to assess potential impacts and risks in its foreshore. In order to establish the FCL for 0.5% annual exceedance probability (AEP) or 200-year recurrence coastal water level conditions, a statistical simulation method using the joint probability approach was used to determine the 200-year recurrence water level-wave height conditions in northern Strait of Georgia. Due to the strong tidally-induced currents that develop in Discovery Passage, the wave field in the passage can change considerably due to wave-current interaction. The most noticeable effect occurs when waves propagate against the current. A wave-current numerical model was used to simulate this process and determine the design wave heights along the foreshore.

For the purpose of this study the Campbell River shoreline was divided into 14 representative sections based on shoreline characteristics and exposure to wave climate. The recommended 2100 FCL values range between 4.1 m GD at Tyee Point and 5.7 m GD at Painter Barclay.

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1 INTRODUCTION

1.1 Background

The City of Campbell River (the City) is located on the east coast of Vancouver Island on Discovery Passage at the northern end of the Strait of Georgia, and along the estuary of the Campbell River. Much of the development in the city is concentrated in lands that are only 4 m above mean sea level. The community has faced flood and erosion hazards both along its riverfront from high river flows and oceanfront from king tides and storm surge.

The Province of BC issued Guidelines in 2011 on flood hazard land use management that included direction related to sea level rise (SLR). In 2018 BC amended the Flood Hazard Area Land Use Management Guidelines to account for SLR for year 2100 and 2200 (2004, amended 2018). The studies by BC Ministry of Environment (2011b) indicate that there will be a significant impact to coastal BC over the next century. Based on a review of scientific literature, global sea level rise from the year 2000 was estimated to be 1 m by the year 2100 and 2 m by 2200. The City recognizes that being a coastal city with limited flood protection infrastructure, the risks[1] can be significant, and that the hazard and consequence posed by anticipated future coastal and river flooding may be better dealt with by using a combination of adaptation strategies, land-use changes and structural and non-structural approaches. Prior to developing such recommendations, the City sought to understand the potential hazard posed by future floods, vulnerabilities in these areas and anticipated consequences.

As part of a three-phase project, the present Phase 3 work focuses on defining the flood construction level (FCL) along the Campbell River foreshore extending from Ocean Grove to Duncan Bay (**Figure 1-1**). FCLs for two time horizons, Year 2050 and Year 2100, were evaluated with consideration of sea level rise in combination with extreme weather and tide events. The results are not expected to be considered as official floodplain mapping[2] but are to serve as a high-level planning tools for the City to assess potential impacts and risks in its foreshore.

[1] Risk is defined as the proabibility of adverse consequences due to inundation flood.

[2] To develop official floodplain maps from the model results requires following legal standards as outlined in EGBC's Professional Practice Guidelines Flood Mapping in BC (EGBC, 2017). Specifically: the flood design standard in the area must be verified and made consistent with the model scenario used; appropriate freeboard must be added to the modelled water levels; the floodmap must be compared to previous floodmapping and local flood hazard zoning (including a possible field investigation of any changes); and the map must be ratified by local government.

Figure 1-1: Campbell River shoreline.

1.2 Flood Construction Level

The water level along the Campbell River foreshore is primarily governed by the sea level and incorporates the combined effects of astronomical tide, storm surge, wave effect, future sea level rise and local uplift/subsidence. The 2011 BC Ministry of Environment Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use (2011b) presents an approach for developing the flood construction level (FCL) as follows:

FCL = Higher High Water Level Large Tide (HHWLT)
+ storm surge during designated storm
+ future sea level rise (SLR) allowance and local subsidence
+ estimated wave effects from designated storm
+ freeboard

Designated Flood Level

The definitions for the FCL is illustrated in the following figure.

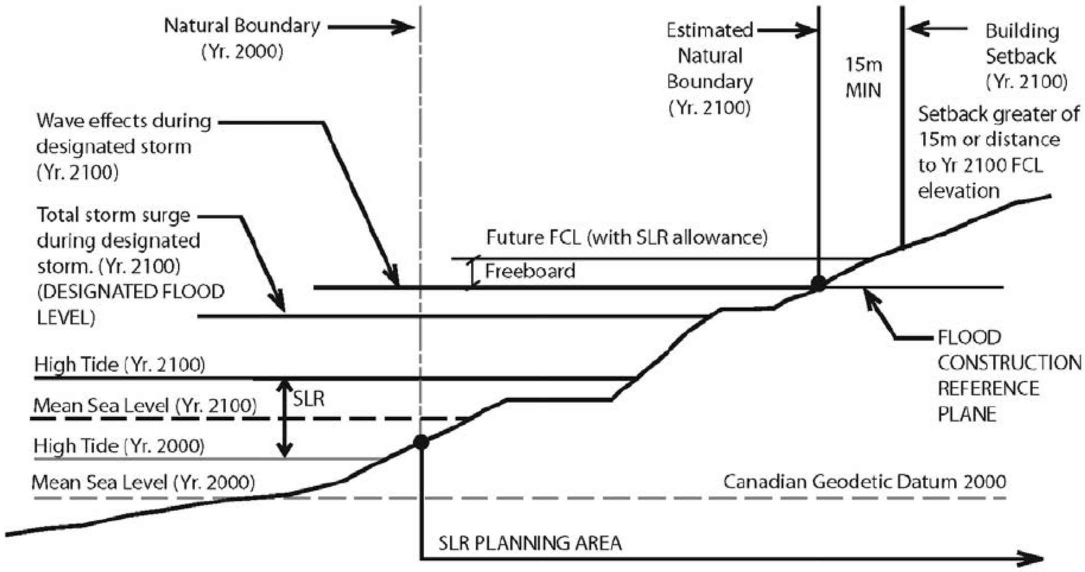

Figure 1-2: Definitions for updated FCL and setback (BC Ministry of Environment, 2011b) .

Although much of the underlying design storm events used by the method presented by the provincial guidelines are 200-year events, the probability of simultaneous occurrence of the events is vaguely if at all defined. The Guidelines for Sea Dikes and Coastal Flood Hazard Land Use – Draft Policy Discuss Paper (2011a) suggests a probability of 200-year storm surge co-occurring with HHWLT of near 0.025% (4000-year return period). Annual exceedance probability (AEP) of this magnitude are stated by the accompanying policy document (BC Ministry of Environment, 2011a) to be justified where the consequence of dike failure has moderate to high consequence, such as the Fraser River Delta where there is potential for several weeks of disruption, major financial losses for multiple owners, multiple people injured, and multiple loss of life. The Campbell River foreshore consists primarily of residential and commercial developments; it is not a continuous sea dike and does not present the same consequence if design water level is exceeded. The design life of the typical residential and commercial development is likely on the order of 50-years to 100-years and this consideration is incorporated into the analysis.

As discussed in the Phase 1 report (Northwest Hydraulic Consultants Ltd., 2018), the additive approach presented in the 2011 BC Ministry of Environment Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use normally resulted in conservative values as it does not account for the probability of simultaneous occurrence of the events. A statistical simulation method using the joint probability method combined with a wave-current numerical model was used to reduce the excessive conservatism inherent in the additive approach.

2 METEOROLOGICAL AND OCEANOGRAPHIC CONDITIONS

The water level along the Campbell River foreshore is primarily governed by the sea level and incorporates the combined effects of tide, storm surge, wave effect, future sea level rise and local subsidence. These processes are discussed in the following sections (Note, parts of this analysis were previously undertaken for the City of Campbell River related to the Downtown Waterfront Site. See Northwest Hydraulic Consultants Ltd., 2018).

2.1 Tides

Tides near Campbell River are mixed with annual mean tidal range of 2.7 m and large tidal range at 4.3 m. Two months of predicted hourly tidal elevations at Campbell River are shown in **Figure 2-1**, illustrating the bi-weekly tidal variability.

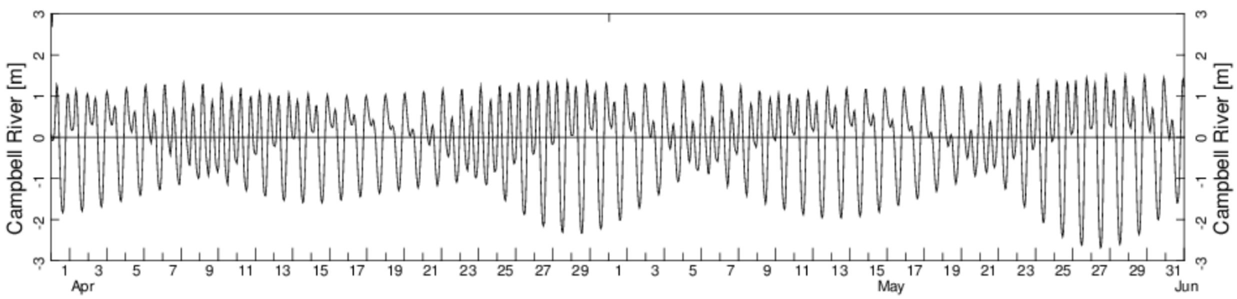

Figure 2-1: Predicted tides at Campbell River from April 1st to May 31st, 2017.

Table 2-1 presents local tidal water levels based on values obtained from Campbell River from 2018 Canadian Tide and Current Tables Volume 6.

Table 2-1: Summary of Campbell River Tide elevations

Sea State	Tide Elevation (m Geodetic Datum)	Tide Elevation (m Chart Datum)
Higher High Water, Large Tide (HHWLT)	1.7	4.6
Higher High Water, Mean Tide (HHWMT)	1.2	4.1
Mean Water Level (MWL)	0.0	2.9
Lower Low Water, Mean Tide (LLWMT)	-1.5	1.4
Lower Low Water, Large Tide (LLWLT)	-2.5	0.4

2.2 Storm Surge

Storm surge is caused by weather effects (wind setup, wave setup, atmospheric pressure uplift) on the ocean. The design storm surge values were calculated from Department of Fishers and Oceans Station 8074 - Campbell River water level data (1972 to 2016) by first removing the tidal component from the measured water level to obtain the tidal residual. Extreme value analysis was then conducted using the Peak-Over-Threshold method by considering tidal residual[3] values occurring when tides were greater than HHWLT. The results are summarised in the table below.

Table 2-2: Summary of design storm surges

Return Period (yr)	Storm Surge (m)
5	0.66
10	0.72
20	0.78
50	0.86
100	0.91
200	0.97

The takeaway from the above analysis is that the value for frequent occurring storm surge events (20% AEP) is about 0.7 m. The difference between the 20% AEP storm surge and less frequent occurring 0.5% AEP storm surge is only 0.3 m.

The maximum observed water level over the 45 years record was 2.35 m Geodetic Datum (GD) on January 15th, 1974. The predicted tide level corresponding to this peak observation water level was 1.64 m GD which is just 0.07 m below HHWLT at Campbell River. The storm surge was 0.71 m which is close to the 10% AEP value.

2.3 Sea Level Rise

The sea level rise policy for BC (BC Ministry of Environment, 2011b) recommends assuming a 1.0 m rise in global mean sea level between the year 2000 and 2100 as show in **Figure 2-2**.

[3] Tidal residual (aka: storm surge) is the difference between the predicted astronomical tide and the actual observed tide levels. This difference is the result of many local, regional and sometimes global environmental factors. The most significant of these factors tend to be atmospheric conditions; specifically wind speed, wind direction and atmospheric pressure.

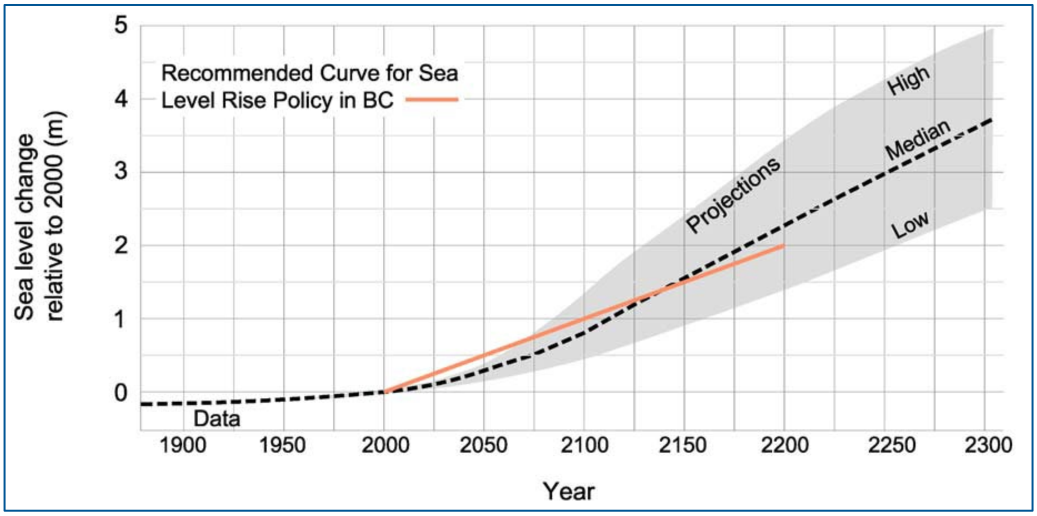

Figure 2-2: Projections of Global Sea Level Rise (2011b).

As part of this study, the impacts of sea level rise were assessed for the years 2050 and 2100. It should be recognized that there is significant uncertainty in sea level rise projections with a range in the rise presented in the draft provincial sea level rise policy and shown in **Figure 2-2**, from about 0.5 m to 1.3 m by 2100 and 1.4 m to 3.4 m by 2200. A 1.0 m sea level rise estimate by 2100 is in the upper range of projections and allows planners to be ahead of the curve. Whereas a 2.0 m rise estimate by 2200 is towards the low to mid-range of projections. Given these uncertainties, reliance on interpolation of simulation results, rather than detailed simulation of finer increments of sea level rise, is considered to be a reasonable and an appropriate approach for intermediate and long-range planning purposes. It is recommended that the City monitor changes in sea level rise estimates and adapt their flood management plans accordingly.

2.4 Land Uplift and Subsidence

Uplift refers to the vertical movement of land at a given location. Uplift may be positive or negative. Negative uplift is also known as subsidence. The rate of uplift/subsidence for Campbell River is reported to be at +4.1 mm per year (BC Ministry of Environment, 2011c). To the year 2100, this translates to a rise in land elevation of 0.41 m.

2.5 Regional Wind Climate

Wind-generated waves are responsible for most of the waves experienced in the Strait of Georgia. The prevailing winds in the Strait of Georgia are predominantly from the northwest (in summer) and southeast (in winter), resulting in storm waves that align approximately with the main axis of Discovery Passage. Long-term wind data near the project site is available from Campbell River Airport, Sentry Shoal wave buoy, and Comox Airport (**Figure 2-3**). These climate stations provide hourly climate records as summarised in **Table 2-3**. The data were used to evaluate the frequency and direction distribution for wind in the northern part of the Strait of Georgia.

Table 2-3: Wind data source from Meteorological Service of Canada.

Station	Station ID	Station Location	Period
Campbell River Airport	1021261	Latitude: 49.95 Longitude: -125.27	1979 – 2013
Campbell River Airport	1021267	Latitude: 49.95 Longitude: -125.27	2013 – current
Sentry Shoal	C46131	Latitude: 49.91, Longitude: -124.99	1992 – current
Comox Airport	1021830	Latitude: 49.16, Longitude: -124.90	1953 – current

Figure 2-3: Wind stations and wave buoy locations.

The local wind climate can be assessed by the use of a wind rose, a graphic presentation of winds for specified areas, utilizing arrows at the cardinal and inter-cardinal compass points to show the direction from which the winds blow and the magnitude and frequency for a given period of time. The wind rose derived from the observed data at Campbell River Airport, Sentry Shoal, and Comox Airport are shown in **Figure 2-4**, **Figure 2-5**, and **Figure 2-6** respectively.

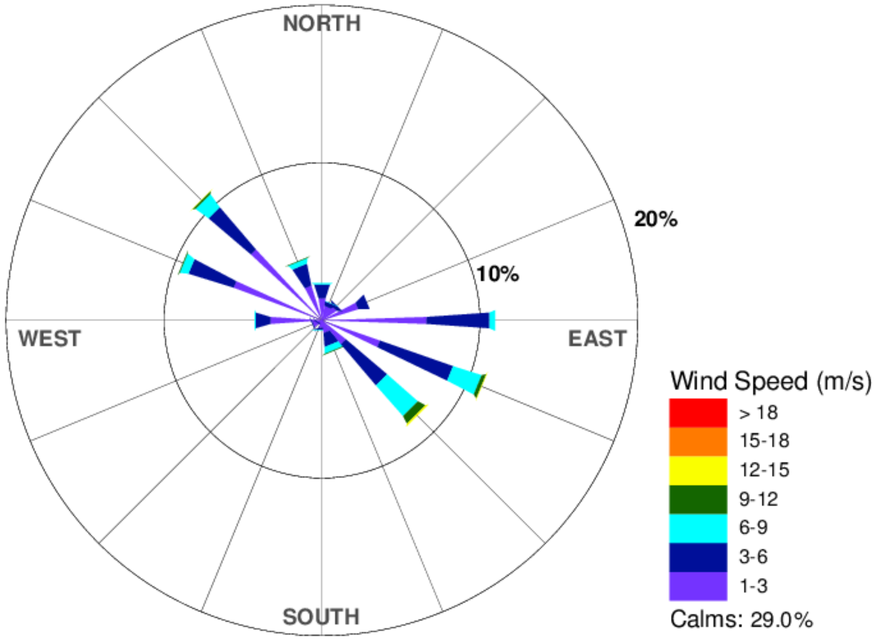

Figure 2-4: Wind distribution plot (wind rose) – Campbell River Airport[4].

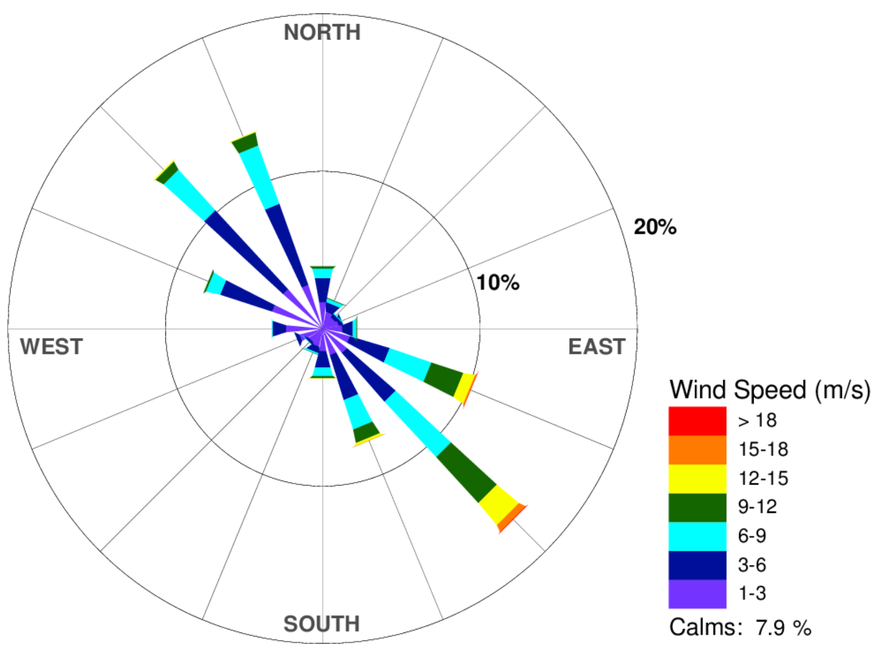

Figure 2-5: Wind distribution plot (wind rose) – Sentry Shoal.

[4] Data from Station 1021261 and Station 1021267 are combined for the Campbell River Airport site.

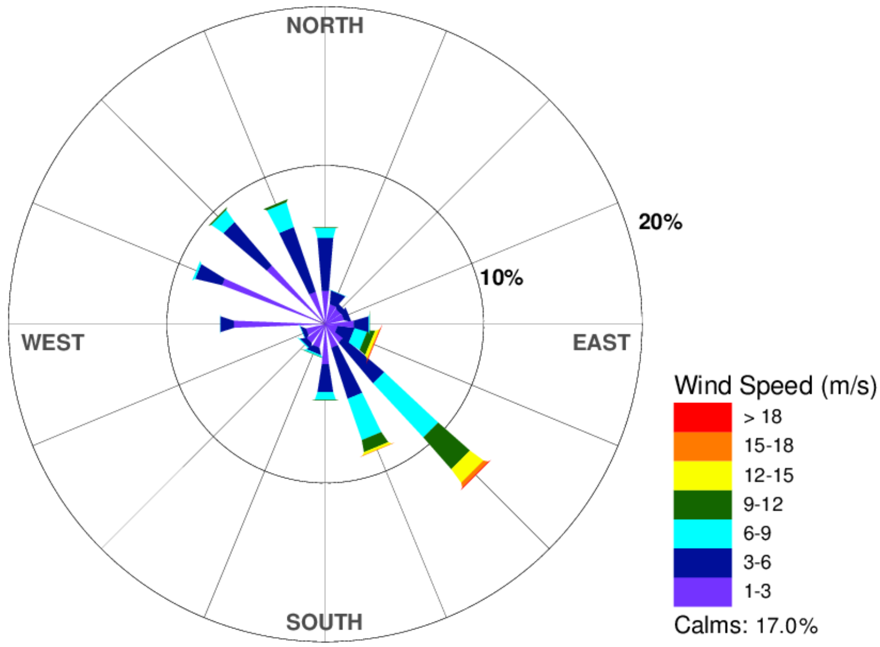

Figure 2-6: Wind distribution plots (wind rose) – Comox Airport

The results show that the strongest winds experienced in the northern part of the Strait of Georgia are from the southeast. Winds measured at Campbell River Airport are calmer than winds measured at Sentry Shoal and Comox Airport, likely because the Campbell River Airport station is located about 5 km inland and at an elevation of about 108 m above sea level and therefore does not adequately represent wind conditions that will generate waves in open water. This station is excluded from the analysis.

Due to the shoreline orientation, the Campbell River foreshores are subjected to greater wave effects from southeasterly storms than northwesterly storms. Frequency analysis was conducted on the Sentry Shoal and Comox Airport hourly wind data for the period of record to obtain the design wind speed[5] for the southeasterly events. The results are summarised in **Table 2-4**.

[5] The design wind speed is derived based on observation data which is the average wind speed for the most recent two-minute period prior to the observation time. This is also considered the "sustained wind" as used in wave hindcasting analysis.

Table 2-4: Summary of design wind speeds at Sentry Shoal and Comox Airport.

	Sentry Shoal – Southeasterly		Comox Airport – Southeasterly	
Return Period (yr)	Speed (m/s)	Speed (km/hr)	Speed (m/s)	Speed (km/hr)
5	21.8	79	21.7	78
10	23.0	83	22.5	81
20	24.2	87	23.3	84
50	25.8	93	24.4	88
100	27.0	98	25.1	90
200	28.2	102	25.8	93

The results show that the design winds calculated on the Sentry Shoal station predictions are slightly higher than the design winds for Comox Airport. Design winds from Sentry Shoal are used in the analysis because it is closer to the project site, it is in open water and its values are less likely influenced by land formations.

2.6 Regional Wave Climate

Wave heights in the Strait of Georgia are limited by fetch distance instead of by wind strength and duration. Looking at 26-years (1992 to 2017) of wave data collected at the Environment and Climate Change Canada (ECCC) Sentry Shoal buoy located 22 km southeast of Campbell River (**Figure 2-3**), there were a total of 51 events in the record for Sentry Shoal with significant wave height (Hs)[6] greater than 3 m. However, the data between 1998 and 1999 (**Figure 2-7**) are doubtful as there were 35 storms with waves over 3 m in these two years, as well as waves over 9 m, which is highly unlikely. Discounting these two years, there were 26 events in 24 years with waves greater than 3 m, with a maximum wave height of 3.6 m (December 12, 2006, November 11, 2007, November 24, 2016).

[6] The significant wave height is defined as the mean wave height of the highest third of the waves.

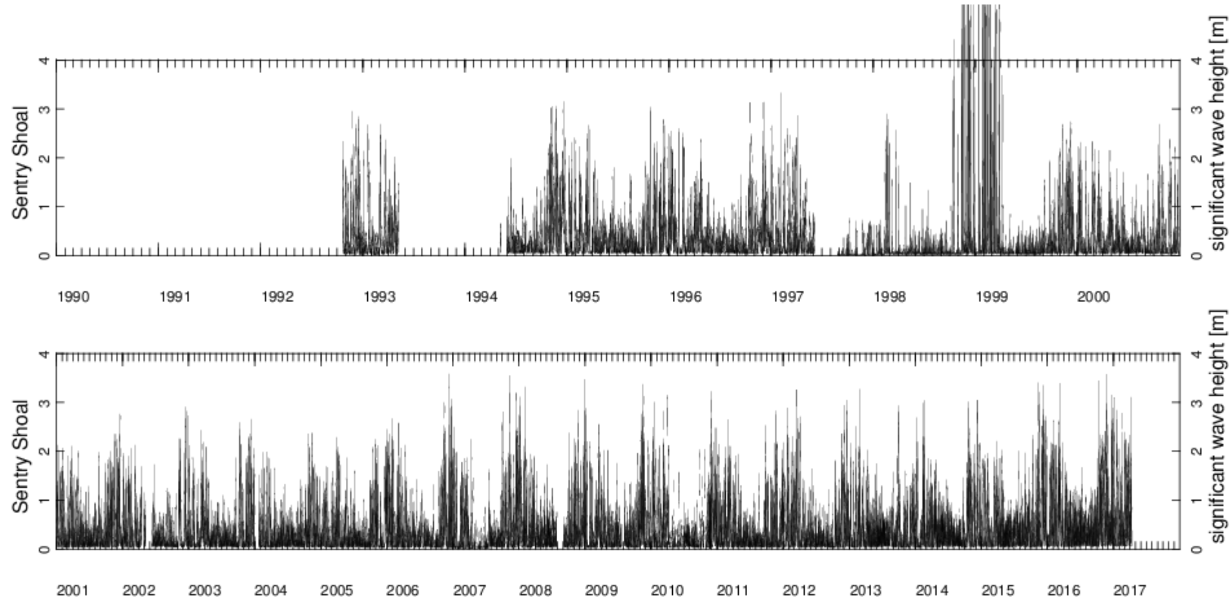

Figure 2-7: Sentry Shoal Wave Buoy Measurements – 1992 to 2017[7].

In addition to the noticeable erroneous data in 1998 and 1999, an examination of the Sentry Shoal data shows that much of the reported data has been flagged as erroneous. Independent assessment was conducted by NHC on selected data and no noticeable difference was found between data that is considered to be good (Quality Code =1) and data that is considered to be erroneous (Quality Code =4). A request was sent to Meteorological Services of Canada for further information on the QA/QC procedure. No reply has been given at the time when this report was prepared.

2.7 Local Wave Climate

Wave-current interaction is important in Discovery Passage due to the strong currents, that can reach up to 9 knots (4.6 m/s), and can result in a large localized increase to wave heights. Due to the strong tidally-induced currents that develop in Discovery Passage, the wave field in the passage can change considerably due to wave-current interaction. The most noticeable effect occurs when waves propagate against the current.

A wave-current model was developed using commercial software Delft3D (Lesser et al., 2004) and SWAN (Booij et al., 1999) to evaluate the wave-current interaction process near in Discovery Passage. The model extends from Brown's Bay at the north boundary to Parksville at the south boundary. The model consists of coupled model domains with progressively fining resolution, with the finest grid resolution is

[7] No data available between May 1993 and June 1994, between June and August 1997, between May and June 2002, August 2008

along the foreshore where it is 20 m (**Figure 2-8**). Detailed model development is provided in the Phase 1 report (Northwest Hydraulic Consultants Ltd., 2018).

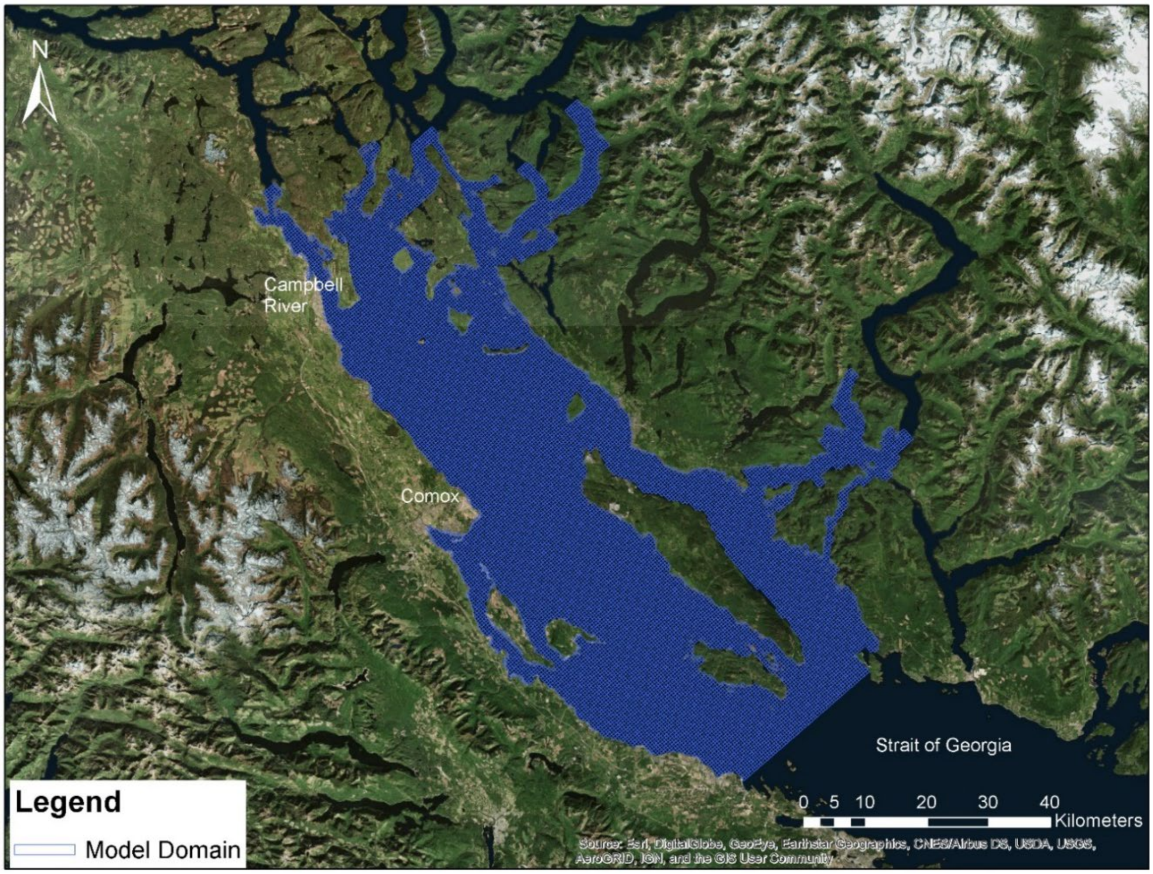

Figure 2-8: Campbell River Hydrodynamic and Wave Model grid domain extents.

High and steep waves can occur in conditions where strong currents oppose the direction of wind waves generated over long fetches. These areas of high and steep waves are known as "rips"[8] and are known to be most severe along the leading edge of the intruding opposing current into the wave field. For this reason, as the tide changes from a ebb-slack to a flood tide, the opposing currents along the leading edge of the flood tide generate the most severe rips.

Figure 2-9 and **Figure 2-10** illustrate the potential impact of tidal current on waves in Discovery Passage. The left panel in **Figure 2-9** shows the surface current vectors during flood tide condition in Discovery Passage. The middle panel shows the wave height distribution for a 65 km/hr southeasterly storm event in the absence of currents (i.e., no wave-current interaction). The colour-contoured field represents significant wave height. The right panel shows the wave height distribution for a 65 km/hr southeasterly event coinciding with the flood tide condition. The vector represents surface current speed and direction

[8] R.E. Thomson, Oceanography of the British Columbia Coast, Canadian Special Publication of Fisheries and Aquatic Sciences 56 (1981)

and the colour contoured field represents significant wave height. The figure shows that without wave-current interaction, the wave height in the channel is about 1.5 m. With opposing tidal current direction to the direction of waves, the wave heights in the channel are increased to about 3.0 m. The three panels in **Figure 2-10** present similar information as that in **Figure 2-9** but for ebb tide conditions in which the surface current and wind are heading in the same direction. The result shows that the wave height in the main channel is reduced slightly under this condition.

While the impact of wave-current interaction does not affect the wave climate near the foreshore as much as that in the channel, the wave-current interaction is a key process in understanding the overall wave climate in Discovery Passage.

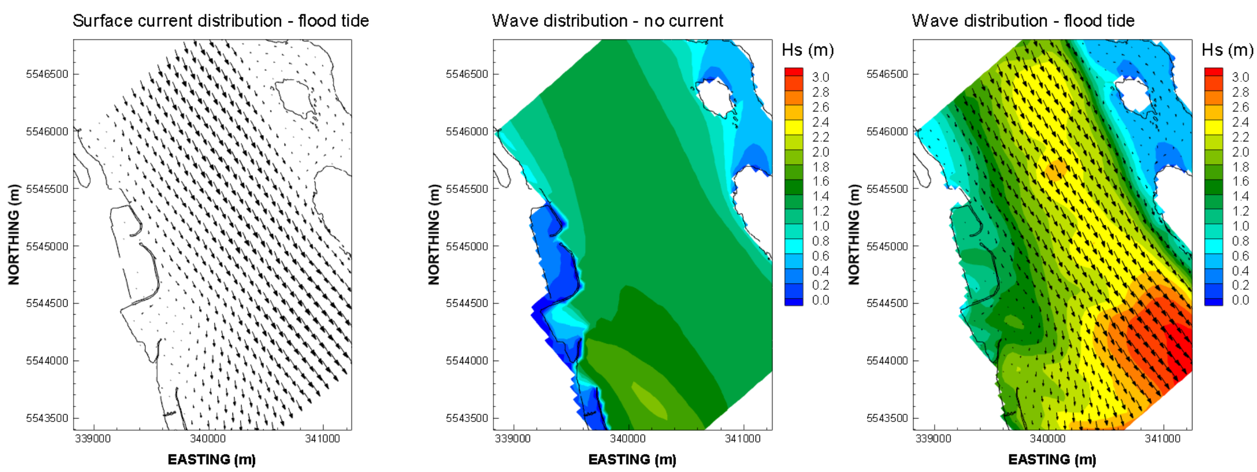

Figure 2-9: Current field, wave height distribution with no current, wave height distribution with flood tide.

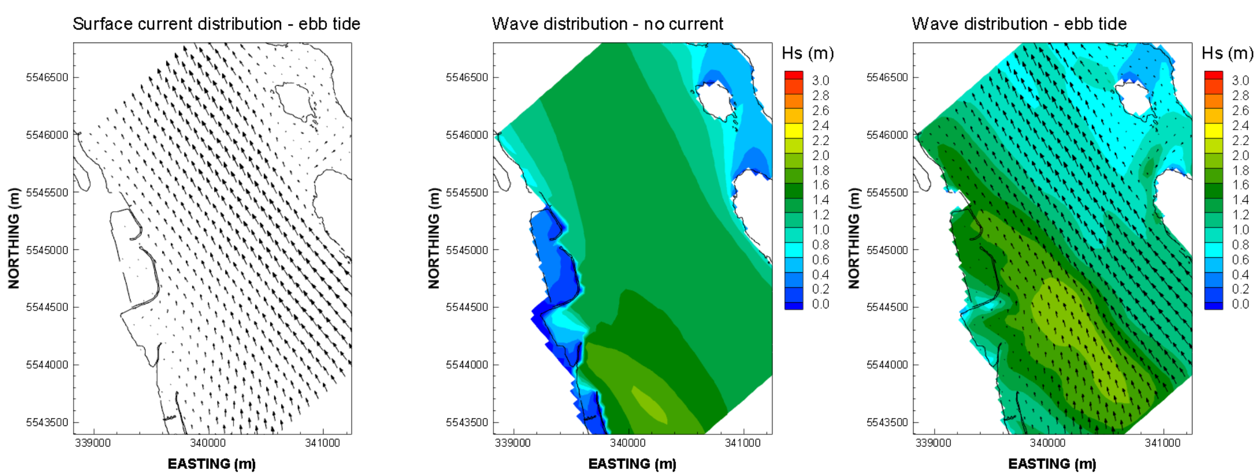

Figure 2-10: Current field, wave height distribution with no current, wave height distribution with ebb tide.

3 FLOOD CONSTRUCTION LEVEL ANALYSIS

As discussed in **Section 1.2**, the water level along the Campbell River foreshore is primarily governed by the sea level and incorporates the combined effects of astronomical tide, storm surge, wave effect, future sea level rise and local uplift/subsidence. To reduce the likelihood of damage from coastal flood inundation, the coastal flood level was assessed and used to derive a minimum construction level – the flood construction level.

The coastal FCL using the probabilistic approach is the sum of:

- 0.5% AEP total water level and deepwater wave conditions as determined by probabilistic analyses of tides, storm surge and designated stroms;
- Estimated wave effects associated with the designated storm;
- Allowances for future SLR to the year 2050 and year 2100
- Allowance for regional uplift or subsidence to the year 2050 and year 2100
- freeboard

Each of these components are described in the following sections.

3.1 Joint Probability of Water Levels and Deep-water Wave Conditions

Storm surge can sometimes coincide with high astronomical tides to produce unusually high water conditions along the British Columbia coast. Meanwhile, the exposure of a site to waves and the likelihood of peak waves for a given storm condition from a specific direction occurring coincident with storm surge and high tides is of paramount concern for determination of the coastal flood hazard. To examine the probability of this at Campbell River, a joint probability analysis was conducted utilizing historical water level record at Campbell River (that includes both astronomical tides and storm surge) and a coincident wave record from the Sentry Shoal buoy. Details of the analysis are provided in the Phase 1 report (Northwest Hydraulic Consultants Ltd., 2018).

Figure 3-1 shows curves of equal probability for combinations of water levels and offshore wave heights at Sentry Shoal. The figure shows that below a wave height of 2.5 m there is little change in the probability of a given water level occurring. Similarly, below a water level of 2 m GD there is little change in the probability of a wave event occurring.

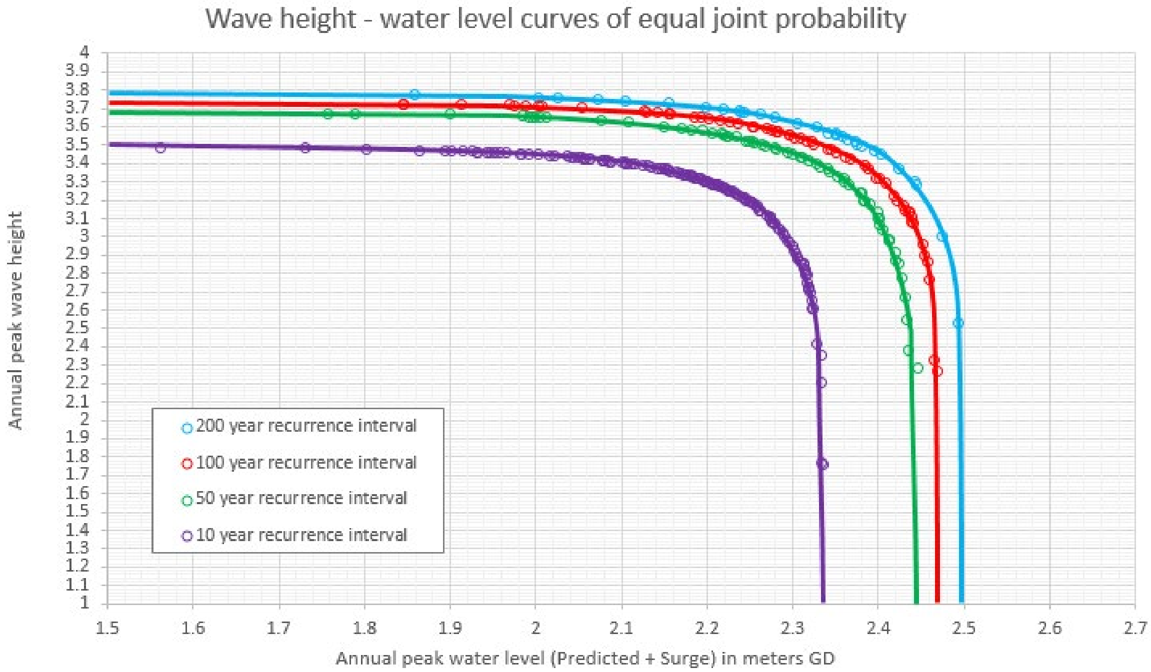

Figure 3-1: Wave height – Water Level Curves of Equal Joint Probability.

For the wave effect assessment study, six combinations of wave height and water level (**Table 3-1**) were selected from the 200-year recurrence interval curve (blue line) from **Figure 3-1** in order to determine the tide and storm conditions that would result in the highest flood level along the shoreline.

Table 3-1: 200-year joint probability recurrence for water level and offshore wave height values

Simulation	Water Level (m GD)	Wave height at Sentry Shoal (m)
1	2.50	2.50
2	2.45	3.40
3	2.35	3.55
4	2.30	3.60
5	2.20	3.70
6	2.10	3.75

Due to the strong tidally-induced currents that develop in Discovery Passage, the wave field in the passage can change considerably because of wave-current interactions. Discussion in Section 2.7 shows that the most noticeable effect occurs when waves propagate against the current direction. The most severe wave conditions in Discovery Passage are expected to occur during flood tide when currents flow towards the southeast, and under southeasterly storm conditions. The results of the modelling also indicate that wave heights are dependent on water depth so the relationship between current speed and wave height is not direct. **Figure 3-2** shows a histogram of tidal range at ECCC Campbell River station for the last 45 years (1972-2017). Positive values represent flood tide conditions when the ocean changes from low tide to high tide while negative values represent ebb tide conditions when the ocean changes from high tide to low tide. The figure shows that flood tide occurred 50% of the time.

For the wave effect assessment study, four tidal conditions (**Table 3-2**) were examined for each of the six 200-year recurrence water level-wave height conditions (**Table 3-1**). The peak water level over the course of each tidal cycle was adjusted to match the design water level value for each selected 200-year recurrence scenarios (**Figure 3-1**). The wind speed required to achieve the offshore design wave height at Sentry Shoal for each scenario was applied to the model. A snapshot of the model's output is shown in **Figure 3-3**. Wave height distributions are shown by colour and wave direction are shown by vectors[9].

Model simulations showed that the highest flood levels (including wave effects) along the shoreline occurred under Simulation 2 which consists of an offshore wave height of 3.4 m coinciding with a design water level of 2.45 m GD.

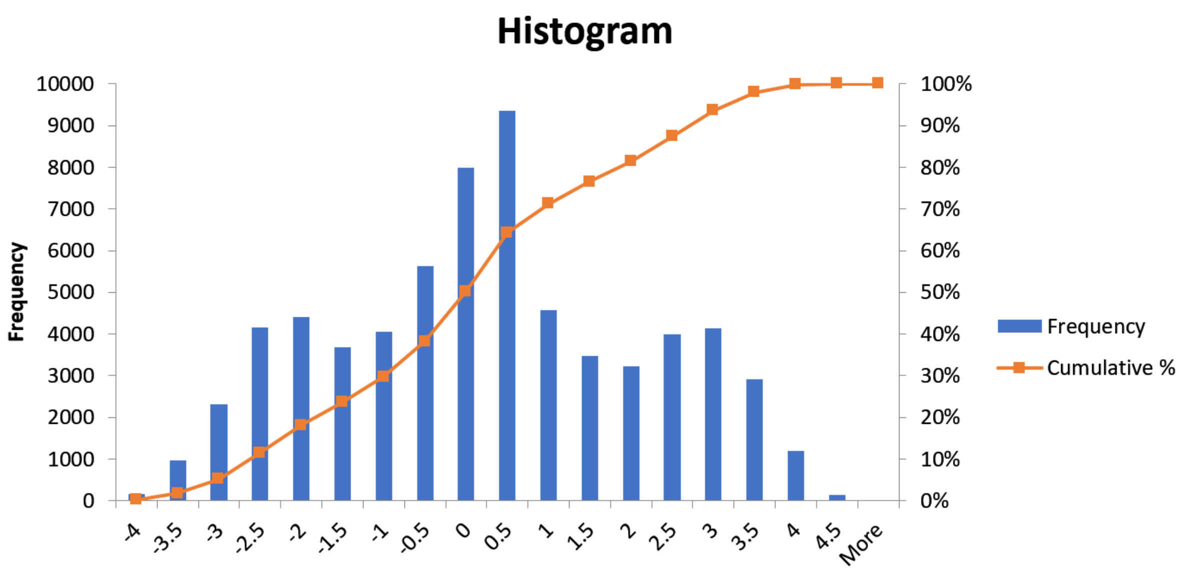

Figure 3-2: Campbell River Station Tidal range histogram.

[9] Vectors have only been shown for every 15 grid cells in the fine grid model

Table 3-2: Summary of modelled tide scenarios.

Simulation	Tidal range	Tidal condition
1	+1.0 m	December 14th, 2016
2	+2.0 m	November 12th, 2016
3	+3.0 m	November 29th, 2016
4	+4.0 m	December 16th, 2016

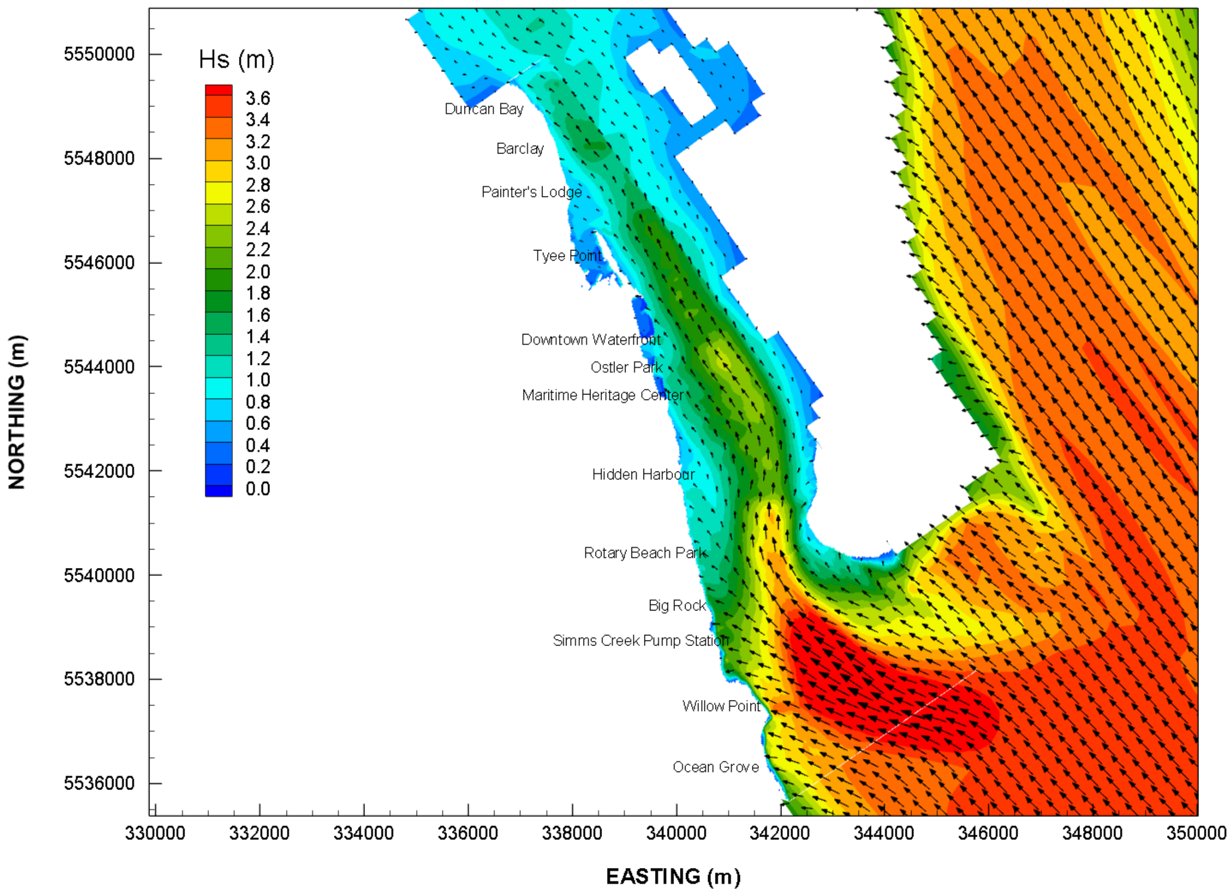

Figure 3-3: Wave height distribution map – Simulation 4.

For the purpose of this study the Campbell River shoreline was divided into 14 representative sections based on shoreline characteristics and exposure to wave climate (**Table 3-3** and **Figure 3-4**). Maximum significant wave heights in the nearshore region at each section were obtained from the model simulations and summarised in **Table 3-4.**

Table 3-3: Section descriptions

Section	Description
1	Ocean Grove
2	Willow Point
3	Frank James Park to Simms Creek Pump Station
4	Simms Creek Pump Station to Big Rock
5	Big Rock to Rotary Beach Park
6	Rotary Beach Park to Hidden Harbour
7	Hidden Harbour to Anchor Inn
8	Anchor Inn to Maritime Heritage Center
9	Ostler Park
10	Downtown Waterfront
11	Tyee Point
12	River mouth to Painter's Lodge
13	Painter's Lodge to Barclay Road
14	Duncan Bay

The shoreline orientation at Duncan Bay, unlike the other sections of the Campbell River shoreline investigated in this study, is more exposed to northerly winds rather than southerly and southeasterly winds. A separate northerly designated storm simulation was conducted to determine the corresponding design wave height for this site.

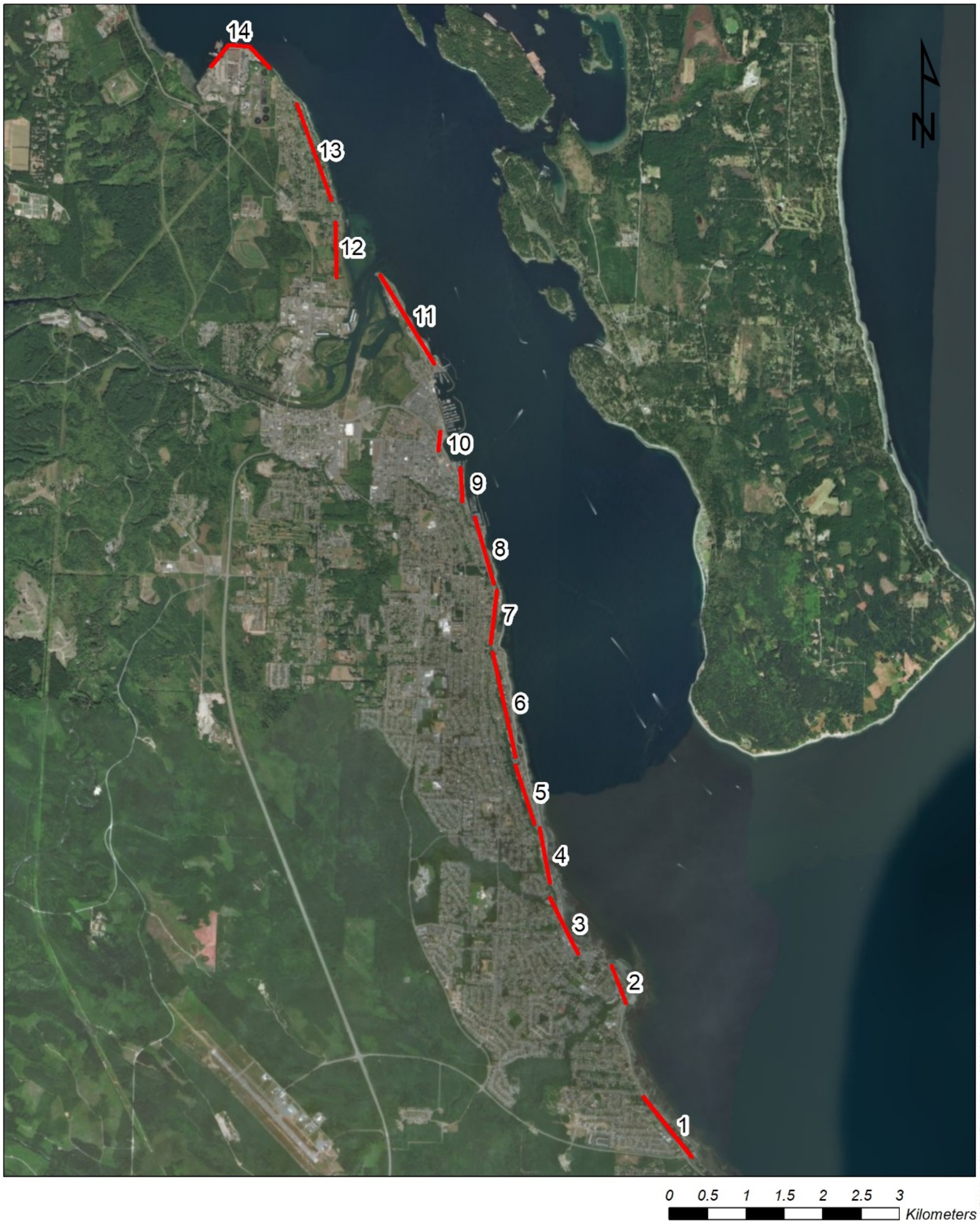

Figure 3-4: Campbell River foreshore sections.

Table 3-4: Nearshore significant wave height at each representative section

Section	Description	Hs (m)
1	Ocean Grove	1.2
2	Willow Point	1.0
3	Frank James Park to Simms Creek Pump Station	1.3
4	Simms Creek Pump Station to Big Rock	1.1
5	Big Rock to Rotary Beach Park	1.0
6	Rotary Beach Park to Hidden Harbour	1.0
7	Hidden Harbour to Anchor Inn	1.1
8	Anchor Inn to Maritime Heritage Center	0.9
9	Ostler Park	0.8
10	Downtown Waterfront	1.1
11	Tyee Point	0.9
12	River mouth to Painter's Lodge	0.8
13	Painter's Lodge to Barclay Road	1.2
14	Duncan Bay	1.1

3.2 Wave Effect

The estimated wave effect can be defined to be 50 percent of the calculated wave run-up on the estimated future shoreline (BC Ministry of Environment, 2011b). Wave run-up is the maximum vertical extent of wave uprush on a beach or structure above the still water level. For design purpose, wave run-up is generally calculated in terms of the two percent exceedance value of wave run-up ($R_{2\%}$), i.e., only two percent of the wave run-up values observed will reach or exceed $R_{2\%}$.

The wave run-up for each section was estimated using the method described in European Overtopping Manual (2016) and summarised in **Table 3-5**. The results were applied to determine the FCL values for existing conditions and future conditions. <u>It is assumed that the future foreshore slope and beach materials will be the same as that of the existing foreshore.</u>

Table 3-5: Summary of estimated $R_{2\%}$ wave run-up along Campbell River foreshore

Section	Description	Hs (m)	Foreshore slope	Surface roughness	Wave run-up $R_{2\%}$(m)
1	Ocean Grove	1.2	2H:1V	Riprap	3.3
2a	Willow Point South	1.0	Vertical Wall	Smooth	1.8
2b	Willow Point Central	1.0	2H:1V	Riprap	2.7
2c	Willow Point North	1.0	3H:1V	Riprap	2.6
3	Frank James Park to Simms Creek PS	1.3	6H:1V	Smooth	2.8
4	Simms Creek Pump Station to Big Rock	1.1	6H:1V	Riprap	2.0
5	Big Rock to Rotary Beach Park	1.0	2H:1V	Smooth / Riprap	2.8
6	Rotary Beach Park to Hidden Harbour	1.0	4H:1V	Riprap	2.5
7	Hidden Harbour to Anchor Inn	1.1	3H:1V	Smooth	3.5
8	Anchor Inn to Maritime Heritage Center	0.9	2H:1V	Smooth / Riprap	3.1
9	Ostler Park	0.8	3.5H:1V	Riprap	2.0
10	Downtown Waterfront	1.1	2H:1V	Riprap	2.1
11	Tyee Point	0.9	7.5H:1V	Smooth	1.0
12	River mouth to Painter's Lodge	0.8	Vertical wall	Smooth	1.8
13	Painter's Lodge to Barclay Road	1.2	Vertical wall	Smooth	2.1
14	Duncan Bay	1.1	2H:1V	Riprap	2.7

3.3 Sea Level Rise

As discussed in **Section 2.3**, the sea level rise policy for BC (BC Ministry of Environment, 2011b) recommends assuming a 1.0 m rise in global mean sea level between the year 2000 and year 2100.

3.4 Uplift/Subsidence

As discussed in **Section 2.4**, the provincial guidelines (BC Ministry of Environment, 2011c) suggest a local uplift rate of 4.1 mm/yr for Campbell River. To the year 2050 and year 2100, this translates to a raise in land elevation of 0.21 and 0.41 m, respectively.

3.5 Freeboard

It is common practice to include provision for uncertainties by incorporating a minimum freeboard. Guidelines for Management of Coastal Flood Hazard Land Use (BC Ministry of Environment, 2011b) defines freeboard allowance to be the greater of:

- 0.6 m, or;

- For flood proofing fill – crest elevation of equivalent sea dike
- For exposed vertical building foundations – the wave-structure interaction
- For tsunami areas – the run-up elevation of the appropriate tsunami hazard

A freeboard allowance value of 0.6 m was adopted for this analysis.

3.6 Summary of Flood Construction Level

Table 3-6, **Table 3-7** and **Table 3-8** summarise the FCL for 2018, 2050 and 2100. **Figure 3-5** shows the spatial distribution of FCL values along the shoreline for 2100.

It should be noted that the FCL values for the Painter-Barclay region (Sections 12 and 13), which consists of coastal bluff shoreline features, should be viewed and applied with caution. Some of the infrastructures are located on top of the bluff which is at an elevation well above the estimated FCL. However, these infrastructures could be at high risk due to ongoing bluff erosion process.

Table 3-6: Flood Construction Levels – 2018

Section	Design Water Level (m)	SLR (m)	Uplift (m)	Wave Effect (m) *	Freeboard (m)	FCL (m GD)
1 – Ocean Grove	2.45	0.18	-0.07	1.7	0.6	4.8
2a – Willow Point	2.45	0.18	-0.07	1.8	0.6	5.0
2b – Willow Point	2.45	0.18	-0.07	1.4	0.6	4.5
2c – Willow Point	2.45	0.18	-0.07	1.3	0.6	4.5
3 - Frank James Park to Simms Creek PS	2.45	0.18	-0.07	1.4	0.6	4.6
4 - Simms Creek Pump Station to Big Rock	2.45	0.18	-0.07	1.0	0.6	4.2
5 - Big Rock to Rotary Beach Park	2.45	0.18	-0.07	1.4	0.6	4.6
6 - Rotary Beach Park to Hidden Harbour	2.45	0.18	-0.07	1.3	0.6	4.4
7 - Hidden Harbour to Anchor Inn	2.45	0.18	-0.07	1.8	0.6	4.9
8 - Anchor Inn to Maritime Heritage Center	2.45	0.18	-0.07	1.6	0.6	4.7
9 - Ostler Park	2.45	0.18	-0.07	1.0	0.6	4.2
10 - Downtown Waterfront	2.45	0.18	-0.07	1.1	0.6	4.2
11 - Tyee Point	2.45	0.18	-0.07	0.5	0.6	3.7
12 - River mouth to Painter’s Lodge	2.45	0.18	-0.07	1.8	0.6	5.0
13 - Painter’s Lodge to Barclay Road	2.45	0.18	-0.07	2.1	0.6	5.2
14 – Duncan Bay	2.45	0.18	-0.07	1.4	0.6	4.6

* Wave effect is calculated to be 50% of wave run-up (Table 3-5) for sloped foreshore and 100% for vertical wall.

Table 3-7: Flood Construction Levels – 2050

Section	Design Water Level (m)	SLR (m)	Uplift (m)	Wave Effect (m) *	Freeboard (m)	FCL (m GD)
1 – Ocean Grove	2.45	0.50	-0.21	1.7	0.6	5.0
2a – Willow Point	2.45	0.50	-0.21	1.8	0.6	5.1
2b – Willow Point	2.45	0.50	-0.21	1.4	0.6	4.7
2c – Willow Point	2.45	0.50	-0.21	1.3	0.6	4.6
3 - Frank James Park to Simms Creek PS	2.45	0.50	-0.21	1.4	0.6	4.7
4 - Simms Creek Pump Station to Big Rock	2.45	0.50	-0.21	1.0	0.6	4.3
5 - Big Rock to Rotary Beach Park	2.45	0.50	-0.21	1.4	0.6	4.7
6 - Rotary Beach Park to Hidden Harbour	2.45	0.50	-0.21	1.3	0.6	4.6
7 - Hidden Harbour to Anchor Inn	2.45	0.50	-0.21	1.8	0.6	5.1
8 - Anchor Inn to Maritime Heritage Center	2.45	0.50	-0.21	1.6	0.6	4.9
9 - Ostler Park	2.45	0.50	-0.21	1.0	0.6	4.3
10 - Downtown Waterfront	2.45	0.50	-0.21	1.1	0.6	4.4
11 - Tyee Point	2.45	0.50	-0.21	0.5	0.6	3.8
12 - River mouth to Painter's Lodge	2.45	0.50	-0.21	1.8	0.6	5.1
13 - Painter's Lodge to Barclay Road	2.45	0.50	-0.21	2.1	0.6	5.4
14 – Duncan Bay	2.45	0.50	-0.21	1.4	0.6	4.7

* Wave effect is calculated to be 50% of wave run-up (Table 3-5) for sloped foreshore and 100% for vertical wall.

Table 3-8: Flood Construction Levels – 2100

Section	Design Water Level (m)	SLR (m)	Uplift (m)	Wave Effect (m) *	Freeboard (m)	FCL (m GD)
1 – Ocean Grove	2.45	1.00	-0.41	1.7	0.6	5.3
2a – Willow Point	2.45	1.00	-0.41	1.8	0.6	5.4
2b – Willow Point	2.45	1.00	-0.41	1.4	0.6	5.0
2c – Willow Point	2.45	1.00	-0.41	1.3	0.6	4.9
3 - Frank James Park to Simms Creek PS	2.45	1.00	-0.41	1.4	0.6	5.0
4 - Simms Creek Pump Station to Big Rock	2.45	1.00	-0.41	1.0	0.6	4.6
5 - Big Rock to Rotary Beach Park	2.45	1.00	-0.41	1.4	0.6	5.0
6 - Rotary Beach Park to Hidden Harbour	2.45	1.00	-0.41	1.3	0.6	4.9
7 - Hidden Harbour to Anchor Inn	2.45	1.00	-0.41	1.8	0.6	5.4
8 - Anchor Inn to Maritime Heritage Center	2.45	1.00	-0.41	1.6	0.6	5.2
9 - Ostler Park	2.45	1.00	-0.41	1.0	0.6	4.6
10 - Downtown Waterfront	2.45	1.00	-0.41	1.1	0.6	4.7
11 - Tyee Point	2.45	1.00	-0.41	0.5	0.6	4.1
12 - River mouth to Painter's Lodge	2.45	1.00	-0.41	1.8	0.6	5.4
13 - Painter's Lodge to Barclay Road	2.45	1.00	-0.41	2.1	0.6	5.7
14 – Duncan Bay	2.45	1.00	-0.41	1.4	0.6	5.0

* Wave effect is calculated to be 50% of wave run-up (Table 3-5) for sloped foreshore and 100% for vertical wall.

Figure 3-5: Year 2100 FCL values.

4 CONCLUSIONS AND RECOMMENDATIONS

The study shows that:

- Of the six 200-year recurrence water level-wave height conditions, the highest flood levels accounting for wave effect along the shoreline occurred under Simulation 2 which consists of an offshore wave height of 3.4 m coinciding with a design water level of 2.45 m GD.

- For the purpose of this study the Campbell River shoreline was divided into 14 representative sections based on shoreline characteristics and exposure to wave climate. The recommended 2100 FCL ranges between 4.1 m GD at Tyee Point and 5.7 m GD at Painter Barclay.

- The FCL values for the Painter-Barclay region, which consists of coastal bluff shoreline features, should be viewed and applied with caution. Some of the infrastructures are located on top of the bluff which is at an elevation well above the FCL. However, these infrastructures could be at high risk due to ongoing bluff erosion process.

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6 CLOSURE

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